

REMEDIATION WORK PLAN VOLUME II

**TWIGG CORPORATION
659 East York Street
MARTINSVILLE, INDIANA**

APPENDIX C

**Evaluation of Monitored Natural Attenuation,
Twigg Manufacturing Facility,
Martinsville, Indiana. August 2011.
T. H. Wiedemeier & Associates, Inc. ,**

EVALUATION OF MONITORED NATURAL ATTENUATION

TWIGG MANUFACTURING FACILITY MARTINSVILLE, INDIANA

Prepared for



**659 East York Street
Martinsville, Indiana 46151**

August 2011

Prepared by



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ACRONYMS AND ABBREVIATIONS

µg/L	Micrograms per liter
AST	Above Ground Storage Tank
bgs	Below Ground Surface
BTEX	Benzene, Toluene, Ethylbenzene, and total Xylenes
CAH	Chlorinated Aliphatic Hydrocarbon
COC	Chemical of Concern
COPC	Chemical of Potential Concern
CSIA	Compound-Specific Isotope Analysis
DCE	Dichloroethene
DO	Dissolved Oxygen
ft/day	Feet per Day
ft/ft	Foot per Foot
FWSA	Former Waste Storage Area
GC/IRMS	Gas Chromatography/Isotope Ratio Mass Spectrometry
gpm	Gallons per Minute
IDEM	Indiana Department of Environmental Management
IDNR	Indiana Department of Natural Resources
ISCO	In-Situ Chemical Oxidation
K	Hydraulic Conductivity
Kg	Kilogram
Kg/ft ³	Kilogram per Cubic Foot
lb	Pound
LNAPL	Light Nonaqueous-Phase Liquid
MNA	Monitored Natural Attenuation
mg/Kg	Milligrams per Kilogram
mg/L	Milligrams per Liter
MIP	Mass in Place
ml/min	Milliliters per Minute
MS/MSD	Matrix Spike/Matrix Spike Duplicate
mV	Millivolts
ORP	Oxidation Reduction Potential
OSHWM	Office of Solid and Hazardous Waste Management
PCE	Tetrachloroethene
pH	Hydrogen Potential
PPM	Part per Million
ROI	Radius of Influence
RWP	Remediation Work Plan
SVE	Soil Vapor Extraction
TCE	Trichloroethene
TCA	Trichloroethane
THWA	T.H. Wiedemeier & Associates, Inc.
TMB	Trimethylbenzene
TOC	Total Organic Carbon

TVH	Total Volatile Hydrocarbons
USCS	Unified Soil Classification System
USEPA	United States Environmental Protection Agency
VC	Vinyl Chloride
VOC	Volatile Organic Compound
MW	Monitoring Well

SECTION 1

INTRODUCTION

This report was prepared by T.H. Wiedemeier & Associates, Inc. (THWA) for the Twigg Corporation (Twigg). It presents an assessment of the ability of natural attenuation to reduce the concentrations and mass of chlorinated aliphatic hydrocarbons (CAHs) detected in soil and groundwater beneath, and downgradient from, the Twigg manufacturing facility (the Site) located at 659 East York Street in Martinsville, Indiana (Figures 1 through 4; 39°25'03"N, 86°25'14"W) and to facilitate Site remediation. For the purposes of this report, the "Site" refers to the entirety of the area impacted by operations at the manufacturing facility located at 659 East York Street, including those areas not owned by Twigg. The term "facility" is used to specify the area owned by Twigg whereupon and wherein manufacturing occurs. The term "study area" is used to indicate the entirety of the area over which data has been collected to assess conditions at the facility and the Site.

This report and the evaluation presented herein are based on historical data made available to THWA and the results of mission-specific groundwater sampling events conducted in April 2010, September 2010, and January/February 2011. These sampling events are described in Section 2. They involved the collection of groundwater elevation, groundwater quality, geochemical, microbiological, and compound-specific isotope data necessary to assess the efficacy of natural attenuation and bioremediation at the Site.

As used throughout this report, monitored natural attenuation (MNA) refers to a management strategy that relies on naturally-occurring mechanisms to reduce contaminant concentrations in soil and groundwater to levels that do not threaten human health or the environment (United States Environmental Protection Agency [USEPA], 1999). Mechanisms of natural attenuation include degradation by indigenous microorganisms and abiotic chemical transformations, as well as physical processes such as dispersion, dilution from recharge, sorption, and volatilization. Because biodegradation (intrinsic bioremediation) and abiotic degradation are the principle mechanisms that remove contaminant mass from the terrestrial subsurface under ambient conditions, much of this report focuses on the evaluation of these processes. In addition, because biodegradation is such an important component of natural attenuation and can be an effective remediation approach on its own, THWA was originally tasked to help evaluate the efficacy of enhanced bioremediation at the Site. Because of the factors discussed in this report, specifically the likely generation of vinyl chloride (VC) as a degradation product of *cis*-1,2-dichloroethene (*cis*-1,1-DCE), it is concluded that enhanced bioremediation would potentially increase the risk posed by constituents found in groundwater at the Site.

1.1 SITE LOCATION

The Site is located near the southeastern edge of Martinsville in the southeast and northeast quarter of the southeast quarter of Section 4, Township 11 North, Range 1 East (Washington Township), Morgan County, Indiana (Figure 1). The Twigg facility and the neighboring Harmon-Motive facility are the only industrial sites in a primarily residential neighborhood.

The Twigg facility includes an approximately 75,000 square foot main building and two small storage buildings to the east of the main building (Figures 2 and 4). The site includes a lawn area to the west, two unoccupied residences and the former waste storage area (FWSA) to the south. The area east of the main building is a paved parking lot.

1.2 PURPOSE AND SCOPE

The primary objective of this report is to evaluate the efficacy of MNA as a remedial option for groundwater impacted by volatile organic compounds (VOCs) at the Site. This objective was accomplished by:

- Reviewing previously reported hydrogeologic and soil and groundwater quality data for the site, including data collected to evaluate the efficacy of the upgradient enhanced bioremediation pilot-testing system;
- Conducting groundwater sampling events to collect specialized data useful for evaluating natural attenuation and enhanced bioremediation. Personnel from Bruce Carter Associates, Inc. (BCA) collected these data;
- Developing an understanding of the shallow saturated zone, including the current distribution of contaminants and degradation products and the distribution of geochemical and molecular biological parameters, and;
- Evaluating site-specific data to aid in the quantification of natural contaminant attenuation processes that are occurring in groundwater at the site.

The work presented herein was completed to determine the relative importance of mechanisms of natural attenuation and to determine if these processes are sufficient to minimize VOC plume expansion and ultimately remediate the solute plume. This work does not include an analysis of the risk associated the use of MNA (or any remedial alternative) to remediate Site contaminants. Instead, it presents a determination of whether or not natural contaminant degradation is occurring to determine if natural attenuation is working to reduce the amount of contaminant mass in the subsurface. It is THWA's understanding that BCA has completed work to evaluate the risk associated with the Site. The results of the work presented in this report, in conjunction with the risk analysis completed by BCA should be used to develop the best remediation approach for this Site. Factors including risk, cost, short and long term effectiveness, and public and State acceptance should be considered when selecting the final remedy for this Site.

1.3 REPORT ORGANIZATION

This report contains ten (10) sections including this introduction (Section 1). Figures, and tables are included at the end of the report. Section 2 presents the site background and history. Section 3 summarizes the physical characteristics of the study area including site geology and hydrogeology. Section 4 describes the nature and extent of soil and groundwater contamination at the site. Section 5 presents an overview of natural attenuation. Section 6 presents an analysis of contaminant and degradation product and compound-specific isotope data. Sections 7 and 8 present analyses of geochemical and molecular biological data, respectively. A summary of significant observations and conclusions and recommendations are provided in Section 9 and references are provided in Section 10.

1.4 LIMITATIONS

This document was prepared by Mr. Todd Wiedemeier, a registered Professional Geologist. The work described herein was conducted in accordance with generally accepted professional engineering and geologic practice. No other warranty exists, either expressed or implied.

In addition to observations made by THWA personnel, this document incorporates Site conditions observed and described by others as reported in records available to THWA as of the date of document preparation. THWA relied, in part, on such data collected by others in the development of interpretations about environmental conditions at the Site. The accuracy, precision, or representative nature of data originally generated by others could not be independently verified by THWA, and such verification would be beyond the scope of this project.

The passage of time may result in changes to Site conditions, technology, or economic conditions that could alter the findings and/or recommendations of the document.

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SECTION 2

SITE BACKGROUND AND HISTORY

This section presents a discussion of the history of the Site. This discussion includes a brief discussion of the operational history of the Twigg manufacturing facility property, a history of the environmental site characterization activities at the Site, and a discussion of remediation operations completed to date.

2.1 OPERATIONAL HISTORY OF THE TWIGG MANUFACTURING FACILITY PROPERTY

Sanborn fire insurance maps, city directories and historical aerial photographs were reviewed to help determine site history (BCA, 1999). The southeast quarter of the main Twigg building was first constructed and operated prior to 1916 as the CG Chase Foundry and Machine Shop. The two small buildings to the east of the main building (Figure 2) were constructed between 1916 and 1942. The three buildings were variously operated as wood furniture factories, a wire gate factory, an aluminum fabricator (storm doors and windows), a vehicle repair shop, a warehouse and a heating and cooling contractor. Twigg Corporation (under a previous owner) first occupied the main building in the 1960's and took over the two small eastern buildings after 1978.

2.2 PREVIOUS SITE INVESTIGATION AND REMEDIATION ACTIVITIES

Numerous investigations have been conducted to trace the history of waste disposal activities at the site and to delineate areas of soil and groundwater contamination. In addition, actions have been taken to remove the source of continuing groundwater contamination. These activities are summarized in the following sections.

2.2.1 Site Investigation at the Twigg Manufacturing Facility

Twigg fabricates metal alloy parts for the aerospace industry. Its process formerly included vapor degreasing of metal parts with chlorinated solvents. The Indiana Department of Environmental Management Office of Solid and Hazardous Waste Management (IDEM/OSHW) inspected the (then current) hazardous waste accumulation storage area (Figures 2, 3, and 4) in 1991 and issued a letter of violation requiring that soil and groundwater sampling be conducted. Since that time, the following has occurred:

- **1991 – 1992:** Soil sampling was conducted by Twigg in 1991 and 1992. This sampling confirmed the presence of tetrachloroethene (PCE) in the soil in the former waste storage area (FWSA).

Two reports dated January 8 and June 8, 1992 were prepared for Twigg by Alt & Witzig Engineering, Inc. of Indianapolis (Alt and Witzig Engineering, Inc, 1992a and 1992b) and were submitted to IDEM/OSHW. The reports discuss investigations in 1991-1992 that included 15 borings to depths of 16 to 20 feet in and around the FWSA. Soil samples were collected continuously and field screened for VOCs, with eleven being analyzed for VOCs. The investigations confirmed the presence of PCE in shallow soils in the FWSA and in soil near the water table (approximately 8 to 20 feet, BGS) beyond the FWSA.

- **1993:** Farlow Environmental Engineers, Inc. (now Bruce Carter Associates, L.L.C. - BCA) was requested to prepare a work plan for an investigation of the extent and magnitude of contaminants associated with the former waste storage area (FWSA). The Work Plan was approved by IDEM in 1994, and the investigation was conducted from 1994 to 1998.
- **1997:** Twigg filed an application with the IDEM/Office of Environmental Response/Voluntary Remediation Program (VRP) in 1997, and the Voluntary Remediation Agreement (VRA) was signed in September, 1997.
- **1998:** The Phase II Investigation Report was submitted to IDEM for review October 30, 1998, and comments on the report were received from Radian Corp (contract reviewer for VRP) in February, 1999.

A report dated October 31, 1998 was prepared by BCA for Twigg and was submitted to IDEM (BCA, 1998). The investigation confirmed the presence of CAHs and metals-lead (Pb), chromium (Cr) and cadmium (Cd) in the FWSA. The metals were limited to the shallow soil in the FWSA and are below Tier II clean-up goals. The CAHs were found primarily in soil near the water table and in the groundwater. The CAH plume in the groundwater extends around the Twigg site and downgradient (west) about one-half mile. The CAHs include tetrachloroethene (PCE), 1,1,1-Trichloroethane (1,1,1-TCA) and their degradation products including trichloroethene (TCE), *cis*-1,2-dichloroethene (*cis*-1,2-DCE), 1,1-dichloroethene (1,1-DCE), 1,1-dichloroethane (1,1-DCA), and chloroethane (CA). BCA, (1998) details the results of this investigation.

Radian Comments and BCA Response

Dames and Moore/Radian Corp submitted comments on the 1998 Phase II Investigation Report. BCA responded to these comments in a letter dated March 11, 1999 and provided several clarifications (BCA, 1999c).

- **1999:** Additional investigation was performed in 1999, and an Addendum to the Phase II Report was submitted in August, 1999. The initial portions of a remediation system began operation in the FWSA on November 3, 1999.

BCA performed investigations in 1999 in response to Radian comments regarding the 1998 Phase II Report. The results were summarized in an addendum report dated August 4, 1999 (BCA, 1999a). The investigation confirmed the presence of secondary sources of CAHs beneath the Twigg main building. The investigation also defined the vertical and horizontal limits of the plume at several locations.

Private Wells Survey: A door-to-door survey of residences located in the neighborhood within and near the groundwater plume was conducted by IDEM and BCA staff to identify any residences with private wells. The results of the survey are summarized in a letter to D. Ridley in December, 1999 (BCA, 1999d).

- **2000 – 2009:** Numerous groundwater and soil sampling events have occurred over the period from 2000 to the present. During this time VOC and geochemical data were collected. In addition, several remediation systems and remediation pilot testing systems have been installed and operated, as described in Section 2.2.2.
- **2010** – Molecular biological data were collected for groundwater to help assess the efficacy of enhanced bioremediation. The results of this work showed that if sufficient carbon were added, then the toxic byproduct VC would likely be produced.
- **2011** – A round of data collection occurred for all Twigg monitoring wells (i.e., MW-1 - MW-19, the PBW series wells, and the PMW series wells) to provide a baseline data set for the analysis of MNA. Data collected included (VOCs; Tables 9 and 10), compound-specific isotope analyses (CSIA; Table 12) geochemical data (Table 13), and microbiological laboratory data (Table 14).

2.2.2 Remediation Activities at the Twigg Manufacturing Facility

Since November 1999, several remediation systems and remediation pilot testing systems have been installed and operated. Figure 4 shows the layout of the remediation systems installed on Twigg property. The following is a summary timeline of remediation activities at the Twigg facility:

- 1999 – Soil vapor extraction (SVE) system installation and start-up (November)
- 2000 – Expansion of SVE to current configuration
- 2004 – Installation and start-up of ozone-sparging system
- 2004 – Installation and start-up of On-site Bioremediation Pilot
- 2006 – Installation and start-up of Leading Edge Bioremediation Pilot
- 2008 – Termination of bioremediation pilot tests & ozone-sparging.
- 2008-2009 – Vapor intrusion studies
- 2009 – Installation of two vapor intrusion mitigation systems
- 2010 - Post- vapor intrusion mitigation sampling
- 2010 – Compound-specific isotope and microbiological evaluations

The Remediation Work Plan (RWP) was submitted to IDEM for review on December 17, 1999. The remediation system outlined in the RWP includes a soil vapor extraction system (SVE) and ozone sparging system for the on-site source areas and bioremediation in the off-site down gradient areas. The on-site SVE system was installed and began operation in 1999 per the RWP, though the system was expanded beyond the original proposed design. The initial on-site ozone sparging system was installed and began operation in 2004. The off-site bioremediation components involved more input and coordination with IDEM, local government (for right-of-way access), and the local community. A pilot test for the bioremediation system was installed on Twigg property, and began operation in 2004. The bioremediation system operated until late September, 2005 and then was monitored through the spring of 2006. The system was restarted in June 2006 with a change in nutrient feed. This system ran until May 2008. A second, separate, bioremediation pilot test was started in August, 2006 near the leading edge of the plume at MW-8.

2.2.2.1 Soil Vapor Extraction System Operation

A single soil vapor extraction (SVE) well (VEW-1) and a SVE equipment shed were installed in the Former Waste Storage Area (FWSA). This system began operation on November 3, 1999. The system was expanded to three vapor extraction wells in December, 1999. A pilot test was conducted in January, 2000 to determine the radius-of-influence (ROI) of the SVE system under various operating conditions. A soil gas survey was conducted in February, 2000 to evaluate the extent of CAHs, principally PCE, in the capillary fringe downgradient of the FWSA which might be removed by SVE.

The RWP proposed the expansion (Phase II) of the SVE system to include secondary CAH source areas located under the Twigg facility. Based on the results of the February, 2000 soil gas survey, Phase II of the SVE system was expanded to include the area up to 200 feet downgradient of the FWSA (Figure 4). Based on the established ROI, Phase II was designed to maximize coverage of the SVE system in the affected areas on the Twigg site outside the FWSA. Six additional vapor extraction wells (VEW-4 through VEW-9) were installed and began operating in May, 2000, ahead of the schedule proposed in the RWP (Figure 4). The expanded SVE system has operated with only minor changes since May, 2000.

The SVE system operated continuously from 1999 through the present with the exception of periods of shut-down due to maintenance, high groundwater levels and/or to protect the system from winter freeze damage. The system was shut down for 2 months in 2000, 2 months in 2001, ½ month in 2002, 8 months in 2003 1½ months in 2004, 8 months in 2005, and 4½ months in 2006. The extended shut-down periods in 2003 and 2005 were due in part to high water levels and the resultant low PCE removal rate and increased stress on the equipment (BCA, 2007).

Based on the monitoring of SVE stack emissions, the cumulative mass of PCE and 1,1,1-TCA removed by the SVE system became asymptotic by the end of 2002 at about 1,450 pounds of PCE and just over 110 or so pounds of 1,1,1-TCA (Figure 5; BCA, 2007). The stack gas concentrations fell from an initial measured level (from the FWSA only) of 507 ppm CAHs on

November 3, 1999 to a measured level (from the entire area) of 4.8 ppm on September 7, 2000. Stack gas concentrations have declined slowly since then with concentrations estimated at 2.7 ppm PCE in September, 2002 (for the entire area), 0.4 to 0.7 ppm in 2003 (prior to mixing with bleed air), 0.24 ppm in 2004, and estimated at 0.0 to 0.24 ppm in 2005-2006. Total CAH removal decreased from an initial rate of approximately 80 pounds per day in November, 1999 to 0.6 pounds per day in September, 2000. From 2000 to 2002 rates varied from 0.34 pounds per day to 0.71 pounds per day (10 to 20 pounds per month), except in Spring 2002 when rates fell to zero due to high water levels. In 2003 the CAH removal rates varied from 0.06 lbs/day to 0.09 lb/day (1.8 to 2.7 lbs/month) and in 2004 the rates varied from 0.03 to 0.05 lbs/day (0.9 to 1.5 lbs/month). For the time period 2005 through 2006 CAH removal rates were estimated at 0.00 to 0.05 lbs/day (0.0 to 1.5 lbs/month) (BCA, 2007).

2.2.2.2 Ozone Sparging

The ozone-sparging system was designed and installed in early 2004. The compressor/ozone generator/controls were placed in the existing remediation shed. Six sparge points were drilled in the upgradient side of the primary source areas (Figure 4) to depths of 45 feet (SP-1, SP-2 and SP-3) and 30 feet (SP-4, SP-5 and SP-6). The system was designed to inject a mixture of ozone and air into the groundwater at each sparge point for about 10 minutes every 80 minutes. The principal mechanism of CAH removal is direct oxidation (Criegee oxidation) of the organic compounds. The operation is reported to be more effective (relative to the operating time) when pulsed (operation rotated across several wells) than when used continuously (BCA, 2007).

The system was started up on April 15, 2004 and operated about 20% of the time during the start-up phase through September 15, 2004. The system was monitored in the shed and at the sparge point well heads for leaks and pressure in the system. Various adjustments were made, including repairing one leak and disconnecting one of the sparge wells (due to a break in the line) and operation improved to about 50% from September 15 to the end of 2004. The system remained at about 50% capacity for most of 2005.

In early 2006, leaks were detected in lines 1, 3, 5, and 6. In mid-2006, attempts were made to pull one of the sparge lines (SP-3) out of the protective outer tube to try to replace the leaking line. A leak in line 2 was detected late 2006. Lines 1, 2, and 6 were repaired and returned to operation. As of the end of 2006, total operating hours of the ozone generator & compressor were approximately 7000 hours.

In 2006 a new sparge line, connected to circuit 3, was run to a holding tank outside the SVE shed. This tank was added to store and treat groundwater purged from monitoring wells around the site. Samples of the stored purge water have been analyzed prior to discharging to the sanitary sewer. Lab results showed no detection of any analytes in the treated purge water. The ozone sparging system was shut down in May 2008.

The impact of the ozone sparging system for remediation of CAHs was likely minimal and only effective for the area immediately surrounding the injection wells. This is because the

ozone sparging points were located some 350 feet upgradient from the center of mass of the ethene solute plume (near MW-4) and some 1,600 feet upgradient from the center of mass of the main ethane solute plume (near MW-6). Ozone is only stable in groundwater for minutes to hours after injection (USEPA, 2006) so the area of influence would be measured in units of several to tens of feet at best.

2.2.2.3 Bioremediation Pilot Testing

Bioremediation pilot testing was conducted in two discrete locations at the Site to determine if biodegradation could be stimulated through the addition of carbon and other substrates.

2.2.2.3.1 Upgradient Bioremediation Pilot Testing

This pilot test was installed in 2004 on the Twigg property downgradient of the FWSA (Figure 4). One injection, one extraction and four monitoring wells were installed in the pilot test area (Figure 4). After start-up and equipment adjustments, nutrient feed injection began on October 7, 2004. The nutrient feed target concentrations were 3 millimolar (mM) butyric acid (264 mg/l), 20 mg/l yeast extract and 0.05 mg/l vitamin B12 (cyanocobalamine). The butyric acid based feed was discontinued in September 2005 to evaluate results and to prepare for a nutrient feed stock change.

In June 2006, the recirculating bioremediation cell was restarted with modified nutrient feeds: molasses, yeast extract, and magnesium sulfate (Epsom salts). The target range was an initial concentration of 3,000 to 4,000 mg/L of sulfate, 3,000 to 4,000 mg/L of molasses and 2-5 mg/L of yeast extract in the cell.

The system ran continuously from June, 2006 through the end of the year, except December 19-22, 2006, when the system was shut down to replace the injection well. Based on the results of the monthly groundwater sampling at wells PMW-1, PMW-1S, and PBW-2, the nutrient feed rate was adjusted several times to maintain the target concentrations in the cell. PBW-1 (the injection well) became clogged due to biofouling or precipitation of iron sulfide in the formation immediately adjacent to the well screen. The well was replaced in December (PBW- 1R) after several attempts to clear the well screen failed. This pilot test was discontinued in May 2008.

2.2.2.3.2 Downgradient Bioremediation Pilot Testing

Monitoring well MW-8 is located approximately 2,000 feet west of the FWSA and is the primary well for monitoring if migration of the chlorinated ethane plume is occurring at the leading edge. CAH concentrations in MW-8 showed indications of an increasing trend through 2007. Since July 2007, concentrations of 1,1,1-TCA have remained fairly constant. In addition to the 1,1,1-TCA observed in MW-8, 1,1-DCE concentrations as high as 31 µg/L were detected in this well in October 2007, a sampling event which gave unusually high concentrations in wells across the Site. Since that time, the 1,1-DCE concentration has fallen to 18.7 µg/L, which is consistent with concentrations of 1,1-DCE observed in this well over time (Table 9; Section 4) . Therefore, Twigg requested that BCA begin implementation of methods to remediate or control migration at the leading edge of the plume.

Prior to installing a pilot system at the leading edge, four groundwater probes were installed (May, 2006) nearby to evaluate whether the geometry of the plume had changed. Two probes (FP-46 and FP-47) were placed near the projected limit of the plume (1 µg/L) based on probes installed nearby in 1999. No CAHs were detected in the probes, indicating that no lateral cross-gradient expansion of the plume had taken place. Probes FP-12A and FP-12B were placed at MW-8 to evaluate whether the vertical shape of the plume had changed. The laboratory results for FP-12A (28-32') confirmed that no CAHs are present at the top of the aquifer and the results for FP-12B (60-64') confirmed that concentrations remain unchanged at depth (Table 10).

While the pilot system at the Twigg property is evaluating remediation of a plume consisting primarily of PCE, the leading edge consists primarily of 1,1,1-TCA and degradation products 1,1-DCA, 1,1-DCE and CA. Therefore, a separate pilot test was initiated to evaluate bioremediation method at the leading edge. Two wells (PBW-3 and PBW-4) were installed 10 feet apart and about 15 feet upgradient of MW-8 with 20-foot well screens set to bracket the 10-foot well screen in MW-8. Groundwater was pumped directly from PBW-4 to PBW-3 through a closed system and nutrients were injected directly into the circulation line. The purpose was to create a large well-mixed roughly cylinder-shaped volume of amended groundwater that would pass through MW-8. In addition to a carbon source (molasses) and trace nutrients (yeast extract), emulsified vegetable oil was added to provide an extended carbon (electron donor) source. The groundwater was circulated between the wells (PBW-3 and PBW-4) for 12 hours. The feed rates and amounts were calculated to create a volume of amended groundwater approximately 12 feet in diameter and 20 feet thick with 2,400 mg/L molasses, 280 mg/L edible oil (emulsified), 4 mg/L yeast extract, and 2,000 mg/L sodium bromide. Injection occurred three times; in August 2006, March 2007, and August 2007.

2.2.3 Activities at Former Harmon-Motive Property

A report dated September 6, 1996 prepared by Heritage Environmental Services, Inc. was provided to Twigg by Harman-Motive (Harman) and was reportedly submitted to IDEM (HES, 1996). The report summarizes groundwater investigation results and delineates the extent and magnitude of chlorinated and non-chlorinated VOCs on and near the Harman facility. The CAHs in the Harman plume include PCE, 1,1,1-TCA, and their degradation products. The Harman data indicate that a groundwater plume of CAHs is present on its site. This plume may adjoin the Twigg plume, but it does not significantly overlap it. Harman began remediation of the plume in 1996, utilizing soil vapor extraction, air sparging and nutrient enhancement. Further information on the plume is included in Section 3.5 of BCA (1999).

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SECTION 3

SITE GEOLOGY AND HYDROGEOLOGY

The following sections describe the physical characteristics of the Site as determined from historical reports. Data and information from BCA (1998, 1999a, 1999b, and 2007) groundwater sampling that occurred during 2010 and 2011, and data supplied by BCA were used to determine the physical characteristics of the site.

3.1 SITE TOPOGRAPHY AND SURFACE WATER HYDROLOGY

As estimated from the U.S. Geologic Survey Martinsville Quadrangle Map, the elevation of the site and the neighboring areas is approximately 605 ± 5 feet above mean sea level (ft msl). A survey of the monitoring wells on and west of the Twigg site indicates ground elevation varies from approximately 602.9 ft msl at MW-5 to 606.6 ft msl at MW-7 (Figure 3 and Table 1). The topography of the neighborhood is essentially level. Surface drainage from the site is to the southeast approximately 1,500 feet via storm sewers to Sartor Ditch, which flows 1.5 miles southwest to Indian Creek and then to the White River.

Two small lakes and Nutter Ditch (Figure 1) are approximately one mile downgradient (west) of the site. The lakes are former gravel pits, which (based on interviews with long-time residents) have been inactive for 20-30 years. They have little or no drainage basins and likely have little impact on groundwater flow. Nutter ditch is continuous and likely drains groundwater during high water table periods or possibly all of the time. Active gravel pits are located on the east bank of the White River and may be downgradient of the site.

3.2 REGIONAL GEOLOGY AND HYDROGEOLOGY

Soil near the site consists of Martinsville loam which is characterized as nearly level, deep, well-drained soil on outwash plains (USDA, 1981). The soil is typically a brown loam underlain by a clay loam and a sandy loam to a depth of approximately five feet.

Underlying soils near the site are Holocene age alluvial deposits of sand, gravel and silt, and Wisconsinan age outwash deposits, chiefly of sand and gravel (IDNR, 1989). Unconsolidated deposits near the site are reported to a depth of approximately 100 feet (IDNR, 1983) below ground surface and are underlain by Mississippian Age Borden Group siltstone and shale (IDNR, 1987 and USGS, 1994). Well logs obtained from the IDNR for Martinsville show primarily sand and gravel deposits to depths of approximately 100 feet underlain by shale bedrock. Several logs also identify isolated layers of fine grained material within the sand and gravel. This stratigraphy is consistent with what has been observed at the site as shown by Figures 6 and 7.

3.3 SITE GEOLOGY

Figures 6 and 7 show hydrogeologic cross-sections for the Site. The locations of these cross-sections are shown on Figure 3. Figure 6 is located along the centerline of the plume, parallel to the direction of groundwater flow. Figure 7 is oriented perpendicular to the direction of groundwater flow. Investigations conducted by BCA found that a layer of finer-grained soil (typically silty sand, but also clayey sand and some sandy lean clay or silt) occurs near the surface. The ground surface in the area is covered with pavement (roads and parking lots), buildings, topsoil/grass and gravel (FWSA). The surficial silty sand/sandy silt layer varies in thickness from zero to approximately 12 feet and is generally 6-10 feet thick.

During the Phase II Investigation one boring (MW-6) west of Twigg was extended to 101.5 feet and encountered clay at 100 feet and shale at approximately 101 feet BGS. Soils overlying the bedrock were found to be predominantly well graded to poorly graded fine to medium sand with trace to little fines and gravel. Sand and gravel layers were identified at MW-6 and MW-8 at approximately 45-50 feet and at MW-6 at approximately 70-96 feet BGS. At MW-1 a layer of silt with little clay and little to some fine sand was found at 75 feet to termination of the boring at 81 feet BGS. A layer of silty sand was also identified at MW-1 at approximately 55 to 60 feet BGS.

The aquifer beneath the site is part of a surficial sand and gravel aquifer which extends throughout the White River Valley. These sand and gravel deposits extend approximately one mile north, south and east of the site. The aquifer is hydraulically connected to (and fed by) buried aquifers to the east and drains to the White River located 2.4 miles west of the site. Typical hydraulic conductivities for the regional aquifer are 8×10^{-3} to 5×10^{-1} cm/sec (USGS, 1994). The water table is commonly within ten feet of the surface in the valley.

3.4 SITE HYDROGEOLOGY

The following sections present an overview of the hydrogeology of the site.

3.4.1 Groundwater Flow Direction and Gradient

Table 1 presents well completion details for the Site including northing and easting coordinates and elevations for ground surface, top of casing (measurement datum), top of well screen and base of well screen. Table 2 presents historical groundwater level measurements and vertical gradient calculations. Table 3 presents horizontal gradient calculations. Table 4 presents historic precipitation data for weather station Martinsville 2 SW (COOP ID = 125307; 39°24'N, 86°27'W) which is located near McDaniel's Field airport, about 2 miles southwest of the Site. Groundwater at the Site has fluctuated a maximum of 5.2 feet over the period of measurement (1994-2011) in MW-1S (Table 2). This is consistent with other wells at the Site, the majority of which exhibited fluctuations on the order of 4.5 to 5 feet over the period of observation (Table 2). Figure 8 presents precipitation data versus time for Martinsville 2SW.

Figure 9 presents plots of groundwater table elevation versus time for selected wells along the groundwater flowpath. The highest water table elevations over the period of measurement occurred in June 1998 and June 2008. Both of these dates corresponded to months with large amounts of precipitation, with June 2008 having the largest amount of precipitation over the period of observation (Figure 8). The lowest water table elevation over the period of measurement occurred in January 2011.

3.4.1.1 Water Table Elevation and Horizontal Gradient Calculations

Figures 10, 11, and 12 present water table elevation maps for May 2008, November 2008, and January/February 2011, respectively. These figures show that the groundwater flow direction is primarily to the west, with a slight southerly component at times. Tables 2 and 4 and Figure 9 show that these figures represent periods of both near-maximum (May 2008) and minimum (January/February 2011) observed water table elevation. Table 3 presents horizontal hydraulic gradient calculations roughly parallel to the groundwater flow direction for various times. Presented in this table are the maximum (0.0027), minimum (0.0020), and average (0.0025) gradients along the groundwater flowpath from well MS-1S to MW-8. As shown by Table 3, the observed horizontal component of the gradient shows little variation.

3.4.1.2 Vertical Gradient Calculations

Several pairs of nested wells are present at the Site including MW-1S/MW-1D, MW-6/MW-6D, and MW10S/MW-10M. Vertical gradients for each well pair were calculated and the results of these calculations are presented in Table 2. Wells MW-1S/MW-1D are located in the FWSA and are screened at 7-17 feet and 50-60 feet bgs, respectively. Where water level measurements were made on the same day, a slight upward gradient was observed to be present at this location, varying from 0.0056 to 0.0005. The vertical gradient at well pair MW-10S/MW-10M, located just north of the FWSA, was observed to be both upward and downward over the period of measurement, with a slightly downward gradient predominating (Table 2). The vertical gradient at well pair MW-6/MW-6D is consistently slightly downward with a vertical gradient varying between 0.0003 and 0.001. The disposition of the solute plume (Section 4) suggests that the overall vertical gradient at the Site is slightly downward.

3.4.2 Hydraulic Conductivity (K)

Constant head permeability tests were performed on eight of the nine monitoring wells during the investigation conducted by BCA (BCA, 1998). The data were evaluated by the method of Bower and Rice (1976) and by the method of Hvorslev (1951). The results are summarized in Table 5, are typical of the sandy material at the Site, and exhibit a fairly narrow range of values. Using the method of Bouwer and Rice (1976), the hydraulic conductivity across the site varies from 2.6×10^{-3} cm/sec and 1.34×10^{-1} cm/sec with a geometric mean of 1.89×10^{-2} cm/sec. Using

the method of Hvorslev (1951), the hydraulic conductivity across the site varies from 1.01×10^{-2} cm/sec and 7.3×10^{-2} cm/sec with a geometric mean of 2.88×10^{-2} cm/sec. These values for hydraulic conductivity are in line with those presented in USGS (1994) for this aquifer which vary between 5×10^{-1} cm/sec and 8×10^{-3} cm/sec. Based on the work of Brown *et al.* (1995), the method of Bouwer and Rice gives better results than the method of Hvorslev. For the cases studied, the Bouwer and Rice analysis was found to give good estimates of hydraulic conductivity (K), with errors ranging from 10% to 100%. Brown *et al.* (1995) found that the estimates of hydraulic conductivity using the method of Bouwer and Rice were consistently superior to those obtained with Hvorslev's (1951) basic time lag method. In general, the Bouwer and Rice method tends to underestimate the hydraulic conductivity, the greatest errors occurring in the presence of a damaged zone around the well or when the top of the screen is close to the water table. Thus, the Site-specific values of hydraulic conductivity as determined by BCA (1999b) will be used for this evaluation.

3.4.3 Effective Porosity

As discussed in Section 3.3, the subsurface materials in which the solutes of interest reside are predominantly well graded to poorly graded fine to medium sand with trace to little fines and gravel. Because of the difficulty involved in accurately determining effective porosity, accepted literature values for the type of sediment comprising the shallow saturated zone were used. Walton (1988) and Domenico and Schwartz (1990) as summarized by USEPA (1998) give a range of effective porosity for fine to medium sand of 10 to 30 percent. A low effective porosity corresponds with a higher computed groundwater seepage velocity. The aquifer matrix, as determined from previous investigations, consists predominantly of poorly- to well-sorted fine- to medium-grained sands with minimal fines and gravel. As a representative value, an effective porosity of 20 percent was assumed for the site.

3.4.4 Groundwater Seepage Velocity

The advective velocity of groundwater (seepage velocity) in the direction parallel to groundwater flow is given by the relationship:

$$\bar{v}_x = -\frac{K}{n_e} \frac{dH}{dL}$$

Where: \bar{v}_x = Average groundwater seepage velocity (interstitial seepage velocity) [L/T]
K = Hydraulic conductivity [L/T]
 $\frac{dH}{dL}$ = Gradient [L/L]
 n_e = Effective porosity [dimensionless]

Using this relationship in conjunction with the site-specific geometric mean hydraulic conductivity of 53.61 ft/day and average hydraulic gradient (0.0021 ft/ft), and an assumed effective porosity of 20 percent, the average groundwater seepage velocity for the site is calculated to be about 205 feet per year (ft/yr). Sensitivity analyses were conducted by varying the value of hydraulic conductivity which is the parameter that tends to exhibit the most variability and is the hardest to quantify. Table 6 contains groundwater seepage velocity calculations. Using the maximum hydraulic conductivity value for well MW-8 of 193 ft/day and the same hydraulic gradient and effective porosity, the maximum groundwater seepage velocity was estimated to be about 740 ft/yr. Using the minimum hydraulic conductivity value for well MW-9 of 7.37 ft/day and the same hydraulic gradient and effective porosity, the maximum groundwater seepage velocity was estimated to be about 28 ft/yr. Additional sensitivity analyses were completed by varying the effective porosity. These calculations are presented in Table 6.

3.4.5 Retarded Solute Transport Velocity

Because of their hydrophobic nature, organic compounds tend to adsorb onto sediment particles during transport in groundwater, causing their migration to be slowed or “retarded” relative to groundwater flow. The difference between the velocity of the groundwater and that of the contaminant is described by the coefficient of retardation, R , which is defined as:

$$R = \frac{v_i}{v_e}$$

Where: R = coefficient of retardation (dimensionless)
 v_i = average linear groundwater velocity parallel to groundwater flow [L/T]
 v_e = average velocity of contaminant parallel to groundwater flow [L/T]

The ratio v_i/v_e describes the relative velocity between the groundwater and the solute. Assuming that sorption is linear, and therefore is adequately described by the distribution coefficient, the coefficient of retardation for an organic solute (for saturated flow) is given by:

$$R = 1 + \frac{\rho_b K_d}{n}$$

Where: R = coefficient of retardation
 ρ_b = bulk density
 K_d = distribution coefficient
 n = total porosity

This relationship expresses the coefficient of retardation in terms of the bulk density and porosity of the aquifer matrix and the distribution coefficient for the contaminant. The distribution coefficient is given by:

$$K_d = K_{oc} f_{oc}$$

Where: K_d = distribution coefficient [L^3/M]

K_{oc} = soil sorption coefficient normalized for total organic carbon content [L^3/M]

f_{oc} = fraction soil organic carbon (mg organic carbon/mg soil) [M/M]

Representative K_{oc} values for the major compounds present at the Site are given in Table 7

Combining the above equations gives:

$$\frac{v_s}{v_r} = 1 + \frac{\rho_b K_d}{n}$$

Solving for the contaminant velocity, v_r , gives:

$$v_r = \frac{v_s}{1 + \frac{\rho_b K_d}{n}}$$

No site-specific data for total organic carbon (TOC) concentrations in the aquifer matrix are available. Based on the fluvio-glacial origin of the fairly homogeneous sands comprising the shallow saturated zone and the observation that groundwater in areas that are not impacted by VOCs generally contains dissolved oxygen, some at concentrations that are near saturation for the temperature and barometric pressure at the Site, it is likely that ambient TOC concentrations in the aquifer are low. Karickhoff (1981) present TOC concentration information for fluvio-glacial deposits comprised of fine sand that range from 0.023 to 0.12 percent (fraction organic carbon = 0.00023 to 0.0012, respectively). The same authors present TOC concentration information for fluvio-glacial deposits comprised of medium sand to gravel that range from 0.017 to 0.065 percent (fraction organic carbon = 0.00017 to 0.00065, respectively). Based on these numbers, the median value for fine sand (0.0715 percent) is considered the most appropriate for use at this site.

Sediments such as those found at the site tend to exhibit a fairly narrow range of bulk density. Walton (1988) presents bulk densities for sand ranging from 1.37 to 1.81 grams per cubic centimeter (g/cm^3). This is consistent with THWA's experience for the types of sediments present at the Site which, based on hundreds of laboratory analyses, have a bulk density on the order of $1.65 g/cm^3$. Based on this, a bulk density of $1.65 g/cm^3$ is used for the solute transport velocities calculated herein. Walton (1988) presents total porosities ranging from 26 to 53 percent. A total porosity of 30 percent was assumed for the calculations presented in this report. Although assumed values introduce uncertainty into the results of any calculation, they can give a general picture against which actual plume behavior may be compared. Table 7 presents estimated retarded solute transport velocities for the constituents found at the Site and potential degradation products using the groundwater seepage velocity calculated using the selected representative hydraulic parameters for the site (Table 6). The results indicate that retarded solute transport velocities range from 102 ft/yr for PCE to 203 ft/yr for VC if a TOC concentration of 0.007 percent is assumed.

SECTION 4

NATURE AND EXTENT OF CONTAMINATION

This section describes the magnitude and extent of CAHs at the Site. Included in this discussion are the eight (8) CAHs that have been detected in soil and/or groundwater in the study area. These compounds include the chlorinated ethenes PCE, TCE, *cis*-1,2-DCE, VC, and 1,1-DCE and the chlorinated ethanes 1,1,1-TCA, 1,1-DCA, and CA. Throughout this report, 1,1-DCE, although a chlorinated ethene, is often discussed in conjunction with the chlorinated ethanes because it is a degradation product associated with the abiotic dehydrohalogenation of 1,1,1-TCA and is not associated with the degradation pathways for chlorinated ethenes, wherein the *cis*-1,2-DCE isomer is the predominant degradation product (Section 5). Tables 8, 9, and 10 summarize soil and groundwater data for CAHS.

4.1 SOIL CONTAMINATION

This section discusses the distribution of CAHS identified in soil in the vicinity of the Twigg manufacturing facility over the period from 1994 through 1999. Table 8 presents available data for chlorinated compounds in soil. In addition to the soil data collected from 1994 through 1999, shallow soil data were collected in 2008. Based on the relative amounts of PCE and 1,1,1-TCA found in soil, it appears that these were the primary constituents that entered the subsurface. Low concentrations of TCE, *cis*-1,2-DCE, 1,1-DCE and 1,1-DCA were also found in soil but based on their low concentrations and distribution (i.e., always associated with parent compounds), these likely resulted from the degradation of PCE and 1,1,1-TCA (Sections 5 through 9). Based on available data, three general areas of soil contamination have been identified (Figures 16 through 19). These areas include the area immediately below and downgradient from the FWSA, the area just to the west of the main Twigg building, and an area beneath Victory Park. Soil contamination associated with operations at the former Harmon-Motive manufacturing facility is not considered in this report. There is no record of releases of chlorinated solvents, therefore, it is probable that the soil and groundwater contamination identified at and immediately downgradient from the Twigg property resulted from small incidental spills and leaks in the FWSA and process losses in the building. The source of the soil contamination found in the vicinity of Victory Park is not known.

No pooled nonaqueous-phase liquid (NAPL) was observed during site characterization activities. The lack of pooled NAPL is further supported by the relatively low concentrations of CAHs found in soil (highest concentration of PCE = 42 mg/kg and highest concentration of 1,1,1-TCA = 3.0 mg/kg; Table 8). The data presented in Table 8 do however show that there was some residual NAPL present in the shallow surface at the Site in the late 1990's. Based on steadily decreasing concentrations of chlorinated ethenes and ethanes in groundwater, it is likely that concentrations of NAPL present in subsurface soils and sediments at the Site have also

decreased over time through a combination of active remediation (Section 3) and natural attenuation (Sections 5 through 9).

4.1.1 Former Waste Storage Area

The former waste storage area (FWSA) is an uncovered gravel area measuring approximately 65 feet x 70 feet and bounded by a 6-foot chain link fence on three sides (Figures 2, 3 and 4). The fourth side is bounded by a concrete storage area for a hydrogen gas AST and an Argon gas AST.

The FWSA was used to store hazardous wastes (PCE and TCA waste solvents and aqueous acidic metal cleaning wastes) from at least the early 1980s (and possibly from the late 1960s) until 1991 (BCA, 1999b). The wastes were stored in 55-gallon drums, which were transferred to the area manually on drum carts or by forklift. The average and maximum number of hazardous waste drums stored in the FWSA is not known. Since the facility was (and is) a small quantity generator of hazardous waste, it was restricted to a maximum of 6,000 kg (approximately 25 drums) of accumulation storage. However, hazardous waste manifests from the early to mid-1990s typically show shipments of 5 to 12 drums including 1 to 3 drums of waste solvent. Since the waste generating operations were unchanged from the 1980s to the early 1990s, accumulation of hazardous waste drums was likely unchanged as well (BCA, 1999b). Thus, it is likely that on average one or two drums of waste solvents were stored in the FWSA at any given time. It is not known whether unused solvent drums were ever stored in the FWSA.

The FWSA was moved to the south storage building (small building east of the main building) in 1991 wherein the waste drums were stored on spill containment pallets on a concrete floor. Use of chlorinated solvents for degreasing at Twigg was phased out in the early to mid-1990s and is believed to have been terminated in 1996 when the last waste solvent was shipped off-site.

Figures 13, 14, and 15, prepared by BCA, show the extent of total aliphatic hydrocarbons (chlorinated ethenes and ethanes) in soil at various depths in the vicinity of the FWSA. Figure 16 shows the extent of chlorinated ethenes in soil at the depth of highest concentration. Figure 17 shows the extent of chlorinated ethenes in soil along the line of highest concentration, which coincides with the centerline of the chlorinated ethene solute plume, parallel to the direction of groundwater flow. Figure 18 shows the extent of chlorinated ethanes in soil at the depth of highest concentration. Figure 19 shows the extent of chlorinated ethanes in soil along the line of highest concentration, which coincides with the centerline of two of the three chlorinated ethane solute plumes, parallel to the direction of groundwater flow.

As shown by Figures 16 through 19, and discussed in the next sections, the majority of contamination found immediately below and downgradient from the FWSA consists predominantly of PCE, with only a small amount of 1,1,1-TCA. It is likely that the contamination found in this area resulted from the storage of spent solvents, and process losses

occurring in the former degreasing area (Figure 13) an area 50 feet north in which vapor degreasing is believed to have been performed in the 1960s.

The majority of chlorinated ethenes found in soil north of East South Street likely originated in the FWSA and are predominantly limited to the area beneath and downgradient from the FWSA (Figures 16 and 17). Concentrations of chlorinated ethenes in soil found near the Twigg facility are more than an order of magnitude higher than those of chlorinated ethanes. The highest concentration of VOCs found in soil was 42 mg/kg of PCE in FB-1/MW-1S in 1994. This soil sample was collected in the FWSA on the Twigg property and several soil samples in this area exhibit PCE concentrations greater than 20 mg/kg (30 mg/kg in FB-4/MW-4, 25 mg/kg in FP-21, 31 mg/kg in FP-22, and 24 mg/kg in FP-24; Table 8 and Figures 16 and 17). In contrast, the highest 1,1,1-TCA concentration observed in the vicinity of the FWSA was 1.73 mg/kg in FB-4/MW-4 with the next highest concentration being 0.58 mg/kg (Table 8 and Figures 18 and 19). The highest concentration of 1,1,1-TCA found in soil in the study area was not found near the Twigg facility; it was found in the vicinity of Victory Park, as discussed below (Figures 18 and 19).

4.1.2 Area West of the Main Twigg Manufacturing Building

Based on available data, the area just to the west of the main Twigg manufacturing building contains minor chlorinated ethane constituents and a lesser amount of chlorinated ethenes. The origin of soil contamination found in this area is not clear but it may have resulted from process losses occurring in the western part of the Twigg building. Soil contamination in this area is characterized by low concentrations of chlorinated ethanes and even lower concentrations of chlorinated ethenes (Table 8 and Figures 16 and 18). The highest concentration of 1,1,1-TCA in this area is 2.5 mg/kg at a depth of 19-20.5 feet bgs (Table 8 and Figure 18). The vertical extent of contamination was defined in FB-7 by two samples that returned ND values for the sampling intervals from 29.0-30.5 ft bgs and 34-35.5 ft bgs. 1,1-DCE is associated with the 1,1,1-TCA found in FB-7. Soil sample collected in the boring for MW-3 contains low concentrations of both chlorinated ethenes and chlorinated ethanes with the lower limit of contamination occurring at a depth of about 21 ft bgs (Table 8).

4.1.3 Area Near Victory Park

The highest concentrations of 1,1,1-TCA observed in the vicinity of the Twigg property and the former Harmon-Motive site occur in the vicinity of Victory Park at a concentration of 3 mg/kg at 45 ft bgs in the soil boring drilled for installation of MW-6. Based on the concentrations of 1,1,1-TCA observed in MW-6, it is likely that concentrations of 1,1,1-TCA in this area are greater than 3 mg/kg. Unfortunately, soil samples were not collected from shallower depths in this boring. The contamination found in this area is limited to 1,1,1-TCA and its degradation product 1,1-DCA. No PCE, TCE, or *cis*-1,2-DCE were identified in soils in

this area (Table 8 and Figures 16 through 19). In addition to the 1,1,1-TCA and 1,1-DCA found in this area, 1,1-DCE is likely present in soils in the vicinity of Victory Park as shown by the presence of this compound in groundwater in MW-6 and the fact that 1,1-DCE is a common degradation product of 1,1,1-TCA. However, testing for 1,1-DCE was not conducted for soil samples collected during drilling of MW-6.

The source of soil contamination present in this area is not known. However, based on the distribution of chlorinated ethenes and ethanes in soil and groundwater at the Site, it does not appear that the source of the contamination found in the vicinity of Victory Park is the FWSA but is instead associated with a separate release that did not originate on Twigg property.

4.2 DISTRIBUTION OF VOCs IN GROUNDWATER

The following sections provide a discussion of CAHs found dissolved in groundwater at the Site. Tables 9 and 10 present historic groundwater sampling results. Figures 20 through 37 present figures showing the three-dimensional distribution of groundwater contamination over time from the late 1990s to 2011. Data from groundwater monitoring wells were given the most weight when preparing these figures but where appropriate, soil and discrete-interval groundwater grab samples collected using a Geoprobe® were considered. Monitoring well data are considered the most reliable because they are replicable and represent fixed locations in space within which representative time-series data can be collected.

Based on available data and the distribution of solutes, it appears that there are commingled plumes of chlorinated ethenes and ethanes. It is likely that the chlorinated ethene plume originates on the Twigg property in the vicinity of the FWSA. The origins of the dissolved chlorinated ethane plumes are somewhat more problematic. Based on the distribution of chlorinated ethanes found in soil and groundwater, it appears that there are three areas from which aqueous-phase ethane plumes originate; one beneath and downgradient from the FWSA, one just to the west of the main Twigg manufacturing building, and one in the vicinity of Victory park. The chlorinated, aqueous-phase ethane plume originating in the vicinity of Victory park contains the highest concentrations of chlorinated ethanes observed in the study area.

4.2.1 Distribution of Chlorinated Ethenes In Groundwater

Tables 9 and 10 present historic groundwater sampling results. Figures 20 through 27 show the distribution of total ethenes in groundwater over the period of observation in plan- and cross-sectional views along the centerline of the plume parallel to the direction of groundwater flow (i.e., along section line A to A' on Figure 3). Figure 28 was prepared by BCA and represents the concentration of total chlorinated ethenes over the period from 1996 through 2009 along a transect oriented perpendicular to groundwater flow along cross section B-B' on Figure 3. The total chlorinated ethene concentrations presented on Figures 20 through 27 represent the sum of the concentrations of PCE, TCE, *cis*-1,2-DCE, and VC. To facilitate summation of total

chlorinated ethene concentrations, non-detect values were assumed to be zero (0) and estimated (J-flagged) values were assumed to be accurate. 1,1-dichloroethene is not included in the summation for total chlorinated ethenes because: a) it is not known to have been spilled, and b) because it is not a byproduct associated with the degradation of PCE and TCE. Instead, 1,1-DCE is included in the total chlorinated ethane concentrations displayed on the figures discussed in the next section (Figures 29-36) because it is a byproduct of 1,1,1-TCA degradation.

Figures 20 through 23 present plan view maps showing the disposition of the total chlorinated ethene plume at the depth of maximum observed concentration in 1998/1999, 2004, 2007, and 2011, respectively. As can be seen by these figures, the extent of the ethene plume as defined by the "ND" isopleth has not significantly changed over the period of observation but the total mass dissolved in groundwater has decreased appreciably. The highest concentration of total chlorinated ethenes observed in groundwater in monitoring wells in 1998/1999 was 13,180 µg/L in MW-4. The highest concentration observed in 2011 was 1,201 µg/L in MW-18 which is located near MW-4, but was not installed until 2006. The concentration of total chlorinated ethenes in MW-4 in 2011 was 840 µg/L.

Figures 24 through 27 present cross-sectional views down the centerline of the total chlorinated ethene plume parallel to the direction of groundwater flow. These figures show that the vertical extent of the solute plume has decreased over the period of observation. This coupled with the steady-state plan view configuration of the plume indicates that the total volume of contaminated groundwater has decreased over the period of observation. This coupled with the significantly lower concentrations observed in 2011 versus 1998/1999 indicates that there is a significantly smaller amount of total ethene mass present in groundwater now than there was when the plume was first delineated.

Figures 20 through 27 show the distribution of total chlorinated ethenes dissolved in groundwater and do not differentiate between the individual chlorinated ethenes PCE, TCE, *cis*-1,2-DCE, and VC, all of which have been detected to greater or lesser degrees in groundwater. The individual chlorinated ethenes are considered in more detail in Sections 6, 7, 8, and 9. It should be noted here however that VC was only detected sporadically. This observation, coupled with conclusive proof that *cis*-1,2-DCE that is produced from the degradation of PCE and TCE is degrading, suggests that the degradation pathway for this compound is oxidative rather than reductive. This is discussed further in Sections 6 through 9.

4.2.2 Distribution of Chlorinated Ethanes in Groundwater

Tables 9 and 10 present historic groundwater sampling results. Figures 29 through 37 show the distribution of total ethanes in groundwater over the period of observation in plan- and cross-sectional views along the centerline of the plume parallel to the direction of groundwater flow (i.e., along section line A to A' on Figure 3). Figure 37 was prepared by BCA and represents the concentration of total chlorinated ethanes over the period from 1996 through 2009 along a transect oriented perpendicular to groundwater flow along cross section B-B' on Figure 3. The

total chlorinated ethane concentrations presented on figures 29 through 36 represent the sum of the concentrations of 1,1,1-TCA, 1,1-DCA, CA, and 1,1-DCE. To facilitate summation of total chlorinated ethane concentrations, non-detect values were assumed to be zero (0) and estimated (J-flagged) values were assumed to be accurate. 1,1-dichloroethene is included in the summation of total chlorinated ethanes because it is a byproduct associated with the degradation of 1,1,1-TCA.

Figures 20 through 23 present plan view maps showing the disposition of the total chlorinated ethane plume(s) at the depth of maximum observed concentration in 1998/1999, 2004, 2007, and 2011, respectively. As can be seen by these figures, the extent of the ethane plume(s) as delineated by the “ND” isopleth has not significantly changed over the period of observation but the total mass dissolved in groundwater has decreased appreciably. Also apparent from these figures, especially Figures 31 and 32, which represent later times (i.e., 2007 and 2011, respectively), is that there appear to be three separate points of origin for the chlorinated ethane plumes observed in the study area. This is consistent with the concentrations of total chlorinated ethanes observed in soil (Figures 18 and 19). One of the plumes appears to originate just west of the main Twigg manufacturing building (the “northern plume”), one of the ethane plumes appears to originate in the vicinity of the FWSA (the “FWSA plume”), and one appears to originate in the vicinity of Victory Park (the “Victory Park” plume). The highest concentrations of total chlorinated ethanes observed in groundwater monitoring wells in the study area are associated with the “Victory Park” plume. In 1998/1999 the highest concentration observed in groundwater was 9,513 µg/L in MW-6. The highest concentration observed in groundwater in 2011 was 2,513 µg/L, again in MW-6.

Figures 33 through 26 present cross-sectional views down the centerline of two of the commingled total chlorinated ethane plumes (the “FWSA plume” and the “Victory Park” plume), parallel to the direction of groundwater flow. These figures show that the vertical extent of the solute plume has decreased over the period of observation. This coupled with the plan view configuration of the plume over time indicates that the total volume of contaminated groundwater has decreased over the period of observation. This coupled with the significantly lower concentrations observed in 2011 versus 1998/1999 indicates that there is a significantly smaller amount of total ethane mass present in groundwater now than there was when the plume was first delineated.

Figures 29 through 37 show the distribution of total chlorinated ethanes dissolved in groundwater and do not differentiate between the individual chlorinated ethanes 1,1,1-TCA, 1,1-DCA, and CA or 1,1-DCE, all of which have been detected to greater or lesser degrees in groundwater. The individual chlorinated ethanes are considered in more detail in Sections 6, 7, 8, and 9.

SECTION 5

OVERVIEW OF NATURAL ATTENUATION

This section presents an introduction to the migration and fate of CAHs in the environment with an emphasis on those processes which result in the attenuation and degradation of these materials. Contained in this section is an overview of physical, chemical, and biological processes that work to bring about natural attenuation and how various types of data are used to evaluate the efficacy of this remedial alternative. Various types of data are available to assess the migration, fate, and ultimate degradation of organic compounds in the terrestrial subsurface including time-series contaminant and degradation product data, geochemical data, data derived using molecular biological tools (MBT), and compound-specific isotope analyses (CSIA). The overall approach for evaluating natural attenuation used in this document was first published by the USEPA in 1998 (USEPA, 1998). Since that time the understanding of the environmental fate of CAHs has increased considerably, as have the techniques used to evaluate the efficacy of natural attenuation. The evaluation of natural attenuation presented in the document represents a combination of the approach presented in USEPA (1998) state-of-the-art data analysis techniques that have been developed since that time including MBTs and CSIA.

5.1 OVERVIEW OF NATURAL ATTENUATION

Monitored natural attenuation involves the use of naturally occurring contaminant degrading and dispersing processes combined with environmental monitoring to remediate contaminated groundwater. This remedial approach has emerged in recent years as a plausible remedial strategy for groundwater impacted by VOCs including chlorinated solvents (chlorinated ethenes, ethanes, and methanes) and petroleum hydrocarbons.

Natural attenuation processes such as biodegradation, hydrolysis, dispersion, dilution, sorption, and volatilization affect the fate and transport of dissolved organic contaminants in all hydrologic systems. When these processes are shown to be protective of human health and the environment, and when an adequate monitoring program is in place to document the effectiveness of these processes, they can be used as an exclusive remedy or as a component of an engineered remedy for contaminated groundwater. Monitored natural attenuation is a term that refers specifically to the use of natural attenuation processes as part of overall site remediation. USEPA (1999) defines MNA as follows:

The term "monitored natural attenuation," as used in this Directive, refers to the reliance on natural attenuation processes (within the context of a carefully controlled and monitored site clean-up approach) to achieve site-specific remedial objectives within a time frame that is reasonable compared to that offered by other more active methods. The "natural attenuation processes" that are at work in such a remediation approach include a variety of physical,

chemical, or biological processes that, under favorable conditions, act without human intervention to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in soil or groundwater. These in-situ processes include biodegradation, dispersion, dilution, sorption, volatilization, and chemical or biological stabilization, transformation, or destruction of contaminants.

The goal of any site characterization effort is to understand the fate and transport of the contaminants of concern over time in order to assess any current or potential threat to human health or the environment. Natural attenuation processes are dominant factors in the fate and transport of many contaminants, including chlorinated solvents and petroleum hydrocarbons. Useful guidance documents for evaluating natural attenuation include Wiedemeier *et al.* (1996, 1999, and 2005), USEPA (1998 and 1999), and Wiedemeier and Chapelle (2000).

MNA has the following advantages over other remedial technologies (USEPA, 1998 and Wiedemeier *et al.*, 1999):

- Contaminants are ultimately transformed to innocuous byproducts (e.g., carbon dioxide, organic acids, ethene, and water), not simply transferred to another phase or location within the environment;
- MNA is less energy-intensive than current pump-and-treat technologies and generally more effective in reducing residual contamination;
- The process is nonintrusive and allows continuing use of infrastructure during remediation;
- With the exception of dig and haul, engineered remediation involves attempting to remediate a three-dimensional solute plume with what are effectively one-dimensional treatment points;
- MNA may pose a smaller threat to potential receptors than engineered remedial technologies (which may transfer contaminants to other media during remediation activities); and,
- MNA is less costly than most conventional, engineered remedial technologies.

Potential Disadvantages include (USEPA, 1998 and Wiedemeier *et al.*, 1999):

- Natural attenuation is subject to natural and institutionally induced changes in local hydrogeologic conditions, including changes in groundwater gradients or velocity, hydrogen potential (pH), electron acceptor concentrations, electron donor concentrations, and potential future contaminant releases;
- Aquifer heterogeneity may complicate site characterization, evaluation, and implementation of natural attenuation (as with any remedial strategy for groundwater);
- Time frames for completion of site remediation may be relatively long; and,
- Intermediate products of biodegradation (e.g., VC) may be more toxic than the original contaminant.

The following subsections provide an overview of natural attenuation mechanisms and strategies used to evaluate the importance of natural mechanisms of contaminant degradation.

Biodegradation processes are of special importance to natural attenuation because they ultimately transform toxic contaminants into nontoxic byproducts. Intrinsic bioremediation occurs when indigenous microorganisms work to bring about a reduction in the total mass of contamination in the subsurface without artificial intervention (e.g., the addition of nutrients). Because of the importance of biodegradation, and in order to provide a foundation for interpreting site data, the following subsections review the major natural biodegradation mechanisms that act upon petroleum hydrocarbons and chlorinated solvents in groundwater.

5.1.1 Review of Biodegradation Processes

Microorganisms obtain energy for cell production and maintenance by facilitation of thermodynamically advantageous reduction/oxidation (redox) reactions involving the transfer of electrons from electron donors to available electron acceptors. This results in the oxidation of the electron donor and the reduction of the electron acceptor. The type of reaction affecting a given organic compound depends upon whether the compound is used as an electron acceptor or an electron donor. Electron donors include natural organic carbon, petroleum hydrocarbons, lightly-chlorinated solvents (e.g., VC, DCE, or DCA), and many of the compounds commonly found in landfill leachate. Electron acceptors are elements or compounds that occur in relatively oxidized states, and may include dissolved oxygen, nitrate, Fe(III), sulfate, carbon dioxide, and highly chlorinated solvents (e.g., PCE, TCE, TCA, carbon tetrachloride [CT] and polychlorinated benzenes).

In addition to being controlled by the energy yield of the reaction, the expected sequence of redox processes also is a function of the oxidizing potential of the groundwater. This potential is a measure of the relative tendency of a solution or chemical reaction to accept or transfer electrons. As each subsequent electron acceptor is utilized by microbes, the groundwater becomes more reducing, and the oxidation-reduction potential (ORP) of the water decreases. The main force driving this change in ORP is microbially-mediated redox reactions. ORP can be used as an indicator of which redox reactions may be operating at a site. Environmental conditions and microbial competition ultimately determine which processes will dominate.

5.1.1.1 Mechanisms of Biodegradation for Reduced Organic Carbon

Reduced organic carbon is used as an electron donor during microbial metabolism. Organic compounds that can be utilized include, among many other things, natural organic carbon (leaves, trees, grass, etc.), petroleum hydrocarbons (e.g., gasoline, diesel fuel, crude oil, etc.), vegetable oil, fatty acids, sugars, ethanol, etc. These materials ultimately are completely degraded to carbon dioxide and water. Electron acceptors for these reactions are elements or compounds that occur in relatively oxidized states, and include naturally-occurring materials such as dissolved oxygen, nitrate, iron(III), sulfate, and carbon dioxide (during fermentation) and

anthropogenic compounds such as highly chlorinated compounds including PCE, TCE, TCA, and CT. Dissolved oxygen is utilized first as the preferred electron acceptor. After the dissolved oxygen is consumed, anaerobic microorganisms will oxidize reduced organic carbon using electron acceptors (as available) in the following order of preference: nitrate, ferric iron hydroxide, sulfate, and finally carbon (methanogenesis). If chlorinated compounds are present they will be used as electron acceptors under the same geochemical conditions in which sulfate reduction and methanogenesis occur. Measurable changes in electron acceptor concentrations occur during biodegradation of oxidizable organic carbon such as petroleum hydrocarbons. This results in the formation of the highly reducing conditions that are required for efficient reductive dechlorination.

5.1.1.2 Mechanisms of Chlorinated Solvent Biodegradation

Whereas reduced organic carbon is biodegraded exclusively through use as a primary substrate (electron donor), chlorinated compounds may undergo biodegradation via three different pathways including:

- **Electron Acceptor Reactions.** Use of the chlorinated compound as an electron acceptor during reductive dehalogenation. Occurs under anoxic conditions. Compounds degraded include PCE, TCE, DCE, vinyl chloride, TCA, and CT;
- **Electron Donor Reactions.** Use of the chlorinated compound as an electron donor during oxidative reactions. Occurs under hypoxic or aerobic conditions. Compounds degraded include DCE and VC; PCE, TCE, TCA and CT will not be degraded via this pathway; and,
- **Cometabolism.** This involves degradation resulting from exposure to a catalytic enzyme fortuitously produced during an unrelated process. Compounds degraded include TCE and DCA

At a given site, one or all of these processes may be operating, although at many sites the reductive dehalogenation pathway appears to be the most important degradation mechanism under natural conditions and is the only biological mechanism that degrades the common chlorinated solvents which include PCE, TCE, TCA, and CT. In such cases, biodegradation of chlorinated solvents is an electron-donor-limited process that will occur only under anoxic conditions. Where anthropogenic carbon (e.g., petroleum hydrocarbons, landfill leachate, etc.) is present, it will be used as an electron donor in the reductive dehalogenation pathway.

5.1.1.2.1 Electron Acceptor Reactions (Reductive Dehalogenation)

Under anoxic conditions, biodegradation of highly chlorinated solvents such as PCE, TCE, and TCA usually proceeds through a process called reductive dechlorination or dehalorespiration. In this process, the halogenated hydrocarbon serves as an electron acceptor rather than as a source of carbon, and loses a halogen atom in exchange for a hydrogen atom. If sufficient carbon is present and the reaction sequence is not interrupted by a competing reaction,

biological reductive dechlorination of chlorinated ethenes proceeds in sequential steps from PCE to TCE to *cis*-1,2-DCE to VC to ethene (Figure 38). Dehalogenation of chlorinated ethanes proceeds in sequential steps, from TCA to DCA to CA, and, in some cases, CA to ethane (Figure 39). The reductive dechlorination of CA to ethane has been reported in the peer-review literature but has not been confirmed by repeated, reproducible studies (Scheutz *et al.*, 2011). This is likely because the rapid hydrolysis of CA to ethanol outcompetes the reductive dechlorination reaction of CA to ethane and the majority of CA produced from reductive dechlorination of DCA is hydrolyzed before it can be further reductively dechlorinated. As reductive dechlorination proceeds from PCE or TCA through the sequence to ethene or chloroethane, respectively, the biodegradation rate decreases (Figure 40). Chlorinated methanes also undergo reductive dechlorination. Depending upon environmental conditions, the sequence of reductive dechlorination may be interrupted, with other processes such as aerobic or anaerobic biodegradation or abiotic degradation (e.g., hydrolysis) then acting upon the degradation products including DCE, VC, DCA, and CA (Figures 38 and 39). Also of interest in this study is that the presence of chlorinated ethanes has an inhibitory effect on the reductive dechlorination of chlorinated ethenes and, to a lesser extent, vice versa (Grostern *et al.*, 2009; Sherwood Lollar, 2010). However, the presence of 1,1,1-TCA does not appear to be precluding the occurrence of PCE reductive dechlorination and once the TCA is gone, as it is over much of the area with chlorinated ethene contamination, the reaction will likely no longer be inhibited and degradation rates will likely increase.

During dechlorination of PCE and TCE, all three isomers of DCE theoretically can be produced; however, Bouwer (1994) reports that *cis*-1,2-DCE is a more common intermediate than *trans*-1,2-DCE, and 1,1-DCE is the least prevalent of the three isomers when they are present as degradation products of PCE and TCE degradation. Based on this, and the fact that *cis*-1,2-DCE is produced in trivial quantities, USEPA (1998) came up with a rule of thumb that if *cis*-1,2-DCE comprises more than 80 percent of the DCE isomers, then the DCE is of biological origin. Care must be taken when using this rule of thumb when TCA is found commingled with PCE and TCE because 1,1-DCE is produced during the abiotic degradation of TCA via the coupled hydrolysis/dehydrohalogenation reaction wherein TCA is degraded to acetic acid and 1,1-DCE at a predictable rate based on groundwater temperature and pH.

The effectiveness of reductive dehalogenation depends on the oxidation state of the chlorinated compound. The highly chlorinated (saturated) ethenes PCE and TCE are also the most oxidized, and therefore the most susceptible to reductive dechlorination. Conversely, VC is the least susceptible to reductive dechlorination because it is the least oxidized of the chlorinated ethenes. In general, the rate of reductive dechlorination of chlorinated solvents has been observed to decrease as the degree of chlorination decreases (Figure 39; Vogel and McCarty, 1985; Bouwer, 1994).

In addition to being affected by the degree of chlorination of the compound, reductive dechlorination also can be controlled by the ORP of the groundwater system. For example, dechlorination of PCE and TCE to DCE can proceed under mildly reducing conditions such as denitrification or iron(III) reduction (Vogel *et al.*, 1987; Wei and Finneran, 2011; this is likely

the predominant reaction degrading PCE and TCE at the Site), while the transformation of DCE to VC or the transformation from VC to ethene requires more strongly reducing conditions such as those that were present during the bioremediation pilot testing that took place at the Site (Freedman and Gossett, 1989; DeStefano *et al.*, 1991; De Bruin *et al.*, 1992). Recently, Wei and Finneran (2011), found that the reductive dechlorination of TCE was not inhibited under Fe(III)-reducing conditions and that Fe(III)-reduction may actually aid dechlorination by maintaining hydrogen concentrations at a level most amenable for dechlorination.

5.1.1.2.2 Electron Donor Reactions

Under aerobic or weakly to moderately reducing conditions, some chlorinated compounds can be utilized as an electron donor in biologically mediated redox reactions (McCarty and Semprini, 1994; Bradley and Chapelle [1996, 1997, 1998, and 2011], and Bradley, 2011). In contrast to reactions in which the chlorinated compound is used as an electron acceptor, only the least oxidized chlorinated compounds such as *cis*-1,2-DCE and vinyl chloride may be utilized as electron donors in biologically mediated redox reactions. For example, Davis and Carpenter (1990) describe the aerobic oxidation of vinyl chloride in groundwater. The aerobic oxidation of VC is significantly faster than the reductive dechlorination of VC to ethene under anoxic conditions. McCarty and Semprini (1994) describe investigations in which vinyl chloride and 1,2-DCA were shown to serve as electron donors. In addition, Bradley and Chapelle (1996 and 1997) show evidence of oxidation of VC and DCE under iron-reducing conditions so long as there is sufficient biologically available Fe (III). Bradley and Chapelle (1998) show evidence that DCE can be oxidized under aerobic conditions. The recent work of Bradley and Chapelle (2011) and Bradley (2011) suggests that the *cis*-1,2-DCE that is produced from the reductive dechlorination of PCE and TCE at sites with characteristics similar to this Site, is being degraded via biological oxidation under hypoxic geochemical conditions. In the past, the degradation of PCE or TCE to *cis*-1,2-DCE with no production of VC was thought to indicate that the reaction had “stalled” at *cis*-1,2-DCE; hence the origin of the colloquial term “*cis*-stall.” However, plume stability analyses, including time-series plots of contaminants and daughter products in individual wells and along the flow path, suggested that the *cis*-1,2-DCE was degrading, but via a heretofore unknown reaction. Recent advancements in the use of CSIA have allowed conclusive confirmation that *cis*-1,2-DCE at these sites was degrading and the work of Bradley and Chapelle (2011) and Bradley (2011) suggests that this degradation is the result of biological oxidation to carbon dioxide and water.

5.1.1.2.3 Cometabolism

When a chlorinated solvent is degraded via cometabolism, it serves as neither an electron acceptor or donor in a biologically mediated redox reaction. Instead, the degradation is catalyzed by an enzyme or cofactor that is fortuitously produced by the microorganism for other purposes. The microorganism derives no known benefit from the degradation of the chlorinated solvent, and may in fact be harmed by it (McCarty and Semprini, 1994).

5.1.2 Lines of Evidence Used to Evaluate Natural Attenuation

Multiple distinct but converging lines of evidence have been used in recent years to demonstrate natural attenuation (National Research Council, 1993; Wiedemeier *et al.*, 1996, 1999, and 2005; USEPA, 1998 and 1999; and Wiedemeier and Chapelle, 2000). The most common lines of evidence used to demonstrate natural attenuation of organic compounds dissolved in groundwater include:

- 1) Historical trends in contaminant data showing plume stabilization and/or loss of contaminant mass over time. Involves the use of contaminant and degradation product data.
- 2) Analytical data showing that geochemical conditions are suitable for biodegradation and that active biodegradation has occurred as indicated by the consumption of electron acceptors and/or the production of metabolic byproducts. These chemical and analytical data can include evidence of:
 - a. Depletion of electron acceptors and donors,
 - b. Increasing metabolic byproduct concentrations,
 - c. Decreasing parent compound concentrations, and/or
 - d. Increasing daughter compound concentrations.
- 3) Microbiological data that support the occurrence of biodegradation.

The first line of evidence involves the use of contaminant concentration and degradation product data to evaluate plume behavior and the occurrence of degradation. In addition, CSIA can be useful for determining if degradation is occurring. Plume stability is analyzed using isopleth maps and plots of contaminant concentration or mass fraction versus time and distance downgradient. Contaminant and degradation product data (i.e., the first line of evidence) is evaluated in Section 6. Data from Tables 8, 9, 10, 11, and 12 were used for these analyses. This line of evidence is critical for determining the temporal and spatial behavior of the solute plume(s) and to determine if any exposure pathways exist for current or potential future receptors. It is THWA's understanding that potential exposure pathways have been evaluated by BCA including the groundwater and vapor pathways.

The second line of evidence utilizes chemical and physical data to evaluate the geochemical conditions in the shallow saturated zone to determine if the conditions conducive to contaminant degradation are present. Table 13 presents geochemical data collected at the Site. Unfortunately, historical geochemical data are often contradictory and not physically/chemically possible. For this reason, THWA recommends that a complete set of geochemical data be collected during the next groundwater sampling event. Care be taken to ensure that accurate and plausible data are collected to begin building a statistically significant and defensible database so that an accurate assessment of geochemical conditions at the Site can be made.

Microbiological laboratory data such as some of the relatively new quantitative real-time polymerase chain reaction (qPCR) techniques can be very useful for determining degradation

pathways. These analyses allow assessment of the microbial population present at a site to evaluate the expressed and potential biodegradation mechanisms. Several microbial analyses were performed using subsurface media collected from the Site. The results of these analyses are presented in Table 14 and discussed in Section 8.

SECTION 6

ANALYSIS OF CONTAMINANT AND DEGRADATION PRODUCT DATA

This section presents an evaluation of available contaminant and degradation product concentration data and CSIA for the chlorinated ethenes and ethanes found at the Site. The purpose of this analysis is to determine the behavior of these compounds in time and space and to determine if degradation is occurring.

A statistically significant historical database of contaminant concentration data showing plume stabilization and/or loss of contaminant mass over time is used to evaluate plume behavior over time and to evaluate the efficacy of natural attenuation. This is the fundamental line of evidence for evaluating MNA as a remedial approach. In fact, historical data are important for evaluating any remediation technique. It is important to note that plume stabilization can occur with or without destructive attenuation mechanisms. In some cases, nondestructive mechanisms of natural attenuation such as dispersion, sorption, and volatilization may be sufficient to cause the solute plume to reach steady-state equilibrium, or even recede if the strength of the NAPL source is decreasing due to natural weathering or engineered remediation.

An analysis of solute concentrations in groundwater is of paramount importance when evaluating natural attenuation. This analysis includes the preparation of isopleth maps that show the distribution of solutes over time. In addition, plots of contaminant concentration versus time and concentration versus distance were prepared and evaluated. When solutes degrade via reductive dechlorination they generate degradation products. For example, the presence of *cis*-1,2-DCE in groundwater is conclusive evidence that degradation is occurring.

6.1 EVALUATION OF PLUME BEHAVIOR AND STABILITY USING ISOPLETH MAPS

This section presents an analysis of the behavior of the total chlorinated solvents in soil and groundwater at the Site over time.

6.1.1 Total Chlorinated Ethenes and Ethanes in Soil

Figures 13 through 19 present isopleth maps showing the distribution of total CAHs (Figures 13, 14, and 15), total chlorinated ethenes (Figures 16 and 17), and total chlorinated ethanes (Figures 18 and 19) in soil in plan- and cross-sectional views. Although limited, shallow, soil data were collected in 2008, no time-series data are available that allow determination of the three-dimensional distribution of chlorinated ethenes and ethanes in soil over time. However, based on steadily decreasing aqueous-phase total chlorinated ethene and ethane concentrations at the Site, the concentrations of chlorinated ethenes and ethanes in soil have very likely decreased

over the period of observation. Although SVE has been ongoing at the site since 1999, it is likely that natural processes of contaminant attenuation have removed the most VOC mass from the soil. This is because the majority of the VOC contamination found in soils at the Site is found below the water table (Figures 17 and 19) and inaccessible to SVE. In addition, as shown by Figure 5, the amount of contaminant mass removed by the SVE system largely occurred prior to 2003 as shown by offgas measurements (BCA, 2007). Bioremediation pilot testing and ozone sparging also likely contributed some to reductions in soil VOC concentrations but these systems only impacted a very small area at the site.

6.1.2 Total Chlorinated Ethenes in Groundwater

Figures 20 through 28 present isopleth maps showing the distribution of total chlorinated ethenes in groundwater for the period from 1998/1999 until early 2011. Figures 20 through 27 were prepared by summing the concentrations of PCE, TCE, *cis*-1,2-DCE, *trans*-1,2-DCE, and VC for a given sampling event. For this analysis, non-detect concentrations were assumed to be zero (0) and estimated concentrations that were “J” flagged were assumed to be accurate. If multiple samples were collected for a given time period (e.g., 1998/1999), then the highest total ethene concentration observed during that time was plotted. The isopleths presented on these figures rely predominantly upon monitoring well data. Where appropriate, soil and/or discrete-interval groundwater probe data were given consideration when preparing solute isopleths, but because they do not represent verifiable or reproducible data points, they are not given as much weight as data collected from monitoring wells. Figures 20 through 23 present plan view time-series maps showing the distribution of chlorinated ethenes at the depth of maximum concentration. Figures 24 through 27 present time-series isopleths of total chlorinated ethenes down the centerline of the solute plume, parallel to the direction of groundwater flow, along section line A to A’ (Figure 3). Figure 28 was prepared by BCA and shows the distribution of total chlorinated ethenes along a cross-section oriented perpendicular to the direction of groundwater flow along line of section B to B’ (Figure 3) for the period roughly from 1998 through 2009.

As can be seen from figures 20 through 27, the footprint (i.e., extent) of the total chlorinated ethene plume has not changed significantly over the period of observation but the highest concentrations observed have decreased significantly since about 1998. This indicates that the footprint of the plume is stable, that the plume is not migrating downgradient, and that the total mass of chlorinated ethenes dissolved in groundwater has decreased significantly over the period of observation. By inference, it can be concluded that the total mass of chlorinated ethenes in soil also has decreased over this period of time since the contaminated soil represents the only known source of continuing groundwater contamination. Based on the discussions presented throughout the remainder of this report, this loss of contaminant mass and plume stabilization is due largely to natural attenuation, although significant contaminant mass was removed via SVE prior to 2003 (Figure 5; BCA, 2007), ozone sparging (likely minimal mass removal), and bioremediation pilot testing. These systems are discussed in more detail in Section 2.2.2.

Based on the estimates presented in Section 3 and summarized in Tables 6 and 7, the estimated groundwater seepage velocity at the Site is on the order of 205 feet per year and solute transport velocities for PCE, TCE, *cis*-1,2-DCE, and VC are on the order of 102 ft/yr, 145 ft/yr, 157 ft/yr, and 203 ft/yr respectively. It should be noted that VC has been detected only sporadically at the Site, and only after bioremediation pilot testing was initiated. As will be shown in later discussions, reductive dechlorination is proceeding to *cis*-1,2-DCE and this DCE is then likely being oxidized before VC is produced. This is fairly commonplace in groundwater systems that are hypoxic (Bradley, 2011; Bradley and Chapelle, 2011), as is the case at this Site. This is discussed further throughout the remainder of this document. Using the groundwater seepage velocity, the center of mass and the leading edge of the solute plume should have migrated about 2,500 feet over the period from January 1999 through January 2011. That is, the plume should have effectively *doubled* in size since 1999, yet the extent of the plume has remained stable and maximum observed concentrations have decreased markedly. Using the solute transport velocities summarized in Table 7, the center of mass and the leading edge of the plume should have migrated between about 1,200 feet (PCE) and 1,900 feet (*cis*-1,2-DCE) downgradient between January 1999 and January 2011. The fact that the extent of the plume has remained stable and the leading edge of the plume has not migrated downgradient provides strong evidence that natural attenuation processes are working to degrade contaminants and control plume migration. This is further supported by the fact that the total amount of contaminant mass in the system is significantly less now than it was in 1999, even though the bulk of soil contamination was trapped below the water table and could not be reached by SVE (Figures 16 and 17).

6.1.3 Total Chlorinated Ethanes in Groundwater

Figures 29 through 37 present isopleth maps showing the distribution of total chlorinated ethanes in groundwater for the period from 1998/1999 until early 2011. Figures 29 through 36 were prepared by summing the concentrations of 1,1,1-TCA, 1,1-DCA, CA, and 1,1-DCE for a given sampling event. For this analysis, non-detect concentrations were assumed to be zero (0) and estimated concentrations that were “J” flagged were assumed to be accurate. Measured concentrations of 1,1-DCE are included in the total ethane concentration summation because it is a known degradation product of abiotic 1,1,1-TCA hydrolysis/dehydrohalogenation and is not known to have been used as a solvent at the Site. If multiple samples were collected for a given time period (e.g., 1998/1999), then the highest total ethane concentration observed during that time was plotted. The isopleths presented on these figures rely predominantly upon monitoring well data. Where appropriate, soil and/or discrete-interval groundwater probe data were given consideration when preparing solute isopleths, but because they do not represent verifiable or reproducible data points, they are not given as much weight as data collected from monitoring wells. Figures 29 through 32 present plan view time-series maps showing the distribution of chlorinated ethanes at the depth of maximum concentration. Figures 33 through 36 present time-series isopleths of total chlorinated ethanes down the centerline of the solute plume, parallel to the direction of groundwater flow along section line A to A' (Figure 3). Figure 37 was prepared by BCA and shows the distribution of total chlorinated ethanes along a cross-section oriented

perpendicular to the direction of groundwater flow along line of section B to B' (Figure 3) for the period roughly from 1998 through 2009.

As can be seen from figures 29 through 36, the footprint (i.e., extent) of the total chlorinated ethane plume has significantly decreased over the period of observation and the highest observed concentrations have decreased significantly since about 1998. This indicates that the footprint of the plume is becoming smaller, that the plume is not migrating downgradient, and that the total mass of chlorinated ethanes dissolved in groundwater has decreased significantly over the period of observation. By inference, it can be concluded that the total mass of chlorinated ethanes in soil also has decreased over this period of time since the contaminated soil represents the only known source of continuing groundwater contamination. Based on the discussions presented throughout the remainder of this report, this loss of contaminant mass and plume stabilization is due largely to natural attenuation, although some contaminant mass has been removed via SVE, ozone sparging (mass removal likely minimal), and bioremediation pilot testing (Section 2.2.2). This is further supported by the fact that the total amount of contaminant mass in the system is significantly less now than it was in 1999, even though the bulk of soil contamination was trapped below the water table and could not be reached by SVE (Figures 18 and 19) and the fact that the concentrations of CAHs in the SVE system's offgas became asymptotic near non-detectable concentrations in 2000 (BCA, 2007). In addition, the cumulative mass of PCE and TCA removed by the SVE system became asymptotic at about 1,450 pounds at the end of 2002 and just over 100 pounds, respectively (Figure 5; BCA, 2007).

Based on the estimates presented in Section 3 and summarized in Tables 6 and 7, the estimated groundwater seepage velocity at the Site is on the order of 205 feet per year and solute transport velocities for 1,1,1-TCA, 1,1-DCA, 1,1-DCE, and CA are on the order of 120 ft/yr, 178 ft/yr, 164 ft/yr, and 153 ft/yr respectively. Using the groundwater seepage velocity, the center of mass and the leading edge of the solute plume should have migrated about 2,500 feet over the period from January 1999 through January 2011. That is, the plume should have effectively *doubled* in size since 1999, yet the extent of the plume has remained stable and maximum observed concentrations have decreased markedly. Using the solute transport velocities summarized in Table 7, the center of mass and the leading edge of the plume should have migrated between about 1,400 feet (1,1,1-TCA) and 2,100 feet (1,1-DCA) downgradient between January 1999 and January 2011. The fact that the extent of the plume has remained stable and the leading edge of the plume has not migrated downgradient provides strong evidence that natural attenuation processes are working to degrade contaminants and control plume migration. Furthermore, the fact that the total amount of contaminant mass in the system is significantly less now than it was in 1999, even though the bulk of soil contamination was trapped below the water table and could not be reached by SVE (Figures 18 and 19). That natural attenuation is the dominant processes working to reduce the mass of chlorinated ethanes in groundwater is further supported by the fact that the SVE system and upgradient bioremediation pilot testing systems are located on Twigg property, at least 1,500 feet upgradient of the highest concentrations of 1,1,1-TCA observed in soil and groundwater in the study area. This being the case, the remediation efforts completed to date have had minimal, if any, impact on the disposition of the main portion of the chlorinated ethane plume which appears to originate in the vicinity of Victory Park.

6.2 EVALUATION OF PLUME STABILITY AND BEHAVIOR USING PLOTS OF CONCENTRATION VERSUS DISTANCE

This section presents a graphical evaluation of plume behavior using plots of total chlorinated ethenes and total chlorinated ethanes along the flowpath at different times. Figure 3 shows the line of section along which these plots were made. The wells along this flowpath used in this analysis were chosen because they are situated along the centerline of the plume based on available data. This analysis includes an analysis for total chlorinated ethenes and ethanes and also an analysis for each of the individual chlorinated ethenes and ethanes found in the Site vicinity. This analysis shows that both the mass and concentrations of CAH constituents in soil and groundwater have been significantly reduced since groundwater monitoring began in 1998. These reductions in contaminant mass and concentration are brought about by a combination of natural attenuation and targeted remediation activities, as discussed further below.

6.2.1 Plots of Total Chlorinated Ethene and Ethane Concentrations Along the Flowpath over Time

Figures 41 and 42 present plots of total chlorinated ethenes and total chlorinated ethanes along the flowpath down the centerline of the plume, respectively. Figure 3 shows the line of section along which these plots were made.

6.2.2 Plots of Concentration versus Distance Downgradient over Time for Total Chlorinated Ethenes

Figure 41 is a plot of total chlorinated ethene concentrations along the flowpath (line of section A-A' on Figure 3) for those time periods from 1998 through 2011 where sufficient data are available. This figure was prepared by summing the concentrations of PCE, TCE, *cis*-1,2-DCE, *trans*-1,2-DCE, and VC for a given sampling event. For this analysis, non-detect concentrations were assumed to be zero (0) and estimated concentrations that were "J" flagged were assumed to be accurate.

Figure 41 shows the following:

- 1) Total chlorinated ethene solute concentrations have decreased fairly steadily over the period of observation;
- 2) The chlorinated ethene plume is anchored at and just downgradient from the FWSA, near MW-4. This is consistent with the soil data shown on Figures 16 and 17, and;
- 3) Total chlorinated ethene concentrations decrease fairly rapidly along the groundwater flow path and by the time groundwater reaches MW-6, the total chlorinated ethene plume has been almost completely degraded. This decrease occurs both with and without remediation activities which were not initiated until November 1999. Thus, the plots for 1998 (June) and 1999 (July) show the behavior of the total ethene plume

along the flowpath prior to initiation of any remediation activities (Section 2.2.2). In addition, the soil contamination observed in the 1990's shown on Figures 16 and 17 in the vicinity of MW-4, the area where the highest chlorinated ethene concentrations in groundwater have originated over the period of observation, has been only minimally impacted by remediation activities that have been performed on the Twigg property. This is because: 1) the SVE system only removes contaminant mass above the water table; 2) the ozone introduced into the aquifer was only stable for a period of minutes to hours and was injected some 350 feet upgradient from MW-4, and; 3) the bioremediation pilot testing system was a recirculation system so that the only organic carbon that would have migrated to the vicinity of MW-4 would have been organic carbon that "escaped" the recirculation cell during periods of system shutdown. Thus, the vast majority of contaminant mass being removed from the system is likely being removed through the mechanisms of natural attenuation.

6.2.2.1 Plots of Concentration versus Distance Downgradient over Time for Total Chlorinated Ethanes

Figure 42 is a plot of total chlorinated ethane concentrations along the flowpath (line of section A-A' on Figure 3) for those time periods from 1998 through 2011 where sufficient data are available. This figure was prepared by summing the concentrations of 1,1,1-TCA, 1,1-DCA, CA, and 1,1-DCE for a given sampling event. For this analysis, non-detect concentrations were assumed to be zero (0) and estimated concentrations that were "J" flagged were assumed to be accurate. Measured concentrations of 1,1-DCE are included in the total ethane concentration summation because it is a known degradation product of abiotic 1,1,1-TCA hydrolysis/dehydrohalogenation and is not known to have been used as a solvent at the Site.

Figure 42 shows the following:

- 1) Total chlorinated ethane solute concentrations have decreased fairly steadily over the period of observation;
- 2) That portion of the chlorinated ethane plume with the highest concentrations appears to be anchored near Victory Park, near MW-6, and not beneath the Twigg property or near the FWSA. This is consistent with the soil data shown on Figures 18 and 19 and suggests that spills on the Twigg property are not the main source of total chlorinated ethanes found in soil and groundwater in the study area, and;
- 3) Total chlorinated ethane concentrations decrease fairly rapidly along the groundwater flow path and by the time the groundwater migrates from MW-6 to MW-8, the total chlorinated ethane plume is almost completely degraded. Of note is that the concentrations of chlorinated ethanes in well MW-8 increased over the period from about 1998 through 2007 (total ethane concentration 1,085 µg/L in 2007) but appears to have stabilized and may be decreasing (total ethane concentration 346 µg/L in 2011). Because the origin of the ethane plume is a significant distance downgradient from the Twigg facility where the majority of remediation activities have occurred, it

is not likely that remediation activities occurring on the Twigg property are having a significant effect on the migration and fate of the total chlorinated ethanes that originate near Victory park and migrate downgradient from there. Thus, the vast majority of chlorinated ethane mass is being removed by natural processes of contaminant attenuation. The exception to this is contaminant mass being removed by the bioremediation pilot testing which occurred in the vicinity of MW-8 starting in August 2006 (Section 2.2.2.3). However, the bulk of chlorinated ethane mass that originates in the vicinity of Victory Park (near MW-6), is completely degraded by the time the groundwater flows from MW-6 to MW-8, so the bioremediation pilot testing activities that occurred in the vicinity of MW-8 likely removed only a trivial amount of contaminant mass compared to that being removed through natural attenuation. In addition, bioremediation pilot testing in the vicinity of MW-8 was only conducted from August 2006 through August 2007 and the hydrogeologic system was anoxic and reductive dechlorination of 1,1,1-TCA was occurring prior to this pilot testing as shown by the molar fraction analysis for the chlorinated ethanes presented in the next section and the geochemistry at the Site (Section 7).

6.2.3 Plots of Individual Chlorinated Ethene and Chlorinated Ethane Concentrations Along the Flowpath over Time

Plots of the individual chlorinated ethenes and chlorinated ethanes along the flowpath for different periods of time are presented in this section. Included in these figures are plots of concentration versus distance and plots of molar fraction versus distance along the flowpath. The plots of concentration versus distance give an indication of the behavior of the various solutes as they move downgradient along the flowpath. The plots of molar fraction versus distance allow an assessment of the occurrence of degradation and in the case of the chlorinated ethanes, degradation mechanisms. These aid in the assessment of the efficacy of natural attenuation over time and space.

6.2.3.1 Plots of Concentration versus Distance Downgradient over Time for Individual Chlorinated Ethenes

Figures 43 through 46 present plots of the concentrations (A) and molar fractions (B) of individual chlorinated ethenes along the flowpath presented on Figure 3 for July 1999, December 2003/January 2004, October 2007, and January/February 2011, respectively. These figures were prepared using the concentrations of PCE, TCE, *cis*-1,2-DCE, *trans*-1,2-DCE, and VC for a given sampling event. For this analysis, non-detect concentrations were assumed to be zero (0) and estimated concentrations that were "J" flagged were assumed to be accurate. Figure 43 extends from MW-1S to MW-8 because the highest concentrations of chlorinated ethenes observed at the Site were seen in July 1999. In order to focus on the area with the highest concentrations of chlorinated ethenes, Figures 44 through 46 run from MW-1S to MW-6. THWA believes that this is appropriate because the vast majority of chlorinated ethene mass

dissolved in groundwater is present upgradient from Victory Park (i.e., MW-6/MW-6D; Figures 20 through 27 and Figure 41).

Figures 43 through 46 show the following:

- 1) The aqueous concentrations of individual chlorinated ethenes have decreased over the period of observation both along the flowpath and in individual wells. For example, the maximum concentration of PCE observed in MW-4 was 13,000 µg/L in July 1999, 5,500 µg/L in January 2004, 3,070 µg/L in October 2007, and 805 µg/L in February 2011;
- 2) The chlorinated ethene plume is anchored at and just downgradient from the FWSA, near MW-4. This is consistent with the soil data from the 1990's shown on Figures 16 and 17, and;
- 3) Chlorinated ethene concentrations decrease fairly rapidly along the groundwater flow path. In the time it takes for groundwater to migrate from MW-4 to MW-6, the chlorinated ethene plume has been almost completely degraded. This decrease occurs both with and without remediation activities which were not initiated until November 1999. Thus, the plots for July 1999 show the behavior of the chlorinated ethenes along the flowpath prior to initiation of any remediation activities (Section 2.2.2). In addition, the soil contamination observed in the 1990's shown on Figures 16 and 17 in the vicinity of MW-4, has been only minimally impacted by remediation activities that have been performed on the Twigg property. This is because: 1) the SVE system only removes contaminant mass above the water table; 2) the ozone introduced into the aquifer during ozone sparging was only stable for a period of minutes to hours and was injected some 350 feet upgradient from MW-4, and; 3) the bioremediation pilot testing system was a recirculation system so that the only injected organic carbon that would have migrated to the vicinity of MW-4 would have been that carbon that "escaped" the recirculation cell, either because of system design inefficiencies or during periods of system shutdown. Thus, the vast majority of contaminant mass being removed from the system is likely being removed through the mechanisms of natural attenuation.
- 4) The changes in the molar fractions of PCE (parent compound) and its degradation products TCE and *cis*-1,2-DCE, coupled with decreasing solute concentrations along the flowpath confirm intrinsic bioremediation (i.e., natural biodegradation) of the chlorinated ethenes. Specifically, the decrease in the molar fraction of PCE accompanied by an increase in the molar fraction of the degradation product *cis*-1,2-DCE along the flowpath confirms degradation via reductive dechlorination. The molar fraction of TCE also likely increases and then decreases along the flowpath between wells MW-4 and MW-6 but the reaction is too fast and the well spacing too great to see this increase. The lack of VC and the lack of *cis*-1,2-DCE accumulation confirms that the *cis*-1,2-DCE also is degrading, likely through oxidative biological degradation mechanisms (McCarty and Semprini, 1994; Bradley and Chapelle [1996, 1997, 1998, and 2011], and Bradley, 2011). These observations are confirmed by

CSIA (Section 6.4) and the molecular biological analyses conducted at the Site (Section 8). In addition, the geochemistry at the site is generally anoxic, conditions that are conducive to the degradation pathways observed at the Site (Section 7).

6.2.3.2 Plots of Concentration versus Distance Downgradient over Time for Individual Chlorinated Ethanes

Figures 47 through 50 present plots of the concentrations (A) and molar fractions (B) of individual chlorinated ethanes along the flowpath presented on Figure 3 for July 1999, December 2003/January 2004, October 2007, and January/February 2011. These figures were prepared using the concentrations of 1,1,1-TCA, 1,1-DCA, CA, and 1,1-DCE for a given sampling event. For this analysis, non-detect concentrations were assumed to be zero (0) and estimated concentrations that were “J” flagged were assumed to be accurate. Measured concentrations of 1,1-DCE are included in the total ethane concentration summation because it is a known degradation product of abiotic 1,1,1-TCA hydrolysis/dehydrohalogenation and is not known to have been used as a solvent at the Site. In order to focus on the area with the highest concentrations of chlorinated ethanes, Figures 47 through 50 run from MW-6 to MW-8. THWA believes that this is appropriate because the highest concentrations of chlorinated ethanes originate in the vicinity of Victory Park (i.e., MW-6/MW-6D; Figures 29 through 36 and Figure 42).

Figures 47 through 50 show the following:

- 1) The aqueous concentrations of individual chlorinated ethanes have decreased over the period of observation both along the flowpath and in individual wells. For example, the maximum concentration of 1,1,1-TCA observed in MW-6 was 9,100 µg/L in July 1999, 6,800 µg/L in January 2004, 6,160 µg/L in October 2007, and 2,360 µg/L in February 2011. Note that there appear to be three distinct sources (i.e., flowpath “starting points”) for chlorinated ethanes in groundwater;
- 2) That portion of the chlorinated ethane plume with the highest concentrations appears to be anchored near Victory Park, near MW-6, and not on the Twigg property or near the FWSA. This is consistent with the soil data shown on Figures 18 and 19 and suggests that spills on the Twigg property are not the main source of total chlorinated ethanes found in soil and groundwater in the study area, and;
- 3) Chlorinated ethane concentrations decrease fairly rapidly along the groundwater flow path. In the time it takes for groundwater to migrate from MW-6 to MW-8, the chlorinated ethane plume has been almost completely degraded. Because the origin of the ethane plume is a significant distance downgradient from the Twigg facility where the majority of remediation activities have occurred, it is not likely that remediation activities occurring on the Twigg property are having a significant effect on the migration and fate of the total chlorinated ethanes that originate near Victory park and migrate downgradient. The exception to this is the bioremediation pilot testing which occurred in the vicinity of MW-8 from August 2006 until August 2007 (Section

2.2.2.3). However, as discussed in Section 6.2.2.1, the amount of ethane mass removed by pilot testing activities is likely small compared to that removed via natural attenuation.

- 4) The changes in the molar fractions of 1,1,1-TCA (parent compound) and its degradation products 1,1-DCA, CA, and 1,1-DCE, coupled with decreasing solute concentrations along the flowpath confirm intrinsic bioremediation (i.e., natural biodegradation) and a relatively minor amount of hydrolysis/dehydrohalogenation of the chlorinated ethanes. Specifically, the decrease in the molar fraction of 1,1,1-TCA accompanied by an increase in the molar fraction of the degradation product 1,1-DCA along the flowpath confirms degradation. The relative proportion of the molar fractions of 1,1-DCA and 1,1-DCE strongly suggest that the majority of 1,1,1-TCA mass is being removed via reductive dechlorination and not by hydrolysis. The general lack of CA until initiation of bioremediation pilot testing activities in the vicinity of MW-8 suggests that the majority of 1,1-DCA removal along the flowpath is being accomplished via an oxidative pathway. These observations are confirmed by CSIA (Section 6.4) and the molecular biological analyses conducted at the Site (Section 8). In addition, the geochemistry at the site is generally anoxic, conditions that are conducive to the degradation pathways observed at the Site (Section 7).

6.3 EVALUATION OF PLUME STABILITY AND BEHAVIOR USING PLOTS OF CONCENTRATION VERSUS TIME IN INDIVIDUAL WELLS

Plots of solute concentrations versus time are useful for assessing the behavior of a solute plume over time. Figures 51 through 61 present plots of PCE, TCE, cis-1,2-DCE, VC (rarely detected), 1,1,1-TCA, 1,1-DCA, CA, and 1,1-DCE over time for wells with significant detectable concentrations of one or more of these compounds. Figures 51 and 52 present plots of solute concentration versus time for wells along the flowpath identified on Figure 3. Figures 53 through 61 present plots of concentration versus time for monitoring wells MW-3, MW-10S, MW-11, MW-12, MW-15, MW-16, MW-17, MW-18, and MW-19, respectively. Because the purpose of this document is to evaluate natural processes of contaminant attenuation and degradation, and because of their proximity to wells that were included in this analysis, those wells installed for the express purpose of facilitating bioremediation pilot testing (i.e., the PMW and PBW series wells) were not included in this analysis of solute concentration trends over time. Table 11 summarizes the concentration trends over time for chlorinated ethenes and ethanes in individual wells.

As shown by Figures 51 through 61 and as summarized in Table 11, the majority of the monitoring wells at the site exhibit decreasing concentration trends. The exceptions to this are the stable concentrations observed in MW-6, MW-8, MW-11, and MW-16, and the stable to potentially slightly increasing trends in chlorinated ethene concentrations in MW-12.

Of note in the concentration versus time analysis for individual wells are the temporal variations in solute concentrations in MW-12 (ethenes) and MW-8 (ethanes).

For MW-12 the concentration of PCE increased about 60% over the period from 10/13/06 (37.7 µg/L) to 10/25/2007 (63.6 µg/L). However, the concentration of this compound has been stable over the past two sampling events (10/25/07 and 2/8/11) with a PCE concentration of 60.1 µg/L in 2011. Future groundwater sampling should be used to ascertain what is happening in this well.

The concentration of 1,1,1-TCA started a steady increase in MW-8 in June 2006 (45 µg/L) and stabilized in October 2007 at a concentration of 209 µg/L. The concentration of 1,1,1-TCA was 220 µg/L on January 31, 2011. The observed increases in 1,1,1-TCA concentration in this well roughly coincide with the onset of bioremediation pilot testing in this area. It is not clear if this pilot testing resulted in the solubilization of additional 1,1,1-TCA since 1,1,1-TCA was detected in soil in the boring for this well in 1997. Future groundwater sampling should be used to ascertain what is happening in this well.

6.4 EVALUATION OF COMPOUND-SPECIFIC ISOTOPE ANALYSES

Compound-specific isotope analysis (CSIA) is an analytical technique used to generate isotopic characterization of individual compounds via gas chromatography-isotope ratio mass spectrometry (GC/IRMS). Isotopic measurements of carbon, hydrogen, oxygen, sulfur, and chlorine can be useful for environmental engineering applications.

During the last decade, quantification of the amount of isotopic fractionation as an indicator of microbiological and chemical transformations (i.e., degradation) of contaminants in groundwater has gained widespread acceptance (USEPA, 2008). Because of the lower bond energy, bacteria preferentially attack chemical bonds containing ^{12}C , thus the remaining material becomes preferentially enriched in ^{13}C . This enrichment in ^{13}C over time or along the flowpath can be detected by modern analytical equipment. In these isotope applications, it has been generally presumed that physical transport processes in groundwater have a negligible effect on isotopic enrichment because isotopic enrichment in the subsurface environment requires the breaking of a chemical bond (Aelion *et al.*, 2010).

The isotopic composition of a sample is generally reported as a deviation of the isotope ratio of a sample from that of the isotope ratio of a reference standard. This deviation is described mathematically as a "del" value (δ) which is defined as:

$$\delta^A X = \frac{(R_{\text{sample}} - R_{\text{std}})}{R_{\text{std}}} \times 1000$$

Where: $\delta^A X$ = Isotope ratio relative to standard ($^{\circ}/_{\text{oo}}$, parts per thousand or "per mil")

R_{sample} = the absolute isotope ratio of the sample = (concentration of heavier isotope)/(concentration of lighter isotope) in the sample

R_{std} = the absolute isotope ratio of the standard = (concentration of heavier isotope)/(concentration of lighter isotope) in the standard

For the commonly measured carbon isotopes,

$$R_{sample} = \left(\frac{[^{13}\text{C}]}{[^{12}\text{C}]} \right)_{sample}$$

$$R_{std} = \left(\frac{[^{13}\text{C}]}{[^{12}\text{C}]} \right)_{VPDB} = 0.011180$$

Multiplying by 1,000 allows the values to be expressed in parts per thousand or parts per "mil" which is expressed as ‰.

A $\delta^{13}\text{C}$ value of 0‰ corresponds to a sample with an isotope ratio that is equal to that of the standard. If $\delta^{13}\text{C}$ is a positive number, then the sample has a greater amount of the heavier isotope than does the standard. For example, a $\delta^{13}\text{C}$ value of +10‰ corresponds to a sample with an isotope ratio that is 10 parts per thousand or 1% higher than that of the standard. Most $\delta^{13}\text{C}$ values measured from subsurface spills are negative; thus, the less negative the $\delta^{13}\text{C}$ value becomes, the more enriched the material is in ^{13}C . For example, a change in the $\delta^{13}\text{C}$ value from -28‰ to -18‰ is indicative of an enrichment in ^{13}C compared to ^{12}C (i.e., an increase in the concentration of ^{13}C) and in typical subsurface environments is conclusive proof that chemical bonds have been broken and that degradation has occurred.

6.4.1 Analysis of Chlorinated Ethene Degradation Using CSIA

Table 12 presents CSIA data for chlorinated ethenes. Figures 62 and 63 present plots of the concentration and $\delta^{13}\text{C}$ value (A) and molar fraction and $\delta^{13}\text{C}$ value (B) of chlorinated ethenes versus distance along the groundwater flow path for April 2010 and January/February 2011, respectively. The data presented in Table 12 and Figures 62 and 63 provide conclusive evidence for degradation of chlorinated ethenes along the groundwater flowpath. Figures 62 and 63 show that the area impacted by bioremediation pilot testing in the vicinity of PMW-1 is limited to the immediate vicinity of the pilot test location. The impact of the bioremediation pilot testing is shown by the decrease in PCE concentration and increase in *cis*-1,2-DCE concentration coupled with the increases in $\delta^{13}\text{C}$ values for PCE, TCE, and *cis*-1,2-DCE from MW-1S/MW-13 to PMW-1 to MW-14. The impact of bioremediation pilot testing operations is absent by the time groundwater reaches MW-4 as shown by the decrease in *cis*-1,2-DCE concentrations, and decrease in $\delta^{13}\text{C}$ values for PCE, TCE, and *cis*-1,2-DCE between MW-14 and MW-4. The limited influence of the bioremediation pilot testing is also evidenced by the fact that the $\delta^{13}\text{C}$ values are essentially "reset" at MW-4. That is, the $\delta^{13}\text{C}$ values decrease to a value that is close

to the value observed upgradient from the bioremediation pilot testing system (MW-1S/MW-13). Downgradient from MW-4, where the center of mass of the chlorinated ethene plume is anchored and the highest chlorinated ethene concentrations are observed, the vast majority, if not all, of the PCE, TCE, and *cis*-1,2-DCE degradation is likely the result of natural biodegradation. Based on the flow path analyses presented in this report, PCE is entirely degraded between MW-19 and MW-6, as is the majority of any TCE and *cis*-1,2-DCE produced from the degradation of PCE.

6.4.2 Analysis of Chlorinated Ethane Degradation Using CSIA

Table 12 presents CSIA data for chlorinated ethanes. Figures 64 and 65 present plots of the concentration and $\delta^{13}\text{C}$ value (A) and molar fraction and $\delta^{13}\text{C}$ value (B) of chlorinated ethanes versus distance along the groundwater flow path for April 2010 and January/February 2011, respectively. The data presented in Table 12 and Figures 64 and 65 provide strong evidence for degradation of chlorinated ethanes along the groundwater flowpath from MW-6 to PBW-3.

The molar fraction plots for 1,1-DCE and CA in the upgradient portions of the plume are somewhat confusing and misleading because 1) The chlorinated ethanes present in groundwater upgradient from MW-19 and those in the vicinity of MW-6 are likely from two distinct areas of soil contamination, and 2) no 1,1,1-TCA is present in concentrations above the detection limit in MW-13, PMW-1, or MW-14. For this reason, Figures 64 and 65 present the data as though there were two starting points.

As shown by Figures 64 and 65, significant concentrations of 1,1,1-TCA, 1,1-DCA, and 1,1-DCE are not present along the flowpath until MW-6. Based on discussions presented in Section 4, this is where the main source of chlorinated ethane contamination appears to be present (i.e., beneath Victory Park). Downgradient from MW-6, the increase in the molar fraction of 1,1-DCA compared to the molar fraction of 1,1-DCE, suggests that the majority of 1,1,1-TCA degradation between MW-6 and MW-8 is the result of biodegradation.

The majority of the 1,1,1-TCA degradation occurring between MW-6 and PBW-3 is the result of natural degradation mechanisms including intrinsic biodegradation and abiotic hydrolysis coupled with dehydrohalogenation. This is supported by the lack of active remediation systems between MW-6 and PBW-3 and the historic change in 1,1,1-TCA concentrations along the flowpath. The impact of the bioremediation pilot testing system on the removal of contaminant mass between MW-6 and PBW-3/MW-8 is considered trivial compared to natural attenuation because the concentration/mass of 1,1,1-TCA in groundwater is already significantly reduced by natural processes by the time 1,1,1-TCA-laden groundwater travels from MW-6 to PBW-3/MW-8. The shift in $\delta^{13}\text{C}$ value for 1,1,1-TCA between PBW-3 and MW-8 observed in 2011, and to a lesser extent, 2010, is somewhat perplexing and additional monitoring should be conducted in the vicinity of MW-8 to ascertain the cause of this shift. This shift may be a relic from bioremediation pilot testing and long-term monitoring will help determine what is occurring in this portion of the Site.

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SECTION 7

ANALYSIS OF GEOCHEMICAL DATA

An evaluation of geochemical conditions is important when evaluating the degradation of CAHs because the degradation of these compounds is dependent upon the prevailing biogeochemistry of the groundwater in which the solute plume resides.

Table 13 presents available geochemical data for the Site. Unfortunately, the geochemical data available for the Site often are contradictory and in some cases, not possible. Available geochemical data do not correlate with operant degradation mechanisms that are confirmed by concentration trends along the flowpath and in individual wells, by molar fraction plots of individual compounds along the flowpath, by CSIA which clearly show that degradation is occurring and by microbiological data (Section 8). The reasons for these contradictions are not clear but are likely related to sampling technique or meter malfunction. Care should be taken during the collection of future geochemical data.

The obvious discrepancies in the geochemical data makes a detailed analysis of geochemical conditions difficult at best. For example, the geochemistry in PBW-1 measured on 10/20/2005 indicates a dissolved oxygen concentration of 3.4 mg/L, a ferrous iron [Fe(II)] concentration of 29.8 mg/L, a methane concentration of 3.98 mg/L, and an ORP of -260 millivolts (mV). This groundwater geochemistry is not possible, nor is the dissolved oxygen concentration of 0.2 mg/L coupled with the presence of methane and an ORP of 310.8 mV observed in MW-6 in February 2011 or the dissolved oxygen concentration of 1.5 mg/L coupled with the methane concentration of 5.8 mg/L observed in MW-14 on 10/20/2005. Similar examples of incorrect geochemical data exist throughout Table 13.

In spite of the problems with the geochemical data presented in Table 13, the area impacted by CAHs appears to be generally anoxic (Figure 66). Furthermore, the detections of methane in groundwater both in areas that were and were not subjected to bioremediation pilot testing and the distribution of contaminants and degradation products, CSIA confirming degradation that is known to occur only under anoxic conditions, and available molecular biological data, suggest that the majority of the Site impacted by CAHs is anoxic and capable of facilitating natural attenuation via contaminant degradation.

As discussed in Section 5, the degradation of chlorinated ethenes and ethanes can occur through a myriad of mechanisms including complete biological reductive dechlorination (dehalorespiration; applies to chlorinated ethenes and ethanes), partial biological reductive dechlorination with biological oxidation or hydrolysis of degradation products, and for 1,1,1-TCA, abiotic hydrolysis coupled with dehydrohalogenation. All of these reactions, to a greater or lesser extent, are dependent upon the prevailing geochemistry at a site and appear to be occurring at this site.

The complete biological reductive dechlorination of PCE, TCE, and *cis*-1,2-DCE, to VC and then ethene occurs when the prevailing geochemistry of the aquifer is sulfate reducing or methanogenic. When this is the case, VC tends to accumulate in groundwater because the degradation rate decreases as the reaction proceeds from $\text{PCE} \rightarrow \text{TCE} \rightarrow \text{cis-1,2-DCE} \rightarrow \text{VC} \rightarrow \text{ethene}$. Limited complete reductive dechlorination to VC and ethene was accomplished during the bioremediation pilot testing that was conducted in the vicinity of the FWSA. Conversely, reductive dechlorination of PCE to TCE to *cis*-1,2-DCE followed by biological oxidation of the *cis*-1,2-DCE to carbon dioxide and water with no production of VC occurs under anoxic conditions (Bradley and Chapelle, 1997; Bradley, 2011; Bradley and Chapelle, 2011). Furthermore, it is now known that iron reduction does not compete with reductive dechlorination to the extent it was once thought; if at all (Wei and Finneran, 2011). This suggests that efficient reductive dechlorination of PCE and TCE to *cis*-1,2-DCE can occur under only mildly reducing (hypoxic) conditions. Based on the geochemical data available for the Site, concentration and molar fraction trends, and CSIA, it appears that under ambient aquifer conditions, PCE is degrading to TCE and then to *cis*-1,2-DCE via reductive dechlorination. The produced *cis*-1,2-DCE is then likely being biologically oxidized to carbon dioxide and water. This degradation pathway has several advantages over the complete reductive dechlorination pathway under which VC tends to accumulate under strongly anoxic conditions because the oxidation of *cis*-1,2-DCE precludes the production of VC. Production of VC appears to be limited to those areas where pilot testing of chlorinated ethene biostimulation was conducted and methanogenic conditions were generated. One drawback to enhanced bioremediation at this Site would be the likely accumulation of VC. The accumulation of VC would occur because the strongly reducing conditions created by enhanced bioremediation would preclude the oxidation of *cis*-1,2-DCE and encourage reductive dechlorination of *cis*-1,2-DCE to VC through reductive dechlorination. That this would happen if sufficient carbon is added to the system is evidenced by the production of limited quantities of VC during pilot testing and the presence of bacteria capable of complete reductive dechlorination of PCE to VC and ethene (i.e., *Dehalococcoides* sp.; Section 8).

The biological reductive dechlorination of 1,1,1-TCA to 1,1-DCA and then to chloroethane occurs under anoxic conditions. Unlike the complete biological reductive dechlorination of chlorinated ethenes, there are abiotic degradation reactions that compete with biological reductive dechlorination of chlorinated ethanes. For example, at least some of the 1,1,1-TCA present in groundwater will be degraded by the coupled abiotic hydrolysis/dehydrohalogenation to acetic acid (80%) and 1,1-DCE (20%). Chloroethane produced by reductive dechlorination is rapidly hydrolyzed to ethanol and hydrochloric acid (HCl) which is likely why reductive dechlorination of CA to ethane is rarely observed. The ethanol produced from the hydrolysis of CA is then further hydrolyzed to acetic acid. Based on the geochemical data available for the Site, concentration and molar fraction trends, and CSIA, it appears that 1,1,1-TCA is degrading via a combination of biological reductive dechlorination and abiotic hydrolysis/dehydrohalogenation.

SECTION 8

ANALYSIS OF MICROBIOLOGICAL DATA

This section presents available microbiological data for the Site, which are presented in Table 14. These data were collected to help evaluate the potential for enhanced bioremediation, and to help elucidate degradation pathways. Based on the previous data presented in this report including the distribution of contaminants and degradation products over time and space, CSIA data confirming degradation, and groundwater geochemical data, it is clear that chlorinated ethenes and ethanes at, and downgradient from, the Twigg manufacturing facility are being attenuated by naturally occurring degradation mechanisms. To help assess the efficacy of enhanced bioremediation at the Site, in September 2010, the identification of the presence or absence of the genes of the following bacterium was undertaken: *Dehalococcoides*, *Dehalococcoides* functional genes (*tceA*, *bcrA*, and *vcrA*), *Dehalobacter*, methane oxidizing bacteria, and soluble methane monooxygenase. These data were collected using *quantitative real-time polymerase chain reaction* (qPCR) analyses. These reactions are used in molecular biology to amplify and simultaneously quantify a targeted DNA molecule. This technique allows both detection and quantification as an absolute number of gene copies or relative amounts of specific DNA compared to normalized DNA input. *Quantitative real-time polymerase chain reaction* assays can be developed to quantify specific organisms capable of degrading contaminants.

8.1 DECHLORINATING BACTERIA

As shown by Table 15, there are several genera of bacteria that will reductively dechlorinate chlorinated ethenes including *Dehalobacter*, *Dehalospirillum* (*Sulfospirillum*), *Dehalococcoides*, *Desulfitobacterium*, and *Clostridium*. Many of these bacteria will also degrade chlorinated ethanes. Of the genera listed in Table 15, only *Dehalococcoides* spp. will completely dechlorinate tetrachloroethene (PCE) to ethene and not all species of this genus will completely dechlorinate PCE via a metabolic (energy yielding) pathway. However, based on the geochemical conditions present at the Site, complete reductive dechlorination to VC and ethene is not required to facilitate Site remediation.

8.1.1 Dehalococcoides

Dehalococcoides is a genus of bacteria within class Dehalococcoidetes, that obtain energy via the oxidation of hydrogen gas (H₂) and subsequent reductive dehalogenation of halogenated organic compounds including chlorinated solvents such as those present at the Site. Several members of the genus *Dehalococcoides* that grow at the expense of a broad variety of organohalides, including halogenated alkanes (e.g., chlorinated ethanes) and alkenes (e.g.,

chlorinated ethenes), and chlorinated benzenes, biphenyls, and dioxins are found in the environment (Schmidt and de Vos, 2004). While PCE-dehalogenating bacteria from genera other than *Dehalococcoides* generally dechlorinate this solvent to *cis*-1,2-dichloroethene, *Dehalococcoides ethenogenes* strain 195 was the first bacteria observed that completely dehalogenates and thus detoxifies PCE in a four-step series of reductive dechlorinations to ethene (Maymo-Gatell, *et al.*, 1997). However, only the first three steps are metabolic, and the dechlorination of VC appears to be a slow, cometabolic reaction that results in the transient accumulation of this highly toxic intermediate unless polychlorinated ethenes are present (Maymo-Gatell *et al.*, 1999; Schmidt and de Vos, 2004). Since this time, several strains of *Dehalococcoides sp.* have been identified that reductively dechlorinate PCE and/or trichloroethene (TCE) to ethene with some of the reactions from vinyl chloride to ethene being cometabolic and some being metabolic (Table 15). Where the degradation of vinyl chloride to ethene caused by *Dehalococcoides sp.* is metabolic, the VC tends to degrade rapidly; where the reaction of vinyl chloride to ethene is cometabolic, vinyl chloride can accumulate. The functional genes *tceA*, *vcrA*, and *bvcA* are used to determine if the reductive dechlorination reaction will fully degrade PCE to ethene via a metabolic pathway or if the reactions will rely on cometabolism during some stage of the degradation pathway, as discussed below. As will be discussed below, the degradation pathways observed at this Site do not rely on the presence of the functional genes *tceA*, *vcrA*, and *bvcA* because the *cis*-1,2-DCE is produced from the degradation of PCE and TCE is likely being biologically oxidized as shown by the lack of VC and ethene under natural conditions and CSIA data confirming degradation.

Available Site-specific 16S rRNA gene data for identification of *Dehalococcoides* species are presented in Table 14. As shown by these data, *Dehalococcoides spp.* is present in the aquifer at the site with the highest observed cell counts (which are still low) being collected in those wells/points situated closest to the bioremediation pilot tests that were previously conducted at the Site. This implies that previous bioremediation pilot testing increased the concentration of *Dehalococcoides spp.* in the aquifer in those areas closest to substrate injection. However, the presence of *Dehalococcoides* in other portions of the aquifer not influenced by bioremediation pilot testing can be inferred by the distribution of contaminants and degradation products (particularly *cis*-1,2-DCE) over time and space, CSIA data confirming degradation, and groundwater geochemical data. The lack of VC in areas other than the area that underwent bioremediation pilot testing, in conjunction with other Site-specific data, suggests that the predominant degradation pathway for chlorinated ethenes at the Site is reductive dechlorination to *cis*-1,2-DCE followed by biological oxidation of the biogenically produced *cis*-1,2-DCE. This combination of degradation pathways (i.e. reductive dechlorination followed by biological oxidation of *cis*-1,2-DCE) is consistent with the Author's experience at similar sites and the work recently published by Bradley and Chapelle (2011) and Bradley (2011). In the past, the degradation of PCE or TCE to *cis*-1,2-DCE with no production of VC was thought to indicate that the reaction had "stalled" at *cis*-1,2-DCE; hence the origin of the colloquial term "*cis*-stall." However, plume stability analyses, including time-series plots of contaminants and daughter products in individual wells and along the flow path such as those completed for this site,

suggested that the *cis*-1,2-DCE was degrading, as they do for this Site, but via a heretofore unknown reaction. Recent advancements in the use of CSIA have allowed conclusive confirmation that *cis*-1,2-DCE at these sites was degrading, even if the reaction mechanism was not understood. This is the case at this Site. The recent work of Bradley and Chapelle (2011) and Bradley (2011) suggests that the degradation of the *cis*-1,2-DCE that is produced from the reductive dechlorination of PCE and TCE at sites with characteristics similar to this Site, is via biological oxidation.

The functional genes *tceA*, *vcrA*, and *bvcA* that are typically used to determine if species of *Dehalococcoides* capable of complete reductive dechlorination of PCE to VC and ethene are present in the aquifer, are below detection limits (Table 14). The lack of these genes at the Site is not surprising since these genes are known to be expressed when TCE or *cis*-1,2-DCE are degraded to VC and/or ethene and are not required for degradation from PCE to TCE to *cis*-1,2-DCE (Figure 67). As suggested by the generation of small quantities of VC during bioremediation pilot testing, addition of an organic carbon substrate would likely result in increases in the concentration of *Dehalococcoides* and the associated functional genes. Of particular importance for this Site is that without knowing which species of *Dehalococcoides* is/are present, it cannot be known conclusively whether vinyl chloride will or will not accumulate but based on the Author's (Todd Wiedemeier) experience with enhanced bioremediation of chlorinated ethenes, and the fact that VC was produced during small-scale bioremediation pilot testing, it is likely that if sufficient organic carbon is added to the subsurface at this Site, significant quantities of VC will be generated. It is especially important to note that the production and accumulation of VC could result in an increase in the risk posed by Site contaminants. Furthermore, available data suggests that natural attenuation is removing significant quantities of CAHs without producing any detectable VC (Sections 4, 6, and 7).

8.1.2 Dehalobacter

Dehalobacter is a genus of bacteria that has been shown to reductively dechlorinate chlorinated ethenes and ethanes (Holliger *et al.*, 1993; Grostern and Edwards, 2006). *Dehalobacter restrictus* is an obligate anaerobe, genetically close to the clostridia. It has been isolated from soil contaminated with chlorinated industrial products. These bacteria respire using PCE or TCE as a terminal electron acceptor and dihydrogen (H₂) as an electron donor (Holliger *et al.*, 1993). In addition, *Dehalobacter restrictus*, strain TCA1, a low G+C, gram positive, obligate H₂-oxidizing bacteria has been shown to reductively dechlorinate chlorinated ethanes. Available 16S rRNA gene data for identification of *Dehalobacter* species are presented in Table 14. As shown by these data, *Dehalobacter* are present in the aquifer at the site with the highest cell counts being collected in those wells/points situated closest to the bioremediation pilot tests that were previously conducted at the Site. This implies that previous bioremediation pilot testing increased the concentration of *Dehalobacter spp.* in the aquifer. However, based on the temporal and spatial behavior of the chlorinated ethanes, it is likely that *Dehalobacter spp.* is ubiquitous at the Site.

METHANE OXIDIZING BACTERIA (METHANOTROPHS) AND SOLUBLE METHANE MONOOXYGENASE

The methanotrophs typically are aerobic bacteria (although some anaerobic methanotrophs are known to exist, typically in marine sediments) that oxidize methane as their only source of energy and carbon through the enzyme methane monooxygenase (MMO). This MMO can cometabolize or transform nongrowth substrates such as chlorinated solvents, by either growing or resting cells (Brigmon, 2001). Cometabolism is a result of nonspecific MMO activity towards organic compounds that do not serve as carbon or energy sources. While many cometabolizing bacterial species have been identified, the best studied are the methanotrophs (Brigmon, 2001). The reason for this is that methanotrophs are ubiquitous and can cometabolize many aliphatic compounds, alkanes, and aromatic compounds (Brigmon, 2001). Methanotrophs have been intensely studied for use in degrading chlorinated solvents, most notably trichloroethylene, to environmentally acceptable concentrations in soils, sediment, and groundwater. Stimulation of methanotrophic bacteria can be accomplished through the addition of organic carbon to the system, some of which will be converted to methane through biodegradation and biotransformation. In addition to their potential importance in cometabolic reactions, methanotrophs are also important because they help reduce the amount of methane resulting from biodegradation of organic compounds being released to the atmosphere (Brigmon, 2001).

Available 16S rRNA gene data for identification of methanotrophs (methane-oxidizing bacteria) are presented in Table 14. As shown by these data, methanotrophs are present in the aquifer at the site with the highest cell counts being collected in those wells/points situated closest to the bioremediation pilot tests that were previously conducted at the Site. This implies that previous bioremediation pilot testing increased the concentration of methanotrophs in the aquifer, likely in response to the increase in methane being produced from the biodegradation of organic carbon. The presence of methanotrophs is of importance at this site because they are known to facilitate the cometabolism of chlorinated ethenes, most notably TCE.

Several observations can be made, and conclusions drawn, from the molecular biological data presented in this section. These are:

- The dechlorinating bacteria *Dehalococcoides spp.* and *Dehalobacter spp.* are present in the aquifer system at the Site. These bacteria are known to reductively dechlorinate chlorinated ethenes and ethanes;
- The concentrations of *Dehalococcoides spp.* and *Dehalobacter spp.* are highest in those areas closest to bioremediation pilot testing injection points, suggesting that these bacteria will grow if additional organic carbon is added to the aquifer system at the Site. However, they are also present in portions of the aquifer that were not impacted by bioremediation pilot testing (e.g., MW-19, Table 14) as shown by the presence of degradation products and the behavior of the solute plumes over time;

- Methane oxidizing bacteria and soluble methane monooxygenase are present at the Site and, again, the concentrations of these are highest in those areas closest to bioremediation pilot testing injection points. The presence of methanotrophs and soluble methane monooxygenase could cause the cometabolism of at least some of the chlorinated compounds present at the Site;
- The addition of organic carbon to the system will very likely increase the population of dechlorinating bacteria at the Site, and thus the rate of biodegradation of chlorinated compounds through biostimulation of the indigenous microbial population, and;
- The functional genes *tceA*, *vcrA*, and *bvcA*, are not present in detectable concentrations at the Site. However, based on the generation of small quantities of VC during bioremediation pilot testing, it is likely that the addition of large quantities of organic carbon will result in the generation of VC which could increase the risk posed by Site contaminants.

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SECTION 9

CONCLUSIONS AND RECOMMENDATIONS

This report presents an assessment of the ability of natural attenuation to reduce the concentrations and mass of CAHs detected in soil and groundwater beneath, and downgradient from, the Twigg manufacturing facility. Various types of data were used for this analysis including groundwater elevation, groundwater quality, geochemical, microbiological, and CSIA data.

All three of the “lines of evidence” discussed in the *Technical Protocol for Evaluating the Natural Attenuation of Chlorinated Solvents in Groundwater* (USEPA, 1998) were used to evaluate the efficacy of natural attenuation for organic contaminants dissolved in groundwater. In addition, several types of data not available at the time (USEPA, 1998) was published were used for this analysis. The evaluation of natural attenuation presented in this document includes:

- 1) A review of Site history including facility usage and historic site characterization and remediation efforts;
- 2) An evaluation of hydrogeologic conditions at the site;
- 3) An evaluation of the nature and extent of contamination;
- 4) Analysis of contaminant and degradation product data including;
 - evaluation of plume behavior and stability using isopleth maps,
 - evaluation of plume behavior and stability using concentration versus time and distance plots, and
 - evaluation of degradation products including molar plots of parent compound and degradation products versus distance plots.
- 5) Analysis of compound-specific isotopic analytical data;
- 6) Analysis of geochemical data, and;
- 7) Analysis of microbiological laboratory data.

The remainder of this section presents the significant observations made as a result of the data evaluation and presents recommendations for further action at the Site.

9.1 OVERARCHING CONCLUSIONS

The overarching conclusion resulting from the evaluation of natural attenuation presented in this document is that natural processes of contaminant attenuation are removing significant amounts of contaminant mass from the shallow subsurface at the Site without the aid of engineered remediation systems. This natural attenuation is limiting solute plume migration and will ultimately bring about complete site remediation. The remainder of this section presents

major points in the form of a bullet list. Each bullet lists significant conclusions reached in the various sections and subsections of this report.

THWA believes that any attempt to facilitate bioremediation via carbon addition on a large scale might actually increase the risk posed by Site contaminants because of the likelihood that VC would be generated.

9.2 SOURCE AREA(S)

- Industrial activities have occurred on the property currently owned by Twigg since about 1916. Many of these industrial activities likely used industrial solvents including PCE and 1,1,1-TCA.
- There is no evidence of mobile (“free-phase”) DNAPL at the Site;

9.2.1 Chlorinated Ethenes

- The soil contamination that is contributing chlorinated ethenes (i.e., PCE) to groundwater appears to be associated with the Twigg property and is predominantly found in the vicinity of, and downgradient from, the FWSA (Figures 16 and 17).

9.2.2 Chlorinated Ethanes

- In contrast to chlorinated ethenes, the soil contamination contributing chlorinated ethanes (i.e., 1,1,1-TCA) to groundwater is found in what appear to be three fairly distinct areas. Two are on/beneath the Twigg property and one appears to be located in the vicinity of Victory Park (Figures 18 and 19).
- Based on available data, the main source of soil contamination that is contributing chlorinated ethanes to groundwater appears to be located somewhere in the vicinity of Victory Park and not on the Twigg property. The exact location of this source is not known. This is supported by the following:
 - The relative lack of TCA in groundwater in the immediate vicinity of the Twigg facility compared to the amount of 1,1,1-TCA found in groundwater in the vicinity of, and downgradient from, Victory Park, as shown by the distribution of chlorinated ethanes in soil and groundwater,
 - the fact that the highest 1,1,1-TCA concentrations observed in soil were found in the vicinity of MW-6, and that the highest concentrations of 1,1,1-TCA in soil in this area may have been missed,
 - The amount of PCE mass (1,450 pounds) versus 1,1,1-TCA mass (110 pounds) removed by the SVE system present on the Twigg property. If the main source of the 1,1,1-TCA found in groundwater in the vicinity of Victory Park had originated on the Twigg property, it is likely that significantly more 1,1,1-TCA would have been removed via SVE, and;
 - If the main source of 1,1,1-TCA contamination found in groundwater had originated on the Twigg property, then the 1,1,1-TCA plume would more closely mimic the

chlorinated ethene plume, with the highest chlorinated ethane concentrations being found on, or just downgradient from, the Twigg facility. That is, the areas with the highest 1,1,1-TCA concentrations would be more closely associated with the highest PCE concentrations.

9.3 REMEDIATION ACTIVITIES

Several remediation systems have been installed at the Site, including SVE, ozone sparging, and bioremediation pilot testing.

9.3.1 Soil Vapor Extraction

- Soil Vapor Extraction was initiated in November 1999.
- About 1,450 pounds of PCE and over 110 or so pounds of 1,1,1-TCA have been removed via SVE.
- The majority of this mass was removed between November 1999 and the end of 2001. Since that time, the SVE system has removed only a small amount of VOC mass.

9.3.2 Ozone Sparging

- An ozone-sparging system was designed and installed in early 2004.
- The ozone sparging points were located some 350 feet upgradient from the center of mass of the ethene solute plume (near MW-4) and some 1,600 feet upgradient from the center of mass of the main ethane solute plume (near MW-6).
- Ozone is only stable in groundwater for minutes to hours after injection (USEPA, 2006) so the area of influence would be measured in units of several to tens of feet at best.

9.3.3 Bioremediation Pilot Testing

- A closed-cell bioremediation pilot testing system located in the vicinity of the FWSA was operated from October 2004 until September 2005 and then from June 2006 until May 2008.
- A bioremediation pilot testing system was operated in the immediate vicinity of MW-8 from October 2004 until September 2005 and then from June 2006 until May 2008. Injection of substrate into this area occurred in August 2006, March 2007, and August 2007.
- The purpose of these pilot tests was to determine the effectiveness of biostimulation through carbon substrate addition.

9.4 IMPACT OF ENGINEERED REMEDIATION ACTIVITIES ON NATURAL ATTENUATION

Although the targeted remediation activities completed at the Site to date have aided natural attenuation, the majority of contaminant mass reduction observed at the Site is most likely the

result of natural processes of contaminant degradation. This conclusion is based on the following observations:

- Significant reductions in solute concentrations (and thus mass) were observed before initiation of any remediation activities.
- Most of the VOC mass in soil that is continuing to contribute to groundwater contamination has remained below the water table and generally out of reach of the SVE efforts that have been completed to date. This is confirmed by the lack of a correlation between precipitation/groundwater elevation and solute concentrations.
- The impact of the ozone sparging system for remediation of CAHs was likely minimal and only effective for the area immediately surrounding the injection wells because ozone is only stable in groundwater for minutes to hours after injection so the area of influence would be measured in units of several to tens of feet at best.
- Bioremediation pilot testing was conducted in closed recirculation cells with only a relatively small amount of organic carbon being released into the aquifer in areas outside of the immediate vicinity of the pilot testing locations.
- The wells with the highest historic concentration of chlorinated ethenes (MW-4) and chlorinated ethanes (MW-6) are located outside those areas impacted by engineered remediation activities. The possible exception to this is any residual organic carbon remaining from upgradient bioremediation pilot testing that may have migrated downgradient after cessation of recirculation pumping. Based on the nature of the bioremediation pilot testing (i.e., closed cell and soluble substrate at relatively low concentrations), it is unlikely that significant amounts of organic carbon migrated outside the immediate vicinity of the bioremediation pilot testing cell.

9.5 ISOPLETH MAPS AND CROSS SECTIONS

- Based on isopleth maps prepared over the period from 1998/1999 through 2011, the “footprint” of the chlorinated ethene solute plume has remained fairly stable over the period of observation and the footprint of the chlorinated ethane plume has become smaller. In addition, chlorinated ethene and ethane solute concentrations have significantly declined, and the total mass of CAHs in the system has decreased markedly.
- Estimates of groundwater seepage velocity suggest that the solute plume should be migrating downgradient at a rate of about 200 feet per year if sorption or degradation were occurring.
- For the chlorinated ethenes, using only the estimated groundwater seepage velocity for the Site, the center of mass and the leading edge of the solute plume should have migrated about 2,500 feet over the period from January 1999 through January 2011. That is, the plume should have effectively *doubled* in size since 1999, yet the extent of the plume has remained stable and maximum observed concentrations have decreased markedly. Using estimated solute transport velocities for the Site, the center of mass and the leading edge of the plume should have migrated between about 1,200 feet (PCE) and 1,900 feet (*cis*-1,2-DCE) downgradient between January 1999 and January 2011. The

fact that the extent of the plume has remained stable and the leading edge of the total chlorinated ethane plume has not migrated downgradient provides strong evidence that natural attenuation processes are working to degrade contaminants and control plume migration.

- For the chlorinated ethanes, using only the estimated groundwater seepage velocity for the Site, the center of mass and the leading edge of the solute plume should have migrated about 2,500 feet over the period from January 1999 through January 2011. That is, the plume should have effectively *doubled* in size since 1999, yet the extent of the plume has remained fairly stable and maximum observed concentrations have decreased markedly. Using estimated solute transport velocities for the Site, the center of mass and the leading edge of the plume should have migrated between about 1,400 feet (1,1,1-TCA) and 2,100 feet (1,1-DCA) downgradient between January 1999 and January 2011. The fact that the extent of the plume has remained stable and the leading edge of the total chlorinated ethane plume has not migrated downgradient provides strong evidence that mechanisms of natural attenuation are working to degrade contaminants and control plume migration.

9.6 PLOTS OF CONCENTRATION VERSUS TIME

- Plots of concentration versus time for the individual chlorinated ethenes and ethanes shows that the concentrations of these compounds are decreasing or stable across much of the Site. There are one or two exceptions to this as described in bullets three and four of this Section (Section 9.6).
- Invariably, those wells exhibiting the highest concentrations of CAHs exhibited decreasing concentrations.
- The concentration of PCE in MW-12 increased about 60% over the period from 10/13/06 (37.7 µg/L) to 10/25/2007 (63.6 µg/L). However, the concentration of this compound was stable over the past two sampling events (10/25/07 and 2/8/11) with a PCE concentration of 60.1 µg/L in 2011. Future groundwater sampling should be used to ascertain what is happening in this well.
- The concentration of 1,1,1-TCA started a steady increase in MW-8 in June 2006 (45 µg/L) and stabilized in October 2007 at a concentration of 209 µg/L. The concentration of 1,1,1-TCA was 220 µg/L on January 31, 2011. The observed increases in 1,1,1-TCA concentration in this well roughly coincide with the onset of bioremediation pilot testing in this area. It is not clear if this pilot testing resulted in the solubilization of additional 1,1,1-TCA since 1,1,1-TCA was detected in soil in the boring for this well in 1997. Future groundwater sampling should be used to ascertain what is happening in this well.

9.7 PLOTS OF CONCENTRATION VERSUS DISTANCE

9.7.1 Chlorinated Ethenes

- The chlorinated ethene plume is anchored at and just downgradient from the FWSA, near MW-4. Chlorinated ethene concentrations decrease fairly rapidly along the groundwater flow path. In the time it takes for groundwater to migrate from MW-4 to MW-6, the chlorinated ethene plume has been almost completely degraded.
- The aqueous concentrations of individual chlorinated ethenes have decreased over the period of observation both along the flowpath and in individual wells. For example, the maximum concentration of PCE observed in MW-4 was 13,000 µg/L, 5,500 µg/L, 3,070 µg/L, and 805 µg/L in July 1999, January 2004, October 2007, and February 2011, respectively.
- The changes in the molar fractions of PCE (parent compound) and its degradation products TCE and *cis*-1,2-DCE, coupled with decreasing solute concentrations along the flowpath confirm intrinsic bioremediation (i.e., natural biodegradation) of the chlorinated ethenes.

9.7.2 Chlorinated Ethanes

- That portion of the chlorinated ethane plume with the highest concentrations appears to be anchored near Victory Park, in the vicinity of MW-6, and not on the Twigg property or near the FWSA. This is consistent with the soil data for the site and suggests that spills on the Twigg property are not the main source of total chlorinated ethanes found in soil and groundwater in the study area.
- The aqueous concentrations of individual chlorinated ethanes have decreased over the period of observation both along the flowpath and in individual wells. For example, the maximum concentration of 1,1,1-TCA observed in MW-6 was 9,100 µg/L, 6,800 µg/L, 6,160 µg/L, and 2,360 µg/L in July 1999, January 2004, October 2007, and February 2011, respectively.
- Chlorinated ethane concentrations decrease fairly rapidly along the groundwater flow path. In the time it takes for groundwater to migrate from MW-6 to MW-8, the chlorinated ethane plume has been almost completely degraded.
- The changes in the molar fractions of 1,1,1-TCA (parent compound) and its degradation products 1,1-DCA, CA, and 1,1-DCE, coupled with decreasing solute concentrations along the flowpath confirm intrinsic bioremediation (i.e., natural biodegradation) and a relatively minor amount of hydrolysis/dehydrohalogenation of the chlorinated ethanes.

9.8 DEGRADATION PRODUCTS

- The presence of *cis*-1,2-DCE and the lack of *trans*-1,2-DCE is conclusive evidence for degradation of chlorinated ethenes. This degradation is occurring in areas with, and those without, bioremediation pilot testing.

- The presence of 1,1-DCA, CA, and 1,1-DCE provides evidence for degradation of 1,1,1-TCA via both biodegradation (produces 1,1-DCA and CA) and hydrolysis coupled with dehydrohalogenation (produces roughly 80% acetic acid and 20% 1,1-DCE). This degradation is occurring in areas with, and those without, bioremediation pilot testing.

9.9 COMPOUND SPECIFIC ISOTOPE ANALYSES

- Compound-specific isotope analyses provide conclusive evidence of degradation of PCE, TCE, *cis*-1,2-DCE, 1,1,1-TCA, 1,1-DCA, and CA at the Site.

9.10 GROUNDWATER GEOCHEMISTRY

- The hydrogeologic system is capable of supporting the biologic degradation of all of the contaminants found dissolved in groundwater at the site.
- The groundwater system is hypoxic with areas that are strongly anoxic (negative ORP and methane and Fe[II]) are present), both in areas that have, and have not undergone bioremediation testing.

9.11 MOLECULAR BIOLOGICAL DATA

- *Dehalococcoides spp.* and *Dehalobacter sp.*, bacteria that are known to degrade chlorinated solvents, are present at the site.

9.12 PREDOMINANT DEGRADATION MECHANISMS

9.12.1 Chlorinated Ethenes

- Based on the geochemical data available for the Site, concentration and molar fraction trends over time and space, and CSIA, it appears that under ambient aquifer conditions, PCE is degrading to TCE and then to *cis*-1,2-DCE via reductive dechlorination. The produced *cis*-1,2-DCE is then likely being biologically oxidized to carbon dioxide and water. This degradation pathway has several advantages over the complete reductive dechlorination pathway under which VC tends to accumulate under strongly anoxic conditions because the oxidation of *cis*-1,2-DCE precludes the production of VC. Production of VC appears to be limited to those areas where pilot testing of chlorinated ethene biostimulation was conducted and methanogenic conditions were generated. One drawback to enhanced bioremediation at this Site would be the likely accumulation of VC. The accumulation of VC would occur because the strongly reducing conditions created by enhanced bioremediation would preclude the oxidation of *cis*-1,2-DCE and encourage reductive dechlorination of *cis*-1,2-DCE to VC through reductive dechlorination. That this would happen if sufficient carbon is added to the system is evidenced by the production of limited quantities of VC during pilot testing and the presence of bacteria capable of complete reductive dechlorination of PCE to VC and ethene (i.e., *Dehalococcoides sp.*).

9.12.2 Chlorinated Ethanes

- Based on the geochemical data available for the Site, concentration and molar fraction trends over time and space, and CSIA, it appears that the predominant degradation mechanisms for 1,1,1-TCA is a combination of:
 - Biological reductive dechlorination where the degradation products are 1,1-DCA and CA. The CA produced by reductive dechlorination is ultimately hydrolyzed to ethanol and the ethanol is then hydrolyzed to acetic acid. The ethanol and acetic acid produced from this reaction can then be used by bacteria for the generation of H₂ to facilitate further biological reductive dechlorination, and;
 - Abiotic hydrolysis/dehydrohalogenation to acetic acid (80%) and 1,1-DCE (20%). Again, this acetic acid can be fermented to H₂ to facilitate biological reductive dechlorination.

9.12.3 Effect of Commingled Ethenes and Ethanes

- Of interest in the study area is that the presence of chlorinated ethanes has an inhibitory effect on the reductive dechlorination of chlorinated ethenes and, to a lesser extent, vice versa (Grostern et al, 2009; Sherwood Lollar, 2010). Thus, it is fortunate that there appear to be two somewhat distinct solute plumes; one is the chlorinated ethene plume originating beneath the Twigg facility, the other being the chlorinated ethane plume, which appears to originate near Victory Park. However, the presence of 1,1,1-TCA does not appear to be precluding the occurrence of PCE reductive dechlorination and once the TCA is gone, as it is over much of the area with chlorinated ethene contamination, the reaction will likely no longer be inhibited, and the degradation rate for chlorinated ethenes will therefore likely increase.

9.13 RECOMMENDATIONS

Based on the information presented in this report it is apparent that natural attenuation and specifically biodegradation are acting very efficiently to remove CAH mass (both chlorinated ethene and chlorinated ethane), from the saturated zone at the Site.

- Risk-based cleanup goals should be evaluated in conjunction with MNA to determine if MNA alone will meet remediation goals.
- Should MNA be selected as part of the overall remediation approach for this Site, groundwater monitoring should be conducted on an annual basis for a period of five years to evaluate trends in CAH concentrations and to ensure that MNA is working as anticipated. After five years, this monitoring frequency should be reevaluated to determine if a two-year sampling frequency is adequate.
- Monitoring should be continued in MW-8 to see if concentrations remain stable or start to increase. If concentrations are seen to increase, then a targeted remediation system should be considered.

- Because historical geochemical data are often contradictory and not physically/chemically possible, THWA recommends that a complete set of geochemical data be collected. Care be taken to ensure that accurate and plausible data are collected to begin building a statistically significant and defensible database so that an accurate assessment of geochemical conditions at the Site can be made.
- An assessment of the efficacy of the SVE system should be made. Based on available data, it appears that the current network of SVE points is no longer effective at removing VOCs from soil gas. In addition, the installation of additional SVE points in the vicinity of MW-3, MW12, and MW-16 should be given consideration to remove any CAH constituents residing above the water table.

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SECTION 10

REFERENCES

- Adrian, L., U. Szewzyk, J. Wecke, and H. Gorlsch, 2000, Bacterial dehalorespiration with chlorinated benzenes. *Nature* 408: 580-583
- Aelion, C. M., P. Hohener, et al., Eds., 2010, *Environmental Isotopes in Biodegradation and Bioremediation*, CRC Press, Taylor and Francis Group, Boca Raton, FL.
- Alt and Witzig Engineering, Inc., 1992a, *Subsurface Investigation*, Twigg Corporation, Martinsville, IN, January 8, 1992
- Alt and Witzig Engineering, Inc., 1992b, *Subsurface Investigation II*, Twigg Corporation, Martinsville, IN
- Barbee, G. C., 1994. "Fate of Chlorinated Aliphatic Hydrocarbons in the Vadose Zone and Ground Water" *Groundwater Monitoring Review*, Winter, 1994, Vol. 14 No. 1, pp. 129-140.
- Bouwer, E.J., 1992, *Bioremediation of Subsurface Contaminants*, In R. Mitchell, editor, *Environmental Microbiology*: Wiley-Liss, New York, p. 287-318.
- Bouwer, E.J., 1994, *Bioremediation of Chlorinated Solvents Using Alternate Electron Acceptors*, In: *Handbook of Bioremediation*, CRC Press, Boca Raton, FL.
- Bouwer, H., and Rice, R.C., 1976, A slug test for determining hydraulic conductivity of unconfined aquifers with completely or partially penetrating wells: *Water Resources Research*, 12(3), p. 423-238.
- Bradley, P. M., 2011, *Reinterpreting the Importance of Oxygen-Based Biodegradation in Chloroethene-Contaminated Groundwater*. *Ground Water Monitoring & Remediation*: In press.
- Bradley, P. M. and F. H. Chapelle, 2011, *Microbial Mineralization of Dichloroethene and Vinyl Chloride under Hypoxic Conditions*: *Ground Water Monitoring & Remediation*: In Press.
- Bradley, P.M., and Chapelle, F.H., 1996, Anaerobic mineralization of vinyl chloride in Fe(III)-reducing aquifer sediments. Accepted for publication in *Environmental Science and Technology*, v. 30, no. 6, p. 2084-2086.
- Bradley, P.M., and Chapelle, F.H., 1997, Kinetics of DCE and VC mineralization under methanogenic and Fe(III)-reducing conditions: *Environmental Science and Technology*, v. 31, p. 2692 - 2696.
- Bradley, P.M., and Chapelle, F.H., 1998, Effect of contaminant concentration on aerobic microbial mineralization of DCE and VC in stream-bed sediments: *Environmental Science and Technology*, v. 30, p. 553-557.
- Brigmon, R. L., 2001, *Methanotrophic Bacteria - Use in Bioremediation*: Westinghouse Savannah River Company, Aiken, S.C., WSRC-MS-2001-00058
- Brown, D. L., T. N. Narasimhan, et al., 1995, An Evaluation of the Bouwer and Rice Method of Slug Test Analysis: *Water Resour. Res.* 31.
- Bruce Carter Associates, LLC, 1998, *Phase II Investigation Report*, Twigg Corporation, Martinsville, Indiana.
- Bruce Carter Associates, LLC, 1999a, *Addendum 1 to Phase II Investigation Report*, Twigg Corporation, Martinsville, Indiana.
- Bruce Carter Associates, LLC, 1999b, *Remediation Work Plan*, Twigg Corporation, Martinsville, Indiana.
- Bruce Carter Associates, LLC, 1999c, *Letter to D. Ridley, IDEM/VRP from J. Kilmer, Bruce Carter Asso., re: Response to Comments on Phase II investigation Report*, Twigg Corp., Martinsville, March 11, 1999.
- Bruce Carter Associates, LLC, 1999d, *Letter to D. Ridley, IDEM/VRP from J. Kilmer, Bruce Carter Asso., re: Door-to-door private well survey*.
- Bruce Carter Associates Consultants, Inc., 2007, *2007 Annual Progress Report, Soil and Groundwater Remediation*, Twigg Corporation, Martinsville, Indiana.
- Chang, Y. C., M. Hatsu, K. Jung, Y. S. Yoo, and K. Takamizawa, 2000, Isolation and characterization of a tetrachloroethylene dechlorinating bacterium, *Clostridium bifermentans* DPH-1. *Journal of Bioscience and Bioengineering* 89(5): 489-491
- Conservation Service, Issue, 1981. USGS, 1994. *Hydrogeologic Atlas of Aquifers of Indiana*, U.S. Geological Survey, *Water Resources Investigation Report* 92-4142, 1994. Vella, P. 1998. "Permanganate Wastewater

- Treatment" in Encyclopedia of Environmental Analysis and Remediation, Meyers, RA, editor. John Wiley & Sons, Inc. c1998.
- Cupples, A. M., A. M. Spormann, *et al.* (2004). Comparative Evaluation of Chloroethene Dechlorination to Ethene by Dehalococcoides-like Microorganisms. *Environmental Science & Technology* 38(18): 4768-4774.
- Davis, J.W., and Carpenter, C.L., 1990, Aerobic biodegradation of vinyl chloride in groundwater samples: Applied and Environmental Microbiology, v. 56, p. 3878.
- De Bruin, W.P., Kotterman, M.J.J., Posthumus, M.A., Schraa, G., and Zehnder, A.J.B., 1992, Complete biological transformation of tetrachloroethene to ethane: Appl Environ. Microbiol., vol. 58, no. 6, p. 1966-2000.
- DeStefano, T.D., Gossett, J.M., and Zinder, S.H., 1991, Reductive dehalogenation of high concentrations of tetrachloroethene to ethene by an anaerobic enrichment culture in the absence of methanogenesis: Applied and Environmental Microbiology, v. 57, no. 8, p. 2287-2292.
- Domenico, P.A. 1987, An analytical model for multidimensional transport of a decaying contaminant species: Journal of Hydrology, v. 91, p. 49-58.
- Domenico, P.A., and Schwartz, F.W., 1990, Physical and Chemical Hydrogeology: John Wiley and Sons, New York, New York, 824 p.
- EPRI, 1984. "Chemical Attenuation Rates, Coefficients, and Constants in Leachate Migration" Electric Power Research Institute, EPRI, EA-3417, Volume I, Project 1619, February, 1984.
- Eves, J., 1999, Treatment of Chlorinated Solvent Contaminants Using Ozone Sparging and Soil Vapor Extraction", 1999 Midwest Focus Groundwater Conference, Chicago, IL
- Fetter, C.W., 1993, Contaminant Hydrogeology: MacMillan, New York, New York, 458 p.
- Finneran, K. T., H. M. Forbush, C. V. Gaw VanPraagh, and D. R. Lovley, 2003, Desulfitobacterium metallireducens sp. nov., an anaerobic bacterium that couples growth to the reduction of metals and humic acids as well as chlorinated compounds. International Journal of Systematic and Evolutionary Microbiology 52: 1929-1935
- Folsom, B.R., Chapman, P.J., and Pritchard, P.H., 1990, Phenol and trichloroethylene degradation by Pseudomonas cepacia G4: Kinetics and interactions between substrates: Appl. Environ. Microbiol., vol. 56, no. 5, p. 1279-1285.
- Freedman, D.L., and Gossett, J.M., 1989, Biological reductive dehalogenation of tetrachloroethylene and trichloroethylene to ethylene under methanogenic conditions: Applied and Environmental Microbiology., v. 55, no. 4, p. 1009-1014.
- Freeze, R. A. and McWhorter, D. B., 1997, A framework for assessing risk reduction due to DNAPL mass removal from low-permeability soils: Groundwater, Volume 35, No. 1, Pages 111 - 123.
- Gerritse, J., O. Drzyzga, G. Kloetstra, M. Keijmel, L. P. Wiersum, R. Hutson, M. D. Collins, and J. C. Gottschal, 1999, Influence of different electron donors and acceptors on dehalorespiration of tetrachloroethene by Desulfitobacterium frappieri TCE1. Applied and Environmental Microbiology 65(12): 5212-5221
- Gerritse, J., V. Renard, T. M. Pedro Gomes, P. A. Lawson, M. D. Collins, and J. C. Gottschal., 1996, Desulfitobacterium sp. Strain PCE1, an anaerobic bacterium that can grow by reductive dechlorination of tetrachloroethene or ortho-chlorinated phenols. Archives of Microbiology 165(2): 132-140
- Grostem, A. and E. A. Edwards, 2006, Growth of Dehalobacter and Dehalococcoides spp. during Degradation of Chlorinated Ethanes. Appl. Environ. Microbiol. 72(1): 428-436.
- Grostem, A. and E. A. Edwards, 2006, A 1,1,1-Trichloroethane-Degrading Anaerobic Mixed Microbial Culture Enhances Biotransformation of Mixtures of Chlorinated Ethenes and Ethanes: Appl. Environ. Microbiol. 72(12): 7849-7856.
- Hanson, R. S., and T. E. Hanson, 1996, Methanotrophic bacteria. Microbiol. Rev. 60:439-471.
- Hartmann, S., and de Bont, J.A.M., 1992, Aerobic vinyl chloride metabolism in Mycobacterium aurum Li: Applied and Environmental Microbiology, v. 58, no. 4, p. 1220-1226.
- Hassett, J.J., Banwart, W.L., and Griffin, R.A., 1983, Correlation of compound properties with sorption characteristics of nonpolar compounds by soils and sediments; concepts and limitations, In, C.W. Francis and S.I. Auerbach, editors, Environment and Solid Wastes: Butterworths, Boston, p. 161-178.
- He, J., K. M. Ritalahti, K. Yang, S. S. Koenigsberg, and F. E. Löffler, 2003b, Detoxification of vinyl chloride to ethane coupled to growth of an anaerobic bacterium: Nature 424:62-65

- He, J., K. M. Ritalahti, M. R. Aiello, and F. E. Löffler, 2003a, Complete detoxification of vinyl chloride by an anaerobic enrichment culture and identification of the reductively dechlorinating population as a *Dehalococcoides* species. *Applied and Environmental Microbiology* 69(2): 996-1003.
- He, J., Y. Sung, *et al.*, 2005, Isolation and characterization of *Dehalococcoides* sp. strain FL2, a trichloroethene (TCE)- and 1,2-dichloroethene-respiring anaerobe: *Environmental Microbiology* 7(9): 1442-1450.
- HES, 1996. "Remediation Start-Up Groundwater Sampling Results - June, 1996" Heritage Environmental Services, Inc.
- Hicks, P. and S. Koenigsberg, 1998. "The Use of Oxygen Release Compound (ORC) and Hydrogen Release Compound (HRC) for Enhanced Bioremediation", National Conference on Environmental Remediation Science and Technology, September, 8-10, Greensboro, North Carolina.
- Holliger, C., G. Schraa, A. J. Stams and A. J. Zehnder, 1993, A highly purified enrichment culture couples the reductive dechlorination of tetrachloroethene to growth: *Appl. Environ. Microbiol.*, v. 59, no. 9, p. 2991-2997.
- Holliger, C., G. Wohlfarth and G. Dickert (1998b). Reductive dechlorination in the energy metabolism of anaerobic bacteria. *FEMS Microbiology Reviews* 22: 383-398.
- Hölscher, T., R. Krajmalnik-Brown, *et al.* (2004). Multiple Nonidentical Reductive-Dehalogenase-Homologous Genes Are Common in *Dehalococcoides*. *Appl. Environ. Microbiol.* 70(9): 5290-5297.
- Howard, P.H., 1989, Handbook of Environmental Fate and Exposure Data for Organic Chemicals, Volume I: Large Production and Priority Pollutants: Lewis Publishers, Inc., Chelsea, MI, 574 p.
- Howard, P.H., 1990, Handbook of Environmental Fate and Exposure Data for Organic Chemicals, Volume II: Solvents: Lewis Publishers, Inc., Chelsea, MI, 546 p.
- Hunkeler, D., R. Aravena, *et al.*, 2005, Assessment of Degradation Pathways in an Aquifer with Mixed Chlorinated Hydrocarbon Contamination Using Stable Isotope Analysis: *Environmental Science & Technology* 39(16): 5975-5981.
- Hvorslev, M. J. 1951, Time Lag and Soil Permeability in Groundwater Observations: Corps of Engineers, U.S. Army, Bulletin No. 36, April.
- IDEM, 1996, Voluntary Remediation Program Resource Guide: Indiana Department of Environmental Management/Office of Environmental Response, 1996.
- IDNR, 1983. Map of Indiana Showing Thickness of Unconsolidated Deposits, Indiana Dept. of Natural Resources, Geological Survey, 1983.
- IDNR, 1987. Bedrock Geologic Map of Indiana, Indiana Dept. of Natural Resources, Geological Survey, 1987.
- IDNR, 1989. Quaternary Geologic Map of Indiana, Indiana Dept. of Natural Resources, Geological Survey, 1989.
- Johnson, D. R., P. K. H. Lee, *et al.*, 2005, Transcriptional Expression of the *tceA* Gene in a *Dehalococcoides*-Containing Microbial Enrichment: *Appl. Environ. Microbiol.* 71(11): 7145-7151.
- Karickhoff, S.W., 1981, Semi-empirical estimation of sorption of hydrophobic pollutants on natural sediments and soils: *Chemosphere*, 10:833-846.
- Karickhoff, S.W., Brown, D.S., and Scott, T.A., 1979, Sorption of hydrophobic pollutants on natural sediments: *Water Resour. Res.*, 13:241-248.
- Kenaga, E.E., and Goring, C.A.I., 1980, ASTM Special Technical Publication 707: American Society for Testing Materials, Washington, D.C.
- Krajmalnik-Brown, R., T. Holscher, *et al.*, 2004, Genetic Identification of a Putative Vinyl Chloride Reductase in *Dehalococcoides* sp. Strain BAV1: *Appl. Environ. Microbiol.* 70(10): 6347-6351.
- Krumholz, L. R., R. Sharp, and S. S. Fishbain, 1996, A freshwater anaerobe coupling acetate oxidation to tetrachloroethylene dehalogenation. *Applied and Environmental Microbiology* 62(11): 4108-4113 (1996).
- Lee, M.D. 1988. Bioremediation of Aquifers Contaminated with Organic Compounds. *CRC Critical Reviews in Environmental Control*. v. 18. p. 29-89.
- Löffler, F., K. Ritalahti, *et al.*, 1997, Dechlorination of Chloroethenes Is Inhibited by 2-Bromoethanesulfonate in the Absence of Methanogens: *Appl. Environ. Microbiol.* 63(12): 4982-4985.
- Magnuson, J. K., M. F. Romine, *et al.*, 2000, Trichloroethene Reductive Dehalogenase from *Dehalococcoides* ethenogenes: Sequence of *tceA* and Substrate Range Characterization: *Appl. Environ. Microbiol.* 66(12): 5141-5147.

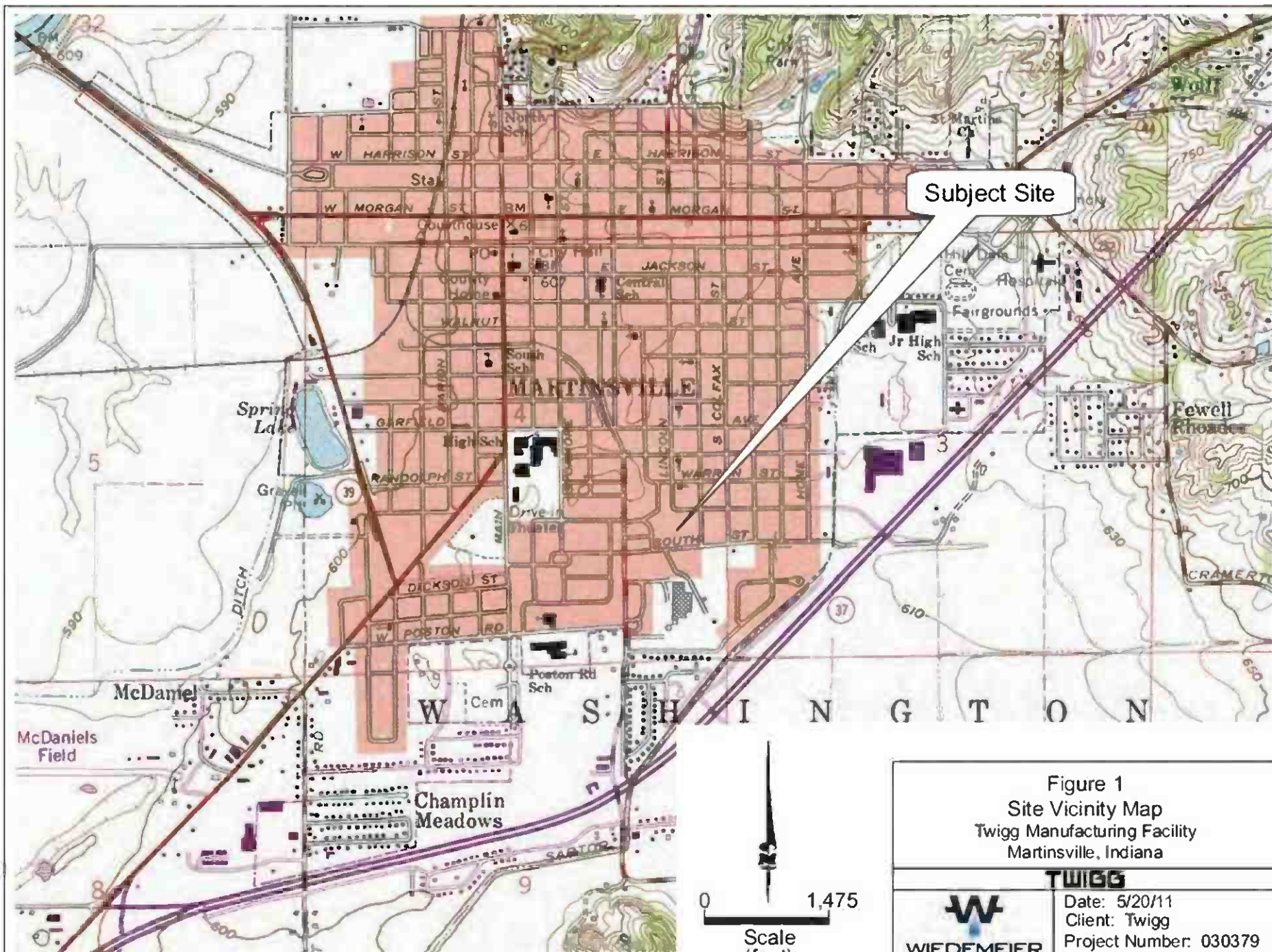
- Maymo-Gatell, X., T. Anguish, *et al.*, 1999, Reductive Dechlorination of Chlorinated Ethenes and 1,2-Dichloroethane by *Dehalococcoides ethenogenes* 195: Appl. Environ. Microbiol. 65(7): 3108-3113.
- Maymó-Gatell, X., Y. T. Chien, J. M. Gossett, and S. H. Zinder, 1997, Isolation of a bacterium that reductively dechlorinates tetrachloroethene to ethene. *Science* 276 (5318): 1568-1571
- McCarty, P. L., 1997, Breathing with Chlorinated Solvents: *Science* 276(5318): 1521-1522.
- McCarty, P.L., and L. Semprini, 1994, Ground-water Treatment for Chlorinated Solvents: In Norris, R.D., R.E. Hinchee, R. Brown, P.L. McCarty, L. Semprini, J.T. Wilson, D. G. Kampbell, M. Reinhard, E.J. Bouwer, R.C. Borden, T.M. Vogel, J.M. Thomas, and C.H. Ward, editors. *Handbook of Bioremediation*. Boca Raton, FL: Lewis Publishers.
- McCarty, P.L., and Semprini, L., 1994, Ground-Water Treatment for Chlorinated Solvents, In: *Handbook of Bioremediation*. Lewis Publishers, Boca Raton, FL.
- McCarty, P.L., Roberts, P.V., Reinhard, M., and Hopkins, G., 1992, Movement and transformations of halogenated aliphatic compounds in natural systems, In: *Fate of Pesticides and Chemicals in the Environment*. Ed., J.L. Schnoor. John Wiley & Sons, Inc. New York, New York p. 191-209.
- Means, J.C., Wood, S.G., Hassett, J.J., and Banwart, W.L., 1980, Sorption of polynuclear aromatic hydrocarbons by sediments and soils: *Environmental Science and Technology*, v. 14, no. 12, p. 1524-1528.
- Miller, E., G. Wohlfahrt, and G. Diekert, 1997, Comparative studies on tetrachloroethene reductive dechlorination by *Desulfotobacterium* sp. strain PCE-S. *Archives of Microbiology* 168(6): 513-519
- Morel, F.M.M. and Hering, J.G., 1993, *Principles and Applications of Aquatic Chemistry*: John Wiley & Sons, Inc., New York
- Murray, W.D. and M. Richardson., 1993, Progress Toward the Biological Treatment of C1 and C2 Halogenated Hydrocarbons: *Critical Reviews in Environmental Science and Technology* 23 (3): 195-217.
- National Oceanic and Atmospheric Administration (NOAA), 1979, *Climatic Atlas of the United States*.
- National Research Council, 1993, *In Situ Bioremediation, When Does it Work?:* National Academy Press, Washington, D.C., 207 p.
- Newell, C.J., McLeod, R.K., Gonzales, J.R., 1996, BIOSCREEN Natural Attenuation Decision Support System; Users Manual; Air Force Center for Environmental Excellence Technology Transfer Division
- Nyer, E., F. Lenzo and J. Burdick, 1998, In-situ Reactive Zones: Dehalogenation of Chlorinated Hydrocarbons: *Groundwater Monitoring and Remediation*, Vol. 18, No. 2, P. 68-72.
- Parsons, F., P.R. Wood, and J. DeMarco, 1984, Transformation of Tetrachloroethene and Trichloroethene in Microcosms and Groundwater: *J. Amer. Water Works Assoc.* 72(2):56-59.
- Ritalahti, K. M., B. K. Amos, *et al.*, 2006, Quantitative PCR Targeting 16S rRNA and Reductive Dehalogenase Genes Simultaneously Monitors Multiple *Dehalococcoides* Strains." Appl. Environ. Microbiol. 72(4): 2765-2774.
- Sale, T. C., and McWhorter, D. B., 2001, Steady state mass transfer from single-component dense nonaqueous phase liquids in uniform flow fields: *Water Resources Research*, Vol. 37, No. 2, pages 393 – 404
- Scheutz, C., N. D. Durant, *et al.*, 2011, Natural and enhanced anaerobic degradation of 1,1,1-trichloroethane and its degradation products in the subsurface - A critical review: Water Research 45(9): 2701-2723.
- Scholz-Muramatsu, H., A. Neumann, M. Messmer, E. Moore, and G. Diekert, 1995, Isolation and characterization of *Dehalospirillum multivorans* gen. nov., sp. nov., a tetrachloroethene-utilizing, strictly anaerobic bacterium. *Archives of Microbiology* 163(1): 48-56
- Semprini, L., P. McCarty, M. Dolan, M. Lang, T. McDonald, J. Bae and P. Kitanidis, 1992, Design and Treatability Study of In-Situ Bioremediation of Chlorinated Aliphatics by Methanotrophs at St. Joseph, Michigan. EPA/600/R-92/126. Sittig, 1985. *Handbook of Toxic and Hazardous Chemicals and Carcinogens*, Second Edition.
- Sewell, G.W. and S.A. Gibson. 1991. "Stimulation of the Reductive Dechlorination of Tetrachloroethene in Anaerobic Aquifer Microcosms by the Addition of Toluene" *Environ. Sci. Technol.* 25 (5): 982-984.
- Sharma, P. K., and P. L. McCarty, 1996, Isolation and characterization of a facultatively aerobic bacterium that reductively dehalogenates tetrachloroethene to cis-1,2-dichloroethene. *Applied and Environmental Microbiology* 62(3): 761-765

- Smidt, H. and W. M. de Vos, 2004, Anaerobic Microbial Dehalogenation: Annual Review of Microbiology 58(1): 43-73.
- Smidt, H., A. D. L. Akkermans, J. van der Oost and W. M. de Vos (2000). Halorespiring bacteria-molecular characterization and detection. Enzyme and Microbial Technology 27: 812-820.
- Sun, B., B. M. Griffin, *et al.*, 2002, Microbial Dehalorespiration with 1,1,1-Trichloroethane: Science 298(5595): 1023-1025.
- Sung, Y., K. M. Ritalahti, *et al.* (2006). "Quantitative PCR Confirms Purity of Strain GT, a Novel Trichloroethene-to-Ethene-Respiring Dehalococcoides Isolate." Appl. Environ. Microbiol. 72(3): 1980-1987.
- Sung, Y., K. M. Ritalahti, R. A. Sanford, J. W. Urbance, S. J. Flynn, J. M. Tiedje, and F. E. Löffler, 2003, Characterization of two tetrachloroethene (PCE)-reducing, acetate-oxidizing anaerobic bacteria, and their description as *Desulfuromonas michiganensis* sp. nov. Applied and Environmental Microbiology 69(5): 2964-2974
- Suyama, A., M. Yamashita, S. Yoshino, and K. Furukawa, 2002, Molecular characterization of the PceA reductive dehalogenase of *Desulfotobacterium* sp. strain Y51. Journal of Bacteriology 184(13): 3419-3425
- Theisen, A. R. and J. C. Murrell (2005). "Facultative Methanotrophs Revisited." J. Bacteriol. 187(13): 4303-4305.
- United States Environmental Protection Agency (USEPA), 1999, Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites, Draft Interim Final: U.S. EPA Office of Solid Waste and Emergency Response Directive 9200.4-17 (<http://www.epa.gov/OUST/directiv/9200417z.htm>)
- United States Environmental Protection Agency, 1998, Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Ground Water: EPA/600/R-98/128. USEPA Office of Research and Development.
- USDA, 1981. "Soil Survey of Morgan County, Indiana" U.S. Department of Agriculture, Soil
- USEPA, 1992, Estimating the Potential for Occurrence of DNAPL at Superfund Sites: USEPA Office of Solid Waste and Emergency Response, 9355.4-07FS, Washington, D.C.
- USEPA, 1986b. "Superfund Public Health Evaluation Manual". United States Environmental Protection Agency, Office of Emergency and Remedial Response, EPA/540/1-86/060, October, 1986.
- USEPA, 2006a, (Huling, S. G. and B. Pevetz, E.) In-Situ Chemical Oxidation: EPA/600/R-06/072
- USEPA, 2006b, Evaluation of the Role of Dehalococcoides Organisms in the Natural Attenuation of Chlorinated Ethylenes in Ground Water: USEPA 600/R-06/029.
- USEPA, 2008, A Guide for Assessing Biodegradation and Source Identification of Organic Ground Water Contaminants using Compound Specific Isotope Analysis (CSIA): EPA 600/R-08/148.
- Vogel, T.M., 1994, Natural Bioremediation of Chlorinated Solvents, in Norris, R.D., R.E. Hinchee, R. Brown, P.L. McCarty, L. Semprini, J.T. Wilson, D. G. Kampbell, M. Reinhard, E.J. Bouwer, R.C. Borden, T.M. Vogel, J.M. Thomas, and C.H. Ward, editors: Handbook of Bioremediation. Boca Raton, FL. Lewis Publishers
- Vogel, T.M., 1994, Natural Bioremediation of Chlorinated Solvents, In: Handbook of Bioremediation. Lewis Publishers, Boca Raton, FL. 1994.
- Vogel, T.M., and McCarty, P.L., 1985, Biotransformation of tetrachloroethylene to trichloroethylene, dichloroethylene, vinyl chloride, and carbon dioxide under methanogenic conditions: Applied Environmental Microbiology, v. 49, no. 5, pp. 1080-1083.
- Vogel, T.M., C.S. Criddle, and P.M. McCarty, 1987, Transformations of Halogenated Aliphatic Compounds: Environmental Sci. Toxicol. 21:722-736.
- Vogel, T.M., Criddle, C.S., and McCarty, P.L., 1987, Transformation of halogenated aliphatic compounds: Environmental Science and Technology, vol. 21, no. 8, p. 722-736.
- Walton, W.C., 1988, Practical Aspects of Groundwater Modeling: National Water Well Association, Worthington, Ohio, 587 p.
- Wei, N. and K. T. Finneran, 2011, The Influence of Ferric Iron on Complete Dechlorination of Trichloroethylene (TCE) to Ethene: Fe(III) Reduction does not Always Inhibit Complete Dechlorination: Environmental Science & Technology: In Press
- Wiedemeier, T.H. and Chapelle, F.H., 2000, Technical Guidelines for Evaluating Monitored Natural Attenuation at Naval and Marine Corps Facilities: Department of the Navy, September.

- Wiedemeier, T.H., 2010, Technical Memorandum *CSIA Analysis for the Twigg Manufacturing Facility, Martinsville, Indiana*, August 30, 2010
- Wiedemeier, T.H., Barden, M.J., Dickson, W.Z., and Major, D.W., 2005, Multiple Lines of Evidence Supporting Natural Attenuation: Lines of Inquiry Supporting Monitored Natural Attenuation and Enhanced Attenuation of Chlorinated Solvents: Westinghouse Savannah River Company, WSRC-TR-2003-00331.
- Wiedemeier, T.H., Rifai, H.S., Newell, C.J., and Wilson, J.T., 1999, *Natural Attenuation of Fuels and Solvents in the Subsurface*, John Wiley & Sons, New York
- Wiedemeier, T.H., Swanson, M.A., Moutoux, D.E., Wilson, J.T., Kampbell, D.H., Hansen, J.E., and Haas, P., 1996a, Technical Protocol for Evaluating the Natural Attenuation of Chlorinated Aliphatic Hydrocarbons in Groundwater: Air Force Center for Environmental Excellence, San Antonio, Texas.
- Wiedemeier, T.H., Swanson, M.A., Wilson, J.T., Kampbell, D.H., Miller, R.N., and Hansen, J.E.; 1996b, Approximation of biodegradation rate constants for monoaromatic hydrocarbons (BTEX) in ground water: *Ground Water Monitoring and Remediation*, v. 16, no. 3, Summer, p. 186-194.
- Wiedemeier, T.H., Wilson, J.T., and Kampbell, D.H., 1996c, Natural attenuation of chlorinated aliphatic hydrocarbons at Plattsburgh Air Force Base, New York, In *Proceedings of the Symposium on Natural Attenuation of Chlorinated Organics in Ground Water*, Dallas, TX: EPA/540/R-96/509, September.
- Wild, A., R. Hermann, and T. Leisinger, 1996 Isolation of an anaerobic bacterium which reductively dechlorinates tetrachloroethene and trichloroethene. *Biodegradation* 7(6): 507-511
- Zaa, C. L. Y., J. E. McLean, et al. (2010). "Dechlorinating and Iron Reducing Bacteria Distribution in a TCE-Contaminated Aquifer." *Ground Water Monitoring & Remediation* 30(1): 46-57.

FIGURES

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Source: BCA, 2007 from USGS 7.5' Quadrangle Map

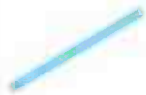
d:\TWIGG\Report\figures\Figure 1.a

Figure 1
Site Vicinity Map
Twigg Manufacturing Facility
Martinsville, Indiana

TWIGG

W
WIEDEMEIER
& ASSOCIATES

Date: 5/20/11
Client: Twigg
Project Number: 030379
Revision Number: 0



Approximate Extent of Chlorinated
Ethene Plume

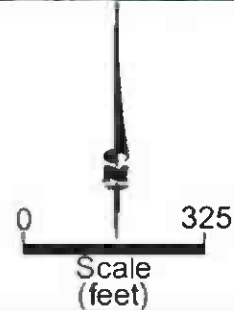


Figure 2
Aerial Photograph of Site Vicinity
Twigg Manufacturing Facility
Martinsville, Indiana

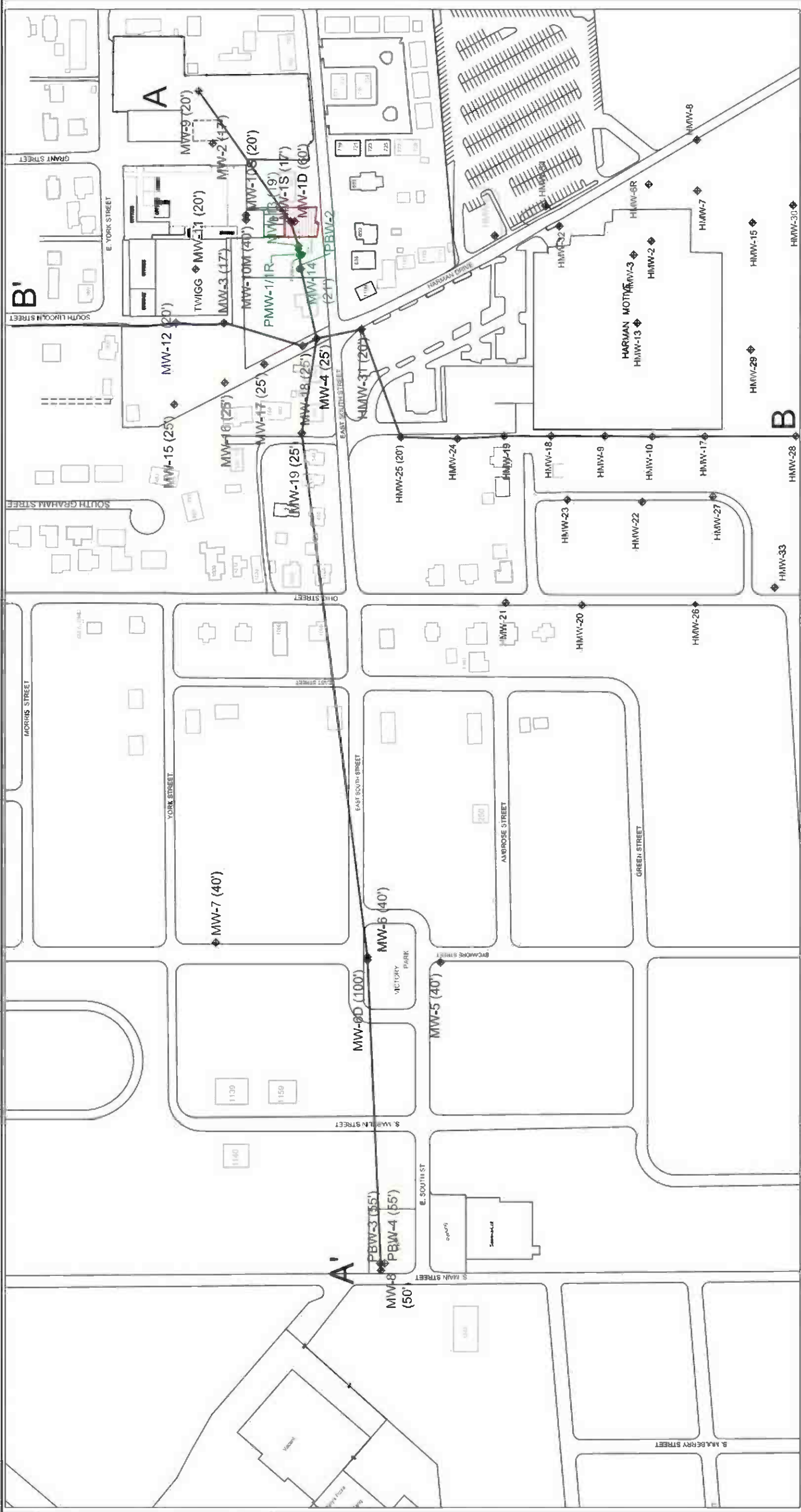
TWIGG



Date: 7/7/11
Client: Twigg
Revision Number: 0

Source: Google Earth

DATA\TWGG\Figures\Figure 2.a



LEGEND:

- MW-5 (40') ♦ 1990's Monitoring Well Locations (base of screen depth in feet)
- MW-11 (20') ♦ May 2000 Monitoring Well Locations (base of screen depth in feet)
- MW-13 (19') ♦ 2004 Monitoring Well Locations (base of screen depth in feet)
- MW-15 (25') ♦ 2006 Monitoring Well Locations (base of screen depth in feet)
- HMW-24 ♦ Harman Becker Monitoring Well Locations



A A' Line of Section for Cross Sections

Portion of A-A' from MW-1 to MW-8 is Line Along Which Flowpath Analysis Was Conducted

Figure 3 Site Map

Twigg Manufacturing Facility
Martinsville, Indiana



Date: 7/12/11
Client: Twigg Aerospace Components
Revision Number: 0
Drawn By: THW



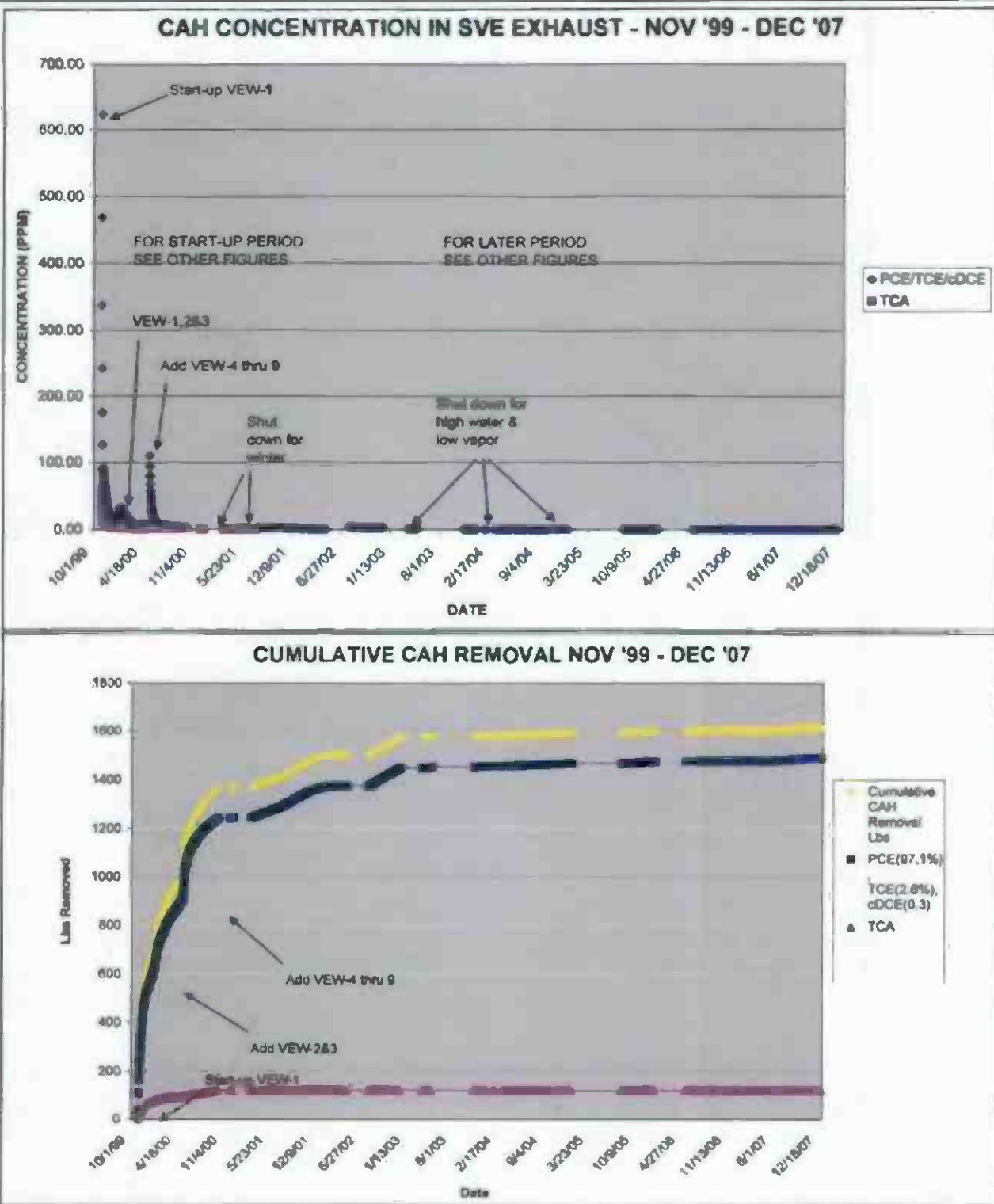

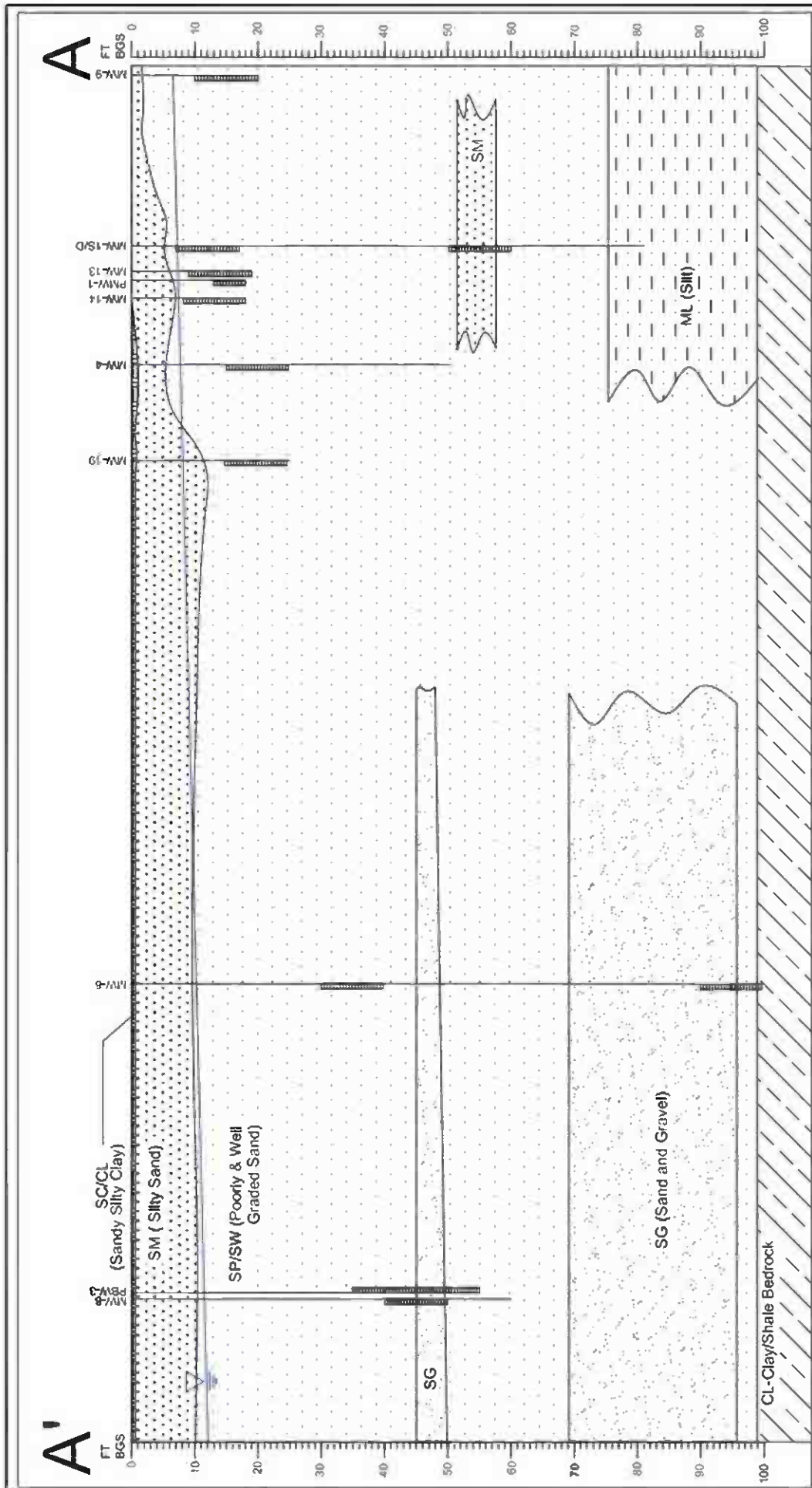


Figure 5
SVE Effluent CAH Concentration and
Cumulative CAH Mass Removed
 Twigg Manufacturing Facility
 Martinsville, Indiana

 WIEDEMEIER & ASSOCIATES	Date: 7/8/11 Client: Twigg Project Number: 030379 Revision Number: 0
---	---



LEGEND:

Monitoring Well Location and Screened Interval(s)

Water Level Measured on 5/22/08

SC/CL = Sandy and Silty Clay

SM = Silty Sand

SP = Poorly Graded (Well Sorted) Sand

SW = Well Graded (Poorly Sorted) Sand

SG = Sand and Gravel

ML = Silt

Base Supplied by Bruce Carter Associates

Figure 6
Hydrogeologic Cross-Section A-A'

Twigg Manufacturing Facility
Marionville, Indiana

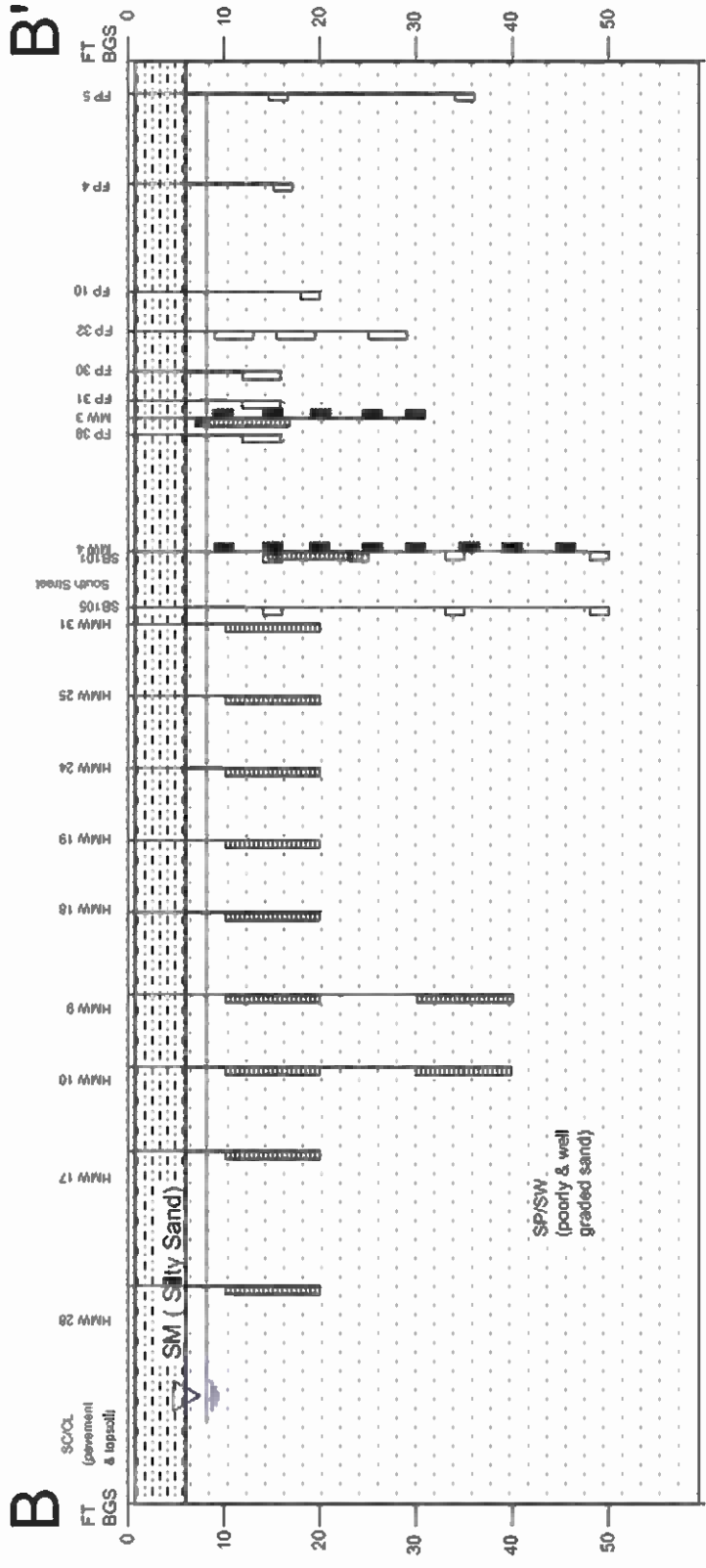
TWIGG

W

WIEDEMEIER & ASSOCIATES

Date: 7/5/11
Client: Twigg Corporation
Revision Number: 0
Drawn By: THW

VERTICAL EXAGGERATION 13.3



LEGEND:

Monitoring Well Location and Screened Interval(s)

Water Level Measured on 5/22/08

- SC/CL = Sandy and Silty Clay
- SM = Silty Sand
- SP = Poorly Graded (Well Sorted) Sand
- SW = Well Graded (Poorly Sorted) Sand
- SG = Sand and Gravel
- ML = Silt

Base Supplied by Bruce Center Associates



Figure 7
 Hydrogeologic Cross-Section B-B'

Twigg Manufacturing Facility
 Martinsville, Indiana



Date: 7/5/11
 Client: Twigg Corporation
 Revision Number: 0
 Drawn By: THW

Figure 8
Precipitation versus Time for Martinsville 2 SW (McDaniel's Field Airport)
 Twigg Manufacturing Facility
 Martinsville, Indiana

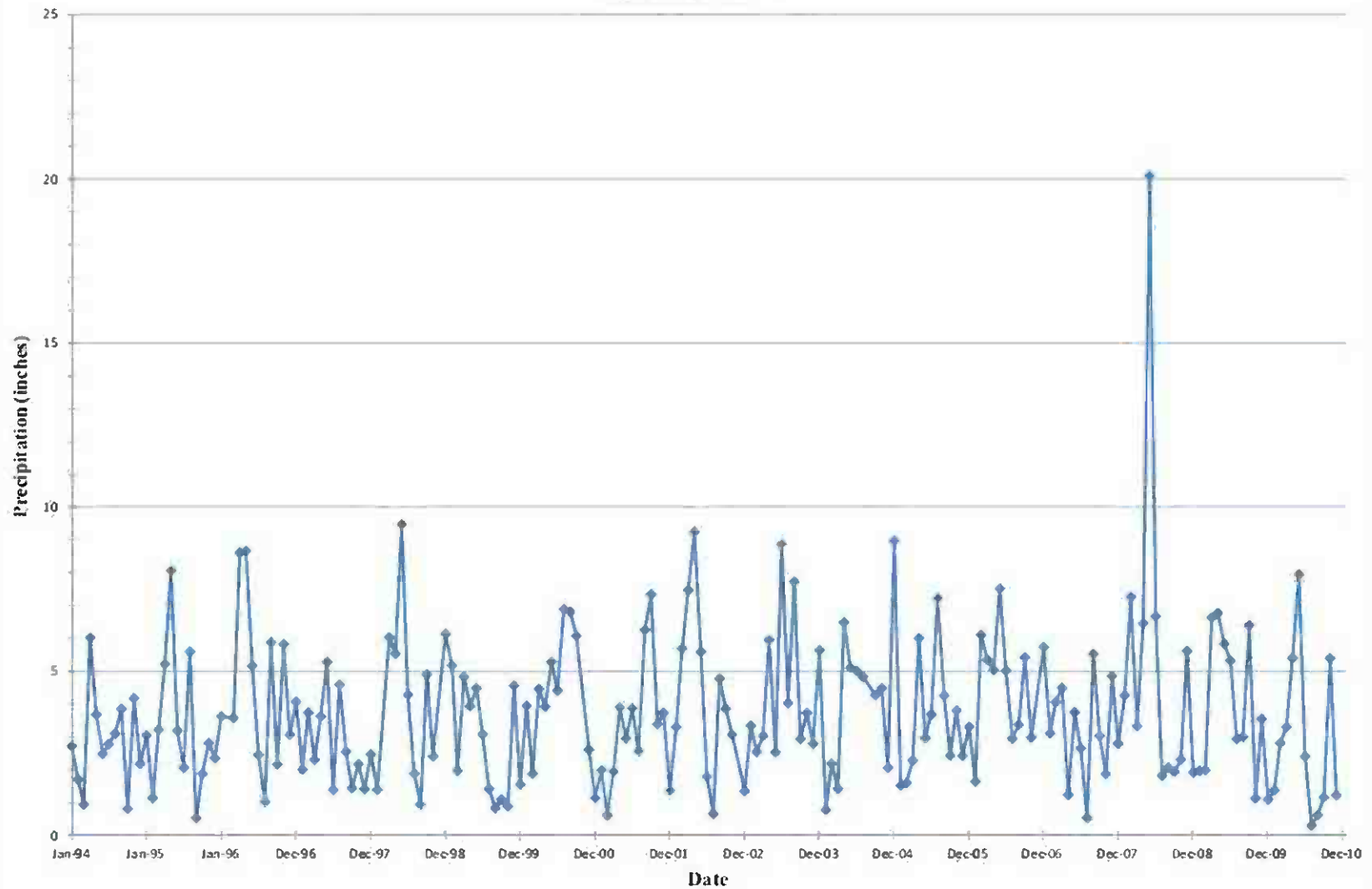
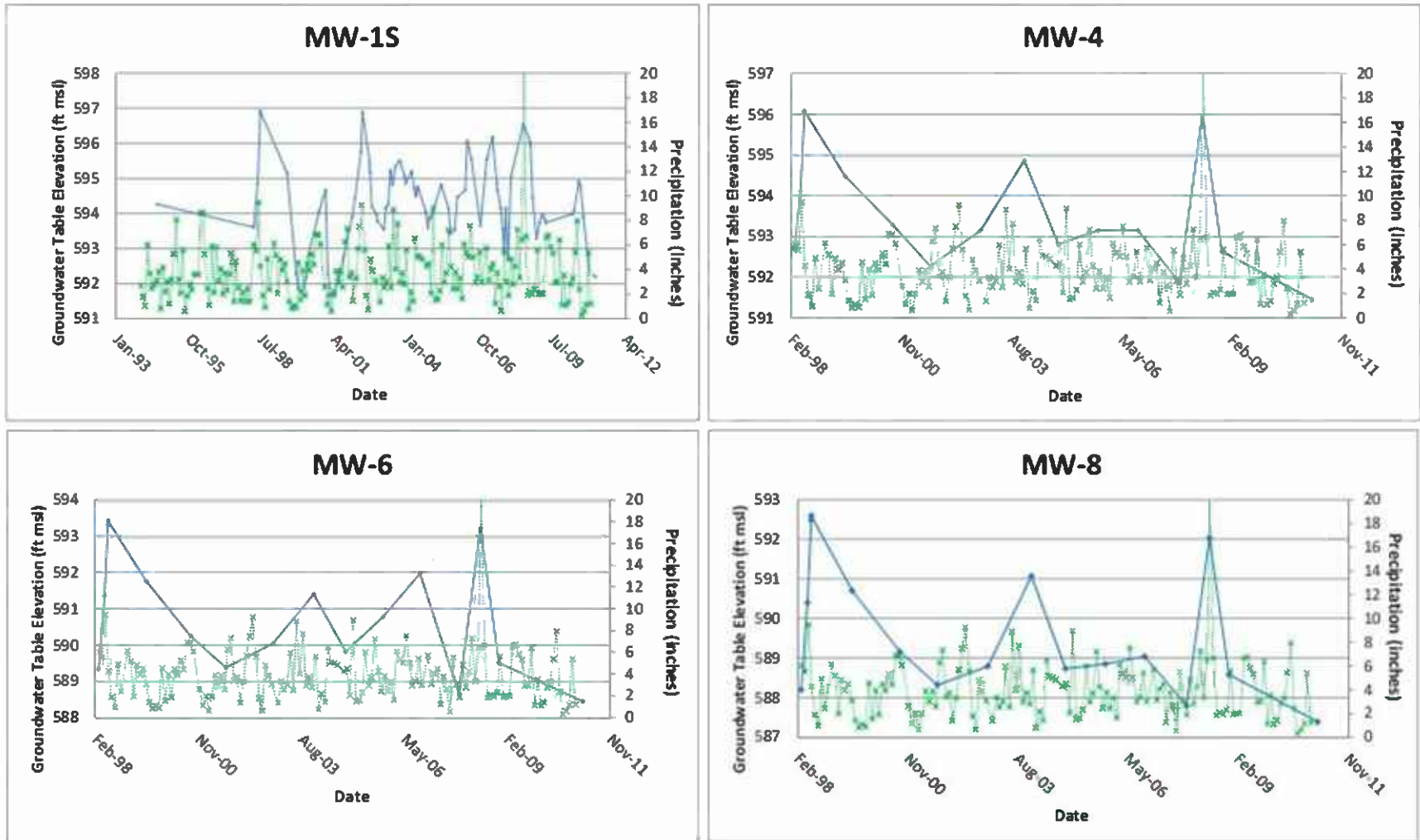
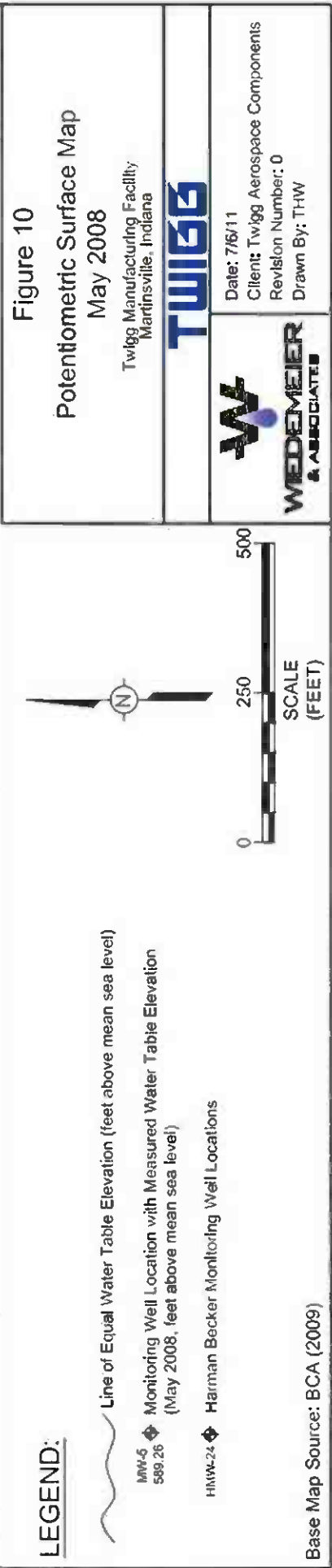


Figure 9
Plots of Groundwater Table Elevation versus Time for Selected Wells Along Flowpath
 Twigg Manufacturing Facility
 Martinsville, Indiana



 Groundwater Table Elevation (ft msl)
 Precipitation (inches)



Date: 7/6/11
Client: Twigg Aerospace Components
Revision Number: 0
Drawn By: THW

Base Map Source: BCA (2009)

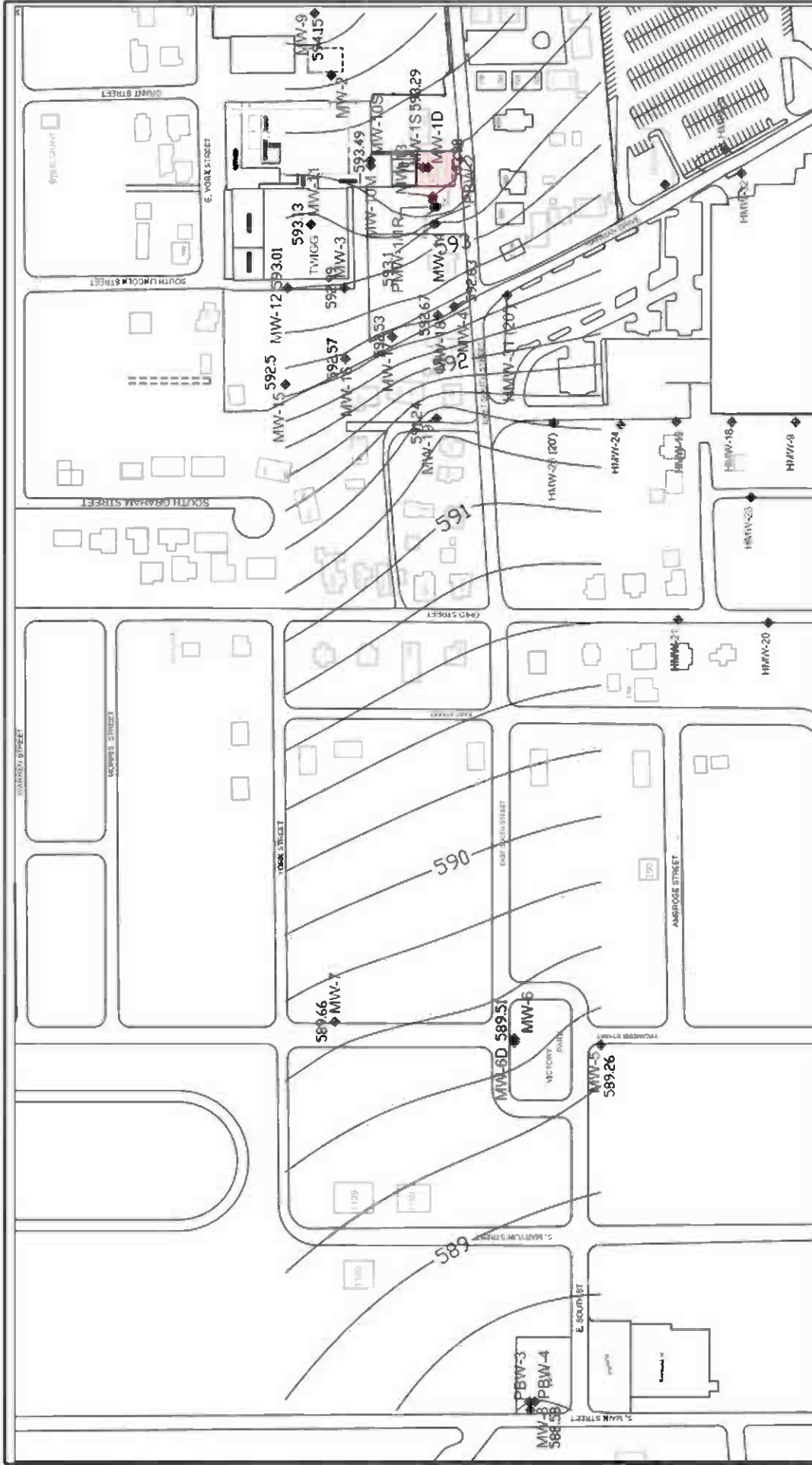


Figure 11

Potentiometric Surface Map November 2008

Twigg Manufacturing Facility
Martinsville, Indiana



Date: 7/8/11
Client: Twigg Aerospace Components
Revision Number: 0
Drawn By: THW

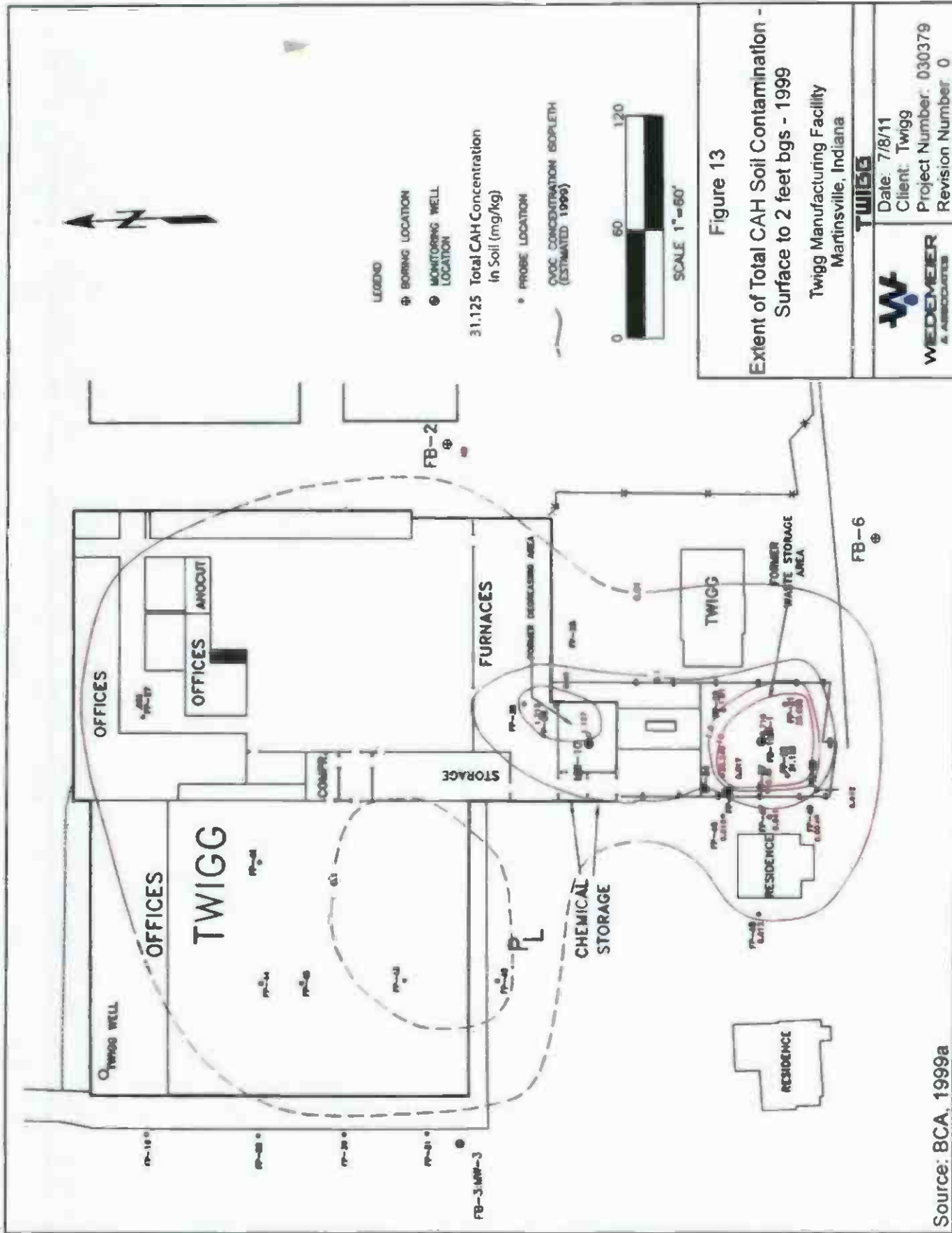


LEGEND:

Line of Equal Water Table Elevation (feet above mean sea level)

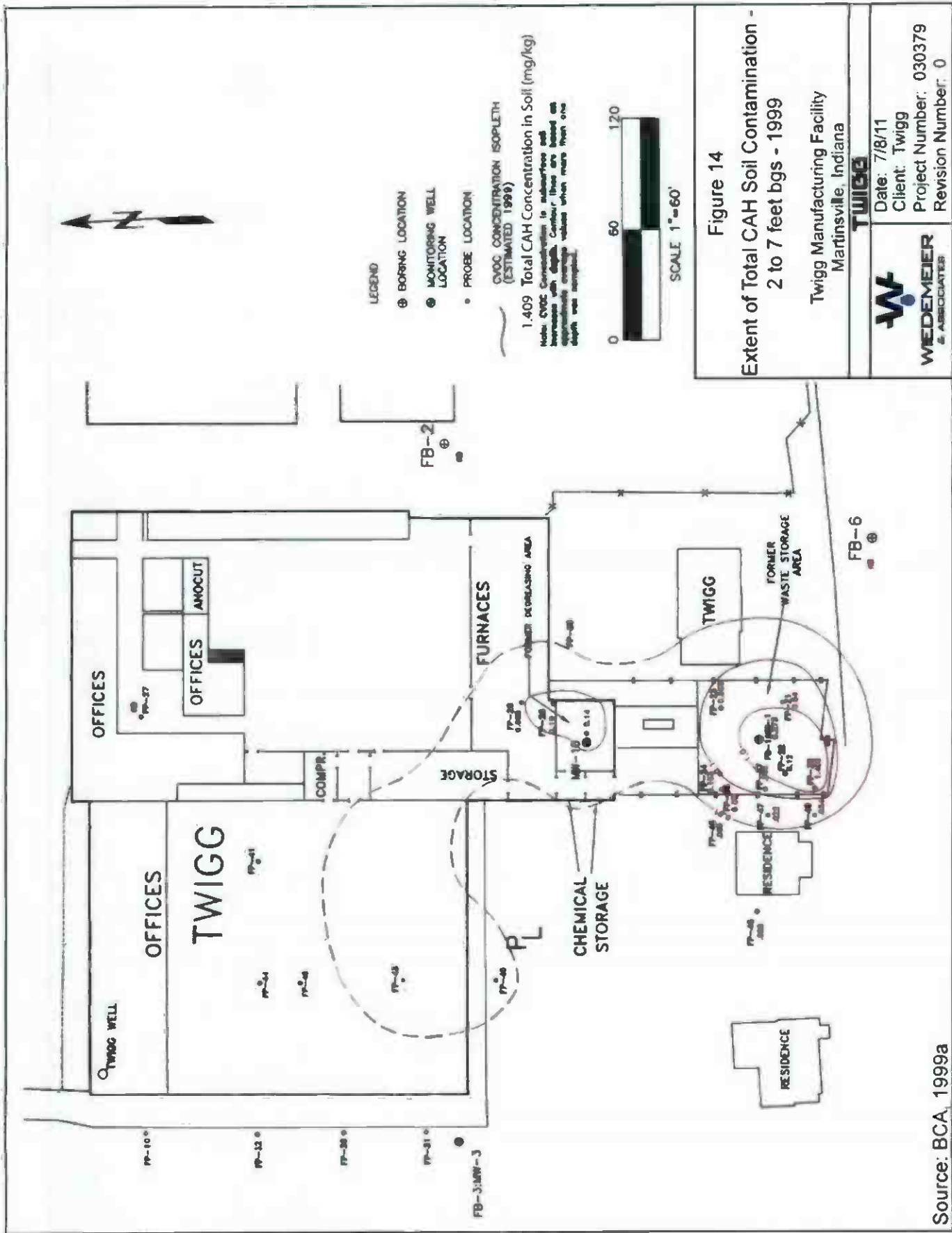
MW-5 589.26 ♦ Monitoring Well Location with Measured Water Table Elevation (November 2008, feet above mean sea level)

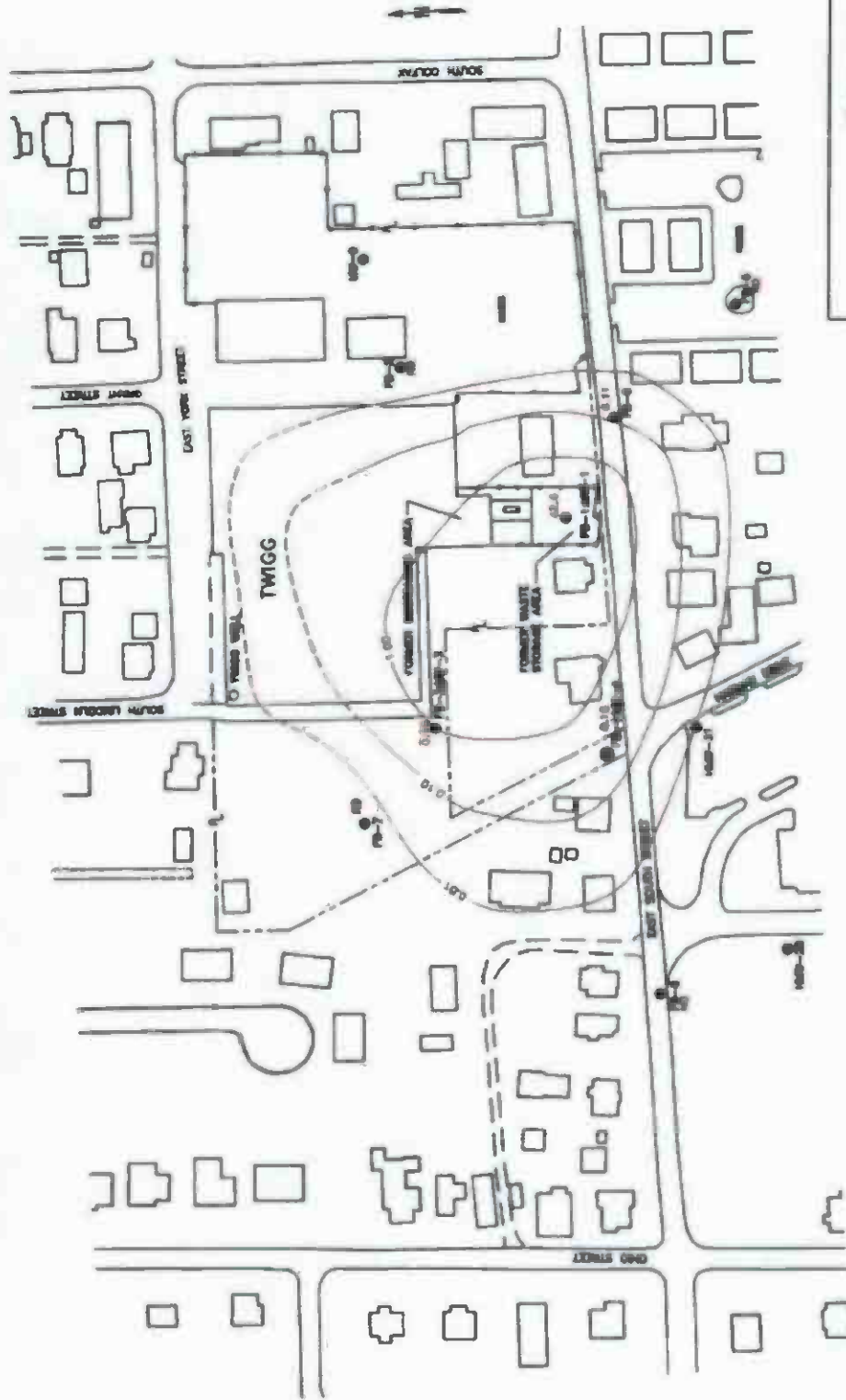
HBMW-24 ♦ Harman Becker Monitoring Well Locations



Source: BCA, 1999a

at TWIGG Manufacturing Facility Figure 13.0




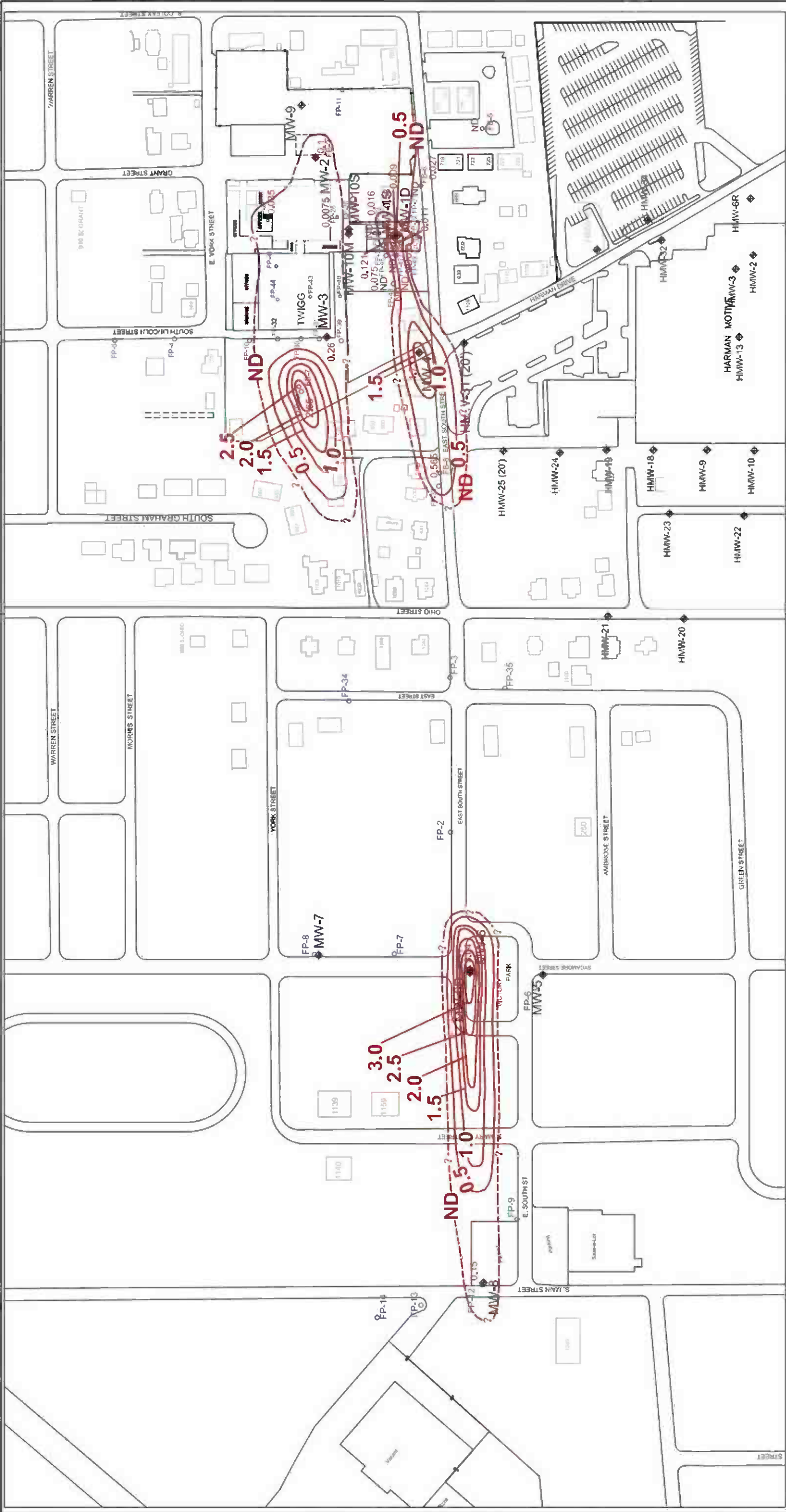


LEGEND
 ● BORING LOCATION
 ● MONITORING WELL

0.016 CAH SOIL CONCENTRATION (MG/KG)



<p>Figure 15</p> <p>Extent of Total CAH Soil Contamination - 7 to 11 feet bgs</p> <p>Twigg Manufacturing Facility Martinsville, Indiana</p>	
 <p>WIEDEMEIER & ASSOCIATES</p>	<p>Date: 7/8/11 Client: Twigg Project Number: 030379 Revision Number: 0</p>



LEGEND:

- ND — Line of Equal Total Chlorinated Ethane Concentration in Soil (mg/kg) at Depth of Maximum Concentration. Contour Interval Variable. Dashed where Approximate.
- FB-8-O 1994 Soil Boring Location
- FP-9-O 1996 - 1999 Soil Boring and Groundwater Sample Locations
- MW-5 1996 - 1999 Monitoring Well Locations
- HMW-24 1999 Hamman Becker Monitoring Well Locations
- Former Waste Storage Area

Figure 18

Total Chlorinated Ethane Concentration in Soil at Depth of Maximum Concentration - 1994-1999

Twigg Manufacturing Facility
Marionville, Indiana

W
WEDENMEIER & ASSOCIATES

Date: 3/12/11
Client: Twigg Aerospace Components
Revision Number: 0
Drawn By: THW

0 200 400
SCALE (feet)

N

A'

A

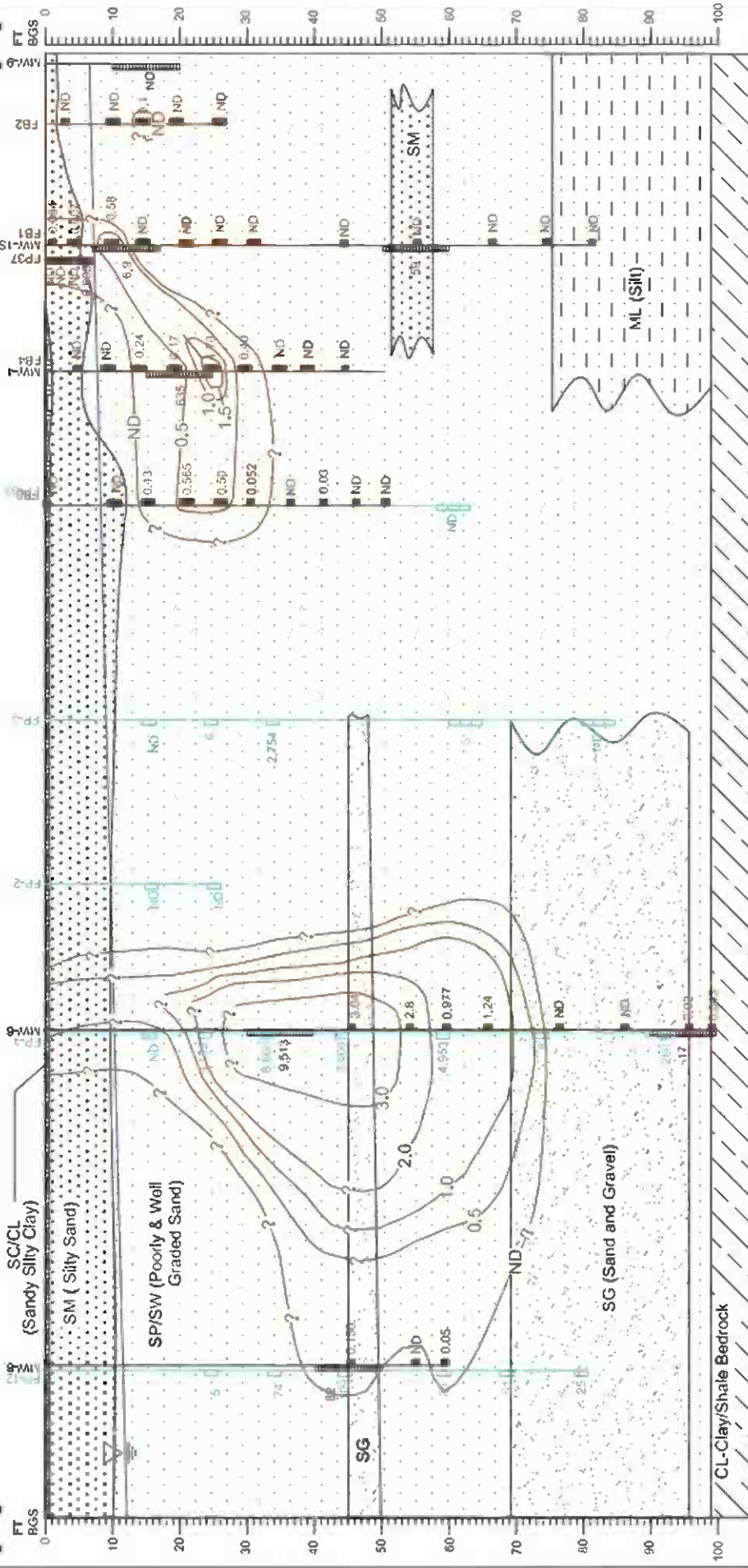


Figure 19

Total Chlorinated Ethane Concentration in Soil Along Flowpath - 1994-1999

Twigg Manufacturing Facility
Martinsville, Indiana

TWIGG

Date: 7/14/11
Client: Twigg Corporation
Revision Number: 0
Drawn By: THW

WIEDENMEIER & ASSOCIATES



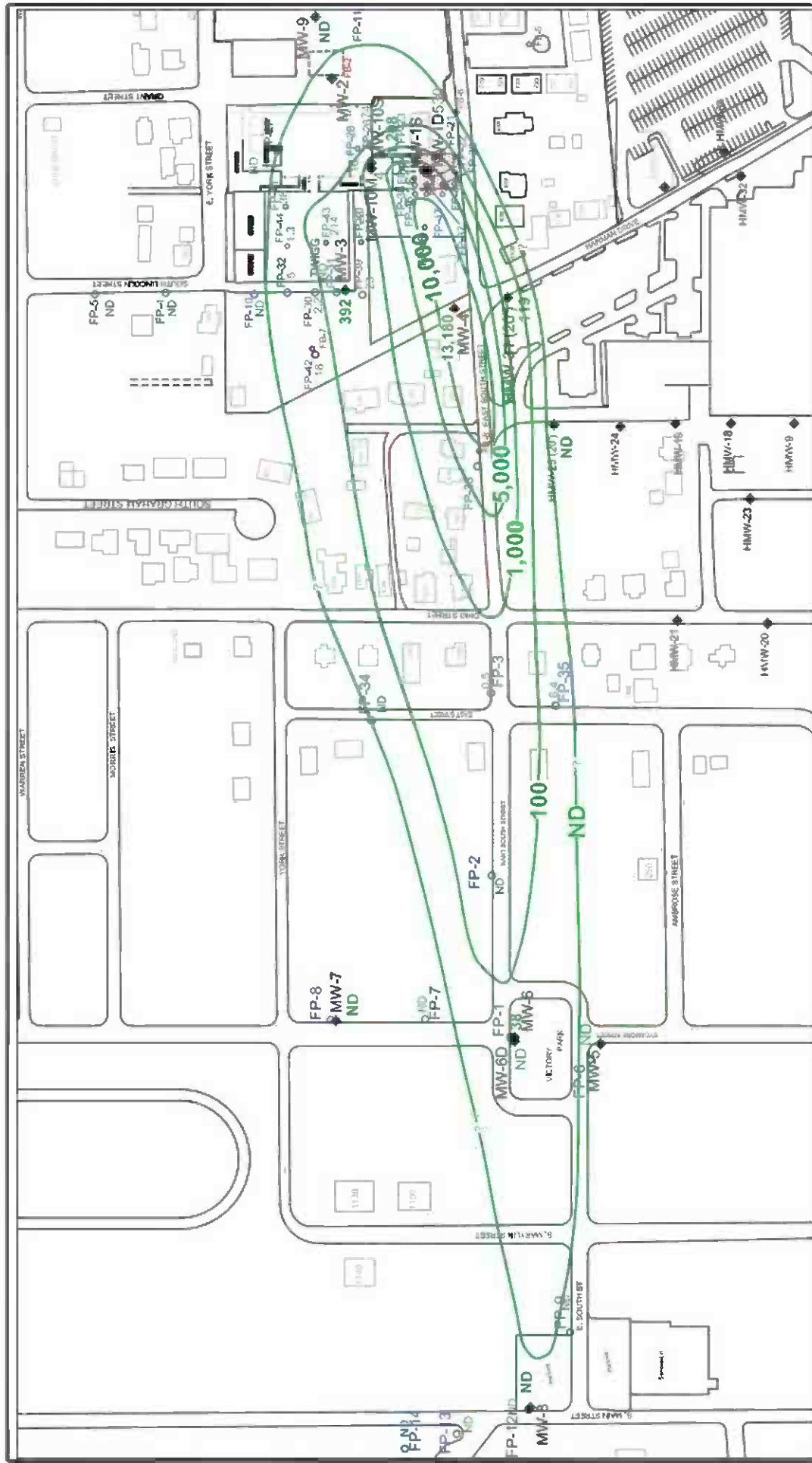


Figure 20
Total Chlorinated Ethene Isopleths at Depth
of Maximum Concentration - 1998/1999*



LEGEND:

Line of Equal Total Chlorinated Ethene Concentration in Groundwater (µg/L)
Contour Interval Variable.

- FB-90 1994 Soil Boring Location
- FP-90 1996 - 1999 Boring and Groundwater Sample Locations
- MW-5 1990's Monitoring Well Locations
- MW-24 1990's Monitoring Well Locations
- MW-25 1990's Monitoring Well Locations

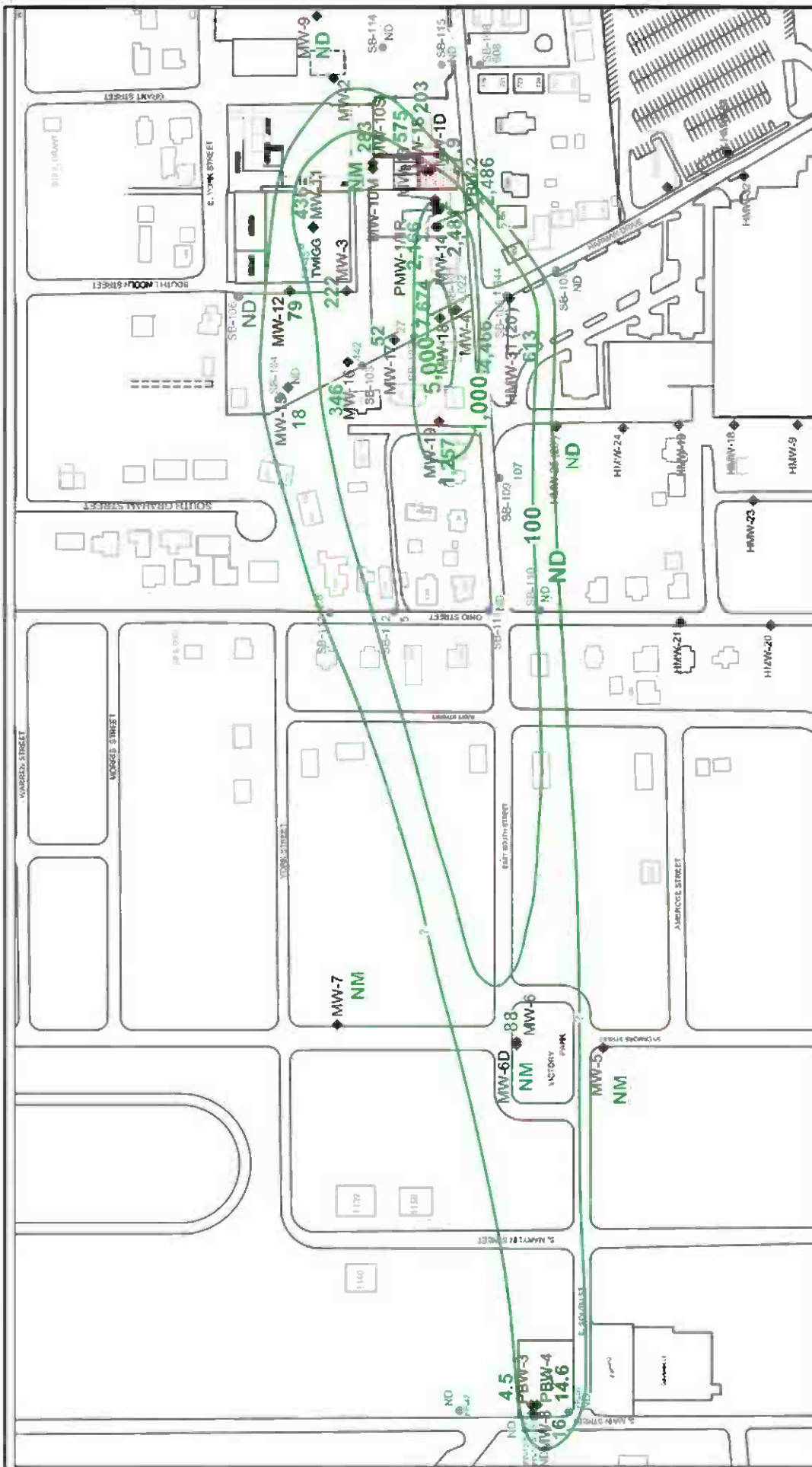
* Highest Measured Concentration - 1998 through 1999

Base Map Source: BCA (2009)

Twigg Manufacturing Facility
Martinsville, Indiana



Date: 7/2/11
Client: Twigg Aerospace Components
Revision Number: 0
Drawn By: THW



LEGEND:

Line of Equal Total Chlorinated Ethene Concentration in Groundwater (µg/L).
Contour Interval Variable.

FP-9O 2006 Groundwater Sample Locations

MW-5 (40) 1990's Monitoring Well Locations

MW-11 (20) May 2000 Monitoring Well Locations

MW-13 (19) 2004 Monitoring Well Locations

MW-19 (25) 2006 Monitoring Well Locations

SB-110 2008 Soil Boring Groundwater Sample Locations

HW-24 Harman Becker Monitoring Well Locations

* Highest measured concentration from 2007.

Base Map Source: BCA (2009)

Figure 22

Total Chlorinated Ethene Isopleths at Depth of Maximum Concentration - 2007*

Twigg Manufacturing Facility
Martinsville, Indiana

TWIGG

WIEDEMEIER & ASSOCIATES

Date: 7/2/11
Client: Twigg Aerospace Components
Revision Number: 0
Drawn By: THW

0 250 500
SCALE (FEET)

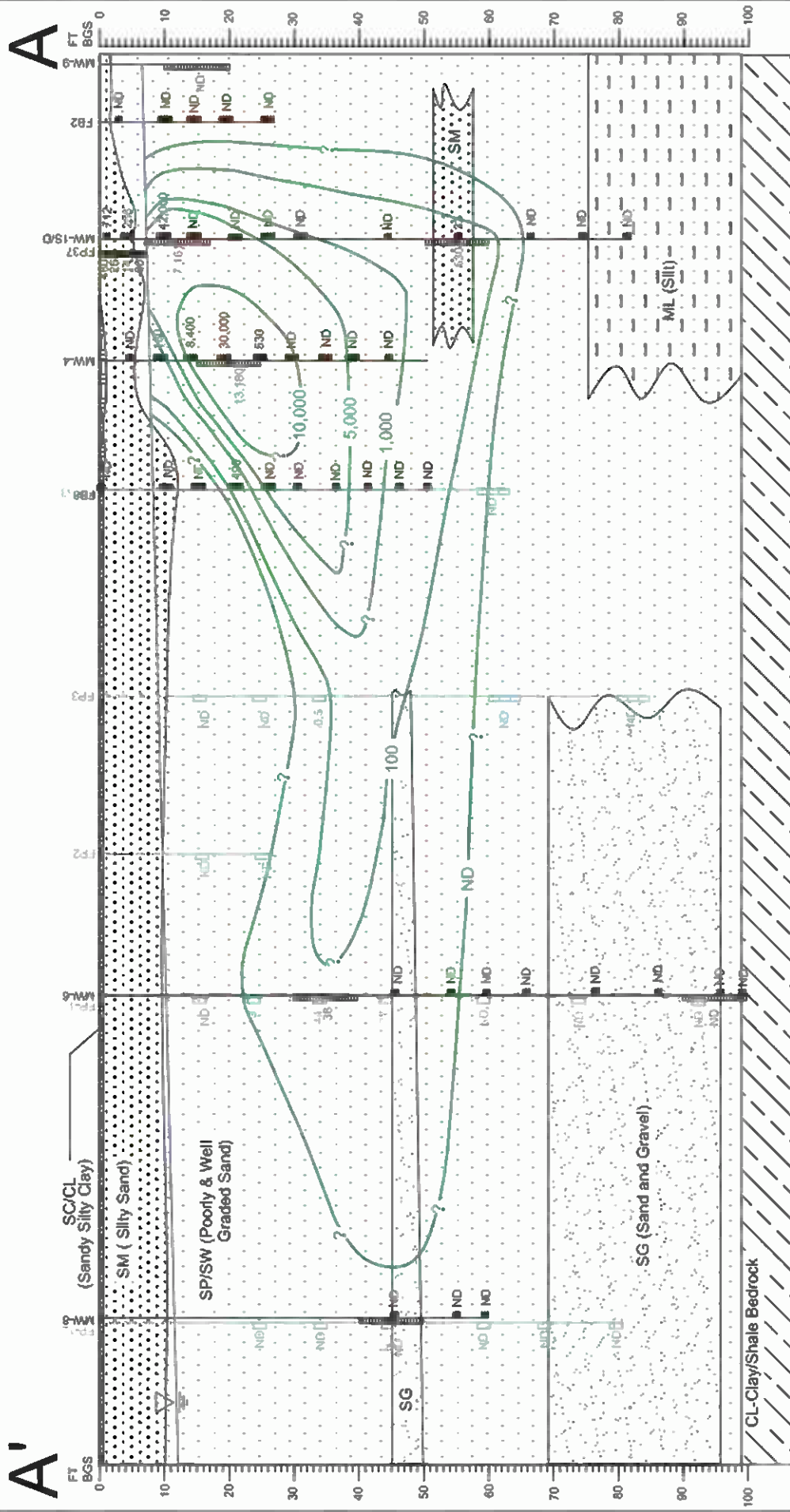


Figure 24
Total Chlorinated Ethene Isopleths Along
Flowpath - 1998/1999*

Twigg Manufacturing Facility
Marlinsville, Indiana



Date: 7/14/11

Client: Twigg Corporation

Revision Number: 0

Drawn By: THW



**WEDENBERGER
& ASSOCIATES**



VERTICAL EXAGGERATION 13.3

7 Water Level Measured on 5/22/08 (Shallowest on Record)

Temporary Well Location and Total Chlorinated Ethene Concentration ($\mu\text{g/L}$) (5/199)180 Soil Sample Location and Total Chlorinated Ethene Concentration in Soil ($\mu\text{g/Kg}$) (1996-1999)

Monitoring Well Location and Total Chlorinated Ethene Concentration in Groundwater (µg/L)

Groundwater Probe Location and Total Chlorinated

Ethene Concentration ($\mu\text{g/L}$) (1996-1999)

Highest Measured Concentration in Monitoring Wells

1998-1999, Other Data Highest Concentration 1996-1999)

Line of Equal Total Chlorinated Ethene Concentration

In Groundwater($\mu\text{g/L}$)

Base Supplied by Bruce Camar Associates



LEGEND:

—▽— Water Level Measured on 5/22/08 (Shallowest on Record)

254 Monitoring Well Location and Total Chlorinated Ethene Concentration in Groundwater (µg/L)

Line of Equal Total Chlorinated Ethene Concentration in Groundwater (µg/L)

*Highest concentration from 2004 unless data not available. If which case 2003 data were used as indicated by an asterisk.

Base Supplied by Bruce Carter Associates

Figure 25

Total Chlorinated Ethene Concentration
Along Flowpath - 2004*

Twigg Manufacturing Facility
Martinsville, Indiana

Twigg

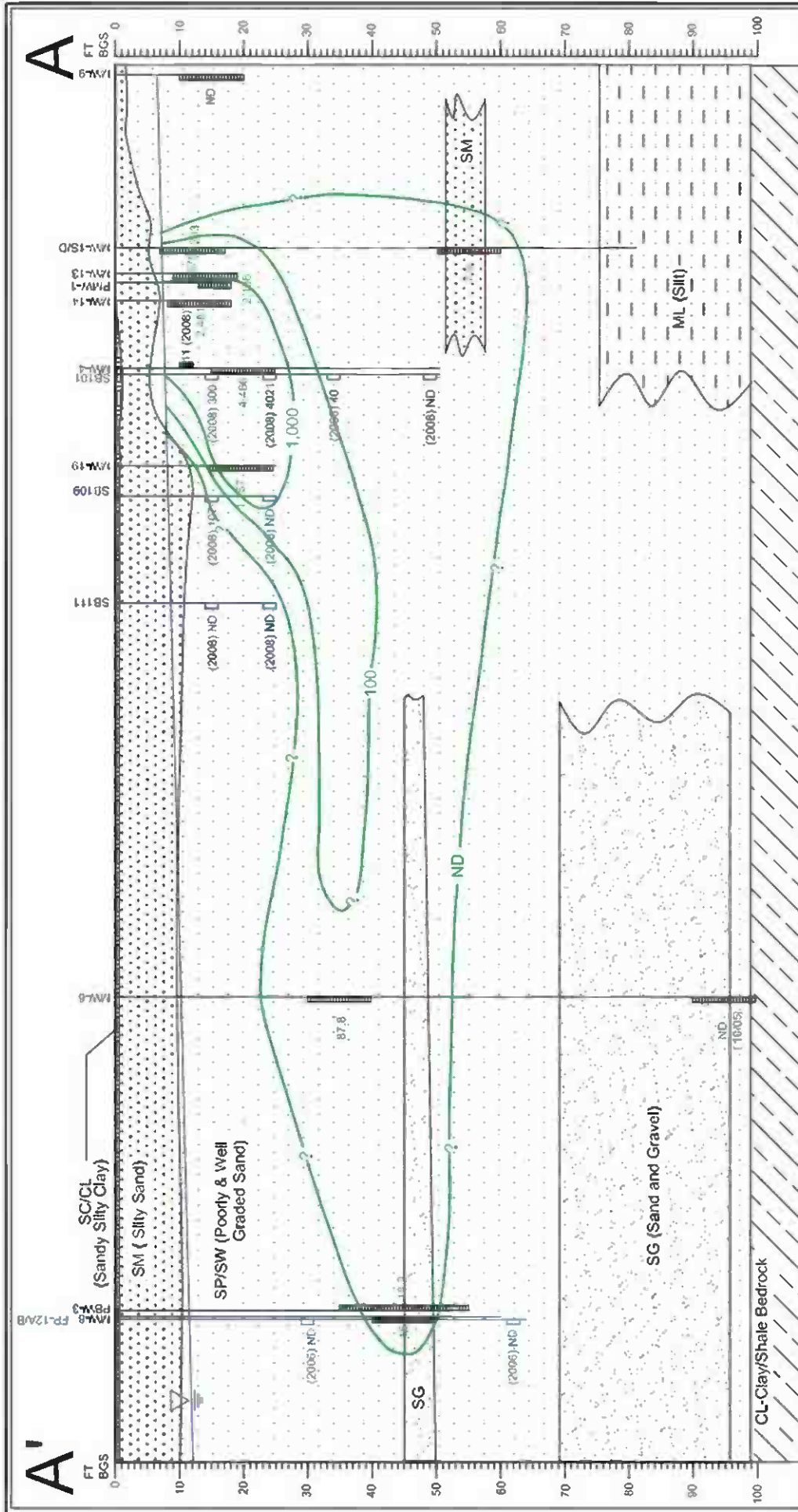


**WIEDEMEIER
& ASSOCIATES**

Date: 6/29/11
Client: Twigg Corporation
Revision Number: 0
Drawn By: THW

0 300 600
HORIZONTAL SCALE
(feet)

VERTICAL EXAGGERATION 13.3



LEGEND: Water Level Measured on 5/22/08 (Shallowest on Record)

Groundwater Probe Location and Total Chlorinated Ethene Concentration (µg/L) (2008)

180 Soil Sample Location and Total Chlorinated Ethene Concentration In Soil (µg/Kg) (2008)
 Monitoring Well Location and Total Chlorinated Ethene Concentration in Groundwater (µg/L) (Highest Concentration Observed in 2007 Except Where Noted)

87.8 Groundwater Probe Location and Total Chlorinated Ethene Concentration (µg/L) (2006)
 Line of Equal Total Chlorinated Ethene Concentration In Groundwater (µg/L)

*Highest measured concentration from 2007 unless otherwise indicated
 Base Supplied by Bruce Cramer Associates

Figure 26

Total Chlorinated Ethene Concentration Along Flowpath - 2007*

Twigg Manufacturing Facility
Martinsville, Indiana

TWIGG

Date: 6/29/11

Client: Twigg Corporation

Revision Number: 0

Drawn By: THW



**WEDENMEIER
& ASSOCIATES**



VERTICAL EXAGGERATION 13.3

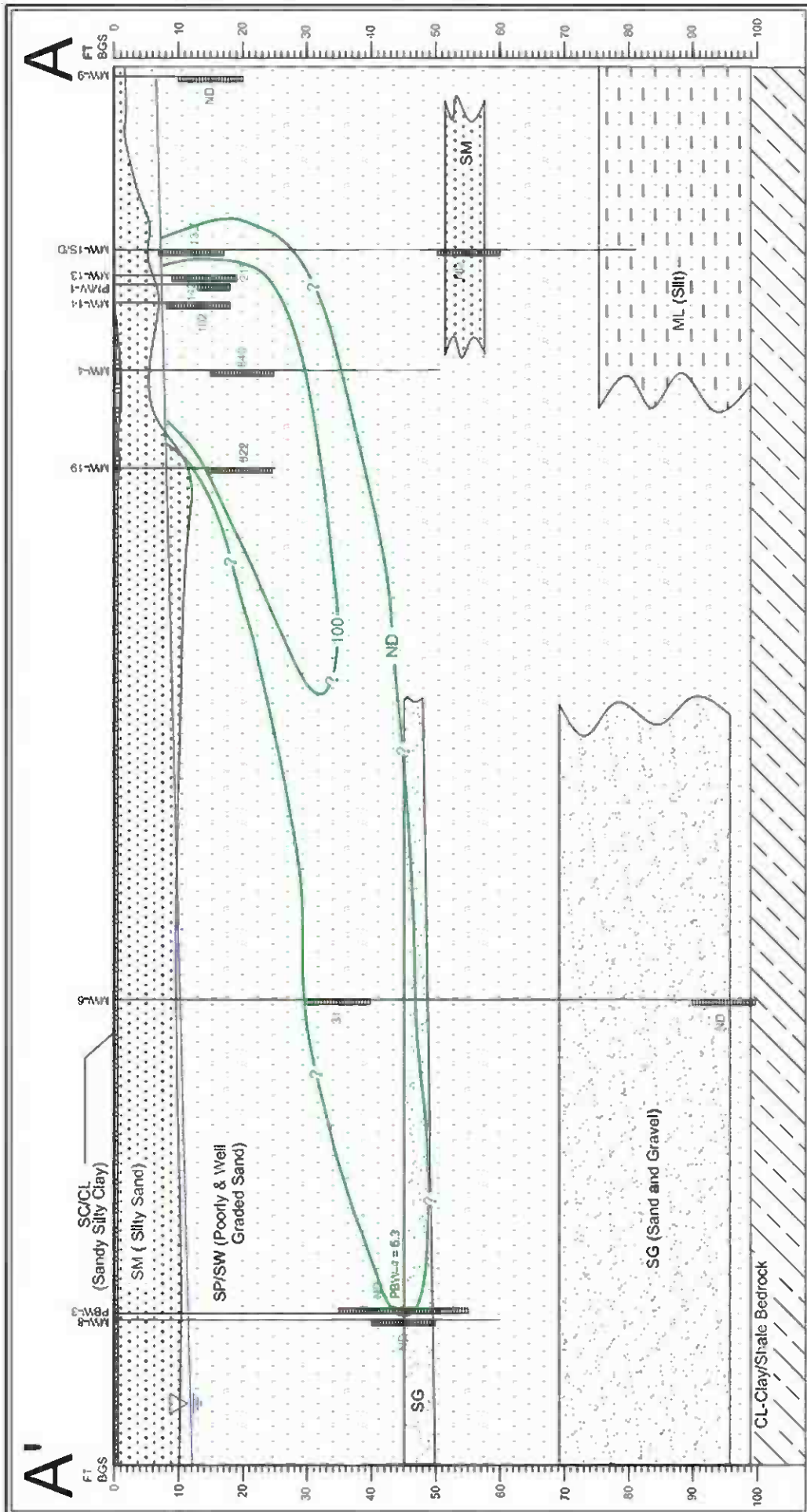


Figure 27

Total Chlorinated Ethene Concentration Along Flowpath - January/February 2011

Twigg Manufacturing Facility
Martinsville, Indiana

TWIGG

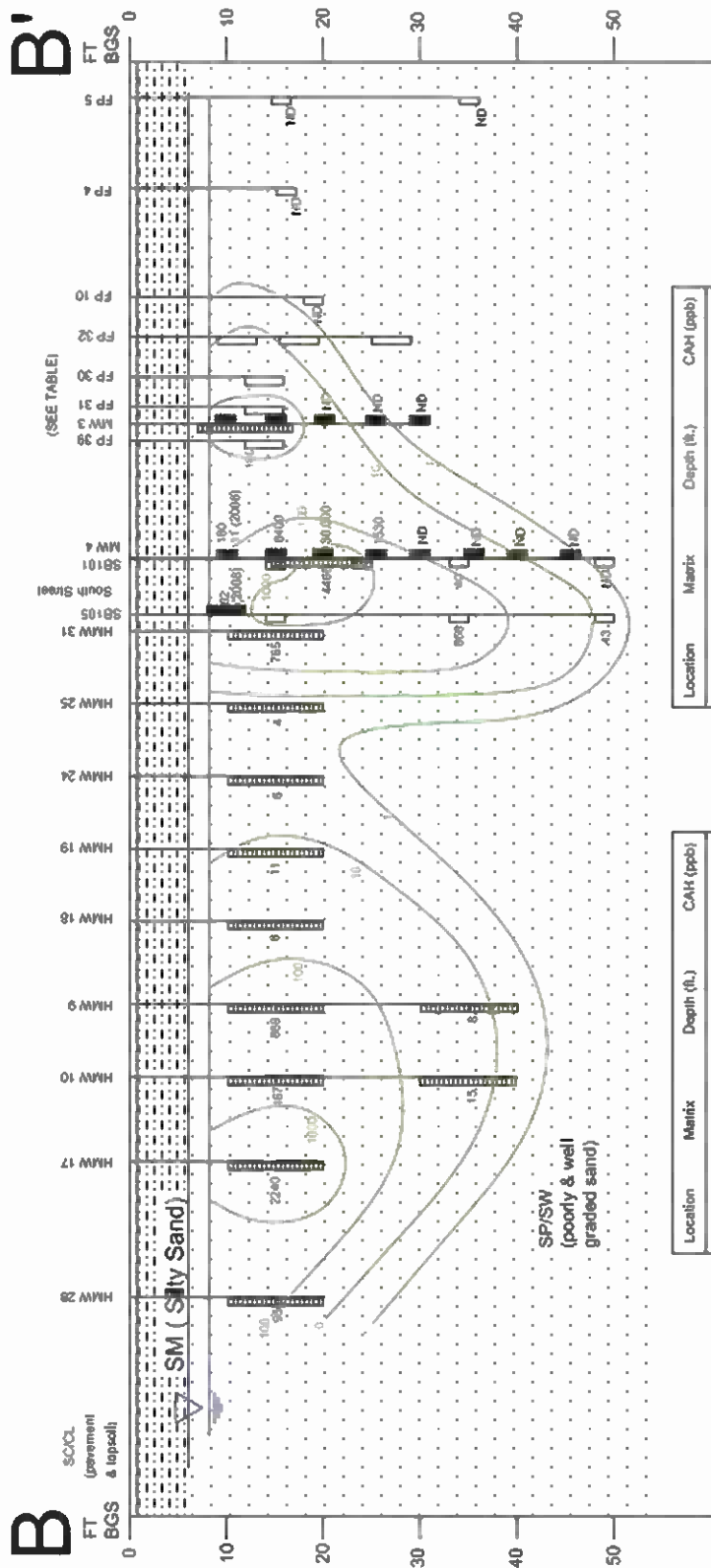
Date: 7/14/11
Client: Twigg Corporation
Revision Number: 0
Drawn By: THW

WEDEMEIER & ASSOCIATES

254

Horizontal Scale
(feet)

Vertical Exaggeration 13.3



Location	Matrix	Depth (ft.)	CATE (ppb)
FP-39	GW	14-17	56
MW-3	GW	7-17	222
MW-3	Soil	9-11'	780
MW-3	Soil	14-15'	410
MW-3	Soil	19-21'	ND
MW-3	Soil	24-26'	ND
FP-31	GW	16-20'	ND

Location	Matrix	Depth (ft.)	CATE (ppb)
FP-30	GW	16-20'	2
FP-32	GW	11-15'	34
FP-32	GW	16-20'	4
FP-32	GW	26-30'	ND
SB-101	GW	12-16'	300
SB-101	GW	21-25'	4021
SB-105	GW	12-16'	1844

LEGEND:

- Temporary Well Location and Total Chlorinated Ethene Concentration (µg/L) (5/99)
- Water Level Measured on 5/22/08 (Shallowest on Record)
- 180 Soil Sample Location and Total Chlorinated Ethene Concentration in Soil (µg/Kg) (1996-1999)
- Monitoring Well Location and Total Chlorinated Ethene Concentration in Groundwater (µg/L) (Highest of Last Three Sampling Events to 2009)
- Groundwater Probe Location and Total Chlorinated Ethene Concentration (µg/L) (1996-1999)
- Line of Equal Total Chlorinated Ethene Concentration (µg/L)

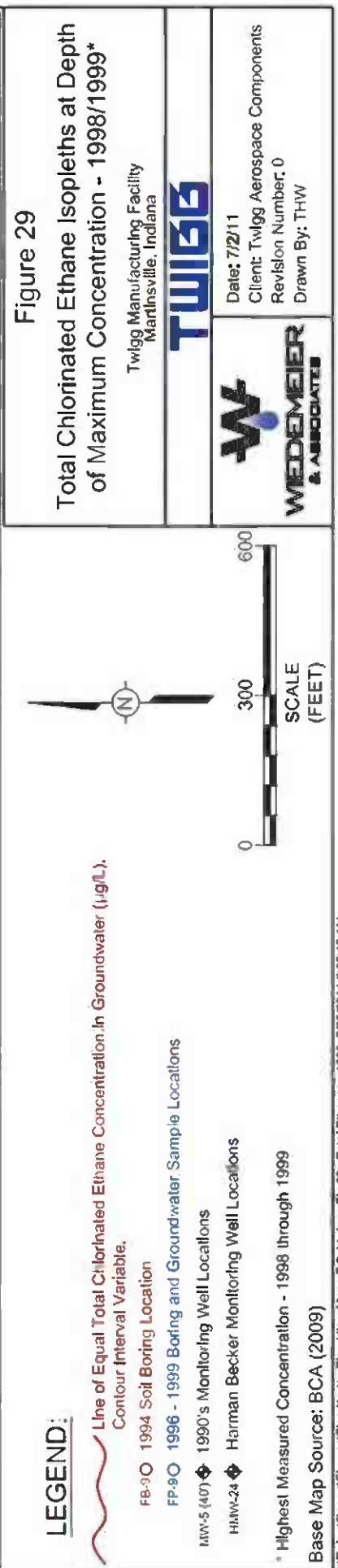
Figure 28
Total Chlorinated Ethene Concentration
Along Flowpath - 1996-2009

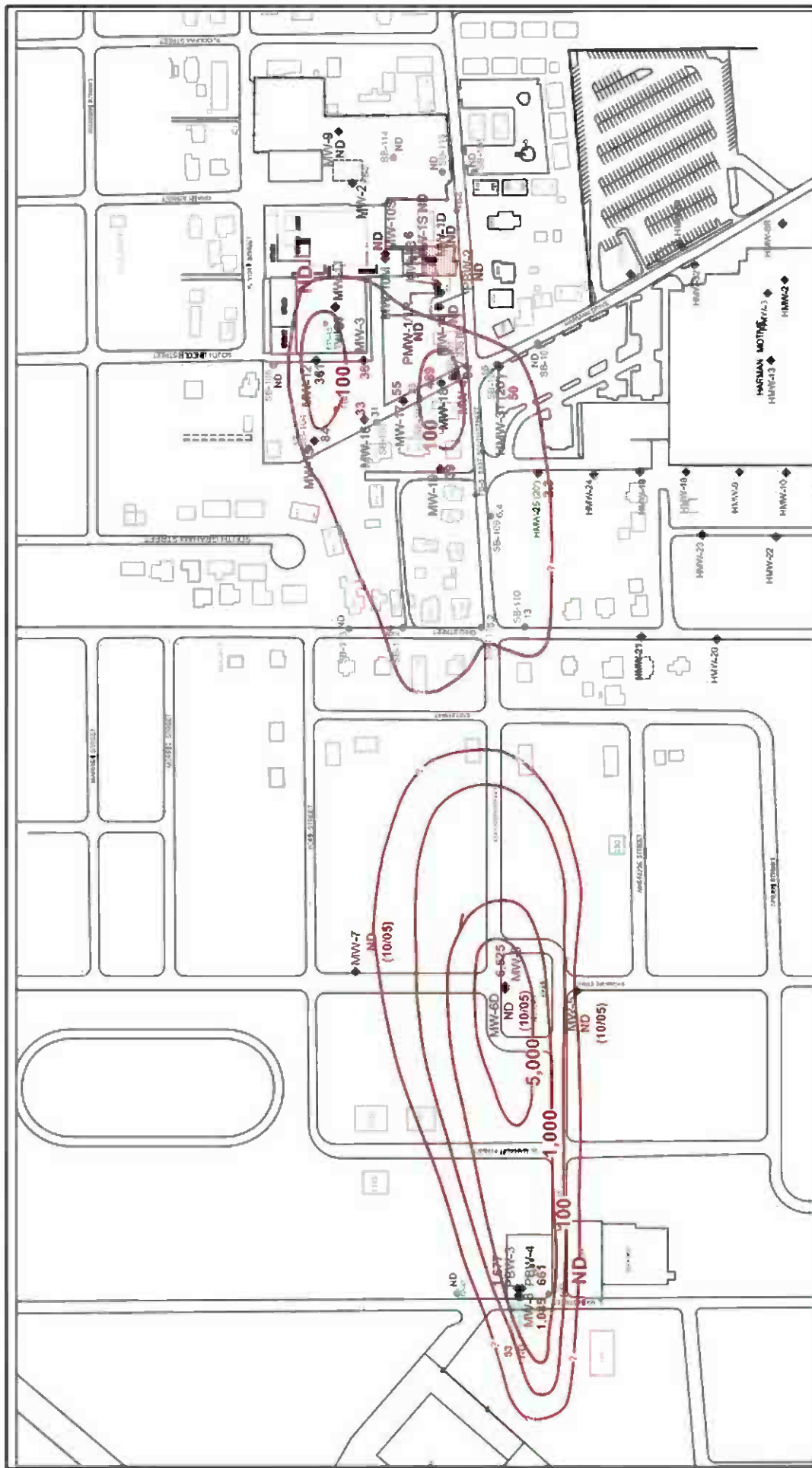
Twigg Manufacturing Facility
Martinsville, Indiana



Date: 7/7/11
Client: Twigg Corporation
Revision Number: 0
Drawn By: THW







LEGEND:

Line of Equal Total Chlorinated Ethane Concentration in Groundwater (µg/L), Contour Interval Variable.

FW-9 2006 Groundwater Sample Locations

MW-5 (40') 1990's Monitoring Well Locations

MW-11 (20') May 2000 Monitoring Well Locations

MW-13 (19') 2004 Monitoring Well Locations

MW-18 (25') 2006 Monitoring Well Locations

SD-110 2008 Soil Boring Groundwater Sample Locations

HMW-24 Harman Becker Monitoring Well Locations

E = Reported value is estimated due to linear range exceedence. Reported concentration estimated from 20x dilution and not considered valid.

Base Map Source: BCA (2009) * Highest measured concentration from 2007.

Figure 31

Total Chlorinated Ethane Isopleths at Depth of Maximum Concentration - 2007*

Twigg Manufacturing Facility
Martinsville, Indiana

twigg

WIEDEMEIER & ASSOCIATES

Date: 7/2/11

Client: Twigg Aerospace Components

Revision Number: 0

Drawn By: THW



SCALE
(FEET)

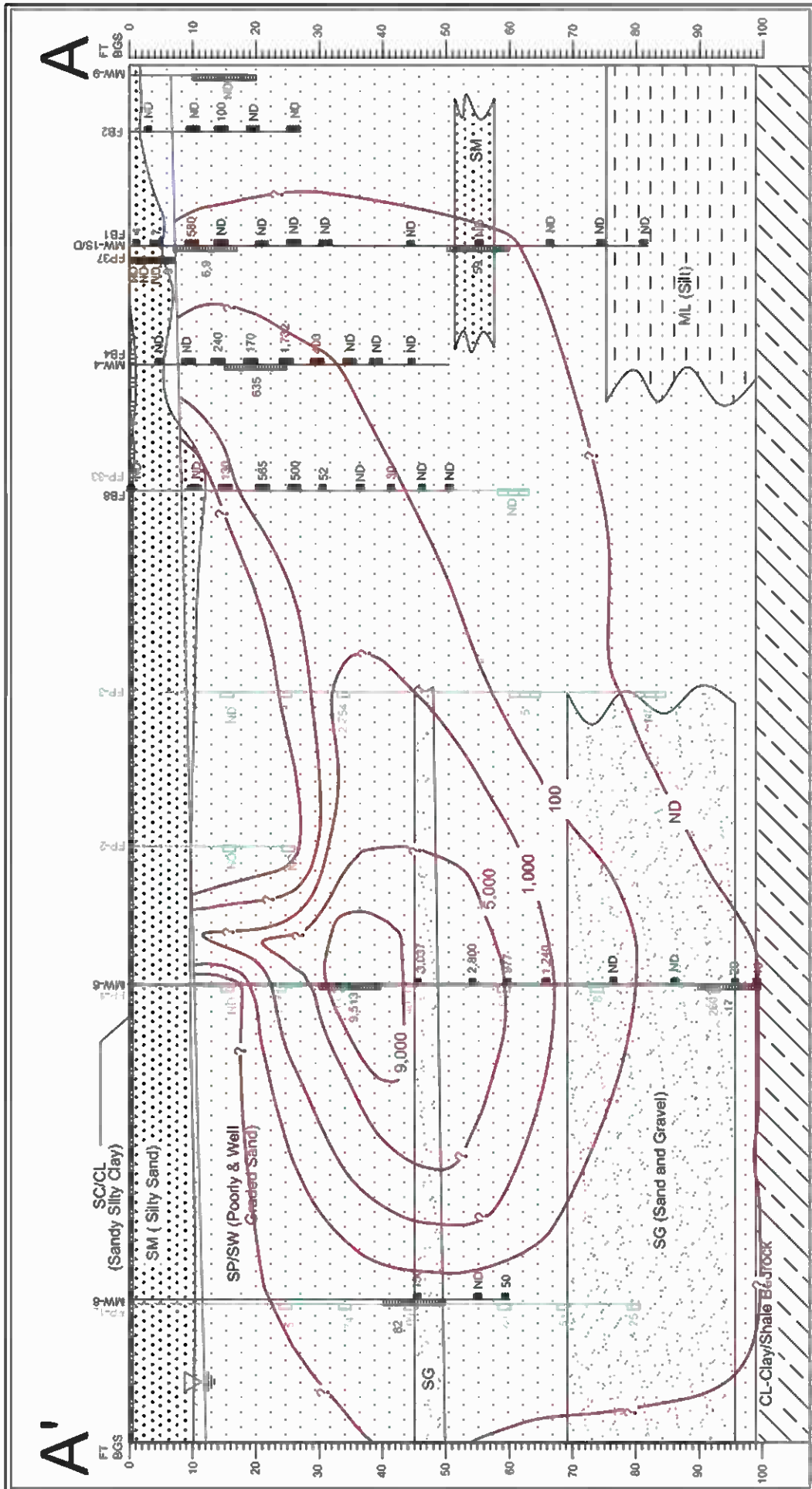


Figure 33

Total Chlorinated Ethane Concentration Along Flowpath - 1998/1999*

Twigg Manufacturing Facility
Martinsville, Indiana

DATE 7/13/11
CLIENT Twigg Corporation
REVISION NUMBER 0
DRAWN BY THW

WEDENBERG & ASSOCIATES

LEGEND:

- Water Level Measured on 5/22/08 (Shallowest on Record)
- Temporary Well Location and Total Chlorinated Ethane Concentration (µg/L)(5/99)
- 180 Soil Sample Location and Total Chlorinated Ethane Concentration in Soil (µg/L)(1994-1999)
- Monitoring Well Location and Total Chlorinated Ethane Concentration in Groundwater (µg/L)
- Highest Measured Concentration in Monitoring Wells 1998-1999, Other Data Highest Concentration 1996-1999
- Groundwater Probe Location and Total Chlorinated Ethane Concentration (µg/L)(1996-1999)
- Line of Equal Total Chlorinated Ethane Concentration in Groundwater (µg/L)

Base Supplied by Bruce Carier Associates

Figure 33

Total Chlorinated Ethane Concentration Along Flowpath - 1998/1999*

Twigg Manufacturing Facility
Martinsville, Indiana

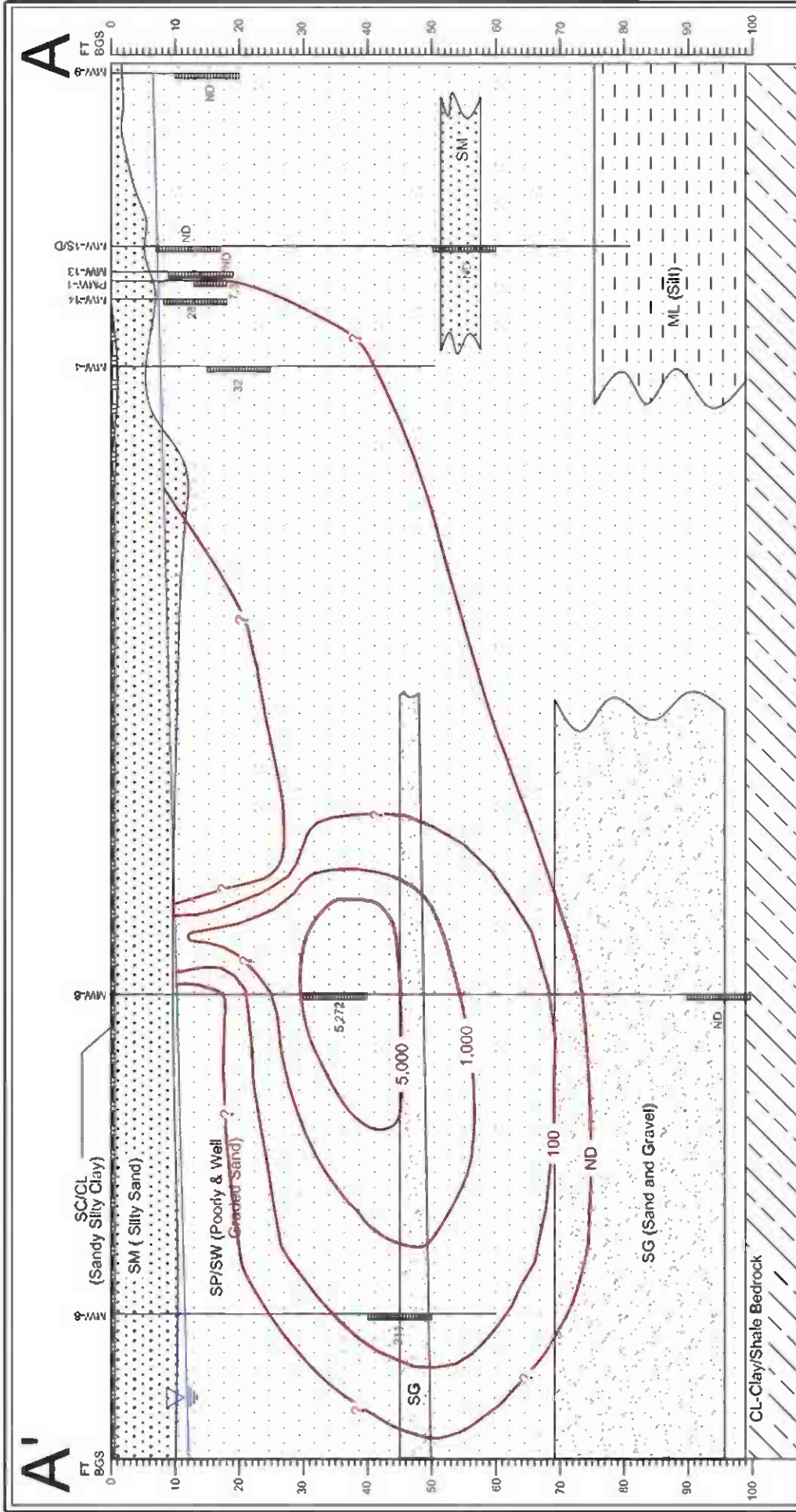
DATE 7/13/11
CLIENT Twigg Corporation
REVISION NUMBER 0
DRAWN BY THW

WEDENBERG & ASSOCIATES

LEGEND:

- Water Level Measured on 5/22/08 (Shallowest on Record)
- Temporary Well Location and Total Chlorinated Ethane Concentration (µg/L)(5/99)
- 180 Soil Sample Location and Total Chlorinated Ethane Concentration in Soil (µg/L)(1994-1999)
- Monitoring Well Location and Total Chlorinated Ethane Concentration in Groundwater (µg/L)
- Highest Measured Concentration in Monitoring Wells 1998-1999, Other Data Highest Concentration 1996-1999
- Groundwater Probe Location and Total Chlorinated Ethane Concentration (µg/L)(1996-1999)
- Line of Equal Total Chlorinated Ethane Concentration in Groundwater (µg/L)

Base Supplied by Bruce Carier Associates



LEGEND:

— Water Level Measured on 5/22/08 (Shallowest on Record)

6,890
Monitoring Well Location and Total Chlorinated Ethane Concentration in Groundwater (µg/L)

Line of Equal Total Chlorinated Ethane Concentration in Groundwater (µg/L)

*Highest concentration from 2004 unless data not available in which case 2003 data were used as indicated by an asterisk. Data Supplied by Bruce Carter Associates

Figure 34

Total Chlorinated Ethane Concentration Along Flowpath - 2004*

Twigg Manufacturing Facility
Martinsville, Indiana

TWIGG

Date: 7/14/11

Client: Twigg Corporation

Revision Number: 0

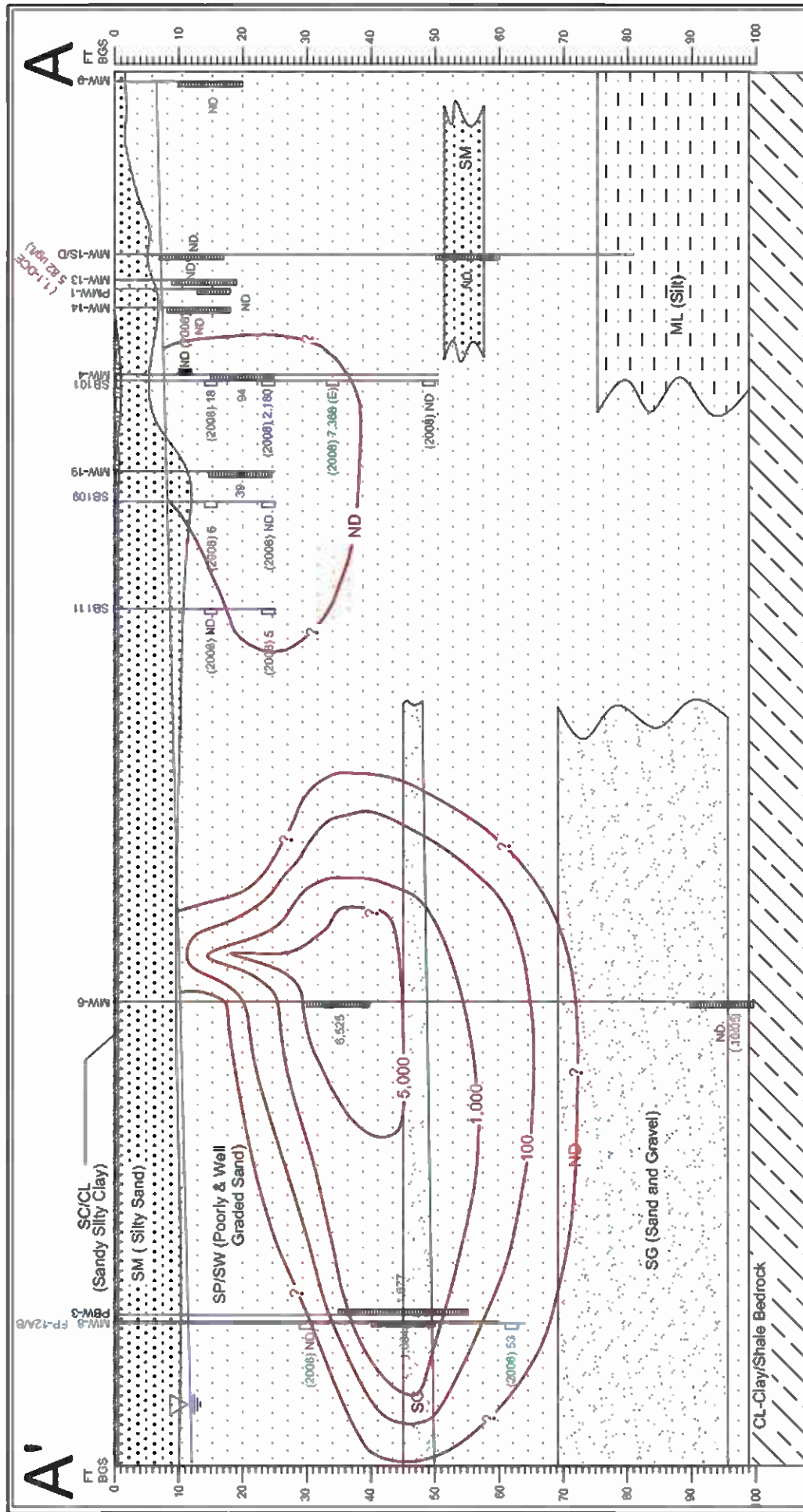
Drawn By: THW



**WEDDEMEIER
& ASSOCIATES**

0 300 600
HORIZONTAL SCALE
(feet)

VERTICAL EXAGGERATION 13.3



LEGEND:

2.2.2. Groundwater Probe Location and Total Chlorinated

Ethane Concentration ($\mu\text{g/L}$)(2008)

END 2008 Soil Data Total Chlorinated Ethane Concentration ($\mu\text{g/Kg}$) (2008)

6.525 Monitoring Well Location and Total Chlorinated Ethane Concentration in Groundwater ($\mu\text{g/L}$)

17 Groundwater Probe Location and Total Chlorinated Ethane Concentration ($\mu\text{g/L}$) (2006)

E = Reported value is estimated due to linear range exceedence. Reported concentration estimated from 20x dilution and not considered valid.



Line of Equal Total Chlorinated Ethane Concentration
In Groundwater ($\mu\text{g/L}$)

*Highest measured concentration from 2007 unless otherwise indicated
Base Supplied by Bruce Carter Associates

Figure 35

**Total Chlorinated Ethane Concentration
Along Flowpath - 2007***

**Twigg Manufacturing Facility
Martinsville, Indiana**

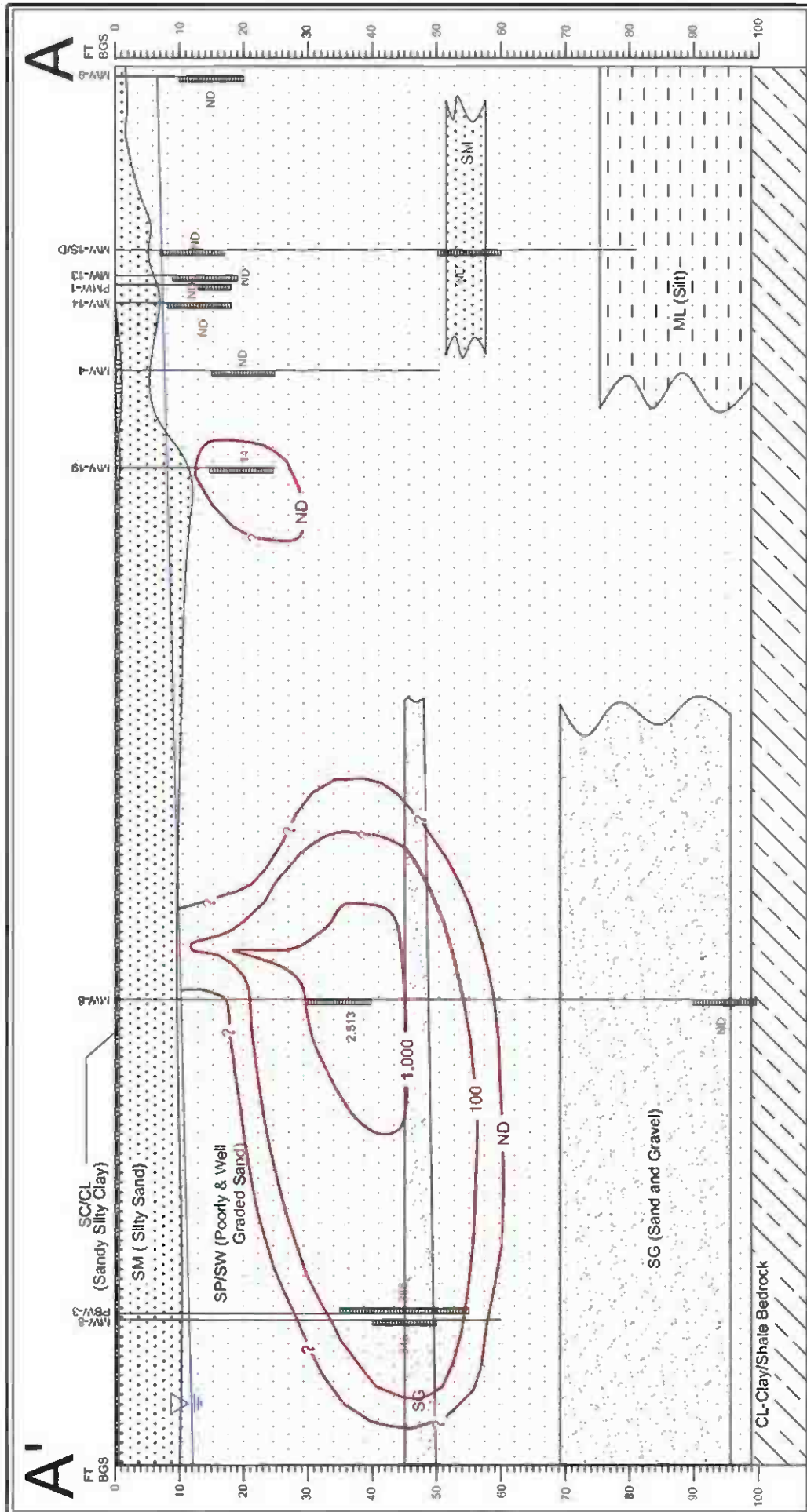
twinkl

WIEDEMAYER
ASSOCIATES

Date: 6/29/11
Client: Twigg
Revision Num:
Drawn By: TH



VERTICAL EXAGGERATION 13.3



LEGEND:

- Water Level Measured on 5/22/08 (Shallowest on Record)
- Monitoring Well Location and Total Chlorinated Ethane Concentration in Groundwater (µg/L)
- Line of Equal Total Chlorinated Ethane Concentration in Groundwater (µg/L)

Figure 36

**Total Chlorinated Ethane Concentration
Along Flowpath - January/February 2011**

Twigg Manufacturing Facility
Marionville, Indiana

TWIGG

WEIDEMEIER & ASSOCIATES

Date: 7/14/11
Client: Twigg Corporation
Revision Number: 0
Drawn By: THW

2,513

HORIZONTAL SCALE
(feet)

0 300 600

VERTICAL EXAGGERATION 13.3

Bases Supplied by Bruce Center Associates

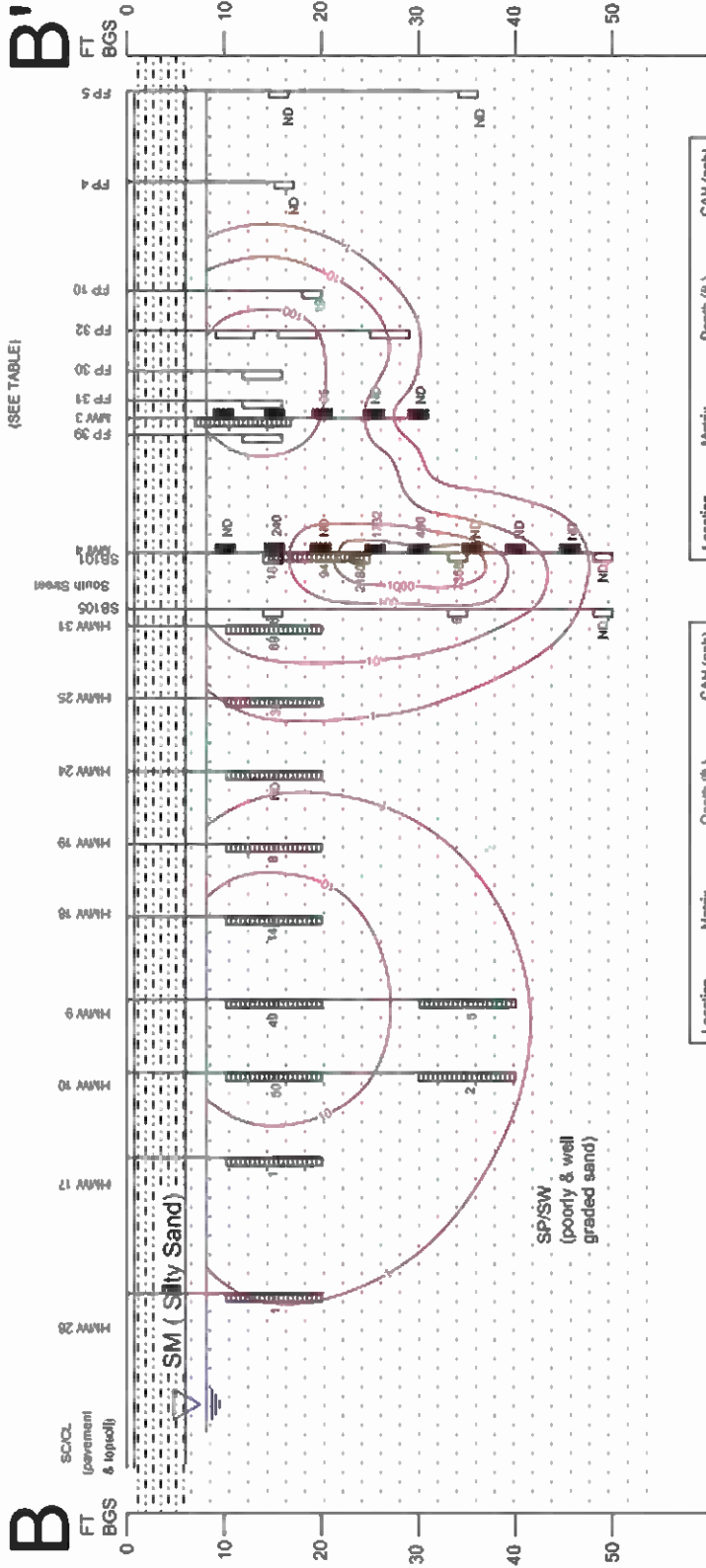


Figure 37
Total Chlorinated Ethane Concentration
Along Flowpath - 1996 - 2009

Twigg Manufacturing Facility
Martinsville, Indiana

Twigg

Date: 6/29/11
Client: Twigg Corporation
Revision Number: 0
Drawn By: THW

W
WEDEMEIER
& ASSOCIATES

0 250 500
HORIZONTAL SCALE
(feet)
VERTICAL EXAGGERATION 13.3

Line of Equal Total Chlorinated Ethane Concentration ($\mu\text{g/L}$)

Source: Bruce Carter Associates, Inc.

0:\Twigg\Report\Figures\Fig 37 - CEA XsectB.dwg, Fig-37 Total Ethenes 1996-2009, 7/26/2011 4:34:18 AM

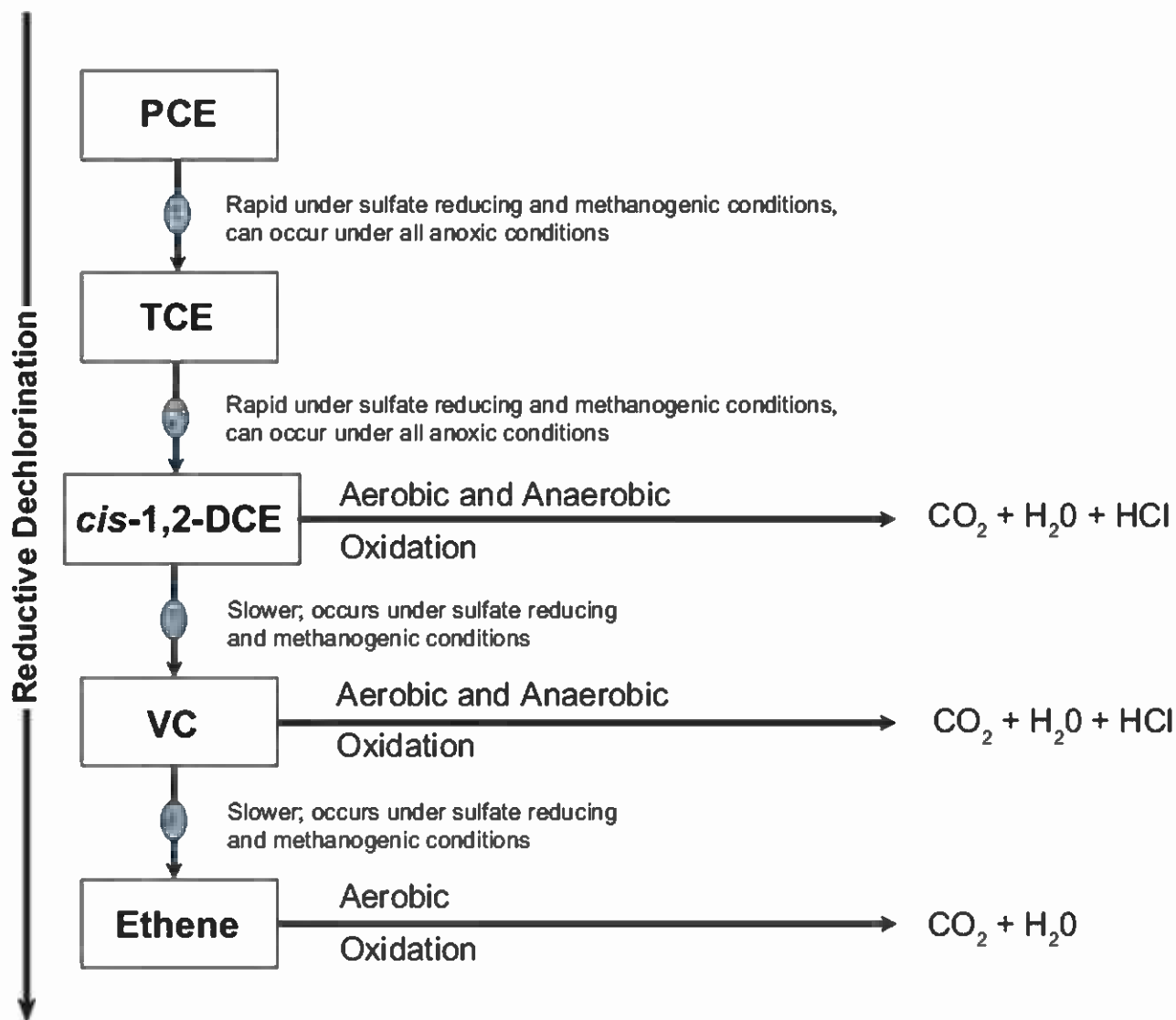


Figure 38
Degradation Reactions for
Chlorinated Ethenes

Twigg Manufacturing Facility
 Martinsville, Indiana

TWIGG



WIEDEMEIER
 & ASSOCIATES

Date: 7/19/11
 Client: Twigg Corporation
 Revision Number: 0

Source: Wiedemeier *et al.* (1999)

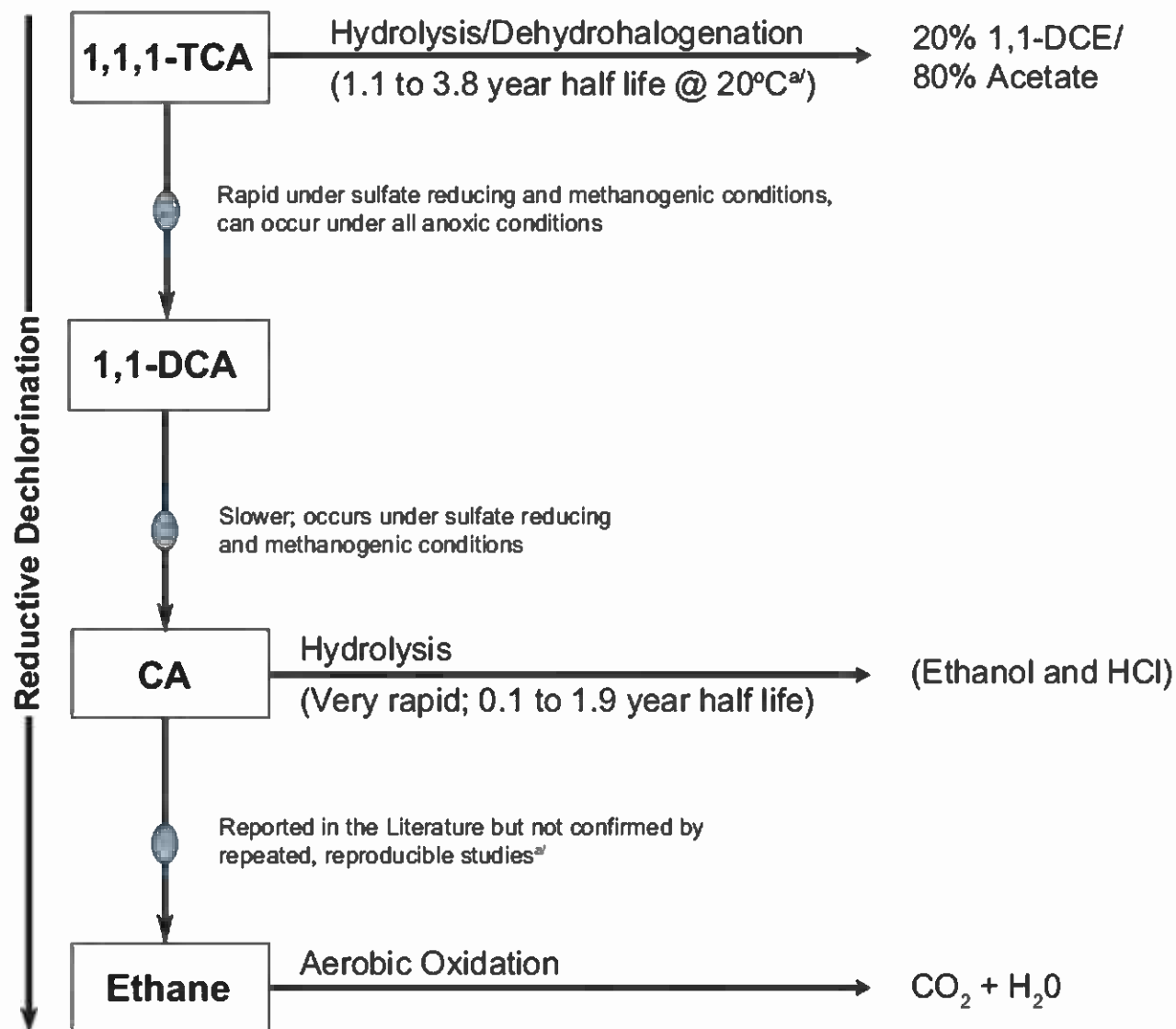


Figure 39
Degradation Reactions for
Chlorinated Ethanes

Twigg Manufacturing Facility
 Martinsville, Indiana

TWIGG



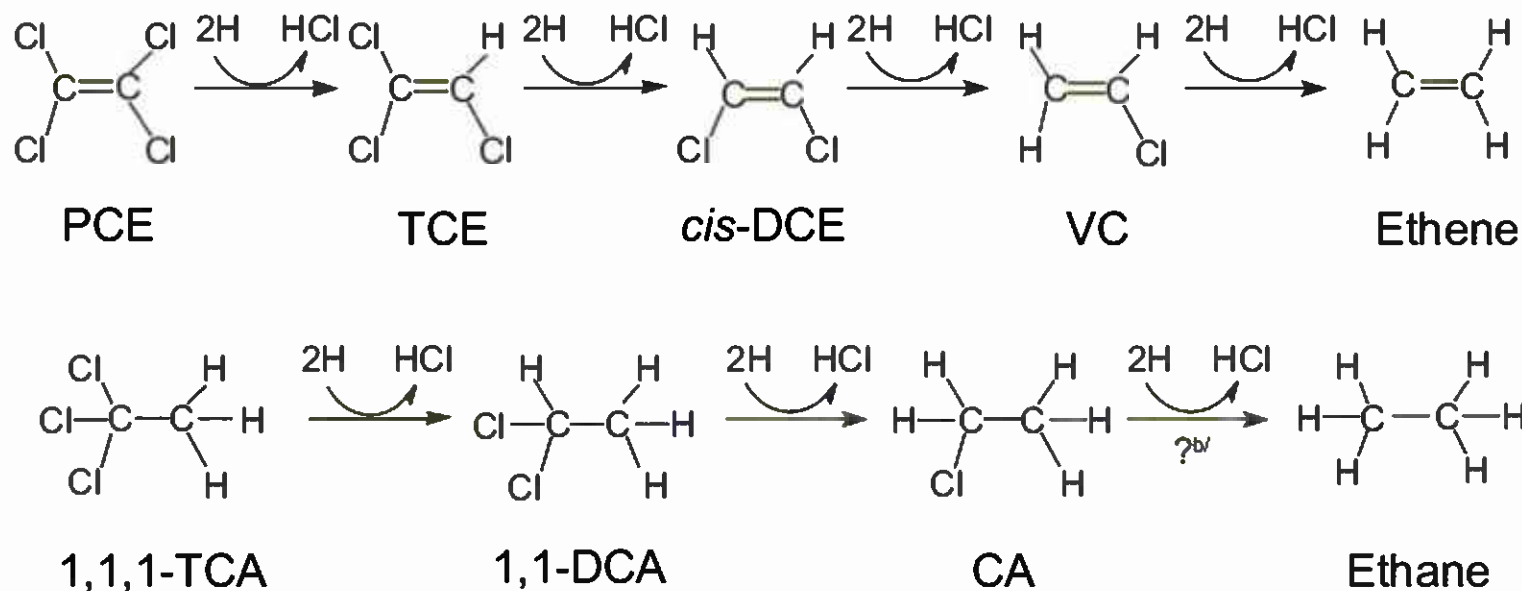
WIEDEMEIER
 & ASSOCIATES

Date: 7/19/11
 Client: Twigg Corporation
 Revision Number: 0

^{a/} Scheutz *et al.*, 2011

Modified from Wiedemeier *et al.* (1999)

Sequential Reductive Dechlorination of Chlorinated Ethenes and Ethanes



Relative Biological Dechlorination Rates^{a/}

PCE > TCE > DCE > VC

TCA > DCA > CA

a/ Rates of Hydrolysis May Be Faster than Rates of Biodegradation, Particularly for TCA and CA (Figure 39)

b/ Reported in the Literature but not confirmed by repeated, reproducible studies (Scheutz *et. al.* 2011)

Figure 40
Sequential Reductive Dechlorination

Twigg Manufacturing Facility
Martinsville, Indiana

TWIGG

W
WIEDEMEIER
& ASSOCIATES

Date: 7/15/11
Client: Twigg Corporation
Revision Number: 0

Figure 41
Concentration of Total Chlorinated Ethenes Along Flowpath -
1998 Through February 2011
 Twigg Manufacturing Facility
 Martinsville, Indiana

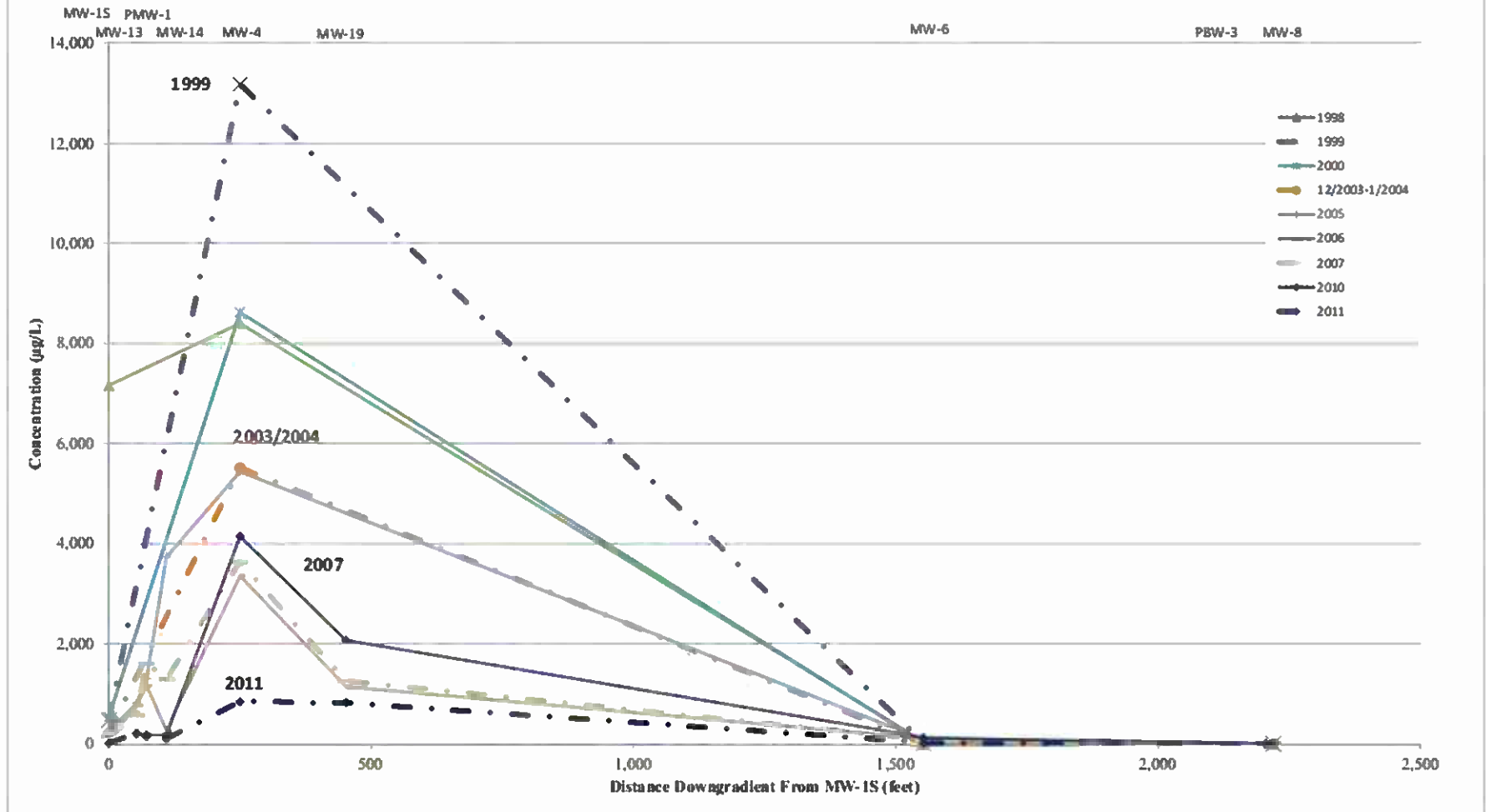
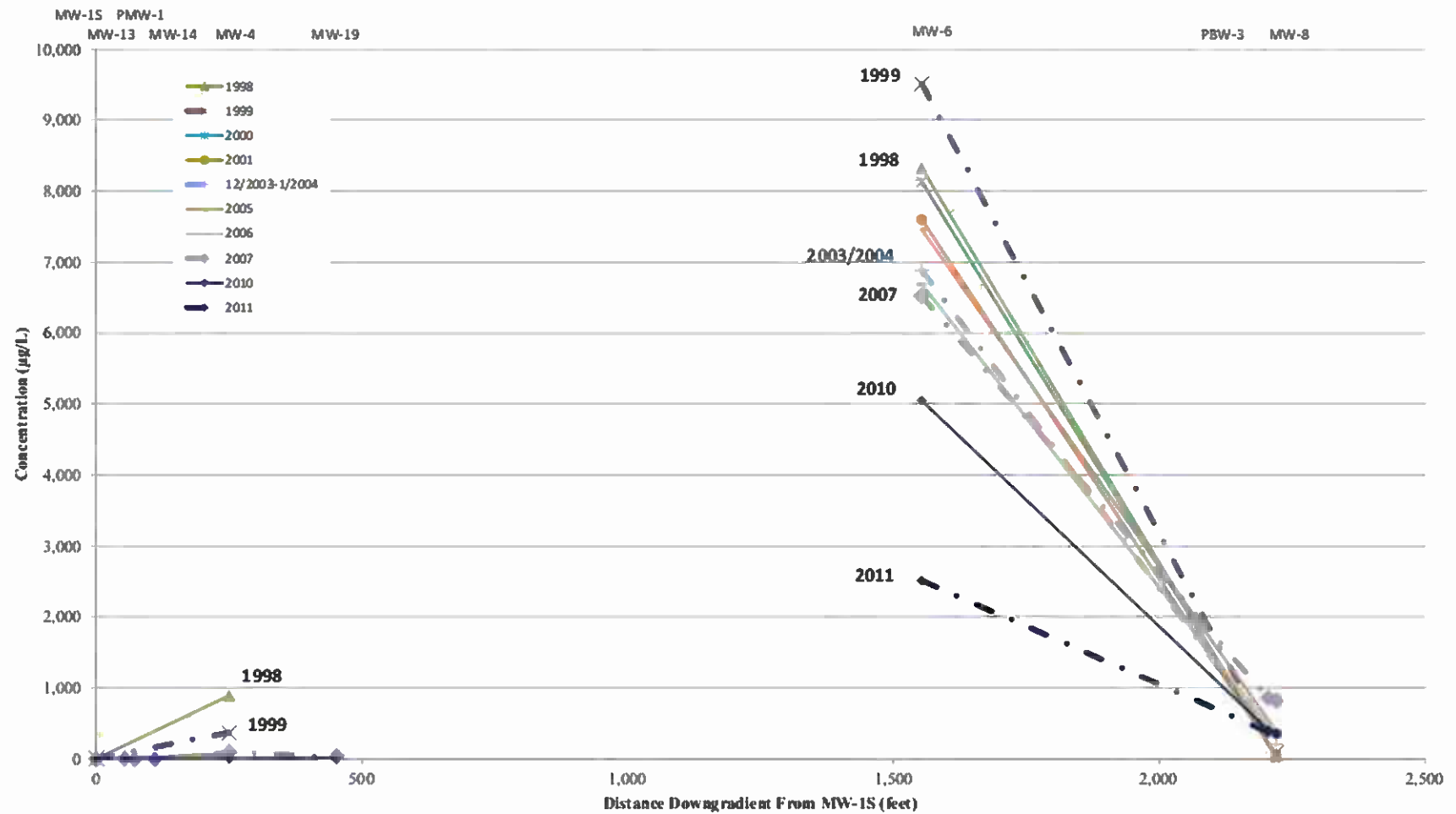


Figure 42
Concentration of Total Chlorinated Ethanes Along Flowpath -
1998 Through February 2011
 Twigg Manufacturing Facility
 Martinsville, Indiana



WIEDEMEIER
 & ASSOCIATES

Concentration (A) and Molar Fraction (B) of Individual Chlorinated Ethenes along Flowpath - July 1999
Twigg Manufacturing Facility
Martinsville, Indiana

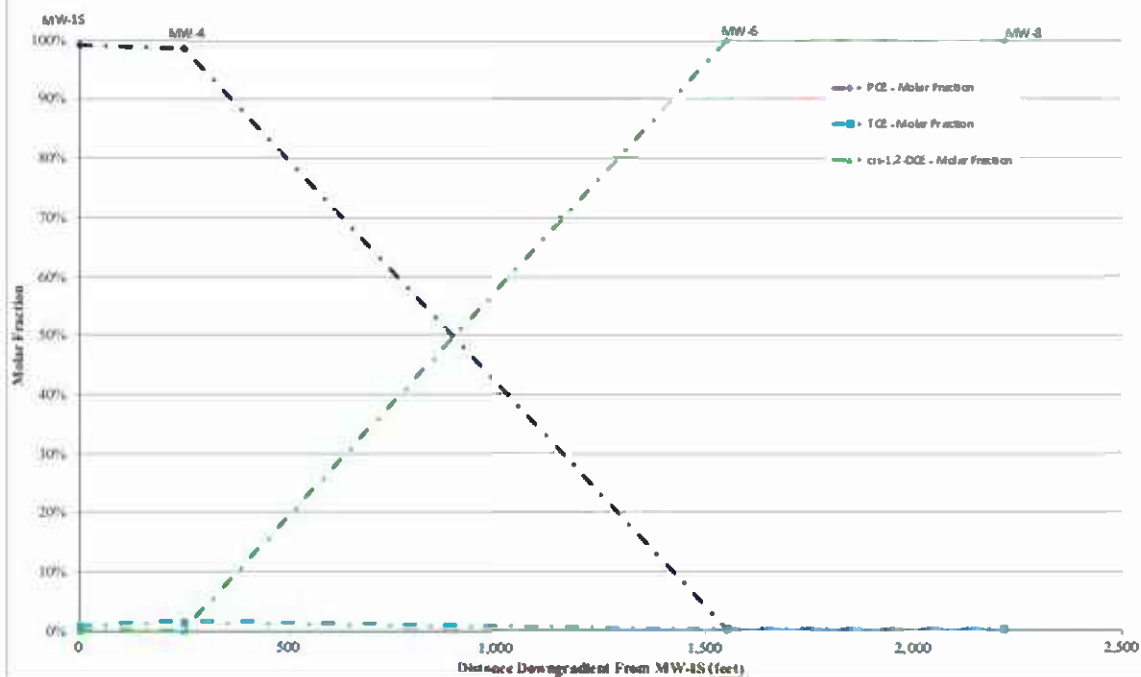
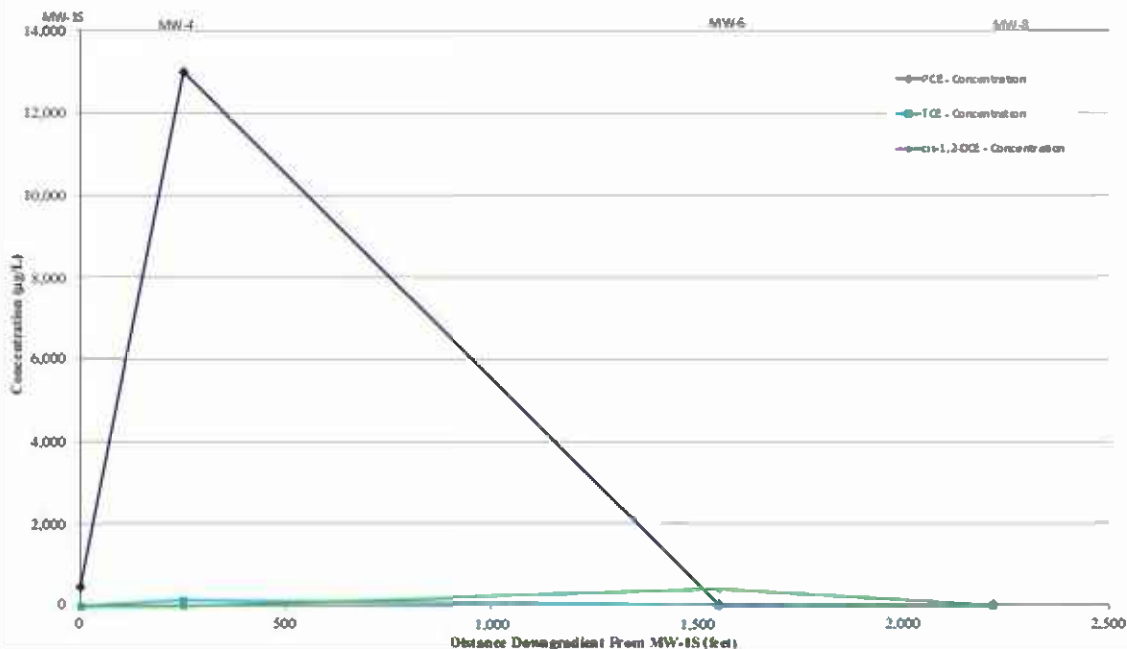


Figure 44
Concentration (A) and Molar Fraction (B) of Individual Chlorinated Ethenes along Flowpath - December 2003/January 2004
 Twigg Manufacturing Facility
 Martinsville, Indiana

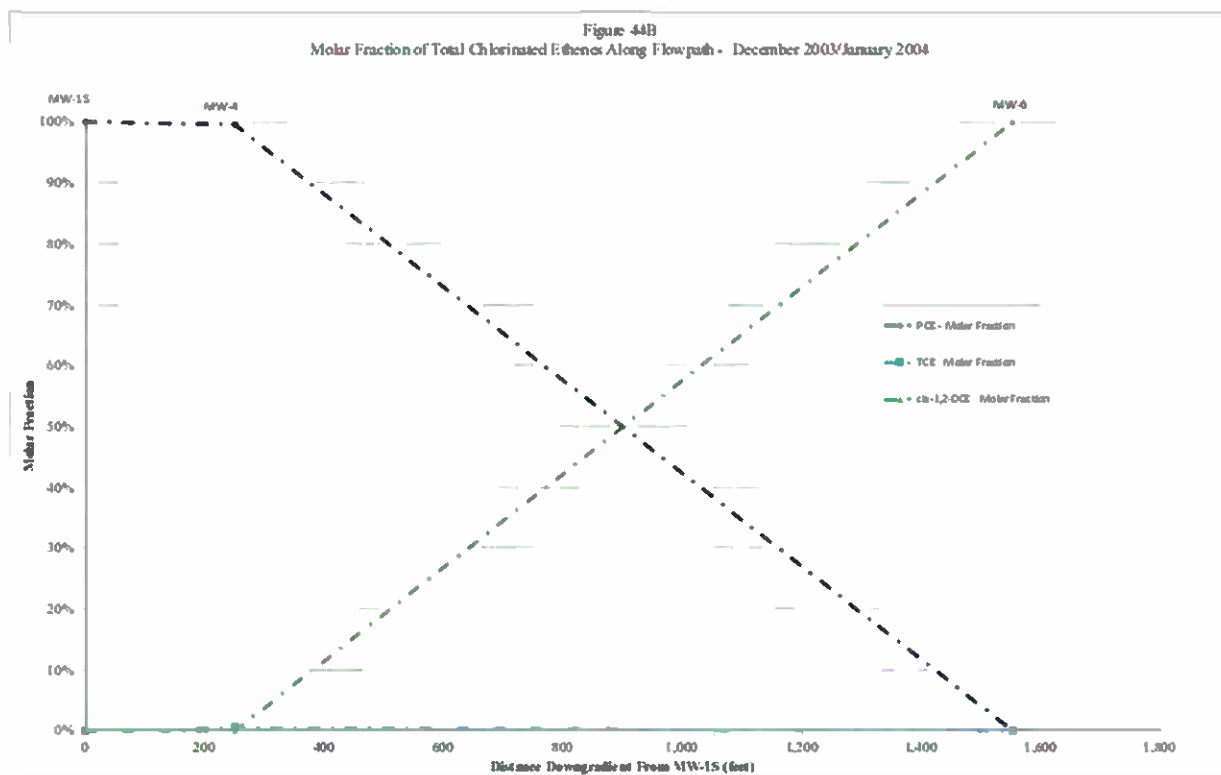
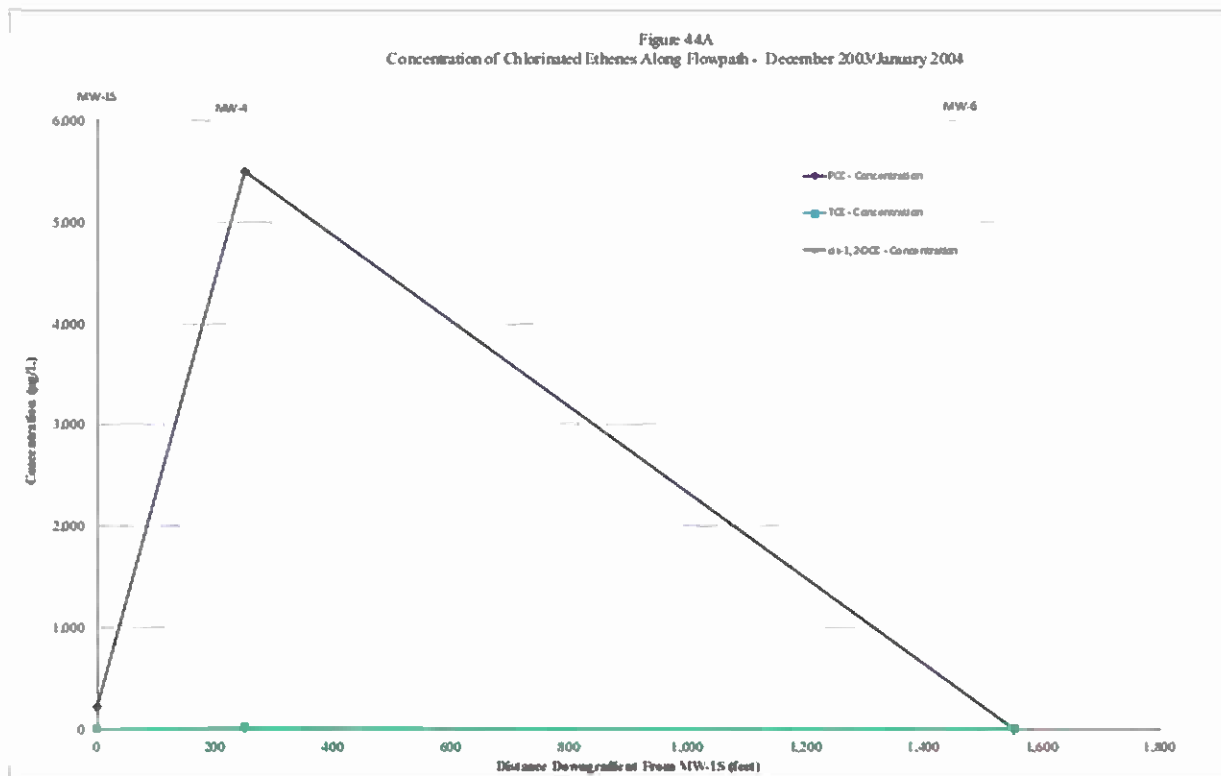


Figure 45
Concentration (A) and Molar Fraction (B) of Individual Chlorinated Ethenes along Flowpath - October 2007
 Twigg Manufacturing Facility
 Martinsville, Indiana

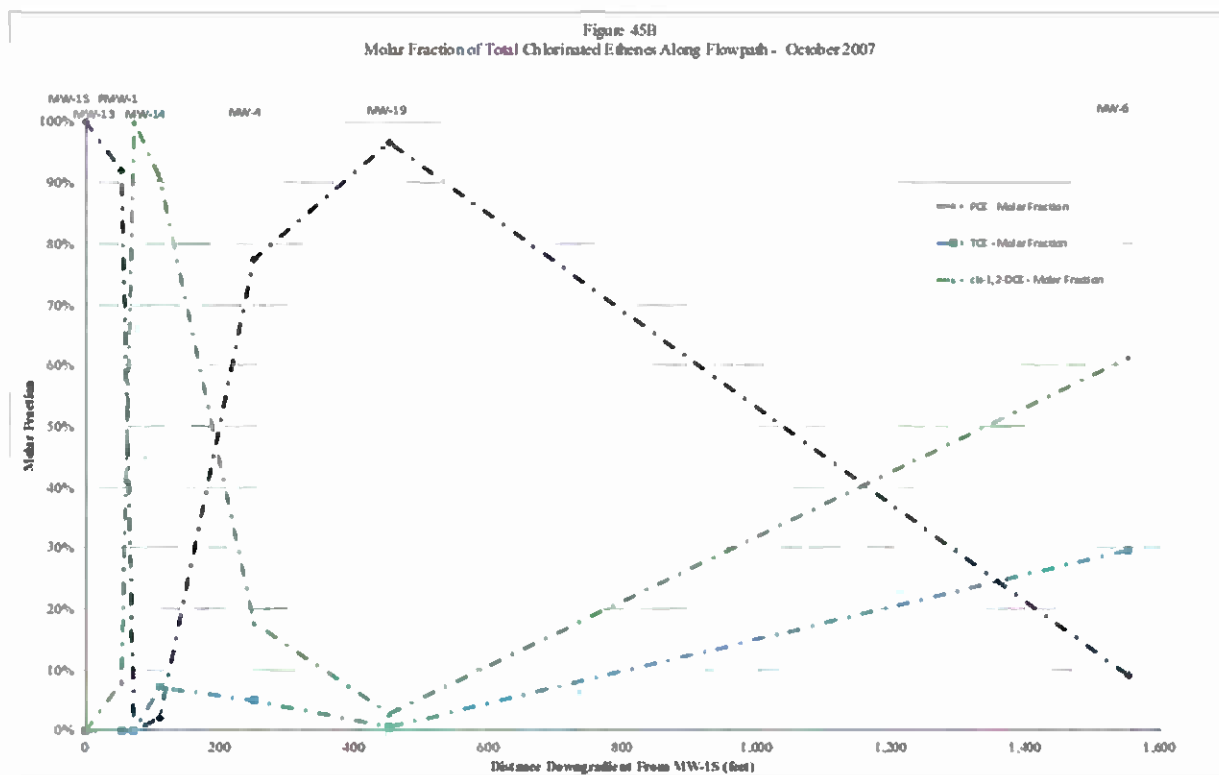
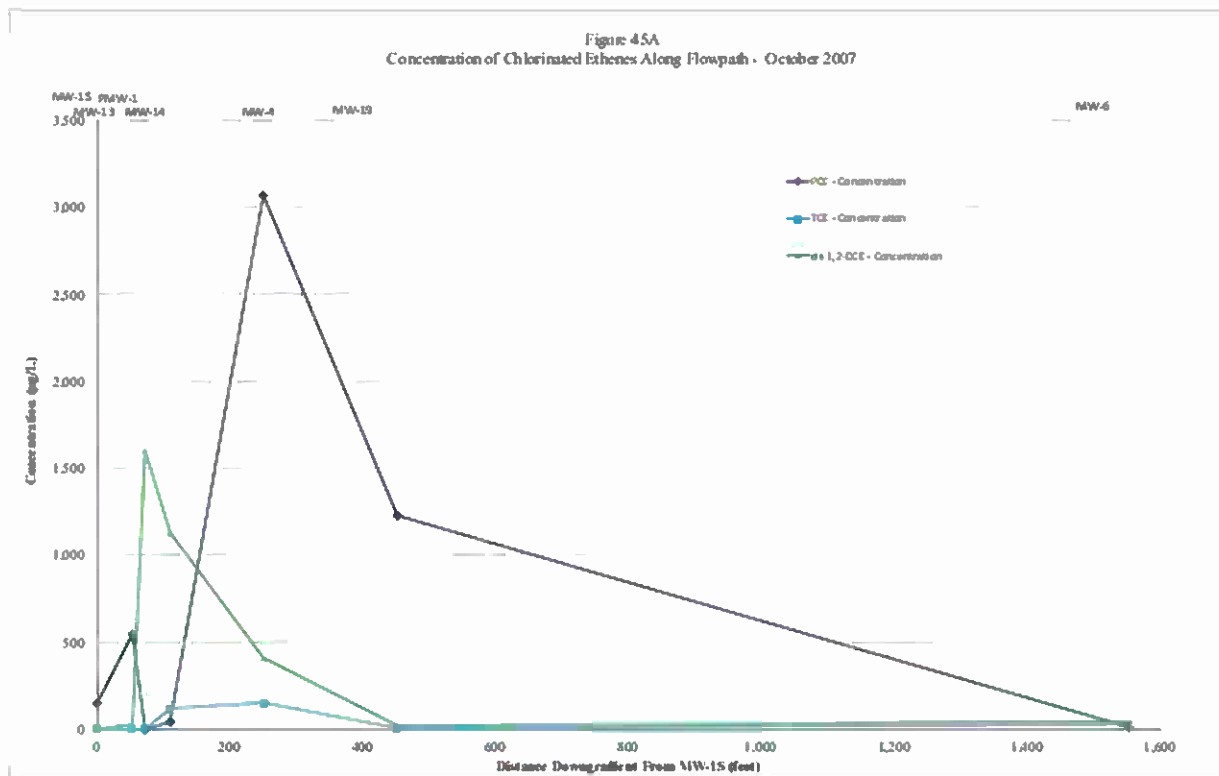
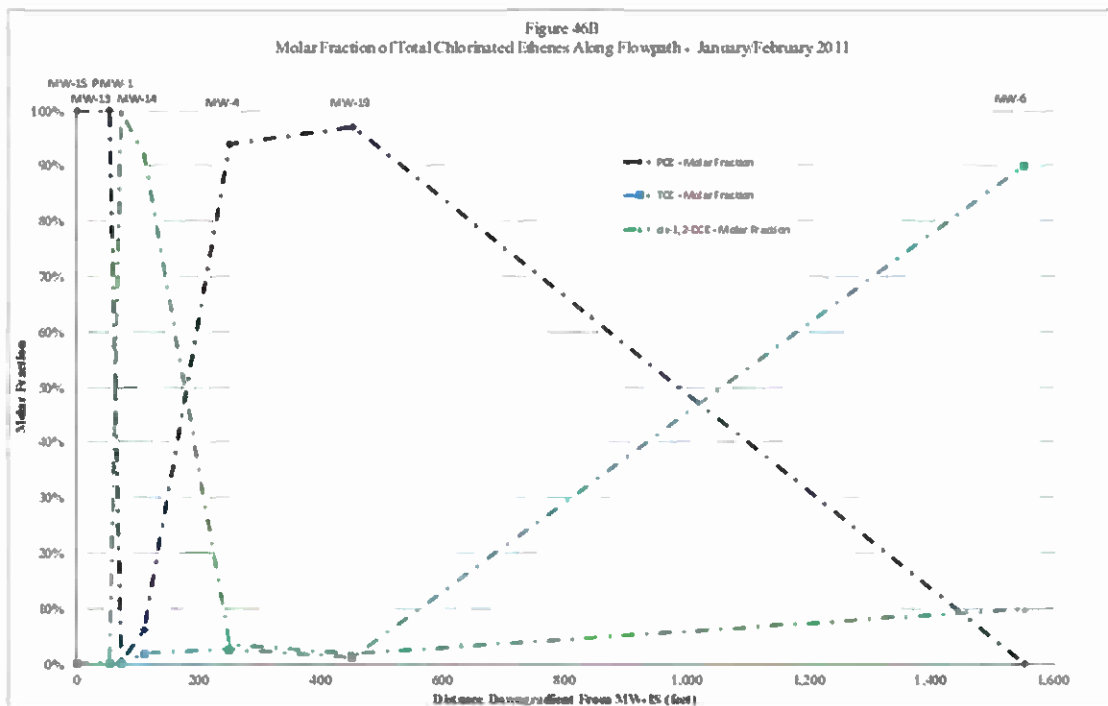
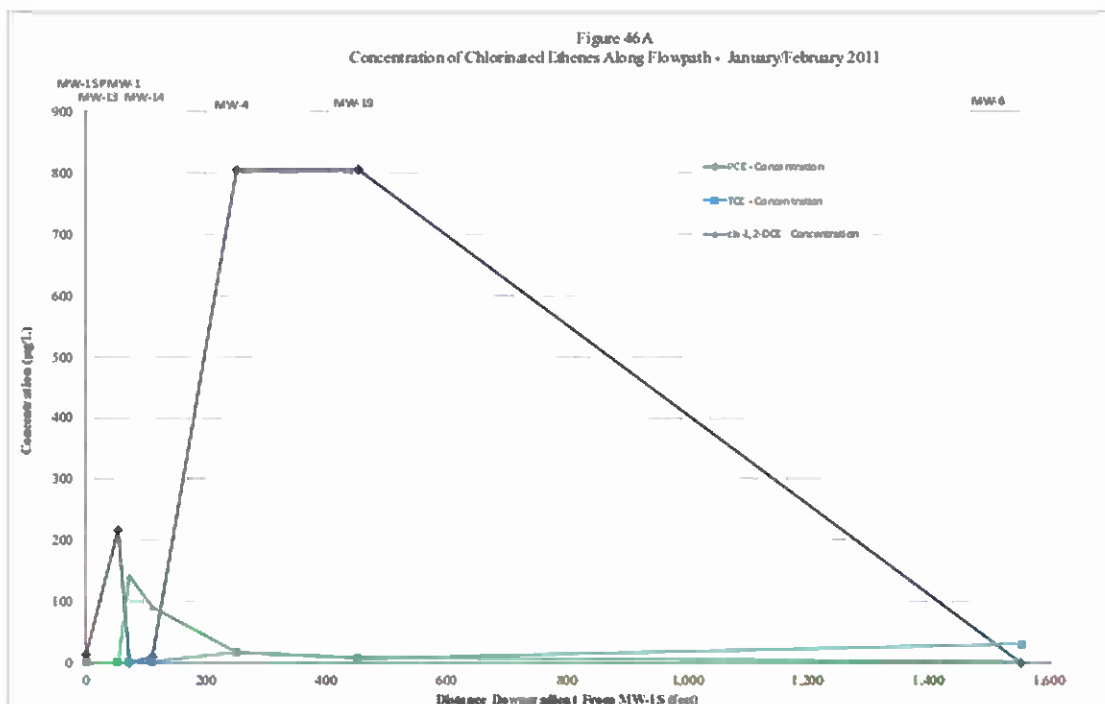


Figure 46
Concentration (A) and Molar Fraction (B) of Individual Chlorinated Ethenes along Flowpath - January/February 2011
 Twigg Manufacturing Facility
 Martinsville, Indiana



Martinsville, Indiana

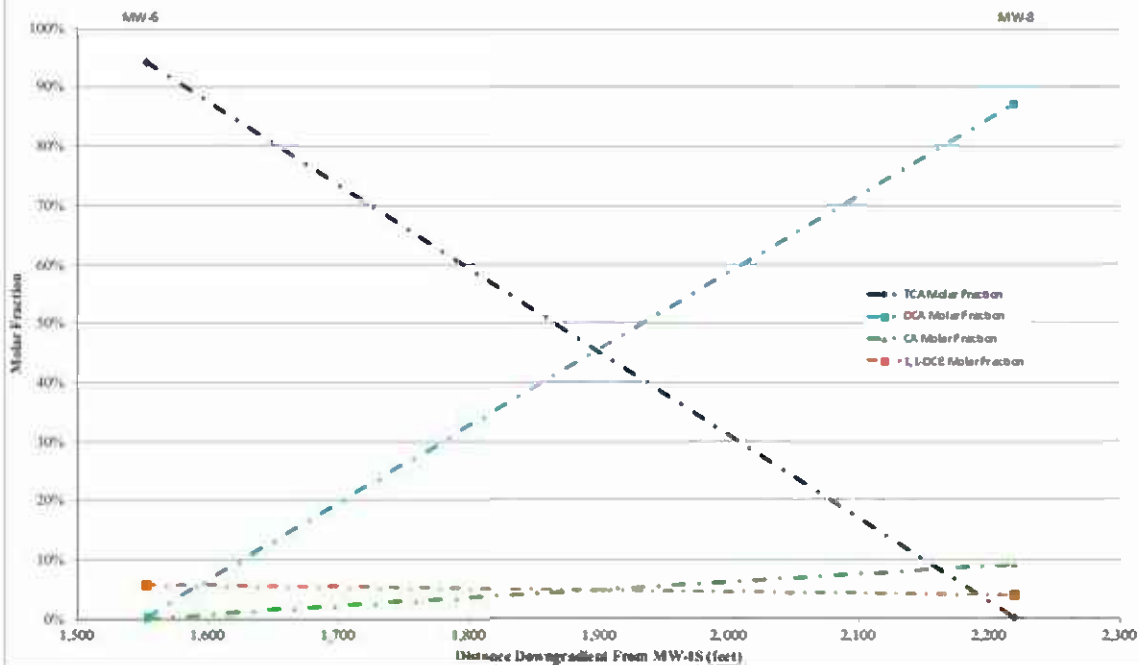
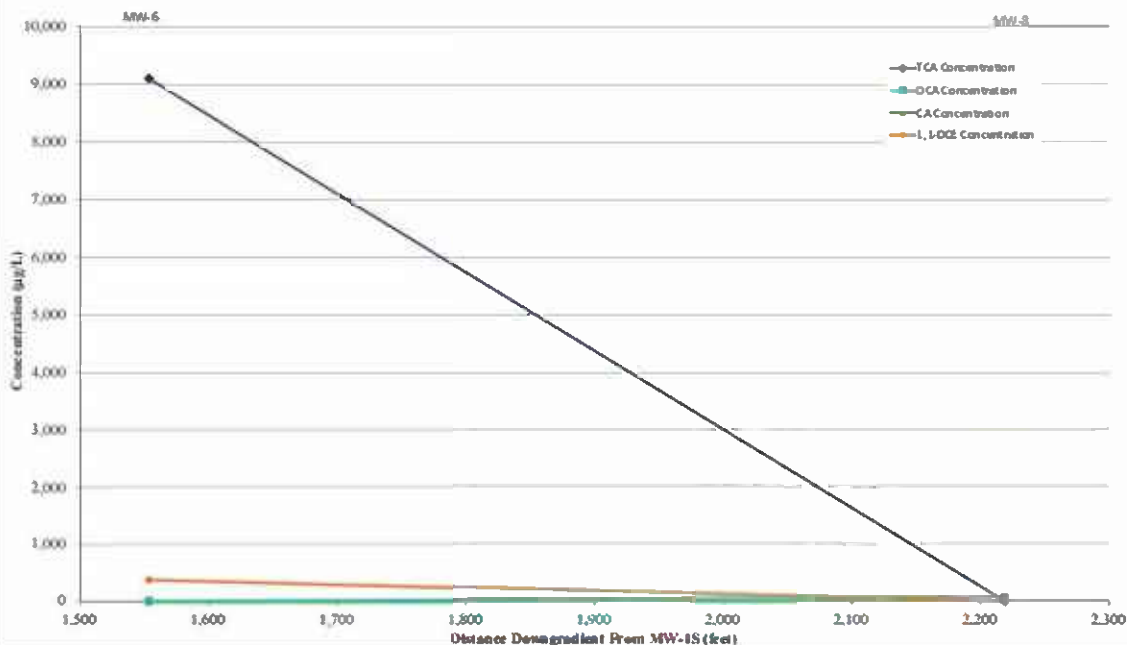


Figure 48
Concentration (A) and Molar Fraction (B) of Individual Chlorinated Ethanes along Flowpath - December 2003/January 2004
Twigg Manufacturing Facility
Martinsville, Indiana

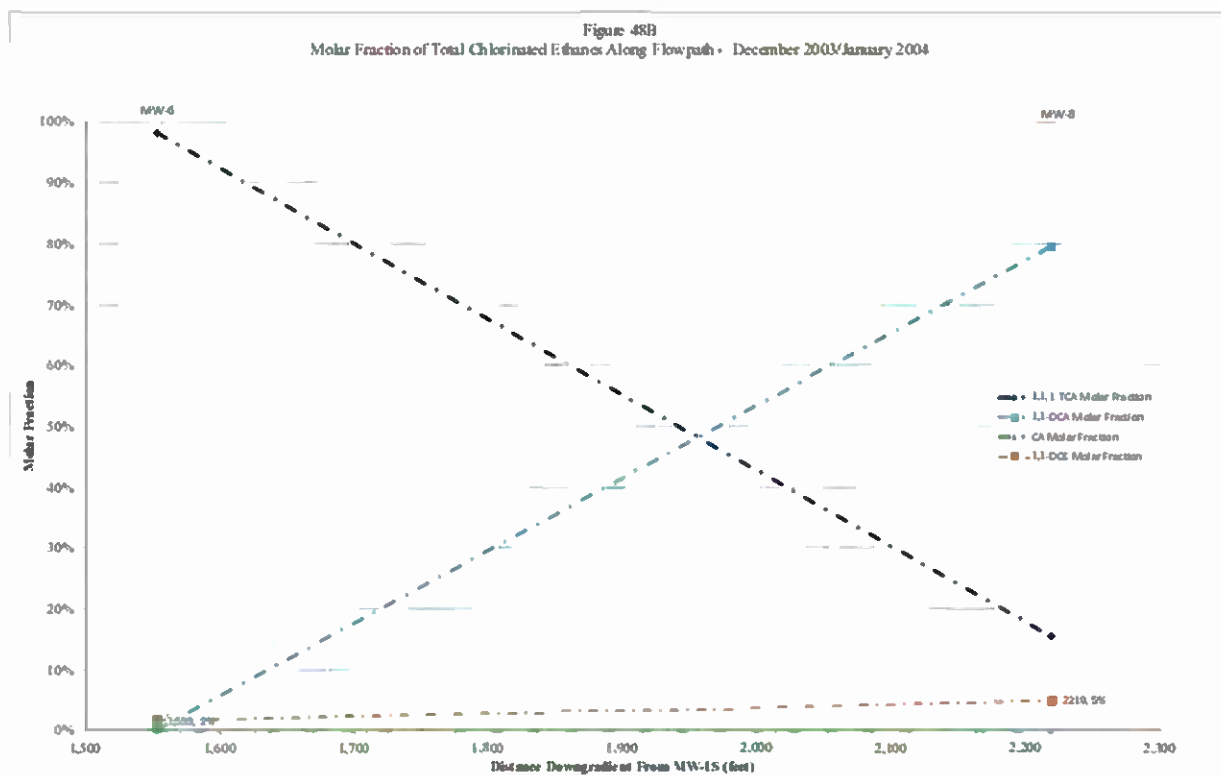
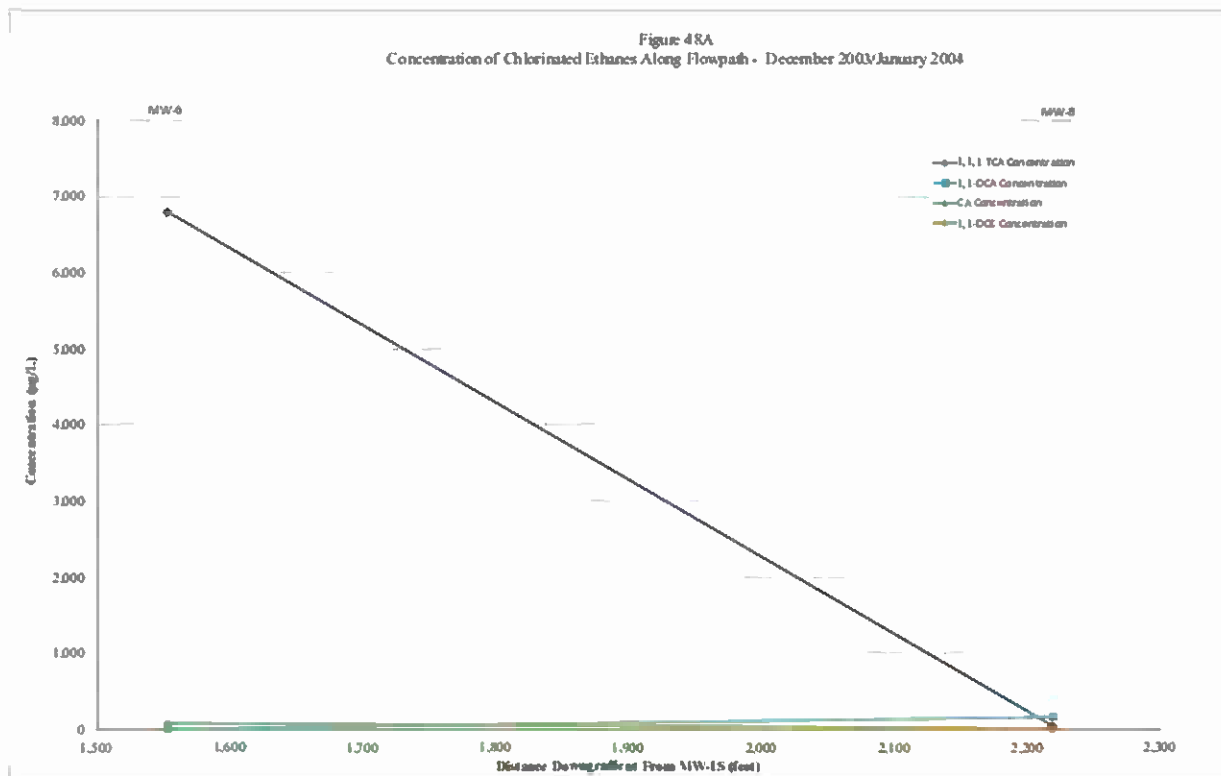


Figure 49
Concentration (A) and Molar Fraction (B) of Individual Chlorinated Ethanes along Flowpath - October 2007
 Twigg Manufacturing Facility
 Martinsville, Indiana

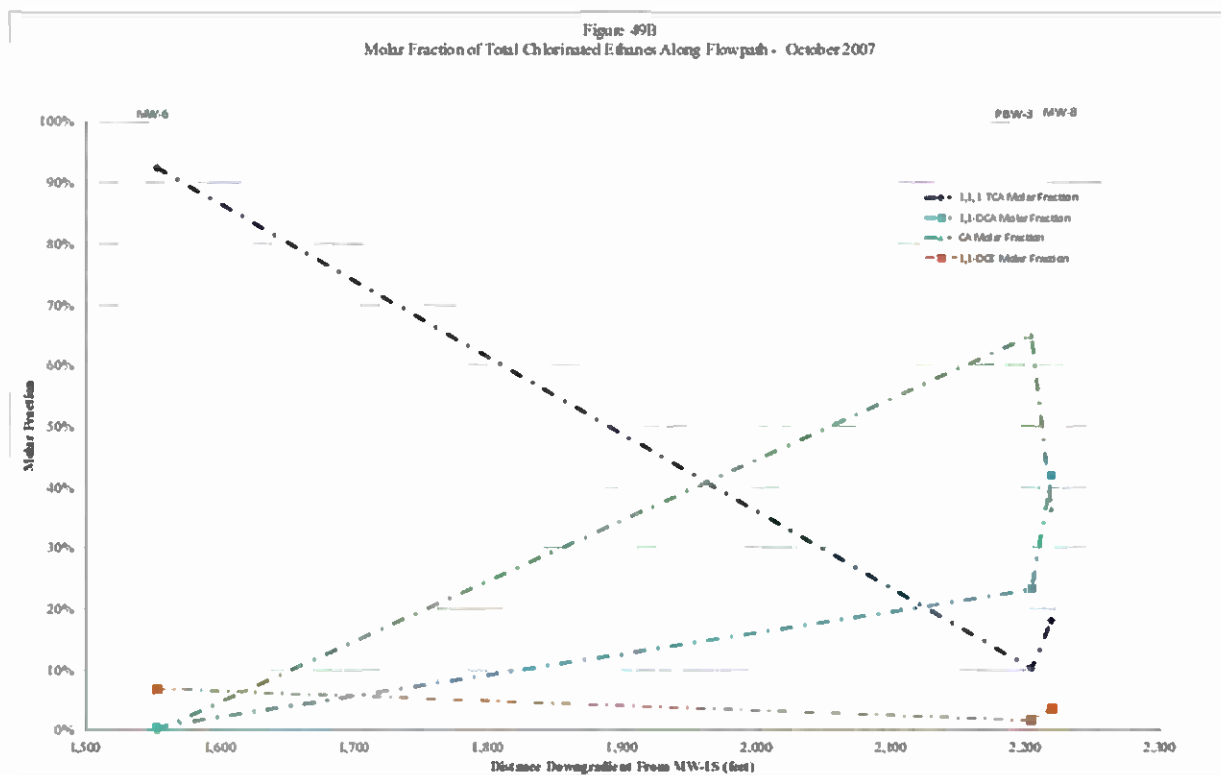
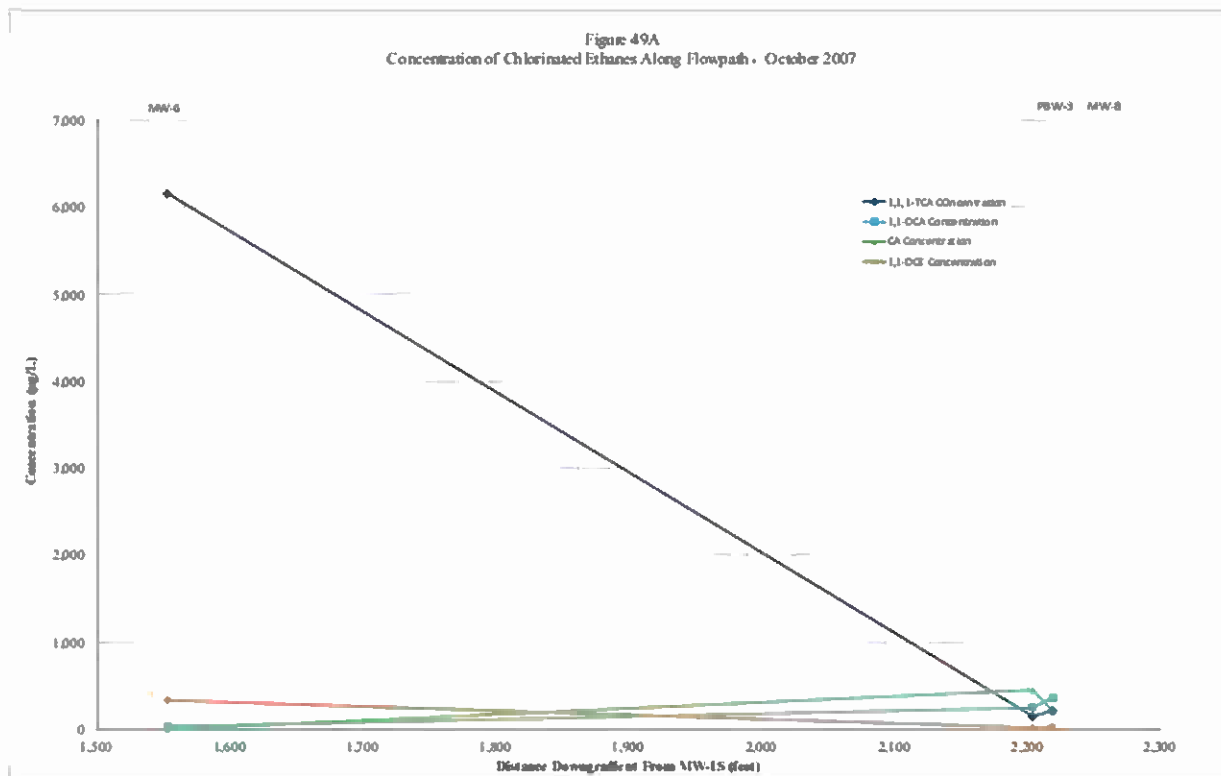


Figure 50
Concentration (A) and Molar Fraction (B) of Individual Chlorinated Ethanes along Flowpath - January/February 2011
 Twigg Manufacturing Facility
 Martinsville, Indiana

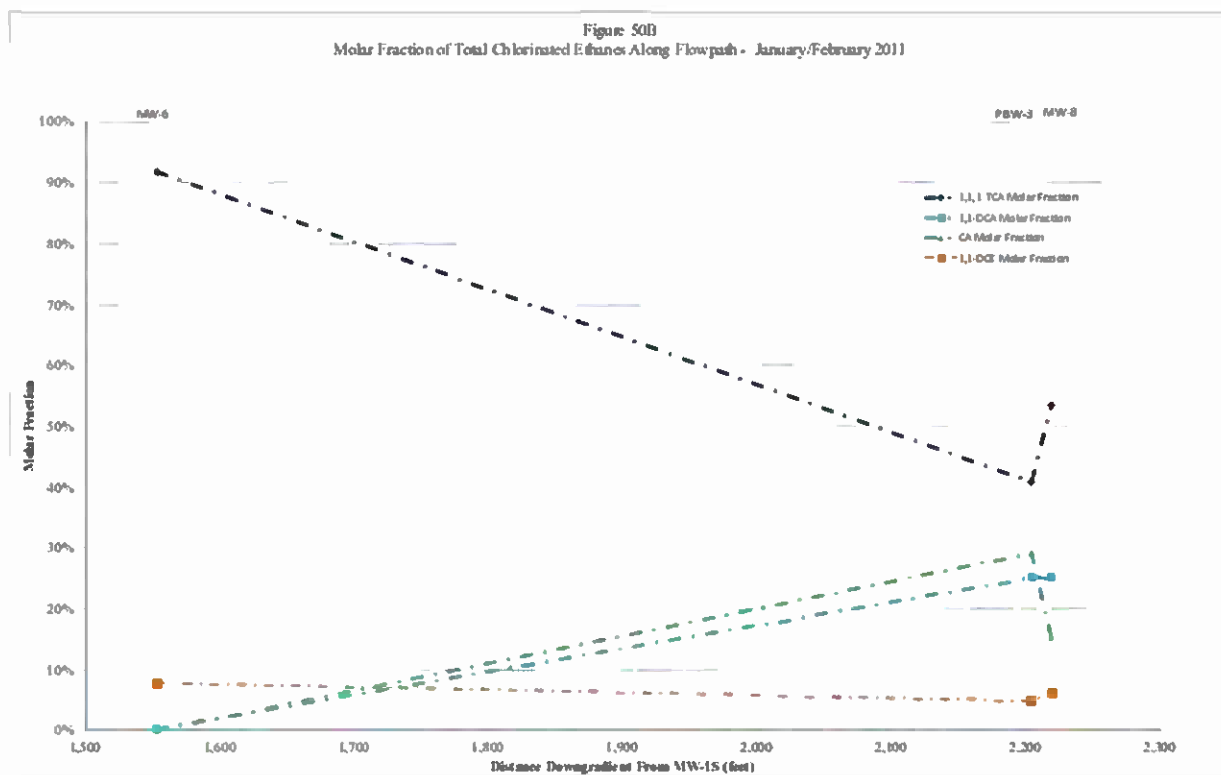
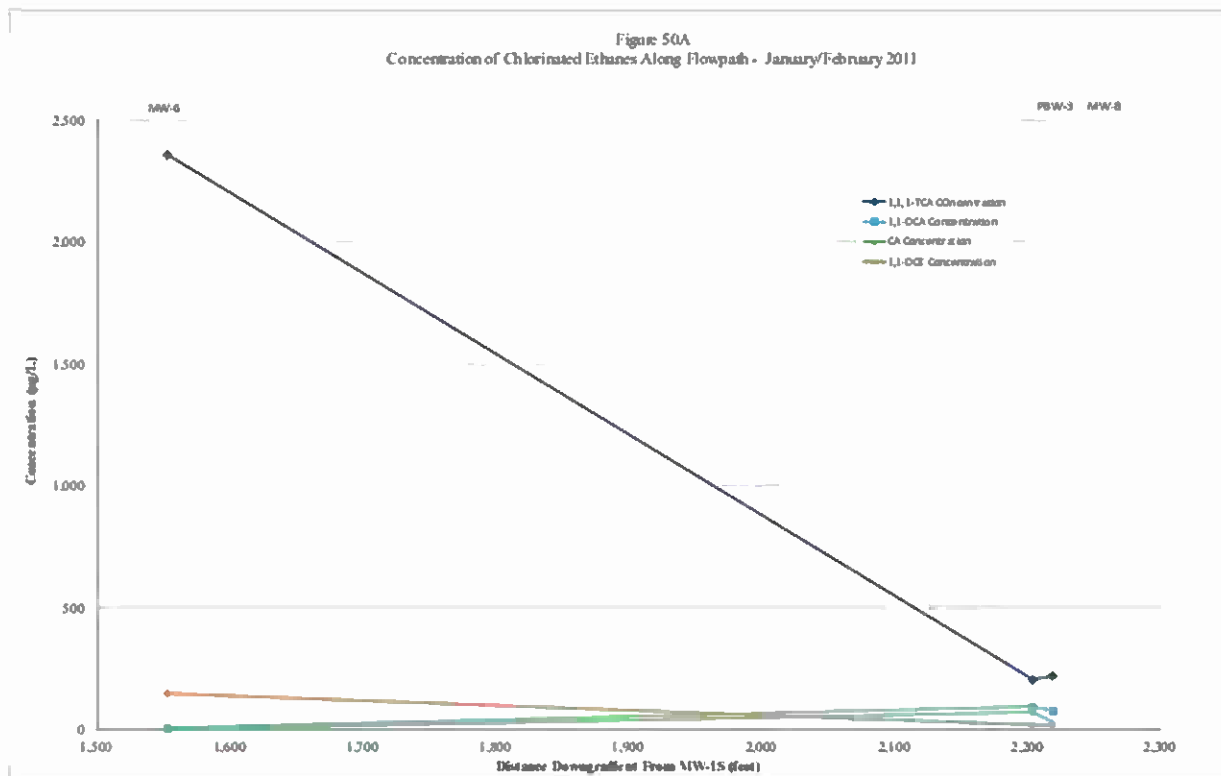


Figure 5I
Plots of Concentration Versus Time Along the Flowpath for Chlorinated Ethenes
 Twigg Manufacturing Facility
 Martinsville, Indiana

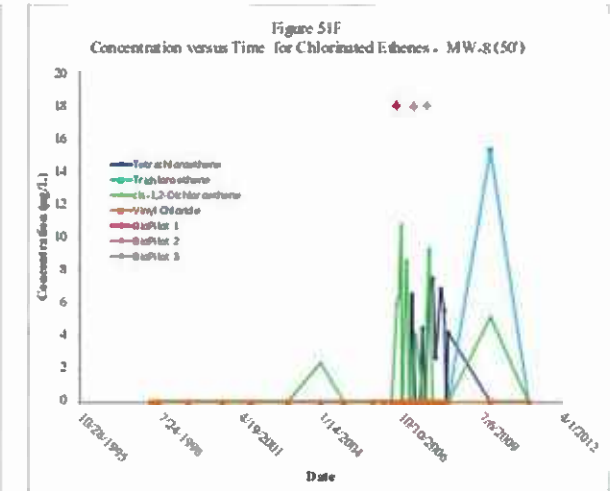
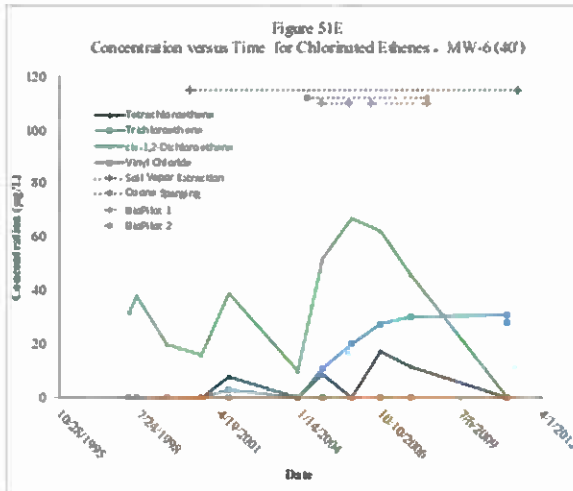
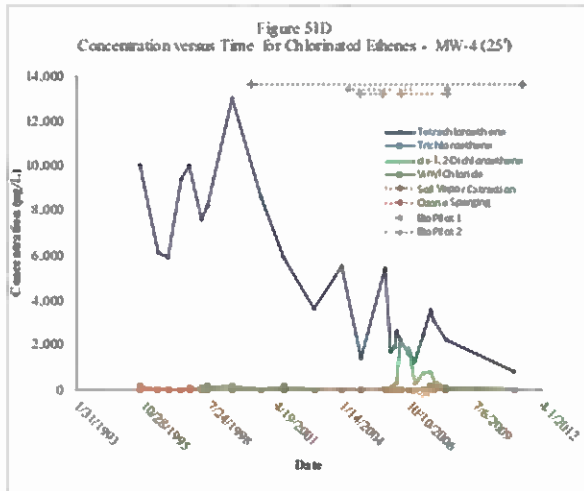
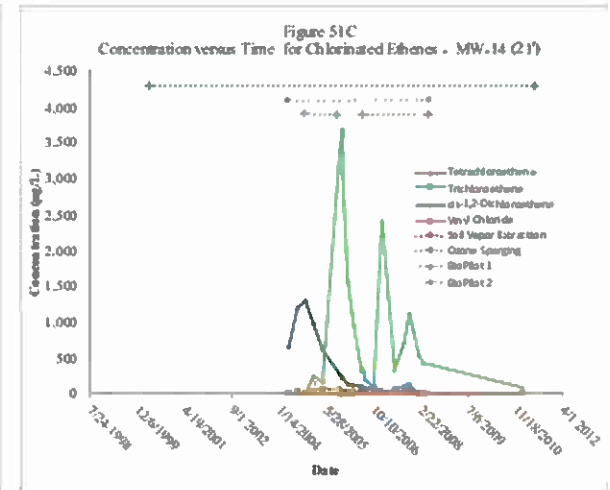
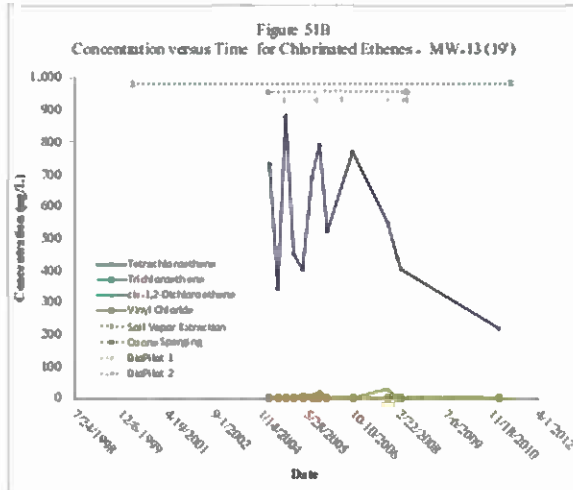
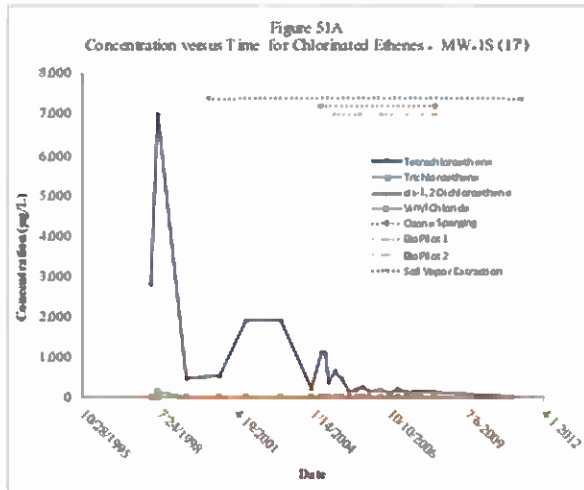


Figure 52
Plots of Concentration Versus Time Along the Flowpath for Chlorinated Ethanes
 Twigg Manufacturing Facility
 Martinsville, Indiana

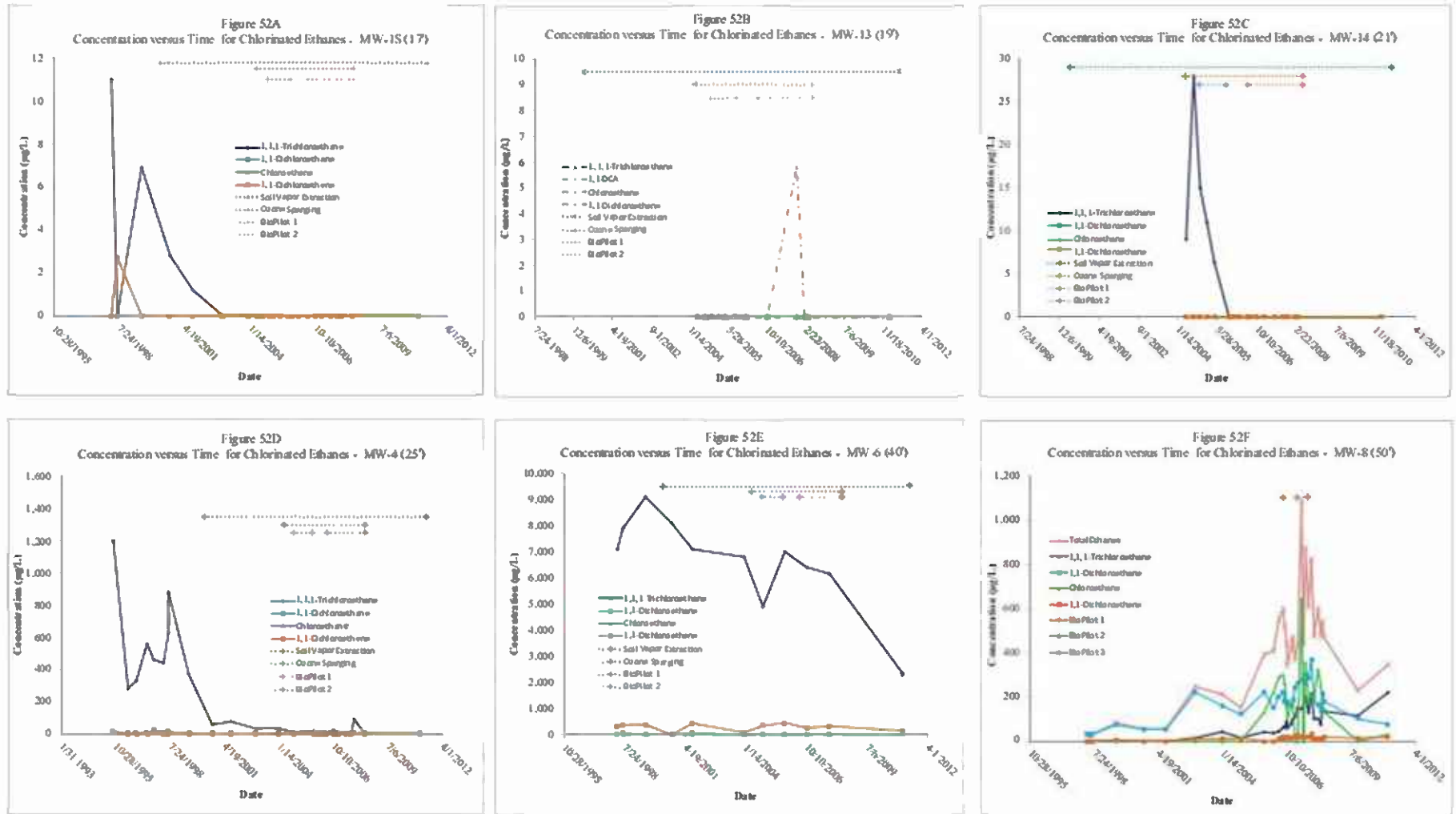


Figure 53
Concentration Versus Time for Chlorinated Ethenes (A) and Ethanes (B) - MW-3 (17')
 Twigg Manufacturing Facility
 Martinsville, Indiana

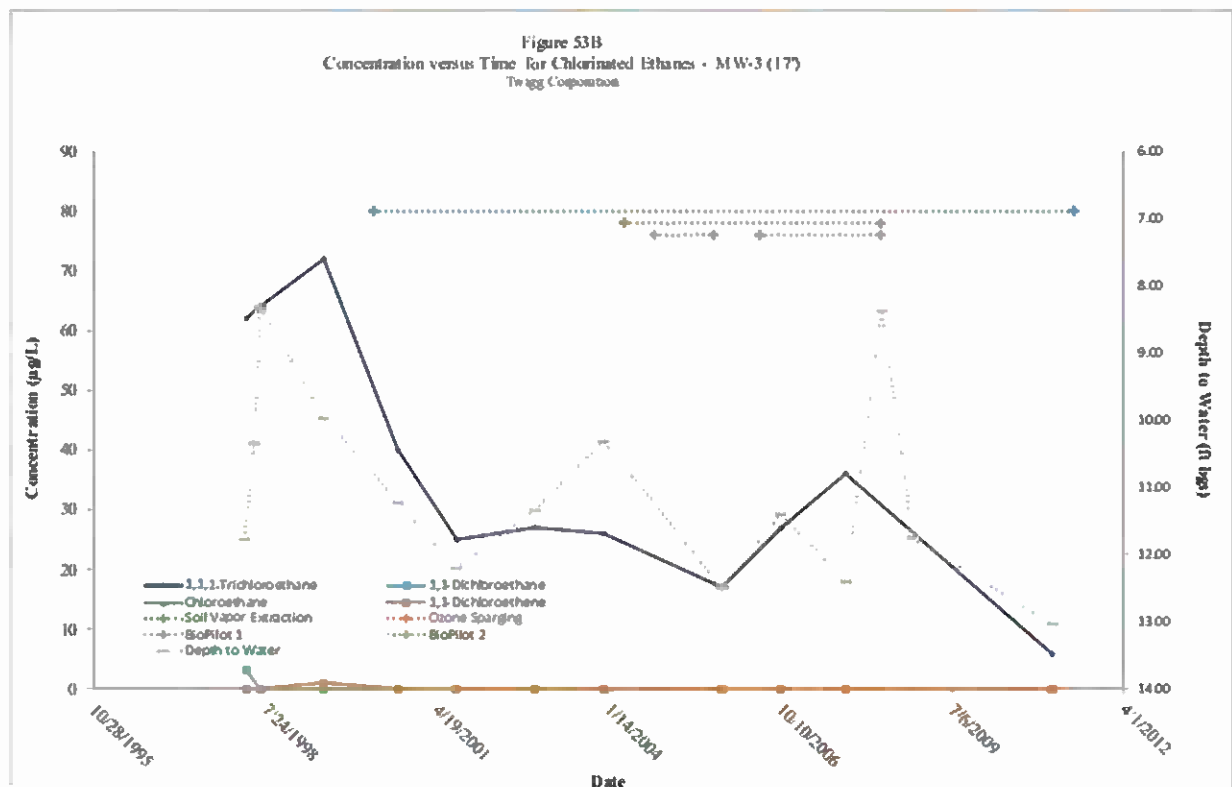
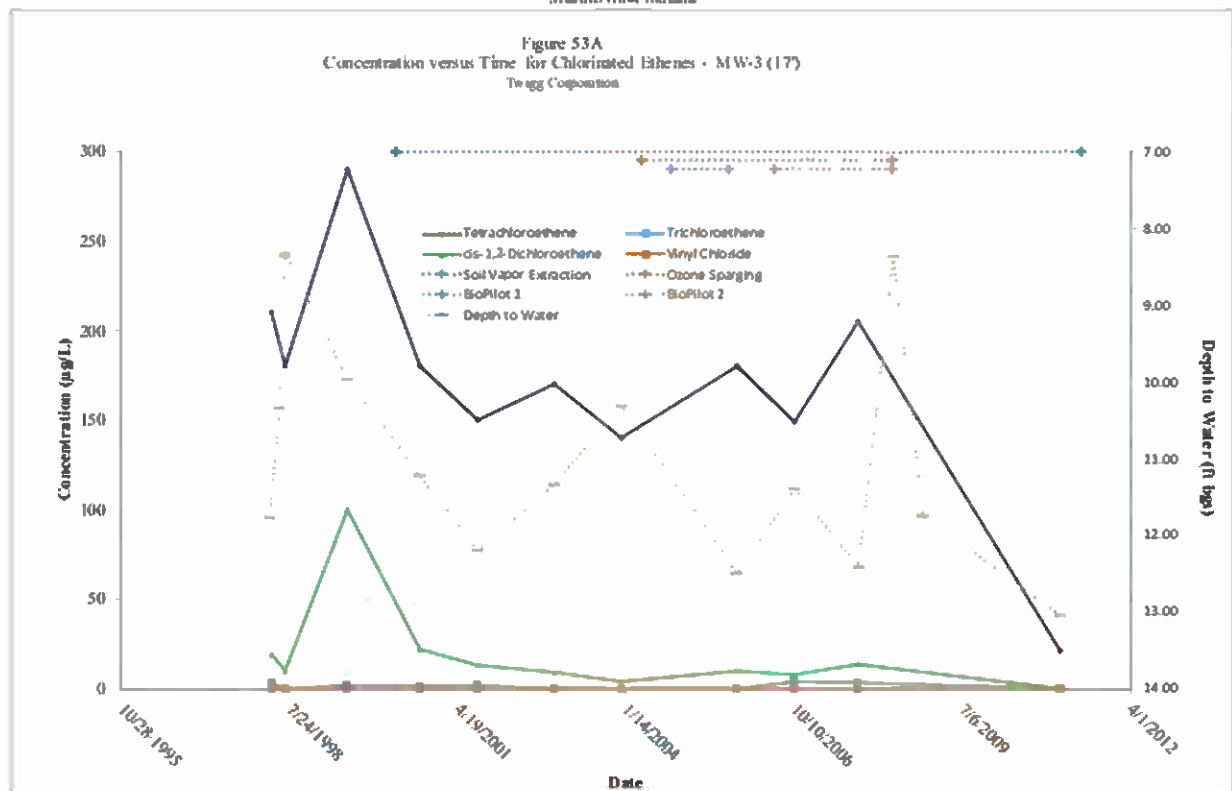


Figure 54
Concentration Versus Time for Chlorinated Ethenes (A) and Ethanes (B) - MW-10S (20')
 Twigg Manufacturing Facility
 Martinsville, Indiana

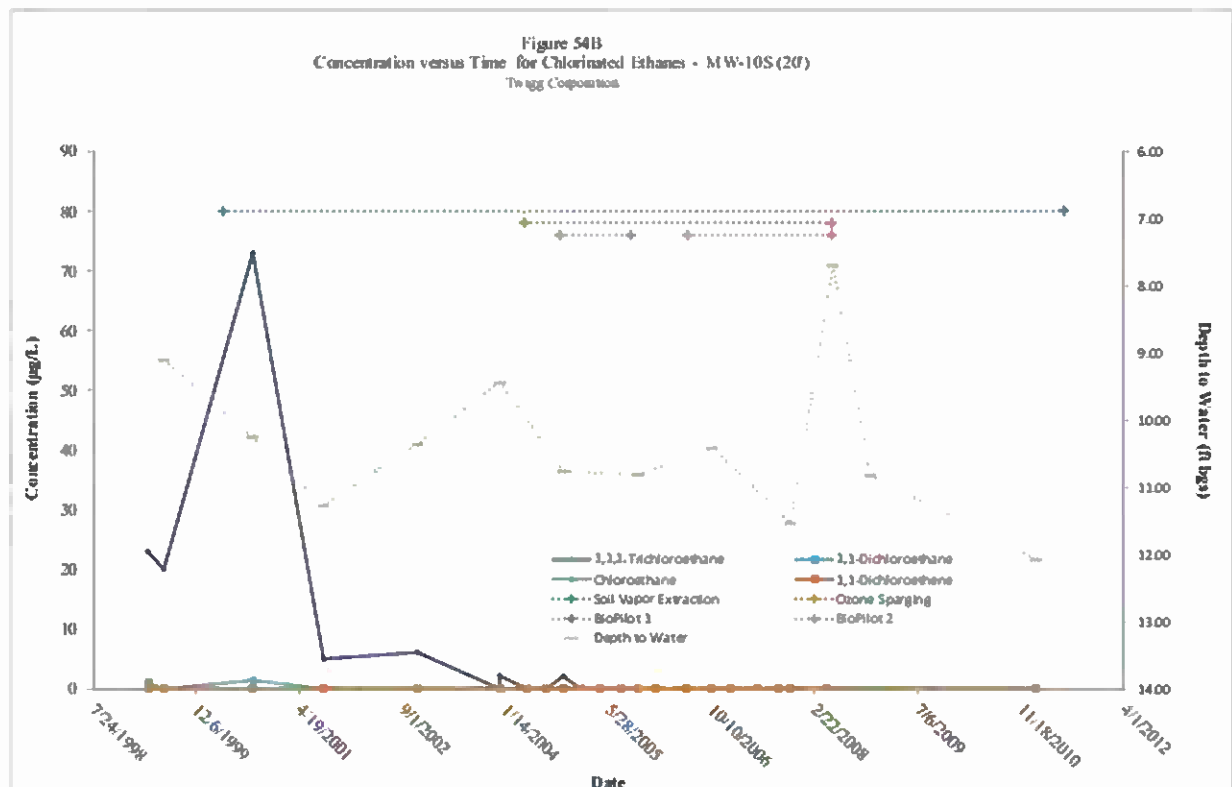
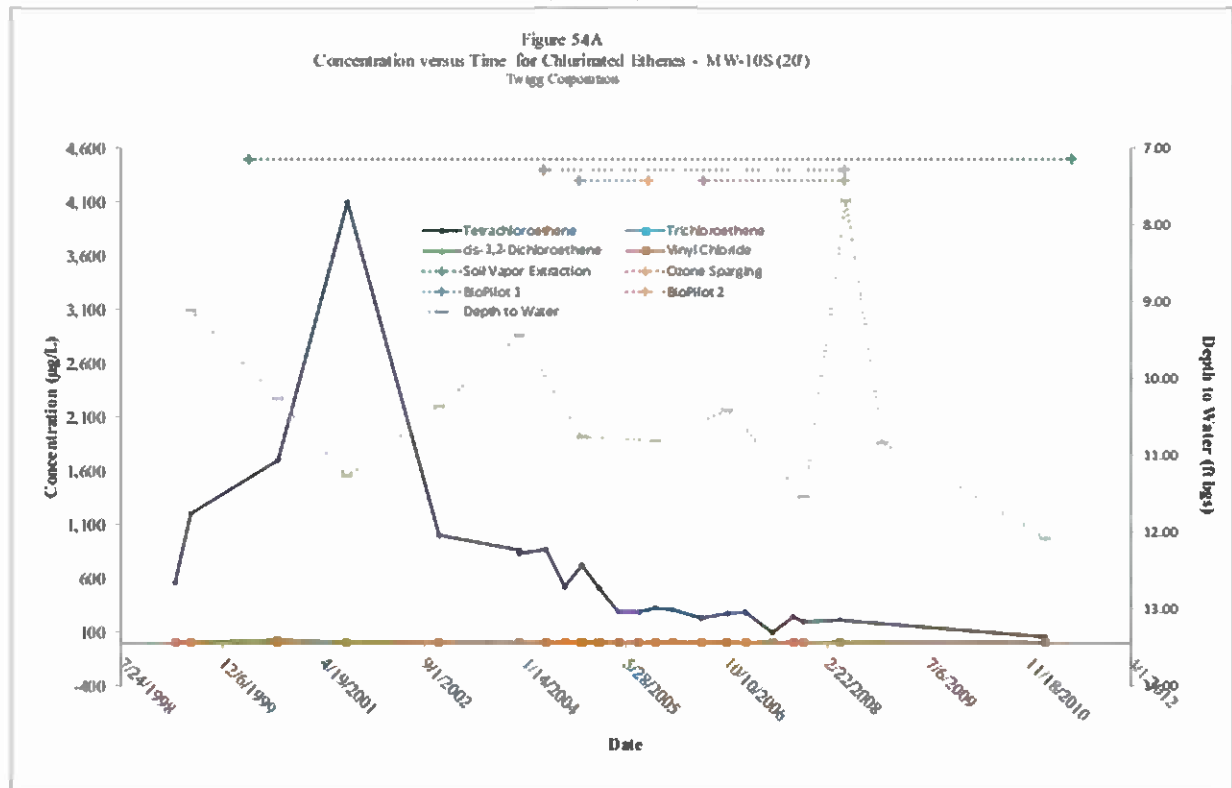


Figure 55
Concentration Versus Time for Chlorinated Ethenes (A) and Ethanes (B) - MW-11 (20')
 Twigg Manufacturing Facility
 Martinsville, Indiana

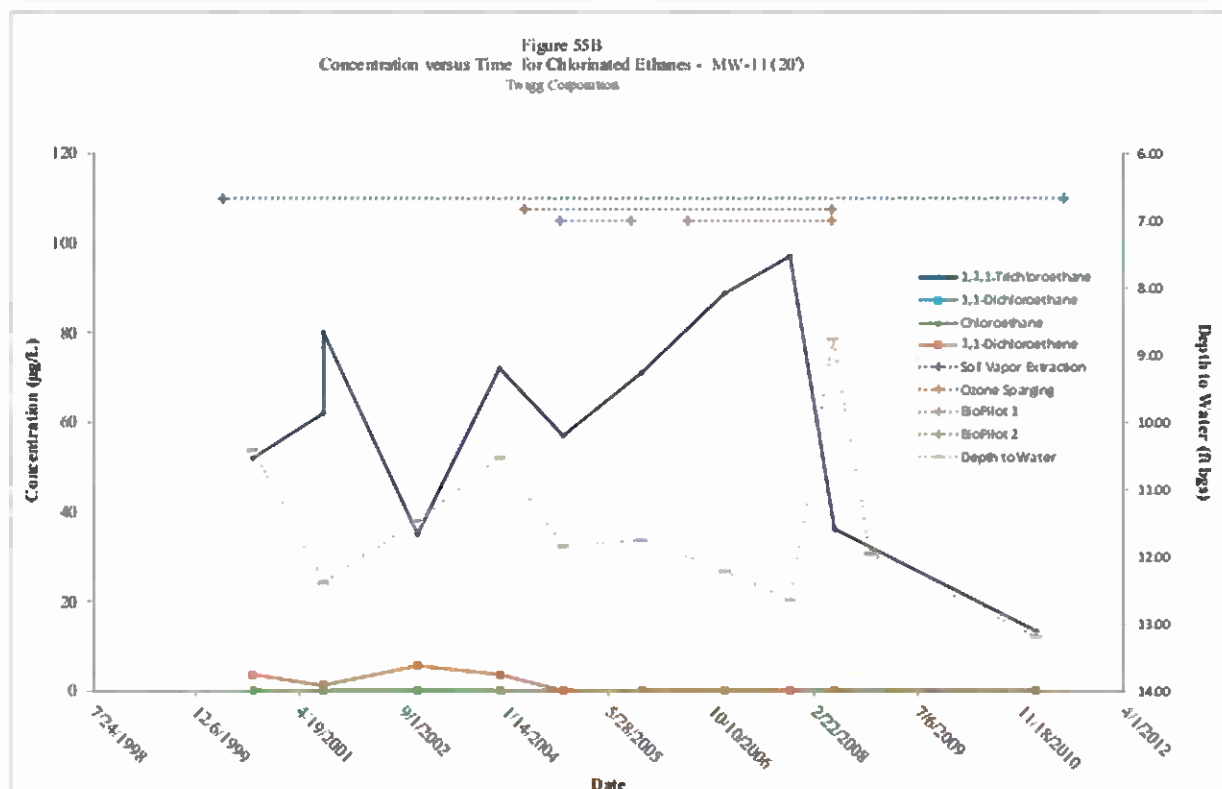
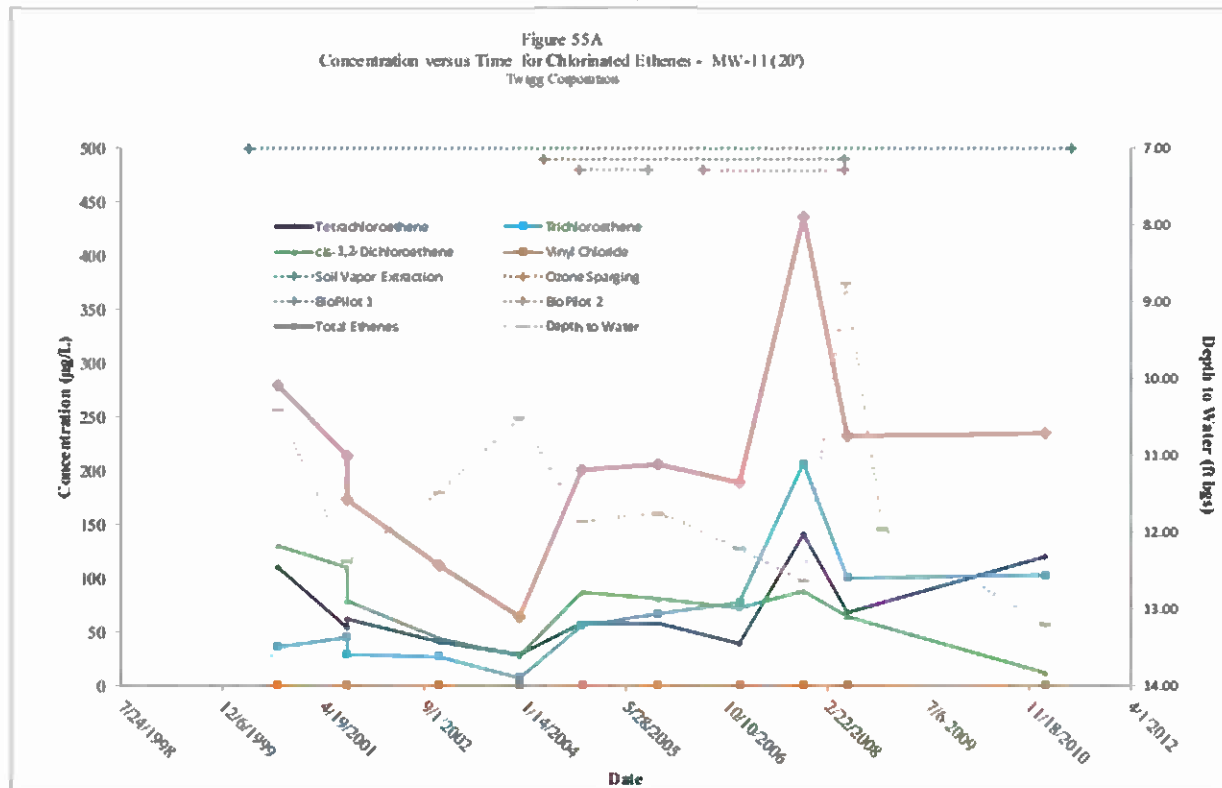


Figure 56
Concentration Versus Time for Chlorinated Ethenes (A) and Ethanes (B) - MW-12 (20')
 Twigg Manufacturing Facility
 Martinsville, Indiana

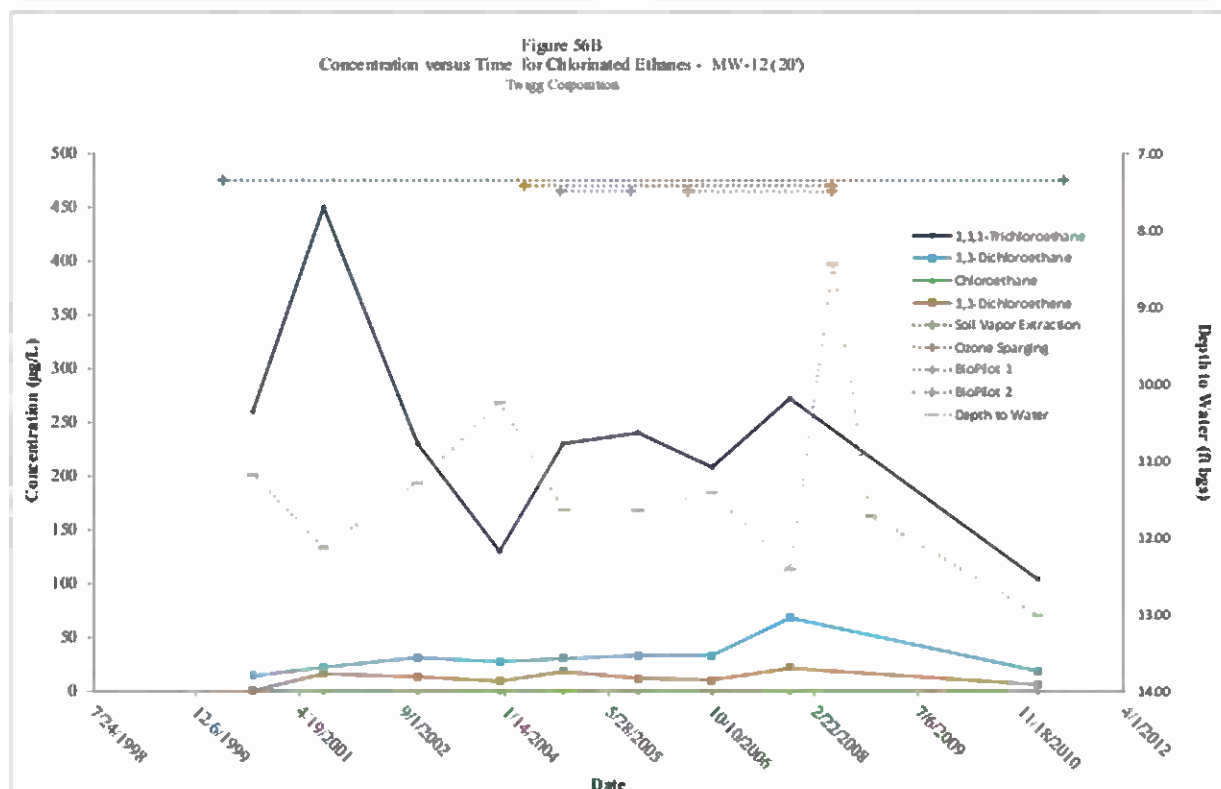
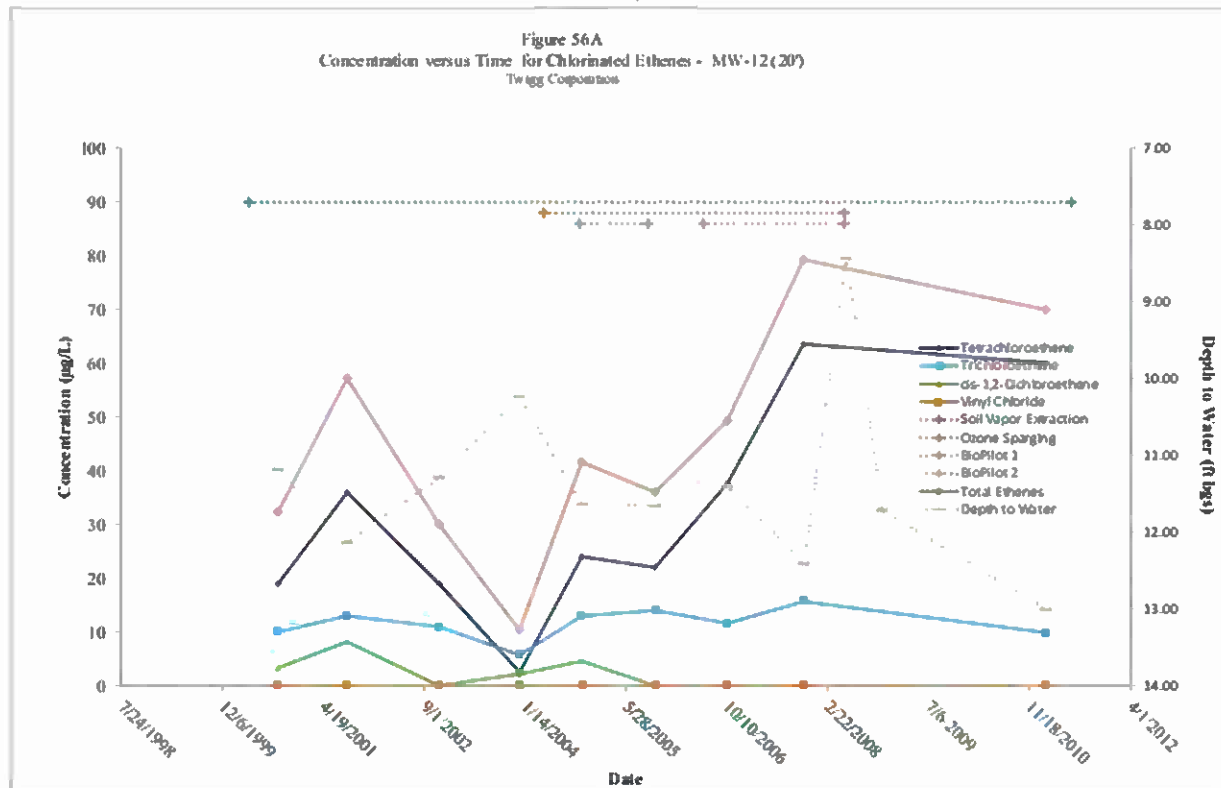


Figure 57
Concentration Versus Time for Chlorinated Ethenes (A) and Ethanes (B) - MW-15 (25')
 Twigg Manufacturing Facility
 Martinsville, Indiana

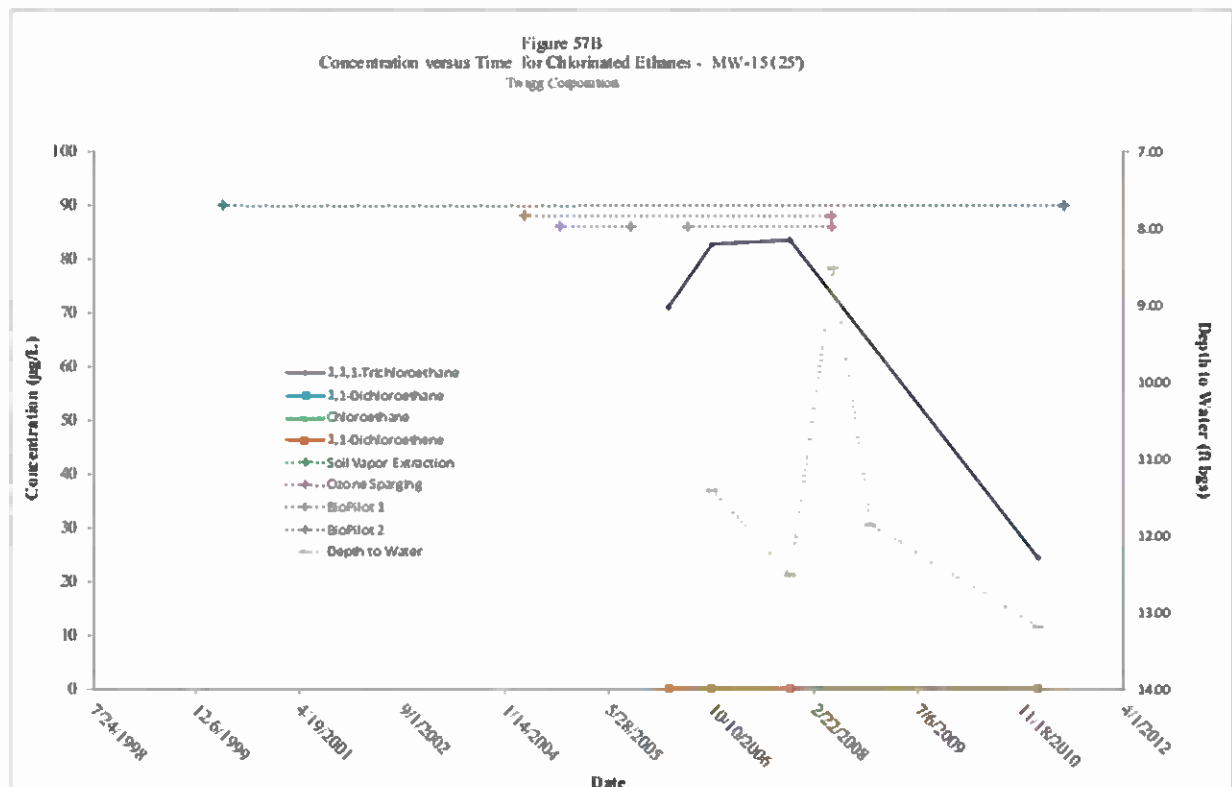
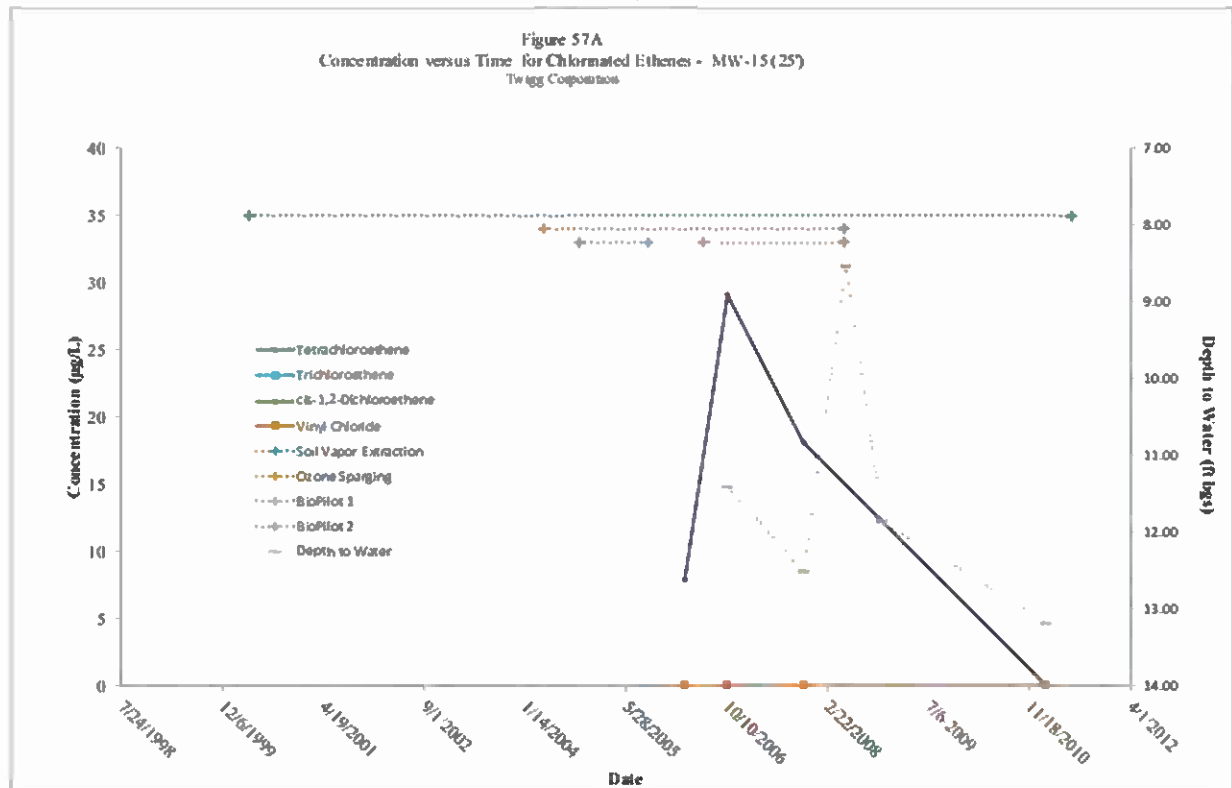


Figure 58
Concentration Versus Time for Chlorinated Ethenes and Ethanes - MW-16 (25')
 Twigg Manufacturing Facility
 Martinsville, Indiana

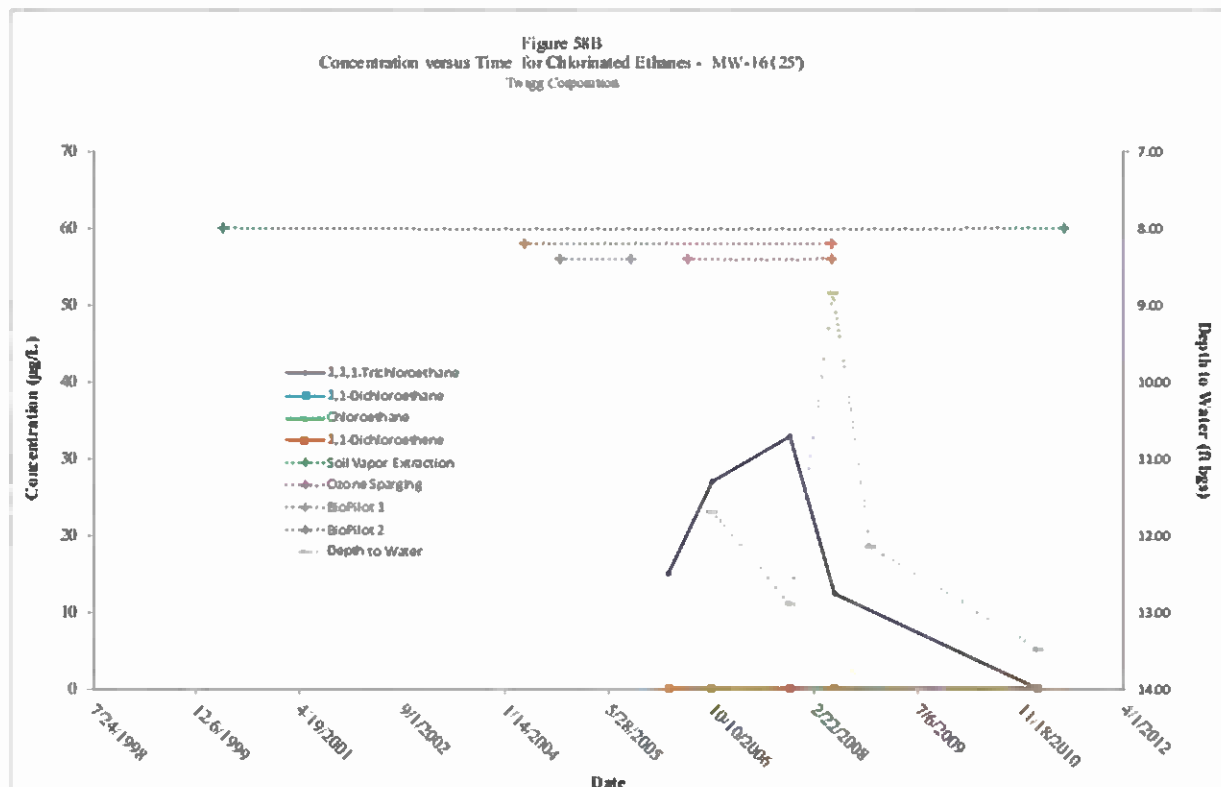
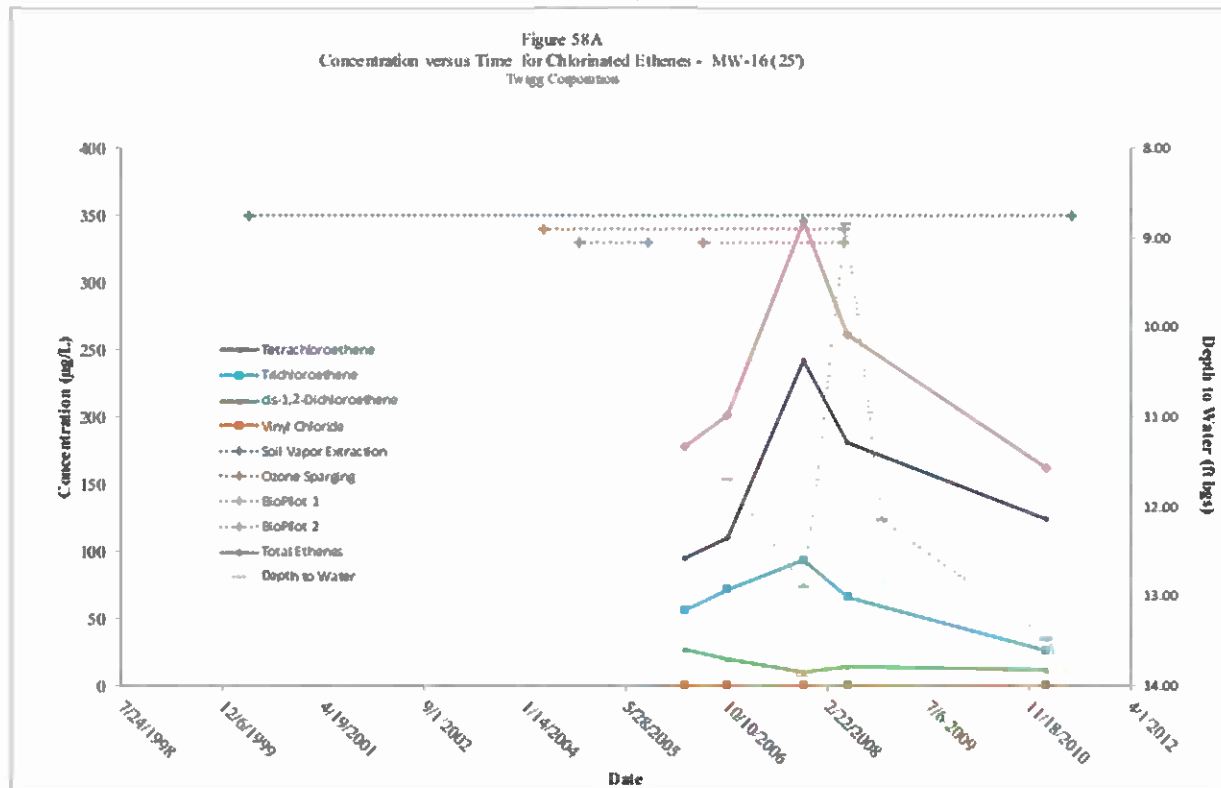


Figure 59
Concentration Versus Time for Chlorinated Ethenes (A) and Ethanes (B) - MW-17 (25')
 Twigg Manufacturing Facility
 Martinsville, Indiana

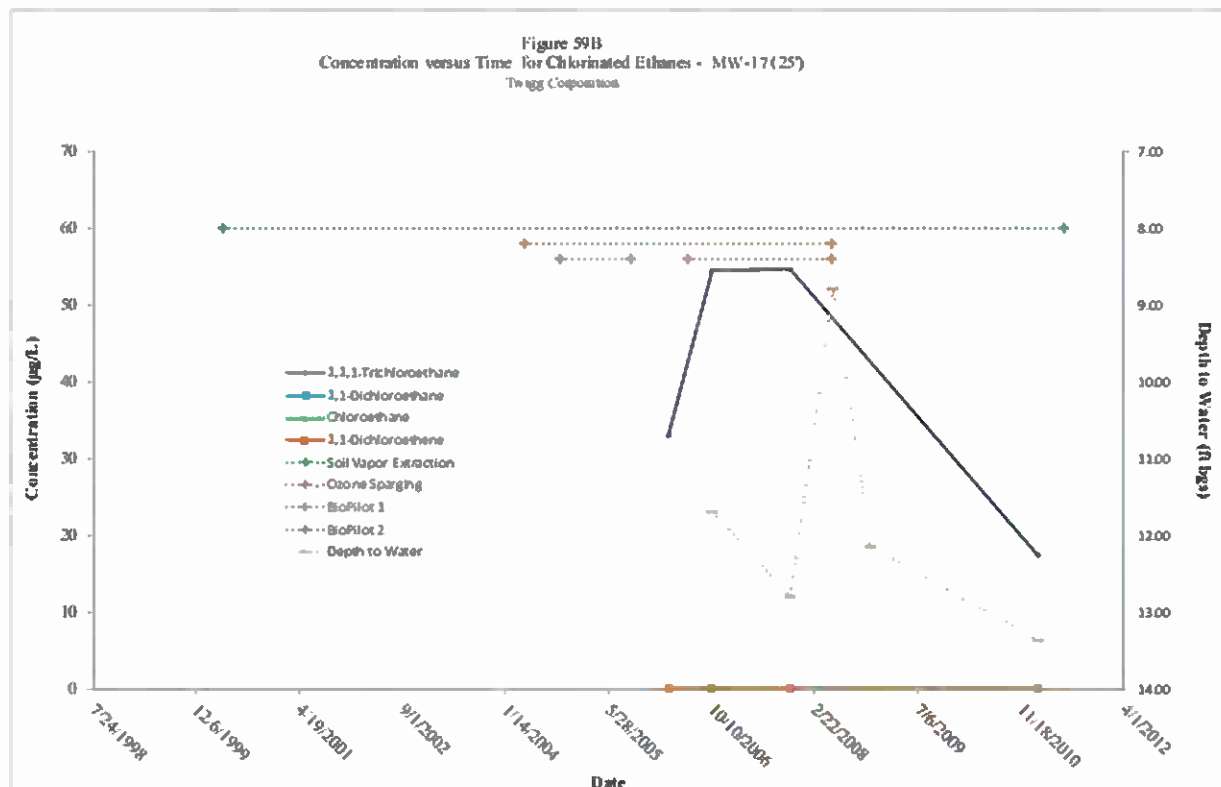
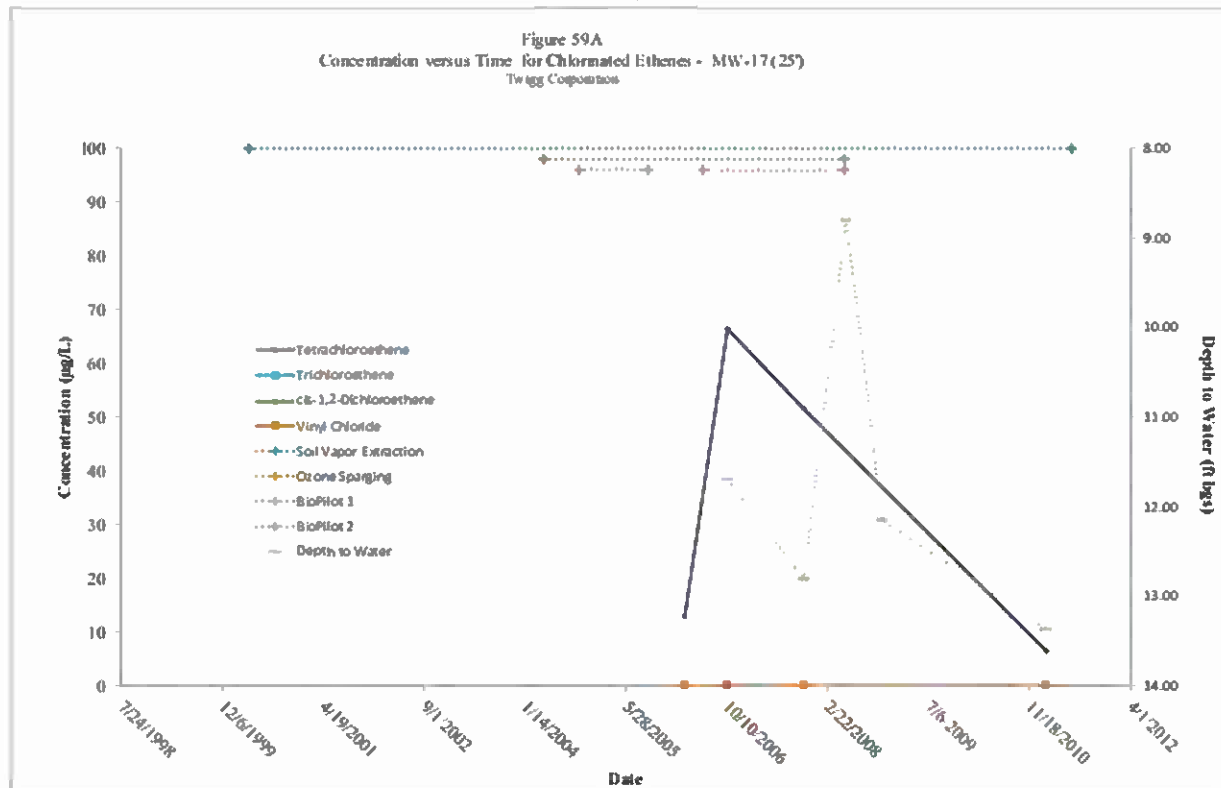
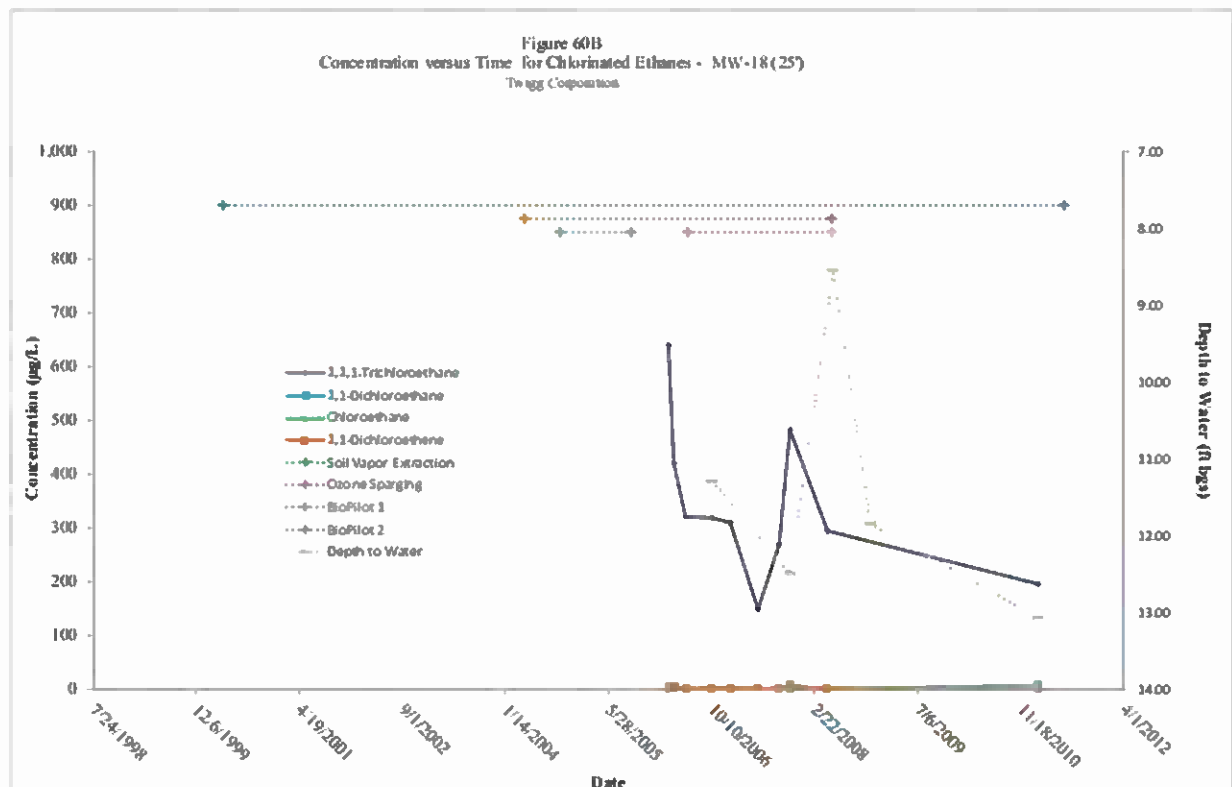
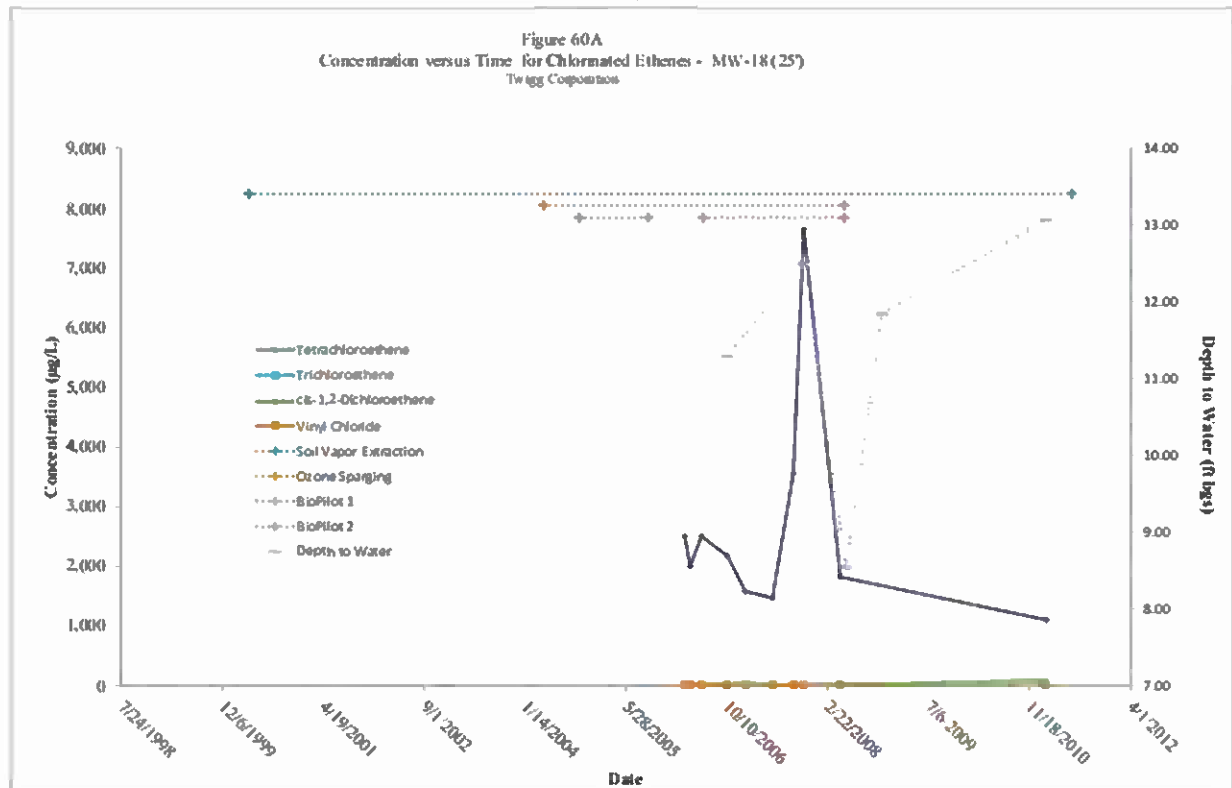


Figure 60
Concentration Versus Time for Chlorinated Ethenes (A) and Ethanes (B) - MW-18 (25')
 Twigg Manufacturing Facility
 Martinsville, Indiana



Martinsville, Indiana

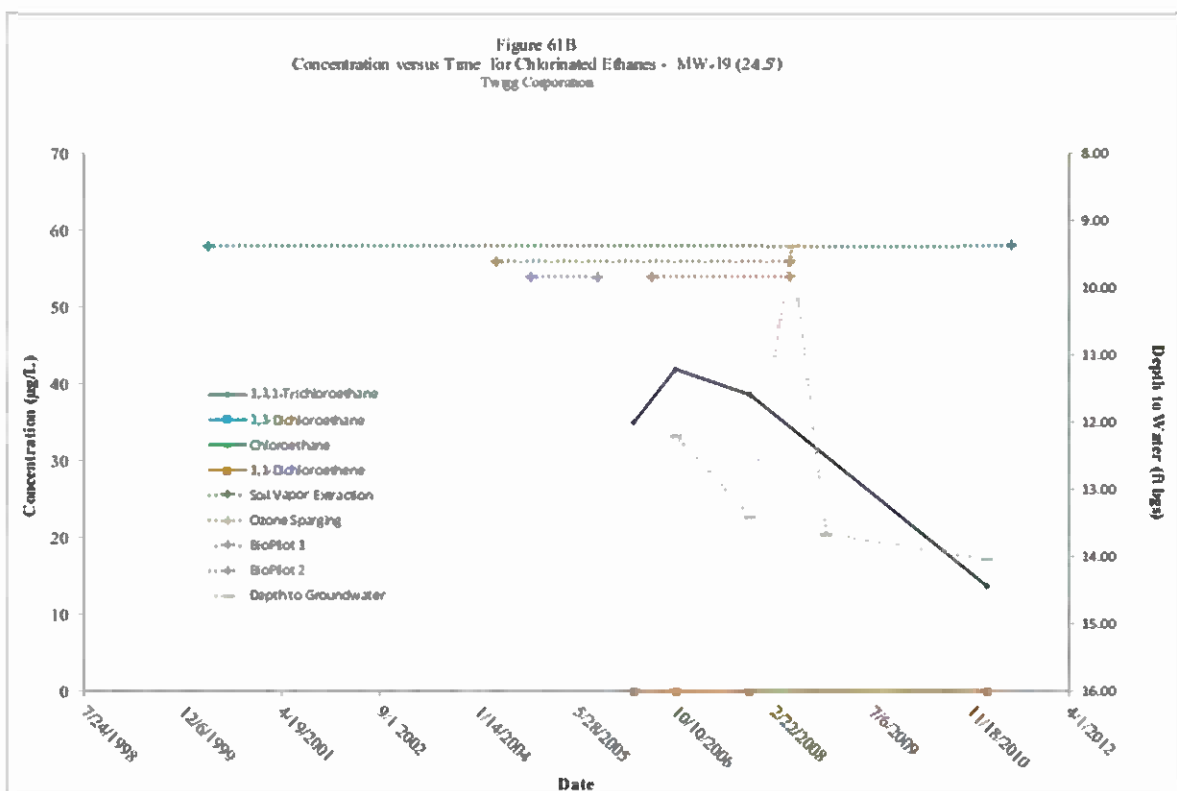
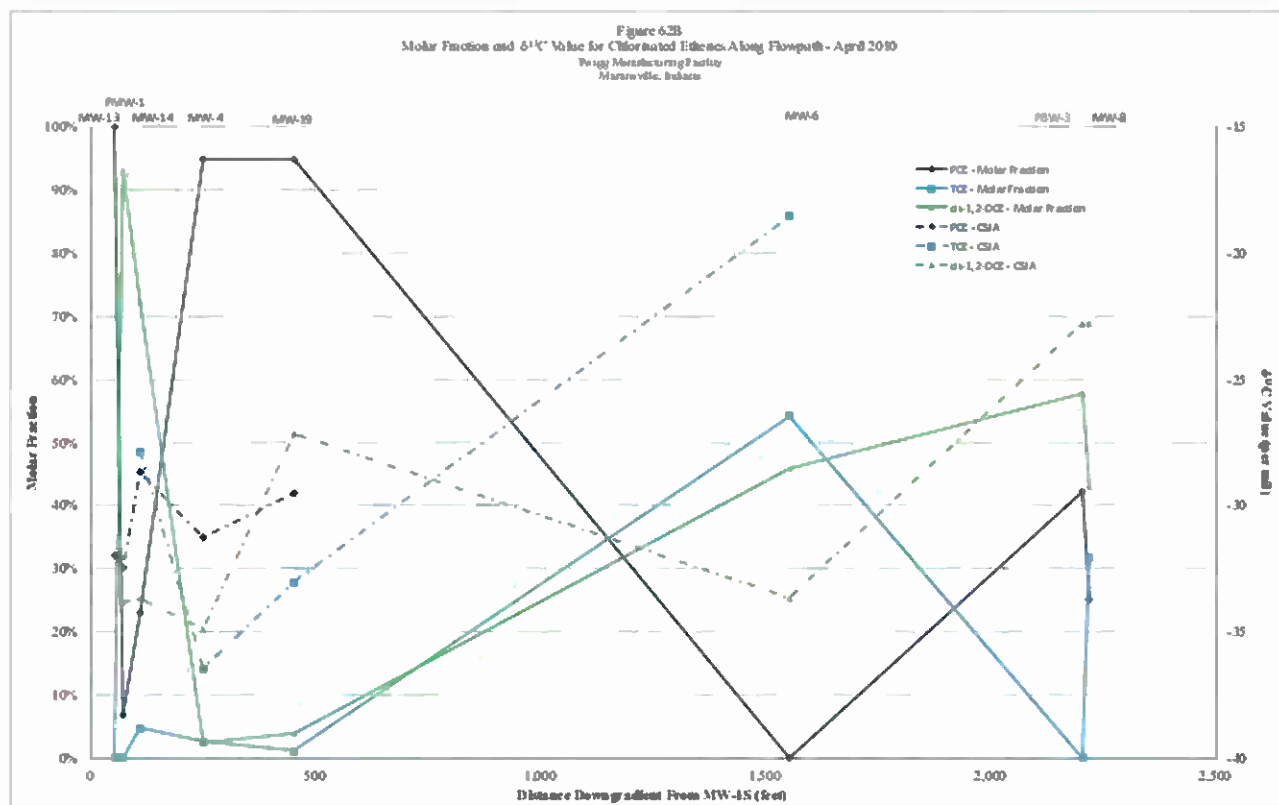
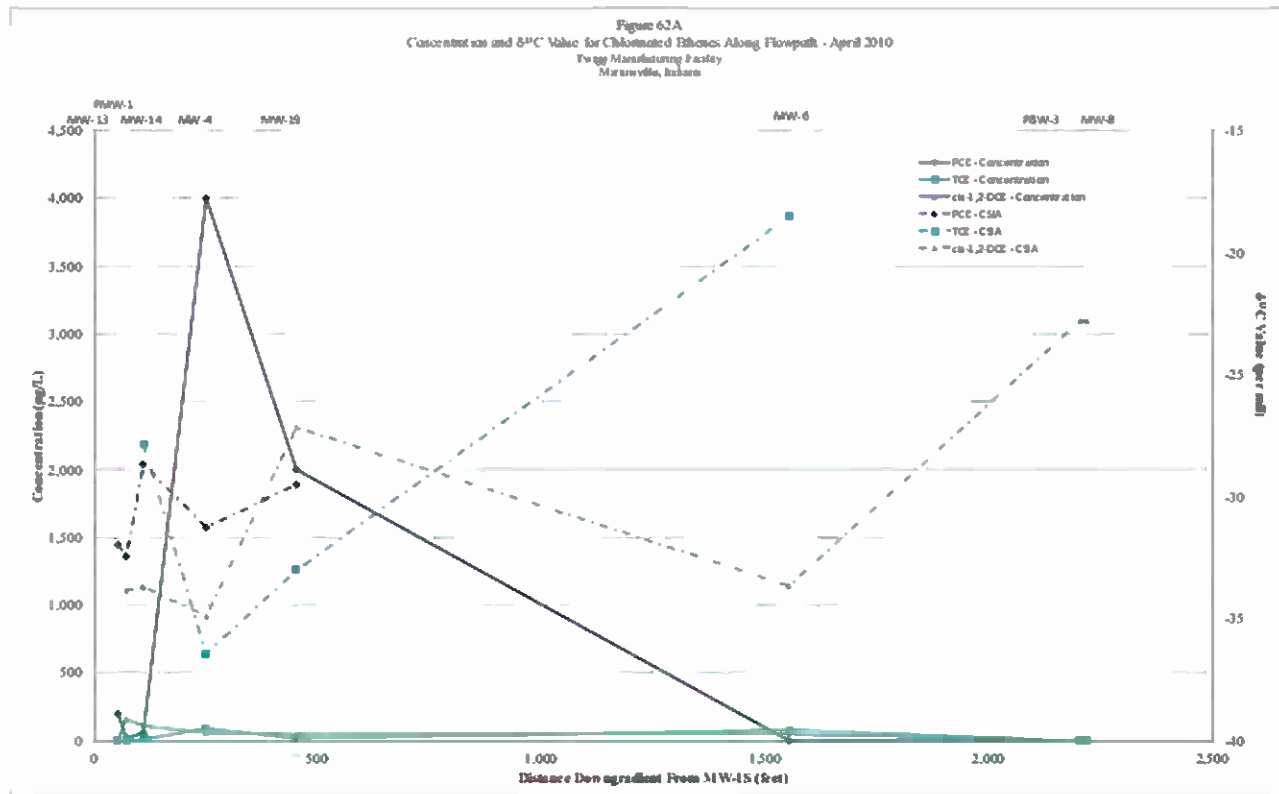
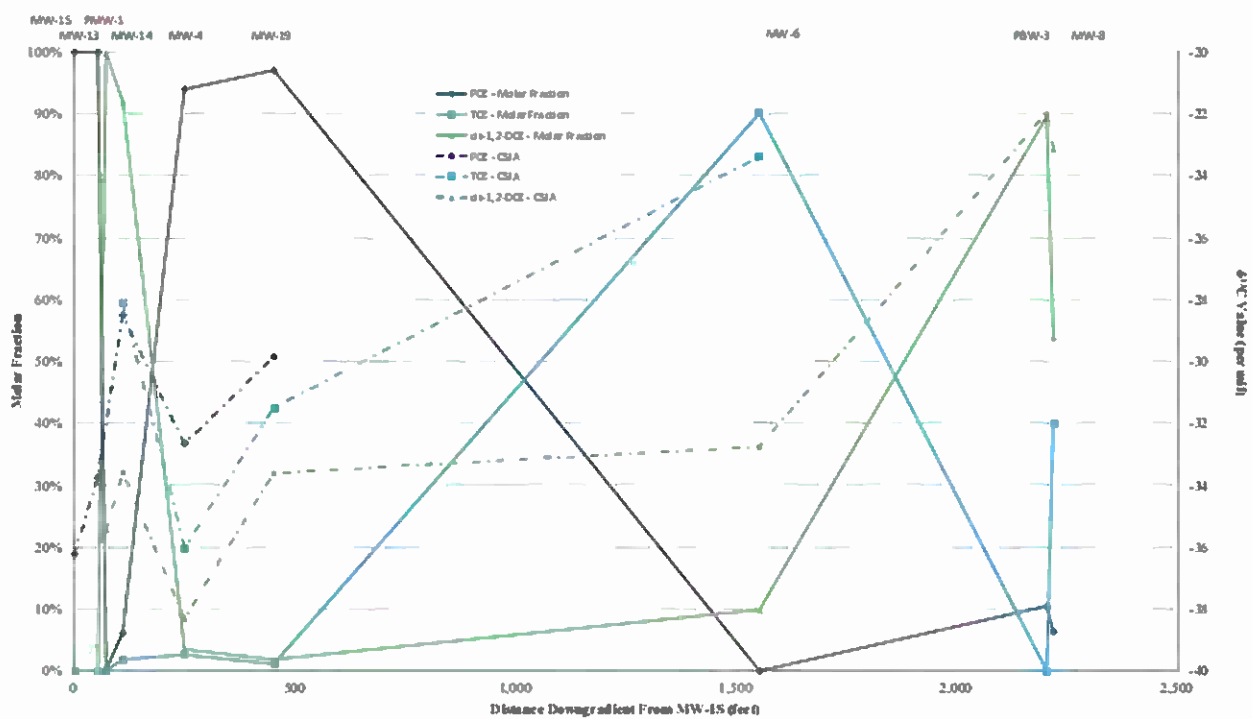
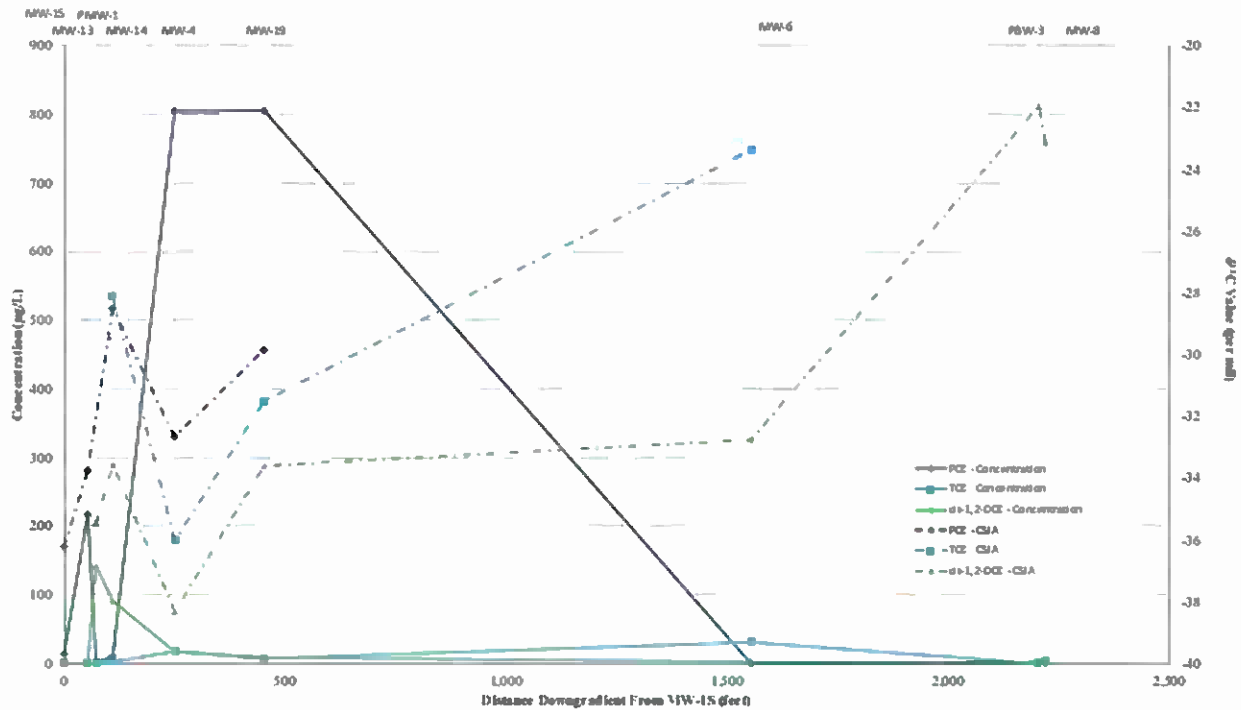


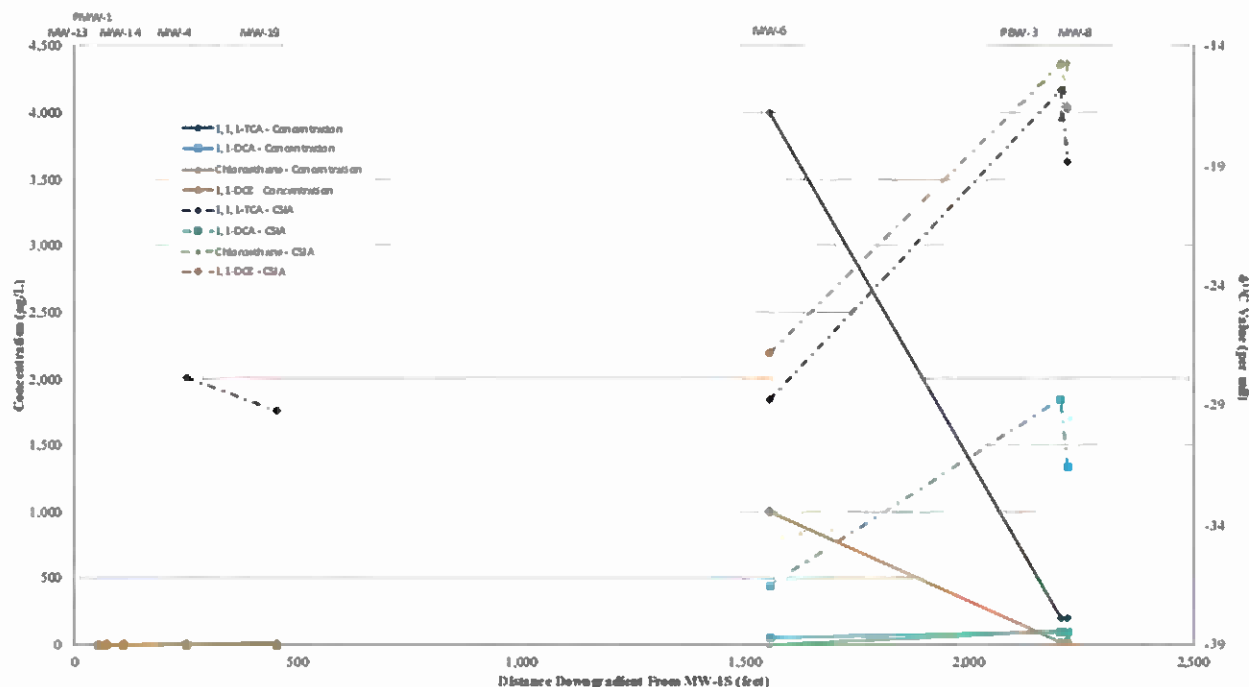
Figure 62
Concentration and $\delta^{13}\text{C}$ (A) and Molar Fraction and $\delta^{13}\text{C}$ (B) of Individual Chlorinated Ethenes along Flowpath - April 2010
 Twigg Manufacturing Facility
 Martinsville, Indiana



Martinsville, Indiana



Concentration and $\delta^{13}\text{C}$ (A) and Molar Fraction and $\delta^{13}\text{C}$ (B) of Individual Chlorinated Ethanes along Flowpath - April 2010
Twigg Manufacturing Facility
Marionville, Indiana



Molar Fraction and $\delta^{13}\text{C}$ Value for Chlorinated Ethanes Along Flowpath - April 2010
Terry Muehlenberg, 82nd Air
Maxwellville, Indiana

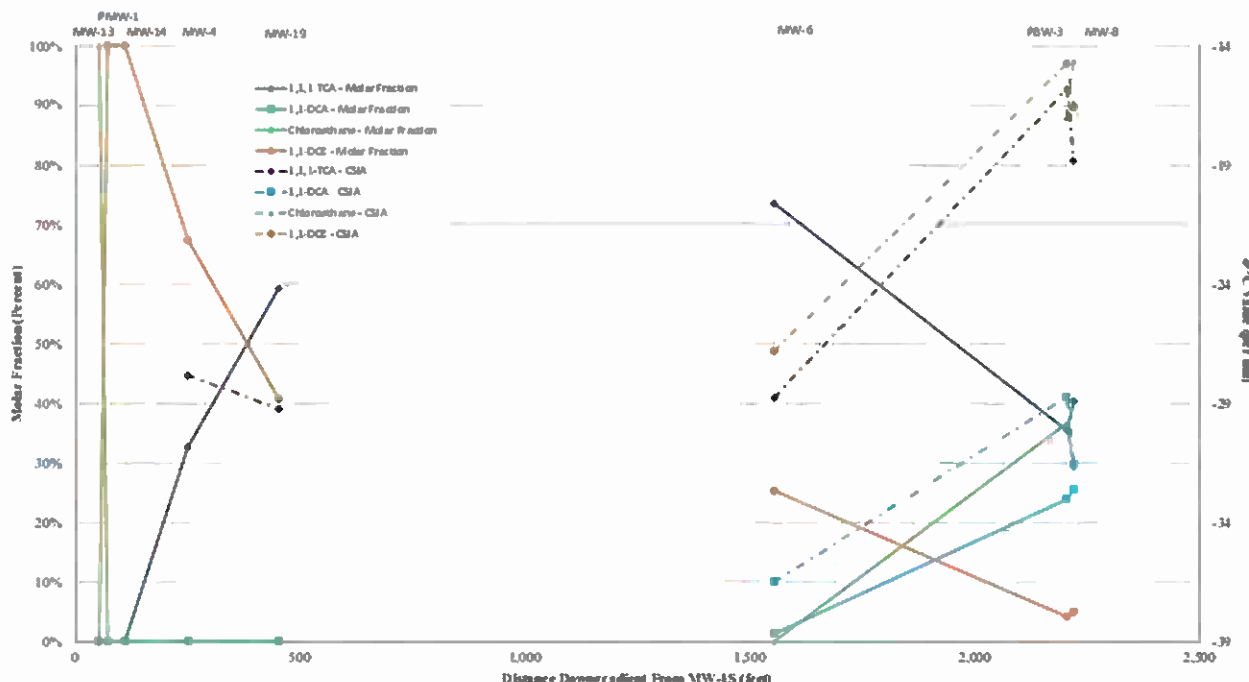
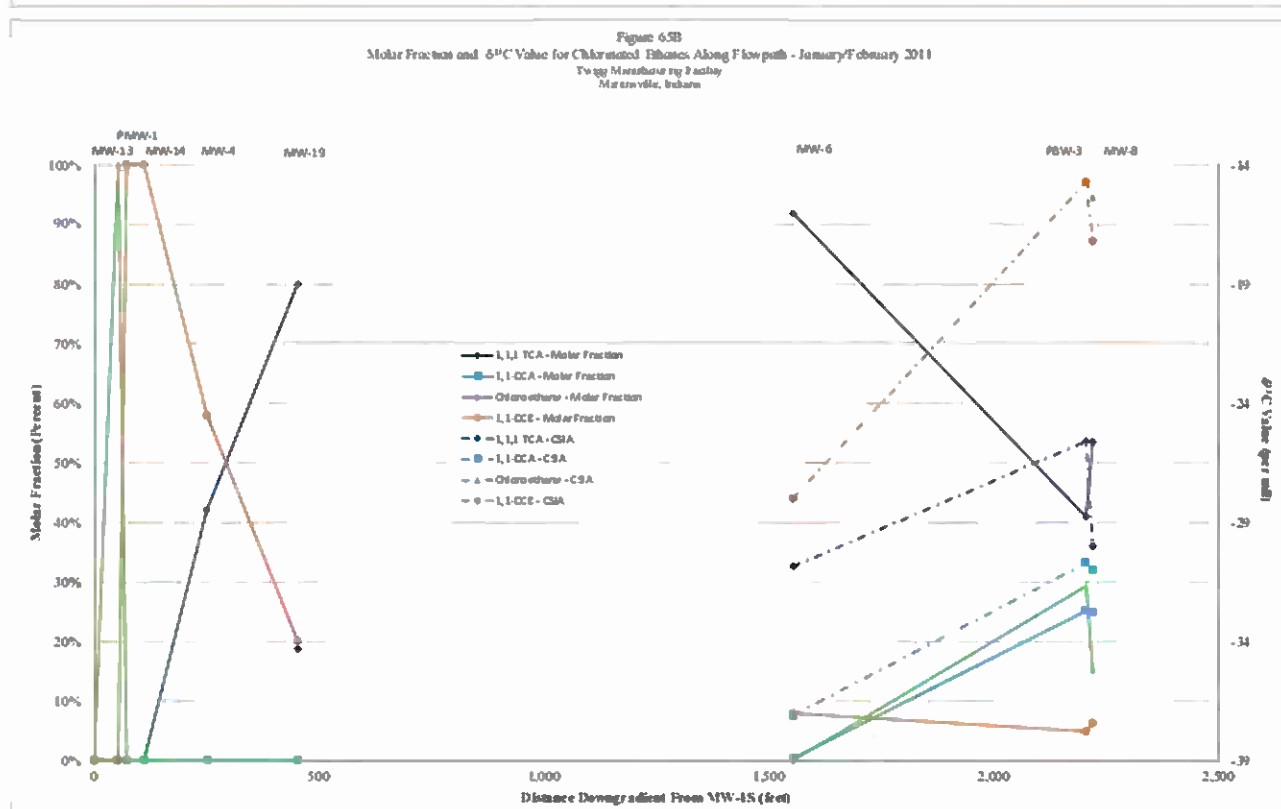
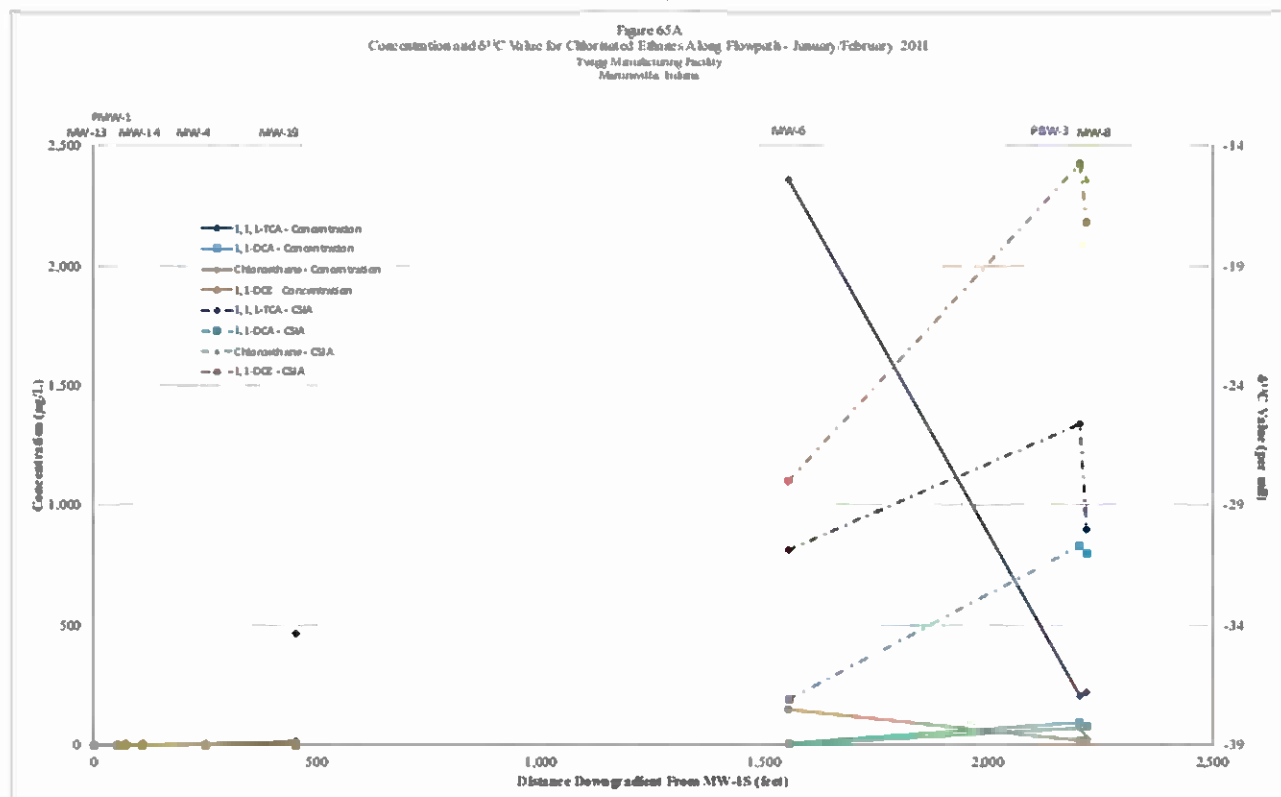


Figure 65
Concentration and $\delta^{13}\text{C}$ (A) and Molar Fraction and $\delta^{13}\text{C}$ (B) of Individual Chlorinated Ethanes along Flowpath - January/February 2011
 Twigg Manufacturing Facility
 Martinsville, Indiana



TABLES

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Table 1
Monitoring Well Completion Information
 Twigg Corporation
 Martinsville, Indiana

Well Identification	Installation Date	Easting	Northing	UTM Source	Stick-up (feet)	Total Boring Depth (feet bgs)	Depth to Top of Screen (feet bgs)	Depth to Bottom Of Screen (feet msl)	Casing Elevation (feet msl)	Ground Surface Elevation ⁽¹⁾ (feet msl)
MW-1S	8/9/1994	549891.7	4363197.7	T	0.0	31.0	7.0	597.0	17.0	604.0
MW-1D	2/24/1998	549891.7	4363200.4	E	0.0	81.0	50.0	554.0	60.0	604.0 a/
MW-2	8/10/1994	549942.1	4363250.7	E	0.0	25.5	7.0	596.9	17.0	603.9 a/
MW-3	8/9/1994	549826.0	4363243.4	T	0.0	31.0	7.0	598.0	17.0	605.0
MW-4	12/14/1994	549815.9	4363183.5	T	0.0	50.5	15.0	589.6	25.0	604.6
MW-5	9/29/1997	549412.4	4363103.3	T	0.0	40.0	30.0	572.9	40.0	602.9
MW-6	9/30/1997	549415.9	4363150.5	T	0.0	65.0	30.0	573.5	40.0	603.5
MW-6D	2/23/1998	549413.9	4363150.5	E	0.0	101.5	90.0	513.4	100.0	603.4
MW-7	10/1/1997	549425.2	4363248.6	T	0.0	40.0	26.0	580.6	36.0	606.6
MW-8	10/1/1997	549213.0	4363141.8	T	0.0	60.0	40.0	564.3	50.0	604.3
MW-9	2/23/1998	549976.0	4363259.7	T	0.0	20.0	10.0	594.3	20.0	604.3
MW-10S	4/13/1999	549895.8	4363229.2	E	0.0	20.0	10.0	594.5	20.0	604.5 a/
MW-10M	4/6/1999	549892.7	4363229.1	E	0.0	40.0	30.0	574.5	40.0	604.5 a/
MW-11	5/3/2000	549860.8	4363261.6	E	0.0	20.0	10.0	595.3	20.0	605.3 b/
MW-12	5/2/2000	549826.1	4363274.4	T	0.0	20.0	10.0	594.9	20.0	604.9
MW-13	4/27/2004	549875.9	4363195.1	T	0.0	19.0	9.0	595.5	19.0	604.5
MW-14	4/27/2004	549861.0	4363193.5	T	0.0	21.0	11.0	593.1	21.0	604.1
MW-15	3/1/2006	549773.3	4363275.5	T	0.0	25.0	15.0	589.6	25.0	604.6
MW-16	3/1/2006	549787.3	4363242.8	T	0.0	25.0	15.0	589.9	25.0	604.9
MW-17	3/1/2006	549799.4	4363217.3	T	0.0	25.0	15.0	589.9	25.0	604.9
MW-18	3/1/2006	549811.1	4363192.5	T	0.0	25.0	15.0	589.7	25.0	604.7
MW-19	3/1/2006	549754.8	4363193.0	T	0.0	25.0	14.5	590.6	24.5	605.1
HMW-25	1995	549752.2	4363128.9	E	0.0	18.0	8.0	595.9	18.0	603.8 c/
HMW-31	1995	549822.0	4363154.4	E	0.0	18.0	7.9	597.1	17.9	605.0 d/
PBW-1	6/7/2004	549873.0	4363194.5	E	0.0	17.0	12.0	592.5	17.0	604.5 e/
PBW-1R	1/1/2006	549874.0	4363194.8	E	0.0	17.0	12.0	592.5	17.0	604.5 e/
PBW-2	6/7/2004	549866.3	4363194.6	E	0.0	17.0	12.0	592.5	17.0	604.5 f/
PBW-3	7/7/2006	549217.5	4363142.4	E	0.0	55.0	35.0	569.3	55.0	604.3 g/
PBW-4	7/7/2006	549217.5	4363139.4	E	0.0	55.0	35.0	569.3	55.0	604.3 g/
PMW-1	6/7/2004	549870.2	4363194.5	E	0.1	18.0	13.0	591.5	18.0	604.5 e/
PMW-1S	6/7/2004	549870.1	4363193.0	E	0.1	18.0	13.0	591.5	18.0	604.5 e/

Notes:

bgs = Below Ground Surface

msl = Feet Above Mean Sea Level

T = Well Easting and Northing located using Trimble GeoXH GPS unit

E = Easting and Northing Coordinates estimated from triangulation calculation from nearest GPS fixed well

NS = Top of casing elevation not surveyed.

(1) Ground surface elevation estimated from Casing elevation.

Ground elevations for "PB" series estimated from nearby wells as Indicated.

a/ Ground Surface Elevation Based on MW-1S Ground Surface Elevation

b/ Ground Surface Elevation Based on MW-3 Coordinates

c/ Ground Surface Elevation Based on MW-19 Coordinates

d/ Ground Surface Elevation Based on MW-4 Coordinates

e/ Ground Surface Elevation Based on MW-13 Coordinates

f/ Ground Surface Elevation Based on MW-14 Coordinates

g/ Ground Surface Elevation Based on MW-8 Coordinates

Table 2
Monitoring Well Gauging Information and Vertical Hydraulic Gradient Calculations
 Twigg Corporation
 Martinsville, Indiana

Well ID	Date	Easting	Northing	Total Boring Depth (feet bgs)	Depth to Top of Screen		Depth to Bottom of Screen		Casing Elevation (feet msl)	Depth to Water (feet)	Water Table Elevation (feet msl)	Vertical Gradient Calculation			
					(feet bgs)	(feet msl)	(feet bgs)	(feet msl)				dH (ft)	dL (ft)	Gradient (ft/ft)	Direction
MW-1S	8/11/1994	549891.7	4363197.7	31.0	7.0	597.0	17.0	587.0	603.78	9.52	594.26				
	3/26/1998								603.78	10.17	593.61				
	5/22/1998								603.78	8.92	594.86				
	6/25/1998								603.78	6.95	596.83				
	6/26/1998								603.78	6.85	596.93				
	7/2/1999								603.78	8.64	595.14				
	11/3/1999								603.78	11.51	592.27				
	11/30/1999								603.78	11.91	591.87				
	1/13/2000								603.78	12.06	591.72				
	3/17/2000								603.78	11.60	592.18				
	4/16/2000								603.78	11.00	592.78				
	9/7/2000								603.78	9.74	594.04				
	12/7/2000								603.78	9.11	594.67				
	1/10/2001								603.78	11.51	592.27				
	2/8/2001								603.78	11.91	591.87				
	4/20/2001								603.78	12.06	591.72				
	6/7/2001								603.78	11.60	592.18				
	8/14/2001								603.78	11.00	592.78				
	12/13/2001								603.78	9.86	593.92				
	1/17/2002								603.78	9.36	594.42				
	4/9/2002								603.78	8.01	595.77				
	5/1/2002								603.78	6.88	596.90				
	8/2/2002								603.78	8.28	595.50				
	8/5/2002								603.78	8.42	595.36				
	8/9/2002								603.78	8.59	595.19				
	9/6/2002								603.78	9.58	594.20				
	11/14/2002								603.78	9.80	593.98				
	11/27/2002								603.78	10.00	593.78				
	2/21/2003								603.78	10.24	593.54				
	3/24/2003								603.78	9.63	594.15				
	4/24/2003								603.78	9.52	594.26				
	5/23/2003								603.78	8.54	595.24				
	6/26/2003								603.78	8.95	594.83				
	8/1/2003								603.78	8.43	595.35				
	9/26/2003								603.78	8.26	595.52				
	12/10/2003								603.78	8.74	595.04				
	12/16/2003								603.78	8.92	594.86				
	3/9/2004								603.78	8.57	595.21				
	4/15/2004								603.78	9.05	594.73				
	4/27/2004								603.78	9.19	594.59				
	5/5/2004								603.78	9.29	594.49				
	6/3/2004								603.78	9.01	594.77				
	6/14/2004								603.78	9.08	594.70				
	9/21/2004								603.78	9.75	594.03				
	10/21/2004								603.78	10.20	593.58				
	11/5/2004								603.78	9.92	593.86				
	12/2/2004								603.78	9.89	593.89				
	4/21/2005								603.78	8.95	594.83				
	8/1/2005								603.78	9.65	594.13				
	8/29/2005								603.78	10.35	593.43				
	10/20/2005								603.78	10.25	593.53				
	12/2/2005								603.78	9.31	594.47				
	3/15/2006								603.78	9.10	594.68				
	4/11/2006								603.78	7.71	596.07				
	6/6/2006								603.78	8.22	595.56				
	10/12/2006								603.78	10.13	593.65				
	12/19/2006								603.78	8.64	595.14				
	1/5/2007								603.78	8.23	595.55				
	1/9/2007								603.78	8.22	595.56				
	3/26/2007								603.78	7.60	596.18				
	5/23/2007								603.78	8.91	594.87				
	6/1/2007								603.78	9.10	594.68				
	7/16/2007								603.78	9.63	594.15				
	8/13/2007								603.78	10.22	593.56				
	9/4/2007								603.78	10.94	592.84				
	9/25/2007								603.78	9.63	594.15				
	10/26/2007								603.78	11.11	592.67				

Table 2
Monitoring Well Gauging Information and Vertical Hydraulic Gradient Calculations
 Twigg Corporation
 Martinsville, Indiana

Well ID	Date	Easting	Northing	Total Boring Depth (feet bgs)	Depth to Top of Screen		Depth to Bottom of Screen		Casing Elevation (feet msl)	Depth to Water (feet)	Water Table Elevation (feet msl)	Vertical Gradient Calculation			
					(feet bgs)	(feet msl)	(feet bgs)	(feet msl)				dH (ft)	dL (ft)	Gradient (ft/ft)	Direction
	12/4/2007								603.78	8.72	595.06				
	5/22/2008								603.78	7.22	596.56				
	8/20/2008								603.78	7.72	596.06				
	8/27/2008								603.78	7.83	595.95				
	9/24/2008								603.78	9.32	594.46				
	11/17/2008								603.78	10.49	593.29				
	12/30/2008								603.78	10.04	593.74				
	2/10/2009								603.78	9.81	593.97				
	3/13/2009								603.78	9.94	593.84				
	3/26/2009								603.78	10.05	593.73				
	3/18/2010								603.78	9.80	593.98				
	4/21/2010								603.78	9.69	594.09				
	6/22/2010								603.78	8.85	594.93				
	7/20/2010								603.78	9.00	594.78				
	8/24/2010								603.78	9.88	593.90				
	11/16/2010								603.78	11.44	592.34				
	2/3/2011								603.78	11.58	592.20				
MW-1D	3/26/1998	549891.7	4363200.4	81.0	50.0	554.0	60.0	544.0	603.78	10.17	593.61	0.00	43	0	
	5/22/1998								603.78	8.92	594.86	0.00	43	0	
	6/25/1998								603.78	6.95	596.83	0.00	43	0	
	6/26/1998								603.78	6.85	596.93	0.00	43	0	
	7/2/1999								603.78	8.64	595.14	0.00	43	0	
	9/7/2000								603.78	9.74	594.04	0.00	43	0	
	8/14/2001								603.78	10.76	593.02	-0.24	43	-0.0056	Up
	11/14/2002								603.78	9.80	593.98	0.00	43	0	
	12/16/2003								603.78	8.92	594.86	0.00	43	0	
	10/21/2004								603.78	10.20	593.58	0.00	43	0	
	10/19/2005								603.78	10.31	593.47				
	10/13/2006								603.78	10.13	593.65				
	10/26/2007								603.78	11.11	592.67	0.00	43	0	
	11/17/2008								603.78	10.45	593.33	-0.04	43	-0.0009	Up
	2/3/2011								603.78	11.56	592.22	-0.02	43	-0.0005	Up
MW-2	8/11/1994	549942.1	4363250.7	25.5	7.0	596.9	17.0	586.9	603.74	8.91	594.83				
	2/8/2011								603.74	11.04	592.70				
MW-3	8/11/1994	549826.0	4363243.4	31.0	7.0	598.0	17.0	588.0	604.75	10.84	593.91				
	3/26/1998								604.75	11.77	592.98				
	5/22/1998								604.75	10.34	594.41				
	6/25/1998								604.75	8.36	596.39				
	6/26/1998								604.75	8.32	596.43				
	7/2/1999								604.75	9.97	594.78				
	9/7/2000								604.75	11.23	593.52				
	8/14/2001								604.75	12.20	592.55				
	11/14/2002								604.75	11.34	593.41				
	12/16/2003								604.75	10.32	594.43				
	10/21/2004								604.75	NM	NM				
	11/4/2005								604.75	12.50	592.25				
	10/13/2006								604.75	11.40	593.35				
	10/26/2007								604.75	12.41	592.34				
	5/22/2008								604.75	8.37	596.38				
	11/17/2008								604.75	11.76	592.99				
	2/8/2011								604.75	13.04	591.71				
MW-4	3/26/1998	549815.9	4363183.5	50.5	15.0	589.6	25.0	579.6	604.35	11.67	592.68				
	5/22/1998								604.35	10.24	594.11				
	6/25/1998								604.35	8.29	596.06				
	6/26/1998								604.35	8.27	596.08				
	7/2/1999								604.35	9.87	594.48				
	9/7/2000								604.35	11.07	593.28				
	8/14/2001								604.35	12.08	592.27				
	11/14/2002								604.35	11.20	593.15				
	12/16/2003								604.35	9.48	594.87				
	10/21/2004								604.35	11.54	592.81				
	10/19/2005								604.35	11.20	593.15				
	10/13/2006								604.35	11.20	593.15				
	10/26/2007								604.35	12.48	591.87				
	5/22/2008								604.35	8.37	595.98				
	11/17/2008								604.35	11.72	592.63				

Table 2
Monitoring Well Gauging Information and Vertical Hydraulic Gradient Calculations
 Twigg Corporation
 Martinsville, Indiana

Well ID	Date	Easting	Northing	Total Boring Depth (feet bgs)	Depth to Top of Screen		Depth to Bottom of Screen		Casing Elevation (feet msl)	Depth to Water (feet)	Water Table Elevation (feet msl)	Vertical Gradient Calculation			
					(feet bgs)	(feet msl)	(feet bgs)	(feet msl)				dH (ft)	dL (ft)	Gradient (ft/ft)	Direction
MW-5	2/10/2011								604.35	12.89	591.46				
	3/26/1998	549412.4	4363103.3	40.0	30.0	572.9	40.0	562.9	602.71	13.40	589.31				
	5/22/1998								602.71	11.40	591.31				
	6/25/1998								602.71	9.45	593.26				
	6/26/1998								602.71	9.36	593.35				
	7/2/1999								602.71	11.00	591.71				
	9/7/2000								602.71	12.51	590.20				
	8/14/2001								602.71	13.36	589.35				
	11/14/2002								602.71	12.71	590.00				
	12/16/2003								602.71	11.34	591.37				
	10/21/2004								602.71		NM				
	10/19/2005								602.71	12.85	589.86				
	5/22/2008								602.71	9.50	593.21				
	11/17/2008								602.71	13.45	589.26				
	1/31/2011								602.71	14.29	588.42				
MW-6	3/26/1998	549415.9	4363150.5	65.0	30.0	573.5	40.0	563.5	603.30	13.96	589.34				
	5/22/1998								603.30	11.93	591.37				
	6/25/1998								603.30	9.98	593.32				
	6/26/1998								603.30	9.88	593.42				
	7/2/1999								603.30	11.54	591.76				
	9/7/2000								603.30	13.05	590.25				
	8/14/2001								603.30	13.92	589.38				
	11/14/2002								603.30	13.26	590.04				
	12/16/2003								603.30	11.90	591.40				
	10/21/2004								603.30	13.48	589.82				
	10/19/2005								603.30	12.52	590.78				
	10/13/2006								603.30	11.33	591.97				
	10/26/2007								603.30	14.64	588.66				
	5/22/2008								603.30	10.08	593.22				
	11/17/2008								603.30	13.79	589.51				
	2/10/2011								603.30	14.85	588.45				
MW-6D	7/2/1999	549413.9	4363150.5	101.5	90.0	513.4	100.0	503.4	603.22	11.52	591.70	0.06	60	0.0010	Down
	9/7/2000								603.22	13.02	590.20	0.05	60	0.0008	Down
	8/14/2001								603.22	13.87	589.35	0.03	60	0.0005	Down
	11/14/2002								603.22	13.23	589.99	0.05	60	0.0008	Down
	12/16/2003								603.22	11.84	591.38	0.02	60	0.0003	Down
	10/21/2004								603.22		NM				
	10/19/2005								603.22	12.61	590.61	0.17	60	0.0028	Down
	1/31/2011								603.22	14.80	588.42				
MW-7	3/26/1998	549425.2	4363248.6	40.0	26.0	580.6	36.0	570.6	606.38	17.05	589.33				
	5/22/1998								606.38	14.98	591.40				
	6/25/1998								606.38	12.97	593.41				
	6/26/1998								606.38	12.86	593.52				
	7/2/1999								606.38	14.58	591.80				
	9/7/2000								606.38	16.12	590.26				
	8/14/2001								606.38	16.96	589.42				
	11/14/2002								606.38	16.35	590.03				
	12/16/2003								606.38	14.92	591.46				
	10/21/2004								606.38		NM				
	10/19/2005								606.38	16.52	589.86				
	5/22/2008								606.38	13.20	593.18				
	11/17/2008								606.38	16.72	589.66				
	1/31/2011								606.38	17.91	588.47				
	3/26/1998	549213.0	4363141.8	60.0	40.0	564.3	50.0	554.3	604.05	15.85	588.20				
MW-8	5/22/1998								604.05	13.65	590.40				
	6/25/1998								604.05	11.56	592.49				
	6/26/1998								604.05	11.46	592.59				
	7/2/1999								604.05	13.35	590.70				
	9/7/2000								604.05	14.89	589.16				
	8/14/2001								604.05	15.73	588.32				
	11/14/2002								604.05	15.26	588.79				
	12/16/2003								604.05	12.98	591.07				
	10/21/2004								604.05	15.32	588.73				
	10/19/2005								604.05	15.20	588.85				
	10/12/2006								604.05	15.01	589.04				
	10/26/2007								604.05	16.25	587.80				

Table 2
Monitoring Well Gauging Information and Vertical Hydraulic Gradient Calculations

Twigg Corporation
Marionville, Indiana

Well ID	Date	Easting	Northing	Total Boring Depth (feet bgs)	Depth to Top of Screen		Depth to Bottom of Screen		Casing Elevation (feet msl)	Depth to Water (feet)	Water Table Elevation (feet msl)	Vertical Gradient Calculation			
					(feet bgs)	(feet msl)	(feet bgs)	(feet msl)				dH (ft)	dL (ft)	Gradient (ft/ft)	Direction
MW-9	5/22/2008								604.05	12.02	592.03				
	11/17/2008								604.05	15.47	588.58				
	1/31/2011								604.05	16.66	587.39				
	3/26/1998	549976.0	4363259.7	20.0	10.0	594.3	20.0	584.3	604.12	9.60	594.52				
	5/22/1998								604.12	8.46	595.66				
	6/25/1998								604.12	6.52	597.60				
	6/26/1998								604.12	6.49	597.63				
	7/2/1999								604.12	8.22	595.90				
	9/7/2000								604.12	9.33	594.79				
	8/14/2001								604.12	10.32	593.80				
	11/14/2002								604.12	9.28	594.84				
	12/16/2003								604.12	8.52	595.60				
	10/21/2004								604.12	NM	NM				
	10/20/2005								604.12	8.42	595.70				
	10/13/2006								604.12	9.31	594.81				
	5/22/2008								604.12	6.89	597.23				
	11/17/2008								604.12	9.97	594.15				
	2/8/2011								604.12	11.15	592.97				
MW-10S	7/2/1999	549895.8	4363229.2	20.0	10.0	594.5	20.0	584.5	604.32	9.11	595.21				
	9/7/2000								604.32	10.26	594.06				
	8/14/2001								604.32	11.27	593.05				
	11/14/2002								604.32	10.36	593.96				
	12/16/2003								604.32	9.44	594.88				
	10/21/2004								604.32	10.76	593.56				
	10/19/2005								604.32	10.81	593.51				
	10/13/2006								604.32	10.41	593.91				
	10/26/2007								604.32	11.54	592.78				
	5/22/2008								604.32	7.69	596.63				
	11/17/2008								604.32	10.83	593.49				
	2/3/2011								604.32	12.08	592.24				
MW-10M	7/2/1999	549892.7	4363229.1	40.0	30.0	574.5	40.0	564.5	604.32	9.12	595.20	0.01	20	0.0005	Down
	9/7/2000								604.32	10.29	594.03	0.03	20	0.0015	Down
	8/14/2001								604.32	11.29	593.03	0.02	20	0.0010	Down
	11/14/2002								604.32	10.36	593.96	0.00	20	0.0000	
	12/16/2003								604.32	9.44	594.88	0.00	20	0.0000	
	10/21/2004								604.32	10.76	593.56	0.00	20	0.0000	
	10/19/2005								604.32	10.72	593.60	-0.09	20	-0.0045	Up
	11/17/2008								604.32	10.83	593.49	0.00	20	0.0000	
	2/3/2011								604.32	12.08	592.24	0.00	20	0.0000	
	9/7/2000	549860.8	4363261.6	20.0	10.0	595.3	20.0	585.3	605.08	10.41	594.67				
MW-11	8/14/2001								605.08	12.38	592.70				
	11/14/2002								605.08	11.48	593.60				
	12/16/2003								605.08	10.52	594.56				
	10/21/2004								605.08	11.86	593.22				
	11/4/2005								605.08	11.75	593.33				
	12/11/2006								605.08	12.22	592.86				
	10/26/2007								605.08	12.64	592.44				
	5/22/2008								605.08	8.76	596.32				
	11/17/2008								605.08	11.95	593.13				
	2/3/2011								605.08	13.20	591.88				
	9/7/2000	549826.1	4363274.4	20.0	10.0	594.9	20.0	584.9	604.73	11.18	593.55				
MW-12	8/14/2001								604.73	12.13	592.60				
	11/14/2002								604.73	11.29	593.44				
	12/16/2003								604.73	10.24	594.49				
	10/21/2004								604.73	11.64	593.09				
	10/19/2005								604.73	11.65	593.08				
	10/13/2006								604.73	11.41	593.32				
	10/26/2007								604.73	12.41	592.32				
	5/22/2008								604.73	8.43	596.30				
	11/17/2008								604.73	11.72	593.01				
	2/8/2011								604.73	13.01	591.72				
	10/21/2004	549875.9	4363195.1	19.0	9.0	595.5	19.0	585.5	604.28	10.84	593.44				
MW-13	10/20/2005								604.28	11.15	593.13				
	10/13/2006								604.28	10.82	593.46				
	10/25/2007								604.28	11.92	592.36				
	5/22/2008								604.28	7.80	596.48				

Table 2
Monitoring Well Gauging Information and Vertical Hydraulic Gradient Calculations

Twigg Corporation
Marionville, Indiana

Well ID	Date	Easting	Northing	Total Boring Depth (feet bgs)	Depth to Top of Screen		Depth to Bottom of Screen		Casing Elevation (feet msl)	Depth to Water (feet)	Water Table Elevation (feet msl)	Vertical Gradient Calculation			
					(feet bgs)	(feet msl)	(feet bgs)	(feet msl)				dH (ft)	dL (ft)	Gradient (ft/ft)	Direction
MW-14	11/17/2008								604.28	10.30	593.98				
	2/4/2011								604.28	12.20	592.08				
	10/21/2004	549861.0	4363193.5	21.0	11.0	593.1	21.0	583.1	603.88	10.62	593.26				
	10/20/2005								603.88	10.70	593.18				
	10/12/2006								603.88	10.40	593.48				
	10/25/2007								603.88	11.63	592.25				
	5/22/2008								603.88	7.51	596.37				
	11/17/2008								603.88	10.78	593.10				
MW-15	2/4/2011								603.88	11.97	591.91				
	10/13/2006	549773.3	4363275.5	25.0	15.0	589.6	25.0	579.6	604.36	11.41	592.95				
	10/26/2007								604.36	12.52	591.84				
	5/22/2008								604.36	8.52	595.84				
	11/17/2008								604.36	11.86	592.50				
	2/9/2011								604.36	13.19	591.17				
MW-16	10/13/2006	549787.3	4363242.8	25.0	15.0	589.9	25.0	579.9	604.72	11.70	593.02				
	10/26/2007								604.72	12.90	591.82				
	5/22/2008								604.72	8.84	595.88				
	11/17/2008								604.72	12.15	592.57				
	2/9/2011								604.72	13.48	591.24				
MW-17	10/13/2006	549799.4	4363217.3	25.0	15.0	589.9	25.0	579.9	604.68	11.70	592.98				
	10/26/2007								604.68	12.80	591.88				
	5/22/2008								604.68	8.79	595.89				
	11/17/2008								604.68	12.15	592.53				
	2/10/2011								604.68	13.37	591.31				
MW-18	10/13/2006	549811.1	4363192.5	25.0	15.0	589.7	25.0	579.7	604.52	11.30	593.22				
	10/26/2007								604.52	12.50	592.02				
	5/22/2008								604.52	8.55	595.97				
	11/17/2008								604.52	11.85	592.67				
	2/10/2011								604.52	13.07	591.45				
MW-19	10/13/2006	549754.8	4363193.0	25.0	14.5	590.6	24.5	580.6	604.91	12.20	592.71				
	10/26/2007								604.91	13.40	591.51				
	5/22/2008								604.91	9.38	595.53				
	11/17/2008								604.91	13.67	591.24				
	2/9/2011								604.91	14.04	590.87				
HMW-25	6/26/1998	549752.2	4363128.9	18.0	8.0	595.9	18.0	585.9	603.60	8.17	595.43				

Notes:

bgs = Below Ground Surface

msl = Feet Above Mean Sea Level

dH = Difference in Elevation Head Between Well Pairs on Same Date.

dL = Vertical Distance Between Measurement Points (Assumed to be center of Screen).

Gradient = dH/dL. Calculated only for dates when measurements were made in both wells of the well pair.

Table 3
Horizontal Hydraulic Gradient Calculations
 Twigg Corporation
 Martinsville, Indiana

Well ID	Distance Down- gradient from MW- 1S (ft)	Distance From Previous Point (ft)	Easting	Northing	Water Table Elevation (feet msl)	dH (feet)	dL (feet)	Gradient Between Wells ^{a/} (ft/ft)	Gradient Between Most Upgradient and Downgradient Wells ^{b/} (ft/ft)
February 2011									
MW-1S	0	0	549891.7	4363197.7	592.20				
MW-13	53	53	549875.9	4363195.1	592.08	0.12	53	0.0023	
MW-14	110	57	549861.0	4363193.5	591.91	0.17	57	0.0030	
MW-4	250	141	549815.9	4363183.5	591.46	0.45	141	0.0032	
MW-19	452	207	549754.8	4363193.0	590.87	0.59	207	0.0029	
MW-6	1553	1,101	549415.9	4363150.5	588.45	2.42	1,101	0.0022	
MW-8	2219	667	549213.0	4363141.8	587.39	1.06	667	0.0016	0.0022
Average								0.0025	0.0022
November 2008									
MW-1S	0	0	549891.7	4363197.7	593.29				
MW-13	53	53	549875.9	4363195.1	593.98	-0.69	53	-0.0130	
MW-14	110	57	549861.0	4363193.5	593.10	0.88	57	0.0154	
MW-4	250	141	549815.9	4363183.5	592.63	0.47	141	0.0033	
MW-19	452	207	549754.8	4363193.0	591.24	1.39	207	0.0067	
MW-6	1553	1,101	549415.9	4363150.5	589.51	1.73	1,101	0.0016	
MW-8	2219	667	549213.0	4363141.8	588.58	0.93	667	0.0014	0.0021
Average								0.0026	0.0021
May 2008									
MW-1S	0	0	549891.7	4363197.7	596.56				
MW-13	53	53	549875.9	4363195.1	596.48	0.08	53	0.0015	
MW-14	110	57	549861.0	4363193.5	596.37	0.11	57	0.0019	
MW-4	250	141	549815.9	4363183.5	595.98	0.39	141	0.0028	
MW-19	452	207	549754.8	4363193.0	595.53	0.45	207	0.0022	
MW-6	1553	1,101	549415.9	4363150.5	593.22	2.31	1,101	0.0021	
MW-8	2219	667	549213.0	4363141.8	592.03	1.19	667	0.0018	0.0020
Average								0.0020	0.0020
October 2007									
MW-1S	0	0	549891.7	4363197.7	592.67				
MW-13	53	53	549875.9	4363195.1	592.36	0.31	53	0.0058	
MW-14	110	57	549861.0	4363193.5	592.25	0.11	57	0.0019	
MW-4	250	141	549815.9	4363183.5	591.87	0.38	141	0.0027	
MW-19	452	207	549754.8	4363193.0	591.51	0.36	207	0.0017	
MW-6	1553	1,101	549415.9	4363150.5	588.66	2.85	1,101	0.0026	
MW-8	2219	667	549213.0	4363141.8	587.80	0.86	667	0.0013	0.0022
Average								0.0027	0.0022
Maximum Average Gradient Over Measurement Period								0.0027	
Minimum Average Gradient Over Measurement Period								0.0020	
Average Gradient Over Measurement Period								0.0025	0.0021

Notes:

- a/ Gradient calculated using the measured difference in groundwater elevation between upgradient and downgradient monitoring wells.
 b/ Gradient calculated using the measured difference in groundwater elevation between MW-1S and MW-8.

Table 4
Historical Precipitation Data for Martinsville 2 SW (Near McDaniel's Field Airport)
 Twigg Corporation
 Martinsville, Indiana

Year	Month												Annual Precipitation
	January	February	March	April	May	June	July	August	September	October	November	December	
1994	2.72	1.7	0.94	6.02	3.68	2.48	2.78	3.1	3.85	0.81	4.18	2.18	34.44
1995	3.05	1.14	3.22	5.21	8.06	3.19	2.06	5.58	0.53	1.88	2.81	2.35	39.08
1996	3.62	1 ^{a/}	3.58	8.6	8.65	5.16	2.45	1.02	5.88	2.16	5.82	3.07	51.1 1 ^{a/}
1997	4.07	2.01	3.74	2.3	3.62	5.28	1.39	4.59	2.55	1.44	2.17	1.41	34.57
1998	2.47	1.39	1 ^{a/}	6.03	5.53	9.47	4.28	1.88	0.94	4.9	2.41	1 ^{a/}	44.63 1 ^{a/}
1999	6.13	5.17	1.97	4.83	3.94	4.48	3.08	1.42	0.83	1.09	0.89	4.56	38.39 1 ^{a/}
2000	1.55	3.95	1.88	4.46	3.92	5.28	4.41	6.89	6.81	6.07	1	2.61	50.76 1 ^{a/}
2001	1.14	1.99	0.61	1.95	3.9	2.96	3.87	2.57	6.26	7.33	3.39	3.73	39.7
2002	1.37	3.3	5.69	7.47	9.24	5.59	1.79	0.66	4.78	3.86	3.07	1 ^{a/}	49.47 1 ^{a/}
2003	1.35	3.34	2.54	3.03	5.95	2.53	8.86	4.03	7.71	2.94	3.73	2.79	48.8
2004	5.64	0.78	2.19	1.42	6.49	5.1	5.01	4.83	1 ^{a/}	4.27	4.48	2.06	42.27 1 ^{a/}
2005	8.96	1.52	1.6	2.28	6	2.97	3.69	7.22	4.26	2.43	3.81	2.42	47.16
2006	3.31	1.64	6.1	5.34	5.04	7.51	5.01	2.95	3.37	5.42	2.98	1 ^{a/}	55.79 1 ^{a/}
2007	5.73	3.11	4.06	4.49	1.24	3.75	2.65	0.54	5.52	3.03	1.87	4.85	40.84
2008	2.79	4.26	7.26	3.33	6.45	20.11	6.67	1.82	2.06	1.94	2.31	5.61	64.61
2009	1.92	1.97	1.99	6.63	6.77	5.83	5.32	2.93	3	6.4	1.13	3.55	47.44
2010	1.09	1.38	2.81	3.3	5.4	7.94	2.4	0.3	0.62	1.16	5.39	1.22	33.01

a/ Incomplete Precipitation Data

Table 5
Summary of Hydraulic Conductivity Values From Aquifer Testing

Twigg Corporation
Martinsville, Indiana

Well ID	Test Type	Hydraulic Conductivity - Bouwer and Rice (1976)			Hydraulic Conductivity - Hvorslev (1951)		
		(cm/sec)	(ft/min)	(ft/day)	(cm/sec)	(ft/min)	(ft/day)
MW-1	Constant Head	1.80E-02	3.54E-02	51.01	2.30E-02	4.53E-02	65.18
MW-1D	Constant Head	9.90E-03	1.95E-02	28.06	1.01E-02	1.99E-02	28.62
MW-4	Constant Head	5.10E-02	1.00E-01	144.53	6.30E-02	1.24E-01	178.54
MW-5	Constant Head	1.80E-02	3.54E-02	51.01	2.00E-02	3.94E-02	56.68
MW-6	Constant Head	2.10E-02	4.13E-02	59.51	2.40E-02	4.72E-02	68.01
MW-7	Constant Head	2.70E-02	5.31E-02	76.52	3.20E-02	6.30E-02	90.69
MW-8	Constant Head	6.80E-02	1.34E-01	192.71	7.30E-02	1.44E-01	206.88
MW-9	Constant Head	2.60E-03	5.12E-03	7.37	2.90E-02	5.71E-02	82.18
		1.89E-02	3.72E-02	53.61	2.88E-02	5.67E-02	81.67
	Harmonic Mean	1.12E-02	2.20E-02	3.17E+01	2.43E-02	4.78E-02	6.88E+01
	Geometric Mean	1.89E-02	3.72E-02	5.36E+01	2.88E-02	5.67E-02	8.17E+01
	Arithmetic Mean	2.69E-02	5.30E-02	7.63E+01	3.43E-02	6.74E-02	9.71E+01

Notes:

a/ Data from Bruce Carter and Associates, 1999b, Remediation Work Plan

Table 6
Groundwater Seepage Velocity Calculations

Twigg Manufacturing Facility
Martinsville, Indiana

Basis for Calculation	K (ft/day)	n _e (percent)	dH/dL (ft/ft)	Calculated Groundwater Seepage Velocity	
				(ft/day)	(ft/Year)
Representative Hydraulic Parameters*	54	20	0.002	0.56	205
Sensitivity Analyses					
Varying Hydraulic Conductivity					
Lowest K observed in MW-9	7	20	0.002	0.08	28
Highest K observed in MW-8	193	20	0.002	2.02	739
Varying Effective Porosity					
Effective Porosity of 10 percent	54	10	0.002	1.13	411
Effective Porosity of 30 percent	54	30	0.002	0.38	137

* Representative hydraulic parameters are those deemed most representative of the Site.
These parameters are used for other calculations presented throughout the report

Table 7
Retarded Solute Transport Velocity Calculations
 Twigg Manufacturing Facility
 Martinsville, Indiana

Compound	Calculated Groundwater Seepage Velocity ^{a/} (ft/day)	Total Porosity ^{b/} (percent)	f_{oc} ^{c/} (dimensionless)	Bulk Density ^{c/} (Kg/L)	K_{oc} ^{d/} L/Kg	Calculated Solute Transport Velocity	
						(ft/day)	(ft/year)
Assuming Fraction TOC = 0.00017							
Tetrachloroethene	0.56	30%	0.00017	1.65	263	0.45	165
Trichloroethene	0.56	30%	0.00017	1.65	107	0.51	186
cis - 1,2-Dichloroethene	0.56	30%	0.00017	1.65	80.2	0.52	191
trans - 1,2-Dichloroethene	0.56	30%	0.00017	1.65	58.9	0.53	194
1,1-Dichloroethene	0.56	30%	0.00017	1.65	64.6	0.53	193
Vinyl chloride	0.56	30%	0.00017	1.65	2.45	0.56	205
1,1,1-Trichloroethane	0.56	30%	0.00017	1.65	183	0.48	175
1,1-Dichloroethane	0.56	30%	0.00017	1.65	40	0.54	198
Chloroethane	0.56	30%	0.00017	1.65	88	0.52	190
Assuming Fraction TOC = 0.0012							
Tetrachloroethene	0.56	30%	0.00120	1.65	263	0.21	75
Trichloroethene	0.56	30%	0.00120	1.65	107	0.33	120
cis - 1,2-Dichloroethene	0.56	30%	0.00120	1.65	80.2	0.37	134
trans - 1,2-Dichloroethene	0.56	30%	0.00120	1.65	58.9	0.40	148
1,1-Dichloroethene	0.56	30%	0.00120	1.65	64.6	0.39	144
Vinyl chloride	0.56	30%	0.00120	1.65	2.45	0.55	202
1,1,1-Trichloroethane	0.56	30%	0.00120	1.65	183	0.25	93
1,1-Dichloroethane	0.56	30%	0.00120	1.65	40	0.44	162
Chloroethane	0.56	30%	0.00120	1.65	88	0.36	130
Assuming Fraction TOC = 0.0007							
Tetrachloroethene	0.56	30%	0.00070	1.65	263	0.28	102
Trichloroethene	0.56	30%	0.00070	1.65	107	0.40	145
cis - 1,2-Dichloroethene	0.56	30%	0.00070	1.65	80.2	0.43	157
trans - 1,2-Dichloroethene	0.56	30%	0.00070	1.65	58.9	0.46	167
1,1-Dichloroethene	0.56	30%	0.00070	1.65	64.6	0.45	164
Vinyl chloride	0.56	30%	0.00070	1.65	2.45	0.56	203
1,1,1-Trichloroethane	0.56	30%	0.00070	1.65	183	0.33	120
1,1-Dichloroethane	0.56	30%	0.00070	1.65	40	0.49	178
Chloroethane	0.56	30%	0.00070	1.65	88	0.42	153

a/ See Section 3 for groundwater seepage velocity calculation

b/ Total porosity taken from literature values

c/ Fraction organic carbon and bulk density from literature values

d/ Soil sorption coefficients from USEPA (1998)

Table 8
Summary of Chlorinated Compound Soil Analytical Data
 Twigg Manufacturing Facility
 Martinsville, Indiana

Sampling Location	Sampling Date	Sampling Depth (feet bgs) *	Easting	Northing	Ground Surface Elevation (ft MSL)	Top of Sample Interval (ft BGS)	Bottom of Sample Interval (ft BGS)	PCE (mg/kg) ^b	TCE (mg/kg)	cis-1,2-DCE (mg/kg)	trans-1,2-DCE (mg/kg)	VC (mg/kg)	1,1-DCE (mg/kg)	1,1,1-TCA (mg/kg)	1,1-DCA (mg/kg)	CA (mg/kg)
FB-1 (MW-1S)	8/9/1994	0.5-1.0	549892	4363198	604.0	0.5	1.0	0.700	0.012	< 0.005 U	< 0.005 U	< 0.010 U	< 0.005 U	0.004	< 0.005 U	< 0.010 U
		4.0-6.0	549892	4363198	604.0	4.0	6.0	0.260	0.006	< 0.005 U	< 0.005 U	< 0.010 U	< 0.005 U	0.007	< 0.005 U	< 0.010 U
		9.0-11.0	549892	4363198	604.0	9.0	11.0	42.00	< 0.005 U	< 0.005 U	< 0.005 U	< 0.010 U	< 0.005 U	0.580	< 0.005 U	< 0.010 U
		14.0-16.0	549892	4363198	604.0	14.0	16.0	< 0.048 U	< 0.025 U	< 0.025 U	< 0.015 U	< 0.076 U	< 0.015 U	< 0.025 U	< 0.010 U	< 0.048 U
		19.0-21.0	549892	4363198	604.0	19.0	21.0	< 0.048 U	< 0.025 U	< 0.025 U	< 0.015 U	< 0.076 U	< 0.015 U	< 0.025 U	< 0.010 U	< 0.048 U
		24.0-26.0	549892	4363198	604.0	24.0	26.0	< 0.048 U	< 0.025 U	< 0.025 U	< 0.015 U	< 0.076 U	< 0.015 U	< 0.025 U	< 0.010 U	< 0.048 U
MW-1D	2/24/1998	29.0-31.0	549892	4363198	604.0	29.0	31.0	< 0.048 U	< 0.025 U	< 0.025 U	< 0.015 U	< 0.076 U	< 0.015 U	< 0.025 U	< 0.010 U	< 0.048 U
		45 - 46	549892	4363200	604.0	45.0	46.0	< 0.005 U	< 0.005 U	< 0.005 U	< 0.005 U	na	na	< 0.005 U	< 0.005 U	na
		55.5 - 56	549892	4363200	604.0	55.5	56.0	0.032	< 0.005 U	< 0.005 U	< 0.005 U	na	na	< 0.005 U	< 0.005 U	na
		65.5 - 66	549892	4363200	604.0	65.5	66.0	< 0.005 U	< 0.005 U	< 0.005 U	< 0.005 U	na	na	< 0.005 U	< 0.005 U	na
		74.5 - 75	549892	4363200	604.0	74.5	75.0	< 0.005 U	< 0.005 U	< 0.005 U	< 0.005 U	na	na	< 0.005 U	< 0.005 U	na
		81.0	549892	4363200	604.0	81.0	81.0	< 0.005 U	< 0.005 U	< 0.005 U	< 0.005 U	na	na	< 0.005 U	< 0.005 U	na
FB-2 (MW-2)	8/10/1994	3.0-4.0	549942	4363251	603.9	3.0	4.0	< 0.048 U	< 0.025 U	< 0.025 U	< 0.015 U	< 0.076 U	< 0.015 U	< 0.025 U	< 0.010 U	< 0.048 U
		8.5-10.5	549942	4363251	603.9	8.5	10.5	< 0.048 U	< 0.025 U	< 0.025 U	< 0.015 U	< 0.076 U	< 0.015 U	< 0.025 U	< 0.010 U	< 0.048 U
		13.5-15.5	549942	4363251	603.9	13.5	15.5	< 0.048 U	< 0.025 U	< 0.025 U	< 0.015 U	< 0.076 U	< 0.015 U	0.100	< 0.010 U	< 0.048 U
		18.5-20.5	549942	4363251	603.9	18.5	20.5	< 0.048 U	< 0.025 U	< 0.025 U	< 0.015 U	< 0.076 U	< 0.015 U	< 0.025 U	< 0.010 U	< 0.048 U
		23.5-25.5	549942	4363251	603.9	23.5	25.5	< 0.048 U	< 0.025 U	< 0.025 U	< 0.015 U	< 0.076 U	< 0.015 U	< 0.025 U	< 0.010 U	< 0.048 U
		9.0-11.0	549826	4363243	605.0	9.0	11.0	0.780	< 0.025 U	< 0.025 U	< 0.015 U	< 0.076 U	< 0.015 U	0.210	< 0.010 U	< 0.048 U
FB-3 (MW-3)	8/9/1994	14.0-16.0	549826	4363243	605.0	14.0	16.0	0.410	< 0.025 U	< 0.025 U	< 0.015 U	< 0.076 U	< 0.015 U	0.260	< 0.010 U	< 0.048 U
		19.0-21.0	549826	4363243	605.0	19.0	21.0	< 0.048 U	< 0.025 U	< 0.025 U	< 0.015 U	< 0.076 U	< 0.015 U	0.066	< 0.010 U	< 0.048 U
		24.0-26.0	549826	4363243	605.0	24.0	26.0	< 0.048 U	< 0.025 U	< 0.025 U	< 0.015 U	< 0.076 U	< 0.015 U	< 0.025 U	< 0.010 U	< 0.048 U
		29.0-31.0	549826	4363243	605.0	29.0	31.0	< 0.048 U	< 0.025 U	< 0.025 U	< 0.015 U	< 0.076 U	< 0.015 U	< 0.025 U	< 0.010 U	< 0.048 U
		4.0-5.0	549816	4363183	604.6	4.0	5.0	< 0.048 U	< 0.025 U	< 0.025 U	< 0.015 U	< 0.076 U	< 0.015 U	< 0.025 U	< 0.010 U	< 0.048 U
		8.5-10.5	549816	4363183	604.6	8.5	10.5	0.180	< 0.025 U	< 0.025 U	< 0.015 U	< 0.076 U	< 0.015 U	< 0.025 U	< 0.010 U	< 0.048 U
FB-4 (MW-4)	12/14/1994	13.5-15.5	549816	4363183	604.6	13.5	15.5	8.400	< 0.025 U	< 0.025 U	< 0.015 U	< 0.076 U	< 0.015 U	0.240	< 0.010 U	< 0.048 U
		18.5-20.5	549816	4363183	604.6	18.5	20.5	30.00	< 0.025 U	< 0.025 U	< 0.015 U	< 0.076 U	< 0.015 U	0.170	< 0.010 U	< 0.048 U
		23.5-25.5	549816	4363183	604.6	23.5	25.5	0.530	< 0.025 U	< 0.025 U	< 0.015 U	< 0.076 U	< 0.015 U	1.700	< 0.010 U	< 0.048 U
		28.5-30.5	549816	4363183	604.6	28.5	30.5	< 0.048 U	< 0.025 U	< 0.025 U	< 0.015 U	< 0.076 U	< 0.015 U	0.400	< 0.010 U	< 0.048 U
		34.0-35.5	549816	4363183	604.6	34.0	35.5	< 0.048 U	< 0.025 U	< 0.025 U	< 0.015 U	< 0.076 U	< 0.015 U	< 0.025 U	< 0.010 U	< 0.048 U
		39.0-40.5	549816	4363183	604.6	39.0	40.5	< 0.048 U	< 0.025 U	< 0.025 U	< 0.015 U	< 0.076 U	< 0.015 U	< 0.025 U	< 0.010 U	< 0.048 U
FB-5	8/10/1994	44.0-45.5	549816	4363183	604.6	44.0	45.5	< 0.048 U	< 0.025 U	< 0.025 U	< 0.015 U	< 0.076 U	< 0.015 U	< 0.025 U	< 0.010 U	< 0.048 U
		3.0-4.0	549961	4363142	604.0	3.0	4.0	< 0.048 U	< 0.025 U	< 0.025 U	< 0.015 U	< 0.076 U	< 0.015 U	< 0.025 U	< 0.010 U	< 0.048 U
		8.5-10.5	549961	4363142	604.0	8.5	10.5	< 0.048 U	< 0.025 U	< 0.025 U	< 0.015 U	< 0.076 U	< 0.015 U	< 0.025 U	< 0.010 U	< 0.048 U
		13.5-15.5	549961	4363142	604.0	13.5	15.5	< 0.048 U	< 0.025 U	< 0.025 U	< 0.015 U	< 0.076 U	< 0.015 U	< 0.025 U	< 0.010 U	< 0.048 U
		18.5-20.5	549961	4363142	604.0	18.5	20.5	< 0.005 U	< 0.025 U	< 0.025 U	< 0.015 U	< 0.076 U	< 0.015 U	< 0.025 U	< 0.010 U	< 0.048 U
		4.0-5.0	549924	4363182	604.0	4.0	5.0	< 0.048 U	< 0.025 U	< 0.025 U	< 0.015 U	< 0.076 U	< 0.015 U	< 0.025 U	< 0.010 U	< 0.048 U
FB-6	12/15/1994	9.0-10.5	549924	4363182	604.0	9.0	10.5	0.110	< 0.025 U	< 0.025 U	< 0.015 U	< 0.076 U	< 0.015 U	< 0.025 U	< 0.010 U	< 0.048 U
		14.0-15.5	549924	4363182	604.0	14.0	15.5	0.750	< 0.025 U	< 0.025 U	< 0.015 U	< 0.076 U	< 0.015 U	< 0.025 U	< 0.010 U	< 0.048 U
		19.0-20.5	549924	4363182	604.0	19.0	20.5	7.700	< 0.025 U	< 0.025 U	< 0.015 U	< 0.076 U	< 0.015 U	< 0.025 U	< 0.010 U	< 0.048 U
		24.0-25.5	549924	4363182	604.0	24.0	25.5	1.700	< 0.025 U	< 0.025 U	< 0.015 U	< 0.076 U	< 0.015 U	< 0.025 U	< 0.010 U	< 0.048 U

Table 8
Summary of Chlorinated Compound Soil Analytical Data
 Twigg Manufacturing Facility
 Martinsville, Indiana

Sampling Location	Sampling Date	Sampling Depth (feet bgs) *	Easting	Northing	Ground Surface Elevation (ft MSL)	Top of Sample Interval (ft BGS)	Bottom of Sample Interval (ft BGS)	PCE (mg/kg) ^b	TCE (mg/kg)	cis-1,2-DCE (mg/kg)	trans-1,2-DCE (mg/kg)	VC (mg/kg)	1,1-DCE (mg/kg)	1,1,1-TCA (mg/kg)	1,1-DCA (mg/kg)	CA (mg/kg)
FB-7	12/21/1994	29.0-30.5	549924	4363182	604.0	29.0	30.5	< 0.048 U	< 0.025 U	< 0.025 U	< 0.015 U	< 0.076 U	< 0.015 U	0.027	< 0.010 U	< 0.048 U
		34.0-35.5	549924	4363182	604.0	34.0	35.5	< 0.048 U	< 0.025 U	< 0.025 U	< 0.015 U	< 0.076 U	< 0.015 U	< 0.025 U	< 0.010 U	< 0.048 U
		39.0-40.5	549924	4363182	604.0	39.0	40.5	< 0.005 U	< 0.025 U	< 0.025 U	< 0.015 U	< 0.076 U	< 0.015 U	< 0.025 U	< 0.010 U	< 0.048 U
		4.0-5.0	549794	4363262	604.5	4.0	5.0	< 0.048 U	< 0.025 U	< 0.025 U	< 0.015 U	< 0.076 U	< 0.015 U	< 0.025 U	< 0.010 U	< 0.048 U
		9.0-10.5	549794	4363262	604.5	9.0	10.5	< 0.048 U	< 0.025 U	< 0.025 U	< 0.015 U	< 0.076 U	< 0.015 U	< 0.025 U	< 0.010 U	< 0.048 U
FB-8	12/19/1994	14.0-15.5	549794	4363262	604.5	14.0	15.5	< 0.048 U	< 0.025 U	< 0.025 U	< 0.015 U	< 0.076 U	0.041	0.810	< 0.010 U	< 0.048 U
		19.0-20.5	549794	4363262	604.5	19.0	20.5	< 0.048 U	0.028	< 0.025 U	< 0.015 U	< 0.076 U	0.150	2.500	< 0.010 U	< 0.048 U
		24.0-25.5	549794	4363262	604.5	24.0	25.5	< 0.048 U	< 0.025 U	< 0.025 U	< 0.015 U	< 0.076 U	0.052	1.100	< 0.010 U	< 0.048 U
		29.0-30.5	549794	4363262	604.5	29.0	30.5	< 0.048 U	< 0.025 U	< 0.025 U	< 0.015 U	< 0.076 U	< 0.015 U	< 0.025 U	< 0.010 U	< 0.048 U
		34.0-35.5	549794	4363262	604.5	34.0	35.5	< 0.048 U	< 0.025 U	< 0.025 U	< 0.015 U	< 0.076 U	< 0.015 U	< 0.025 U	< 0.010 U	< 0.048 U
		9.0-10.5	549738	4363170	605.0	9.0	10.5	< 0.048 U	< 0.025 U	< 0.025 U	< 0.015 U	< 0.076 U	< 0.015 U	< 0.025 U	< 0.010 U	< 0.048 U
		14.0-15.5	549738	4363170	605.0	14.0	15.5	< 0.048 U	< 0.025 U	< 0.025 U	< 0.015 U	< 0.076 U	< 0.015 U	0.130	< 0.010 U	< 0.048 U
		19.0-20.5	549738	4363170	605.0	19.0	20.5	0.490	< 0.025 U	< 0.025 U	< 0.015 U	< 0.076 U	0.015	0.550	< 0.010 U	< 0.048 U
		24.0-25.5	549738	4363170	605.0	24.0	25.5	< 0.048 U	< 0.025 U	< 0.025 U	< 0.015 U	< 0.076 U	< 0.015 U	0.500	< 0.010 U	< 0.048 U
		29.0-30.5	549738	4363170	605.0	29.0	30.5	< 0.048 U	< 0.025 U	< 0.025 U	< 0.015 U	< 0.076 U	< 0.015 U	0.052	< 0.010 U	< 0.048 U
MW-6	2/23/1998	34.0-35.5	549738	4363170	605.0	34.0	35.5	< 0.048 U	< 0.025 U	< 0.025 U	< 0.015 U	< 0.076 U	< 0.015 U	< 0.025 U	< 0.010 U	< 0.048 U
		39.0-40.5	549738	4363170	605.0	39.0	40.5	< 0.048 U	< 0.025 U	< 0.025 U	< 0.015 U	< 0.076 U	< 0.015 U	0.300	< 0.010 U	< 0.048 U
		44.0-45.5	549738	4363170	605.0	44.0	45.5	< 0.048 U	< 0.025 U	< 0.025 U	< 0.015 U	< 0.076 U	< 0.015 U	< 0.025 U	< 0.010 U	< 0.048 U
		49.0-50.5	549738	4363170	605.0	49.0	50.5	< 0.048 U	< 0.025 U	< 0.025 U	< 0.015 U	< 0.076 U	< 0.015 U	< 0.025 U	< 0.010 U	< 0.048 U
		45.0	549416	4363151	603.5	45.0	45.0	< 0.005 U	< 0.005 U	< 0.005 U	< 0.005 U	< 0.010 U	na	3.000	0.037	< 0.010 U
		55.0	549416	4363151	603.5	55.0	55.0	< 0.005 U	< 0.005 U	< 0.005 U	< 0.005 U	< 0.010 U	na	2.700	0.100	< 0.010 U
		60.0	549416	4363151	603.5	60.0	60.0	< 0.005 U	< 0.005 U	< 0.005 U	< 0.005 U	< 0.010 U	na	0.940	0.037	< 0.010 U
		65.0	549416	4363151	603.5	65.0	65.0	< 0.005 U	< 0.005 U	< 0.005 U	< 0.005 U	< 0.010 U	na	0.770	0.470	< 0.010 U
		75 - 76	549416	4363151	603.5	75.0	76.0	< 0.005 U	< 0.005 U	< 0.005 U	< 0.005 U	na	na	< 0.005 U	< 0.005 U	na
		84.5-85.5	549416	4363151	603.5	84.5	85.5	< 0.005 U	< 0.005 U	< 0.005 U	< 0.005 U	na	na	< 0.005 U	< 0.005 U	na
MW-8	10/1/1997	95 - 96	549416	4363151	603.5	95.0	96.0	< 0.005 U	< 0.005 U	< 0.005 U	< 0.005 U	na	na	0.012	0.008	na
		99.5 - 100	549416	4363151	603.5	99.5	100.0	< 0.005 U	< 0.005 U	< 0.005 U	< 0.005 U	na	na	0.028	0.015	na
		45.0	549213	4363142	604.3	45.0	45.0	< 0.005 U	< 0.005 U	< 0.005 U	< 0.005 U	< 0.010 U	na	0.130	0.020	< 0.010 U
		55.0	549213	4363142	604.3	55.0	55.0	< 0.005 U	< 0.005 U	< 0.005 U	< 0.005 U	< 0.010 U	na	< 0.005 U	< 0.005 U	< 0.010 U
		60.0	549213	4363142	604.3	60.0	60.0	< 0.005 U	< 0.005 U	< 0.005 U	< 0.005 U	< 0.010 U	na	0.029	0.021	< 0.010 U
FP-21	3/2 - 3/4/99	0.5-2.0	549899	4363195	604.0	0.5	2.0	25.000	0.068	< 0.061 U	< 0.061 U	< 0.120 U	< 0.061 U	< 0.061 U	< 0.061 U	< 120 U
FP-22	3/2 - 3/4/99	6.0-8.0	549899	4363195	604.0	6.0	8.0	0.540	< 0.056 U	< 0.056 U	< 0.056 U	< 0.110 U	< 0.056 U	< 0.056 U	< 0.056 U	< 110 U
FP-23	3/2 - 3/4/99	0.5-2.0	549887	4363196	604.0	0.5	2.0	31.00	0.099	0.013	< 0.005 U	< 0.010 U	< 0.005 U	< 0.011	< 0.005 U	< 10 U
FP-23	3/2 - 3/4/99	2.0-4.0	549887	4363196	604.0	2.0	4.0	0.120	< 0.005 U	< 0.005 U	< 0.005 U	< 0.010 U	< 0.005 U	< 0.005 U	< 0.005 U	< 10 U
FP-23	3/2 - 3/4/99	0.5-2.0	549898	4363206	604.2	0.5	2.0	1.600	0.100	< 0.050 U	< 0.050 U	< 0.160 U	< 0.050 U	< 0.050 U	< 0.050 U	< 100 U
FP-23	Duplicate	0.5-2.0	549898	4363206	604.2	0.5	2.0	0.320	0.045	0.008	< 0.005 U	< 0.010 U	< 0.005 U	0.085	< 0.005 U	< 10 U
FP-24	3/2 - 3/4/99	6.0-8.0	549898	4363206	604.2	6.0	8.0	0.360	0.088	< 0.005 U	< 0.005 U	< 0.010 U	< 0.005 U	0.016	< 0.005 U	< 10 U
FP-24	3/2 - 3/4/99	0.5-2.0	549887	4363205	604.2	0.5	2.0	24.00	2.100	0.039	< 0.005 U	< 0.010 U	0.011	0.110	< 0.005 U	< 10 U
FP-24	4.0-6.0	549887	4363205	604.2	4.0	6.0	0.092	0.016	0.005	< 0.005 U	< 0.005 U	< 0.010 U	< 0.005 U	0.040	< 0.005 U	< 10 U

Table 8
Summary of Chlorinated Compound Soil Analytical Data
Twigg Manufacturing Facility
Martinsville, Indiana

Sampling Location	Sampling Date	Sampling Depth (feet bgs) *	Eastings	Northings	Ground Surface Elevation (ft MSL)	Top of Sample Interval (ft BGS)	Bottom of Sample Interval (ft BGS)	PCE (mg/kg) ^b	TCE (mg/kg)	cis-1,2-DCE (mg/kg)	trans-1,2-DCE (mg/kg)	V C (mg/kg)	1,1-DCE (mg/kg)	1,1,1-TCA (mg/kg)	1,1-DCA (mg/kg)	C A (mg/kg)
FP-25	3/2 - 3/4/99	0-2 2-4	549896 549896	436329 436329	604.5 604.5	0.0 2.0	2.0 4.0	1.100 0.140	0.027 < 0.005 U	< 0.005 U < 0.005 U	< 0.005 U < 0.005 U	< 0.010 U < 0.010 U	< 0.005 U < 0.005 U	< 0.005 U < 0.005 U	< 0.005 U < 0.005 U	< 10 U < 10 U
FP-26	3/2 - 3/4/99	0-2.0 8.0-10.0	549904 549904	436329 436329	604.5 604.5	0.0 8.0	2.0 10.0	5.400 0.190	< 0.190 U < 0.005 U	< 0.190 U < 0.005 U	< 0.190 U < 0.005 U	< 0.380 U < 0.010 U	< 0.190 U < 0.005 U	< 0.190 U < 0.005 U	< 0.190 U < 0.005 U	< 380 U < 10 U
FP-27	3/2 - 3/4/99	0-2 6-8	549901 549901	436328 436328	604.5 604.5	0.0 6.0	2.0 8.0	< 0.005 U < 0.005 U	< 0.005 U < 0.005 U	< 0.005 U < 0.005 U	< 0.005 U < 0.005 U	< 0.010 U < 0.010 U	< 0.005 U < 0.005 U	0.035 < 0.005 U	< 0.005 U < 0.005 U	< 10 U < 10 U
FP-28	3/2 - 3/4/99	0-2 6.0-8.0	549904 549904	436326 436326	604.5 604.5	0.0 6.0	2.0 8.0	1.200 0.085	0.006 < 0.005 U	< 0.005 U < 0.005 U	< 0.005 U < 0.005 U	< 0.010 U < 0.010 U	< 0.005 U < 0.005 U	0.008 < 0.005 U	< 0.005 U < 0.005 U	< 10 U < 10 U
FP-36	5/6/1999	0.0-2.0 2.0-4.0 4.0-6.0 6.0-8.0	549884 549884 549884 549884	4363205 4363205 4363205 4363205	604.0 604.0 604.0 604.0	0.0 2.0 4.0 6.0	2.0 4.0 6.0 8.0	0.017 0.022 0.050 0.270	< 0.005 U < 0.005 U < 0.005 U < 0.014	< 0.005 U < 0.005 U < 0.005 U < 0.005 U	< 0.005 U < 0.005 U < 0.005 U < 0.005 U	< 0.010 U < 0.010 U < 0.010 U < 0.010 U	< 0.005 U < 0.005 U < 0.005 U < 0.005 U	< 0.005 U < 0.005 U 0.040 < 0.005 U	< 0.005 U < 0.005 U < 0.005 U < 0.005 U	< 10 U < 10 U < 10 U < 10 U
FP-37	5/6/1999	0.0-2.0 2.0-4.0 4.0-6.0 6.0-8.0	549884 549884 549884 549884	4363199 4363199 4363199 4363199	604.0 604.0 604.0 604.0	0.0 2.0 4.0 6.0	2.0 4.0 6.0 8.0	0.480 0.026 0.014 0.053	< 0.005 U < 0.005 U < 0.005 U 0.007	< 0.005 U < 0.005 U < 0.005 U < 0.005 U	< 0.005 U < 0.005 U < 0.005 U < 0.005 U	< 0.010 U < 0.010 U < 0.010 U < 0.010 U	< 0.005 U < 0.005 U < 0.005 U < 0.005 U	< 0.005 U < 0.005 U < 0.005 U 0.009	< 0.005 U < 0.005 U < 0.005 U < 0.005 U	< 10 U < 10 U < 10 U < 10 U
FP-38	5/6/1999	0.0-2.0 2.0-4.0 4.0-6.0 6.0-8.0	549884 549884 549884 549884	4363190 4363190 4363190 4363190	604.2 604.2 604.2 604.2	0.0 2.0 4.0 6.0	2.0 4.0 6.0 8.0	0.019 0.006 0.006 1.400	< 0.005 U < 0.005 U < 0.005 U 0.009	< 0.005 U < 0.005 U < 0.005 U < 0.005 U	< 0.005 U < 0.005 U < 0.005 U < 0.005 U	< 0.010 U < 0.010 U < 0.010 U < 0.010 U	< 0.005 U < 0.005 U < 0.005 U < 0.005 U	< 0.005 U < 0.005 U < 0.005 U < 0.005 U	< 0.005 U < 0.005 U < 0.005 U < 0.005 U	< 10 U < 10 U < 10 U < 10 U
FP-46	6/30/1999	0.0-2.0 4.0-6.0	549879 549879	4363205 4363205	604.5 604.5	0.0 4.0	2.0 6.0	0.010 0.005	< 0.005 U < 0.005 U	< 0.005 U < 0.005 U	< 0.005 U < 0.005 U	< 0.010 U < 0.010 U	< 0.005 U < 0.005 U	< 0.005 U < 0.005 U	< 0.005 U < 0.005 U	< 10 U < 10 U
FP-47	6/30/1999	0.0-2.0 4.0-6.0	549879 549879	4363199 4363199	604.5 604.5	0.0 4.0	2.0 6.0	0.041 0.022	< 0.005 U < 0.005 U	< 0.005 U < 0.005 U	< 0.005 U < 0.005 U	< 0.010 U < 0.010 U	< 0.005 U < 0.005 U	< 0.005 U < 0.005 U	< 0.005 U < 0.005 U	< 10 U < 10 U
FP-48	6/30/1999	0.0-2.0 4.0-6.0	549860 549860	4363200 4363200	604.5 604.5	0.0 4.0	2.0 6.0	0.012 0.005	< 0.005 U < 0.005 U	< 0.005 U < 0.005 U	< 0.005 U < 0.005 U	< 0.010 U < 0.010 U	< 0.005 U < 0.005 U	< 0.005 U < 0.005 U	< 0.005 U < 0.005 U	< 10 U < 10 U
FP-49	6/30/1999	0.0-2.0 4.0-6.0	549879 549879	4363190 4363190	604.5 604.5	0.0 4.0	2.0 6.0	0.094 0.034	< 0.005 U < 0.005 U	< 0.005 U < 0.005 U	< 0.005 U < 0.005 U	< 0.010 U < 0.010 U	< 0.005 U < 0.005 U	< 0.005 U < 0.005 U	< 0.005 U < 0.005 U	< 10 U < 10 U
SB-101	12/1/2008	8.0-12.0	549814	4363186	604.5	8	12	0.011	< 0.005 U	< 0.005 U	< 0.005 U	< 0.002 U	< 0.005 U	< 0.005 U	< 0.005 U	< 5 U
SB-102	12/1/2008	8.0-12.0	549804	4363207	605.0	8	12	0.007	< 0.005 U	< 0.005 U	< 0.005 U	< 0.002 U	< 0.005 U	< 0.005 U	< 0.005 U	< 5 U
SB-103	12/1/2008	8.0-12.0	549786	4363242	605.0	8	12	0.006	< 0.005 U	< 0.005 U	< 0.005 U	< 0.002 U	< 0.005 U	< 0.005 U	< 0.005 U	< 5 U
SB-104	12/1/2008	8.0-12.0	549775	4363274	604.5	8	12	< 0.006 U	< 0.006 U	< 0.006 U	< 0.006 U	< 0.002 U	< 0.006 U	< 0.006 U	< 0.006 U	< 6 U
SB-105	12/1/2008	8.0-12.0	549826	4363156	605.0	8	12	0.063	0.006 U	< 0.006 U	< 0.006 U	< 0.002 U	< 0.006 U	< 0.006 U	< 0.006 U	< 6 U

Notes:

* Reported as dry basis.

a/ feet bgs = feet below ground surface

b) mg/kg = milligrams per kilogram

4) Mean of Sample and Field Duplicate

polymers to be analyzed

Table 9
Groundwater Laboratory Analytical Results for Monitoring Wells
 Twigg Manufacturing Facility
 Martinsville, Indiana

Well ID	Date	PCE (µg/L)	TCE (µg/L)	cis-1,2-DCE (µg/L)	trans-1,2-DCE (µg/L)	1,1-DCE (µg/L)	Vinyl Chloride (µg/L)	TCA (µg/L)	DCA (µg/L)	CA (µg/L)	Ethene (ug/L)	Ethane (ug/L)
MW-1S	Installed 8/9/1994											
MW-1S	3/27/1998	2,800	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	11	< 5 U	< 10 U	na	na
MW-1S	6/26/1998	7,000	140	21	< 5 U	3	< 2 U	< 5 U	< 5 U	< 10 U	na	na
MW-1S	7/2/1999	470	3	< 1 J	< 1 J	< 1 U	< 1 J	7	< 1 U	< 1 J	na	na
MW-1S	9/7/2000	530	3	< 1 J	< 1 J	< 1 J	< 1 J	3	< 1 J	< 1 J	na	na
MW-1S	8/16/2001	1,900	1	< 1 U	< 1 U	< 1 U	< 1 U	1	< 1 U	< 5 U	na	na
MW-1S	11/15/2002	1,900	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-1S	12/18/2003	220	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-1S	4/27/2004	1,100	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-1S	6/15/2004	1,100	14	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-1S	7/29/2004	370	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-1S	10/21/2004	650	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-1S	10/21/2004	600	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-1S	1/14/2005	470	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-1S	4/20/2005	140	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-1S	8/1/2005	190	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-1S	10/20/2005	250	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-1S	1/11/2006	150	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-1S	6/6/2006	180	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-1S	10/13/2006	99	< 2 U	< 5 U	< 5 U	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
MW-1S	1/9/2007	203	< 2 U	< 5 U	< 5 U	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
MW-1S	5/23/2007	118	< 2 U	< 5 U	< 5 U	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
MW-1S	9/4/2007	138	< 2 U	< 5 U	< 5 U	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
MW-1S	10/26/2007	150	< 2 U	< 5 U	< 5 U	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
MW-1S	4/24/2008	126	< 2 U	< 5 U	< 5 U	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
MW-1S	2/3/2011	13.7	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-1S ^a	2/3/2011	30	na	na	na	na	na	na	na	na	na	na
MW-1D	Installed 2/24/1998											
MW-1D	3/27/1998	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	na	< 1 J	< 1 J	na	na	na
MW-1D	6/25/1998	490	33	7	< 5 U	< 5 U	< 2 U	59	< 5 U	< 10 U	na	na
MW-1D	7/23/1998	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	na	< 1 J	< 1 J	na	na	na
MW-1D	9/9/1998	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	na	< 1 U	< 1 U	na	na	na
MW-1D	9/9/1998	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	na	< 1 U	< 1 U	na	na	na
MW-1D	6/30/1999	3	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	na	na
MW-1D	9/6/2000	1	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	na	na
MW-1D	9/6/2000	5	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	na	na
MW-1D	8/14/2001	28	2	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	< 5 U	na	na
MW-1D	11/14/2002	15 B	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-1D	12/17/2003	3 J	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-1D	10/22/2004	4 JB	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-1D	10/19/2005	6	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-1D	10/13/2006	9	< 2 U	< 5 U	< 5 U	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
MW-1D	10/25/2007	8	< 5 U	< 5 U	< 5 U	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
MW-1D	2/3/2011	< 1 U	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-2	Installed 8/10/1994											
MW-2	2/8/2011	< 1 U	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	11.7	< 5 U	< 5 U	na	na
MW-3	Installed 8/9/1994											
MW-3	4/8/1998	210	3	19	na	< 1 U	na	62	3	na	na	na
MW-3	6/26/1998	180	< 5 U	10	< 5 U	< 5 U	< 2 U	64	< 5 U	< 10 U	na	na
MW-3	7/2/1999	290	2	100	4	1	< 1 J	72	< 1 J	< 1 J	na	na
MW-3	9/6/2000	180	1	22	< 1 J	< 1 J	< 1 J	40	< 1 J	< 1 J	na	na
MW-3	8/15/2001	150	2	13	< 5 U	< 1 U	< 1 U	25	< 1 U	< 5 U	na	na
MW-3	11/14/2002	170	< 5 U	9	< 5 U	< 5 U	< 2 U	27	< 5 U	< 5 U	na	na

Table 9
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Well ID	Date	PCE (µg/L)	TCE (µg/L)	cis-1,2-DCE (µg/L)	trans-1,2-DCE (µg/L)	1,1-DCE (µg/L)	Vinyl Chloride (µg/L)	TCA (µg/L)	DCA (µg/L)	CA (µg/L)	Ethene (ug/L)	Ethane (ug/L)
MW-3	12/17/2003	140	< 5 U	4 J	< 5 U	< 5 U	< 2 U	26	< 5 U	< 5 U	na	na
MW-3	11/4/2005	180	< 5 U	10	< 5 U	< 5 U	< 2 U	17	< 5 U	< 5 U	na	na
MW-3	10/13/2006	149	4	8	< 5 U	< 5 U	< 1 U	27	< 5 U	< 5 U	na	na
MW-3	10/25/2007	205	3	14	< 5 U	< 5 U	< 1 U	36	< 5 U	< 5 U	na	na
MW-3	2/8/2011	21.2	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	5.83	< 5 U	< 5 U	na	na
MW-4	Installed 12/14/1994											
MW-4 ^{3MS}	9/14/1995	10,000	160	13	< 50 U	14	< 10 U	1,200	< 50 U	< 50 U	na	na
MW-4 ^{3MS}	6/13/1996	6,100	< 50 U	< 50 U	< 50 U	< 50 U	< 50 U	280	< 50 U	< 50 U	na	na
MW-4 ^{3MS}	11/11/1996	5,900	< 100	< 100	< 100 U	< 100	< 20 U	330	< 100	< 100 U	na	na
MW-4 ^{3MS}	5/28/1997	9,400	< 5	< 5	< 5 U	< 5	< 2 U	560	< 5	< 5 U	na	na
MW-4 ^{3MS}	9/24/1997	10,000	55	55	< 5 U	18	< 2 U	460	22	< 5 U	na	na
MW-4	3/27/1998	7,600	61	29	< 1 J	< 1 J	na	440	6	na	na	na
MW-4	6/26/1998	8,200	110	30	< 5 U	5	< 2 U	630	< 5 U	< 10 U	na	na
MW-4	6/26/1998	8,200	130	73	< 5 U	< 1 U	< 2 U	880	12	< 10 U	na	na
MW-4	7/2/1999	13,000	150	30	< 10 J	< 10 J	< 5 J	370	< 10 J	< 10 J	na	na
MW-4	9/7/2000	8,600	24	< 10 J	< 10 J	< 10 J	< 10 J	56	< 10 J	< 10 J	na	na
MW-4	8/16/2001	5,900	120	1	< 1 U	< 1 U	< 1 U	74	< 1 U	< 5 U	na	na
MW-4	11/15/2002	3,600	16	< 5 U	< 5 U	< 5 U	< 2 U	31	< 5 U	< 5 U	na	na
MW-4	1/5/2004	5,500	19	< 2 U	< 5 U	< 5 U	< 2 U	32	< 5 U	< 5 U	na	na
MW-4	10/22/2004	1,400	2 J	< 5 U	< 5 U	< 5 U	< 2 U	8	< 5 U	< 5 U	na	na
MW-4	10/19/2005	5,400	7	32	< 5 U	< 5 U	< 2 U	15	< 5 U	< 5 U	na	na
MW-4	1/11/2006	1,700	6	110	< 5 U	< 5 U	< 2 U	8	< 5 U	< 5 U	na	na
MW-4	3/15/2006	1,900	< 5 U	270	< 5 U	< 5 U	< 2 U	9	< 5 U	< 5 U	na	na
MW-4	4/11/2006	2,600	4 J	330	4 J	< 10 U	< 4 U	8 J	< 10 U	< 10 U	na	na
MW-4	6/6/2006	2,200	6 J	2,100	40	< 20 U	< 8 U	9 J	< 20 U	< 20 U	na	na
MW-4	10/13/2006	1,590	15	1,750	35	< 5 U	< 1 U	19	< 5 U	< 5 U	na	na
MW-4	10/13/2006	1,670	14	1,840	32	< 5 U	< 1 U	19	< 5 U	< 5 U	na	na
MW-4	1/9/2007	1,250	9	321	11	< 5 U	< 1 U	8	< 5 U	< 5 U	na	na
MW-4	5/23/2007	2,480	25	752	18	< 5 U	< 1 U	7	< 5 U	< 5 U	na	na
MW-4	9/4/2007	3,540 E	130	796 E	20	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
MW-4	10/26/2007	3,070	153	411	18	5	< 1 U	89	< 5 U	< 5 U	na	na
MW-4	4/24/2008	2,230	68	88	6	< 5 U	< 1 U	6	< 5 U	< 5 U	na	na
MW-4 ^{1u}	4/22/2010	4,000	90	60	na	6 B	na	4 J	< 100 U	< 5	na	na
MW-4	2/10/2011	805	17.5	17.2	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	< 10.0	< 10.0
MW-4	2/10/2011	797	17.8	17.8	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	< 10.0	< 10.0
MW-4 ^{1u}	2/10/2011	1,200	17	13	na	na	na	1.9 J	na	na		
MW-5	Installed 9/29/1997											
MW-5	3/27/1998	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	na	< 1 J	< 1 J	na	na	na
MW-5	6/25/1998	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	< 2 U	na	na
MW-5	6/30/1999	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	na	na
MW-5	9/6/2000	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	na	na
MW-5	8/14/2001	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	< 5 U	na	na
MW-5	12/16/2003	< 5 U	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-5	10/19/2005	< 5 U	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-5	1/31/2011	< 1 U	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-6	Installed 9/30/1997											
MW-6	3/27/1998	< 1 J	< 1 J	32	< 1 J	320	na	7,100	39	na	na	na
MW-6	6/25/1998	< 5 U	< 5 U	38	< 5 U	380	< 2 U	7,900	46	< 10 U	na	na
MW-6	7/2/1999	< 50 U	< 10 J	20	< 10 J	390	< 10 J	9,100	23	< 10 J	na	na
MW-6	9/7/2000	< 10 J	< 10 J	16	< 10 J	< 10 J	< 10 J	8,100	30	< 10 J	na	na
MW-6	8/16/2001	8	3	39	1	440	< 2 U	7,100	60	< 5 U	na	na
MW-6	12/18/2003	< 5 U	< 5 U	10	< 5 U	82	< 2 U	6,800	8	< 5 U	na	na
MW-6	10/22/2004	9 B	11	52	< 5 U	340	< 2 U	4,900	32	< 5 U	na	na
MW-6	10/19/2005	< 20 U	20	67	< 20 U	460	< 8 U	7,000	< 20 U	< 20 U	na	na

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Well ID	Date	PCE (µg/L)	TCE (µg/L)	cis-1,2-DCE (µg/L)	trans-1,2-DCE (µg/L)	1,1-DCE (µg/L)	Vinyl Chloride (µg/L)	TCA (µg/L)	DCA (µg/L)	CA (µg/L)	Ethene (ug/L)	Ethane (ug/L)
MW-6	10/13/2006	17	28	62	< 5 U	256	< 1 U	6,410	20	< 5 U	na	na
MW-6	10/25/2007	12	30	46	< 5 U	334	< 1 U	6,160 E	31	< 5 U	na	na
MW-6"	4/21/2010	< 5	80	< 100 U	na	1,000	na	4,000	< 100 U	< 5	na	na
MW-6	2/10/2011	< 1 U	31.0	< 5 U	< 5 U	147	< 2 U	2,360	6	< 5 U	< 10.0	< 10.0
MW-6	2/10/2011	< 1 U	28.3	< 5 U	< 5 U	138	< 2 U	2,290	6	< 5 U	< 10.0	< 10.0
MW-6"	2/10/2011	9	30	12	na	350	na	2,000	3 J	na		
MW-6D	Installed 2/23/1998											
MW-6D	4/16/1999	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	7	10	< 1 J	na	na
MW-6D	7/2/1999	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	2	4	< 1 J	na	na
MW-6D	7/2/1999	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	2	4	< 1 J	na	na
MW-6D	9/6/2000	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	na	na
MW-6D	8/14/2001	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	< 5 U	na	na
MW-6D	11/14/2002	9 B	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-6D	12/16/2003	< 5 U	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-6D	10/19/2005	< 5 U	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-6D	1/31/2011	< 1 U	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-7	Installed 10/1/1997											
MW-7	3/26/1998	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	na	< 1 J	< 1 J	na	na	na
MW-7	6/23/1998	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	< 5 U	na	na
MW-7	6/30/1999	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	na	na
MW-7	9/6/2000	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	na	na
MW-7	8/14/2001	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	< 5 U	na	na
MW-7	12/16/2003	< 5 U	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-7	10/19/2005	< 5 U	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-7	1/31/2011	< 1 U	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-8	Installed 10/1/1997											
MW-8	3/27/1998	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	na	< 1 J	29	na	na	na
MW-8	5/22/1998	< 5 U	< 5 U	< 5 U	na	< 5 U	na	< 5 U	26	na	na	na
MW-8	6/23/1998	< 5 U	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	32	< 5 U	na	na
MW-8	7/2/1999	< 1 J	< 1 J	< 1 J	< 1 J	3	< 1 J	< 1 J	74	5	na	na
MW-8	9/6/2000	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	54	< 1 J	na	na
MW-8	8/15/2001	< 1 U	< 1 U	< 1 U	2	< 1 U	< 1 U	< 1 U	56	< 5 U	na	na
MW-8	11/14/2002	< 5 U	< 5 U	< 5 U	< 5 U	11	< 2 U	15	220	< 5 U	na	na
MW-8	1/5/2004	< 5 U	< 2 U	2	< 5 U	10	< 2 U	42	160	< 5 U	na	na
MW-8	10/21/2004	< 5 U	< 5 U	< 5 U	< 5 U	14	< 2 U	16	120	< 5 U	na	na
MW-8	10/19/2005	< 5 U	< 5 U	< 5 U	14	< 5 U	< 2 U	41	220	130	na	na
MW-8	3/15/2006	< 2 U	< 5 U	< 5 U	13	< 5 U	< 2 U	37	150	220	na	na
MW-8	6/6/2006	< 5 U	< 5 U	< 5 U	< 5 U	14	< 2 U	45	200	290	na	na
MW-8	8/11/2006	< 5 U	< 5 U	6	< 5 U	16	< 2 U	61	220	300	na	na
MW-8	9/6/2006	< 5 U	< 5 U	6	< 5 U	12	< 2 U	65	180	260	na	na
MW-8	10/6/2006	< 2 U	< 2 U	11	< 5 U	16	< 1 U	87	181	154	na	na
MW-8	10/12/2006	< 2 U	< 2 U	< 5 U	< 5 U	17	< 1 U	59	167	100	na	na
MW-8	12/11/2006	< 2 U	< 2 U	9	< 5 U	16	< 1 U	78	167	156	na	na
MW-8	1/9/2007	< 2 U	< 2 U	< 5 U	< 5 U	17	< 1 U	99	185	169	na	na
MW-8	2/12/2007	7	< 2 U	< 5 U	< 5 U	19	< 1 U	109	240	< 5 U	0.09	0.44
MW-8	3/26/2007	< 2 U	< 2 U	4 J	< 5 U	25	< 1 U	151	260 E	< 5 U	na	na
MW-8	5/23/2007	< 2 U	< 2 U	2 J	< 5 U	18	< 1 U	146	277	644	na	na
MW-8	6/26/2007	4	< 2 U	< 5 U	< 5 U	20	< 1 U	158	260 E	< 5 U	na	na
MW-8	7/25/2007	< 5 J	< 5 J	< 5 J	< 5 J	21 J	< 2 J	200	296	355	na	na
MW-8	9/12/2007	7 J	< 20 U	9 J	< 50 U	17 J	< 10 U	129	282	179	na	na
MW-8	10/26/2007	8	< 2 U	< 5 U	< 5 U	31	< 1 U	214 E	368 E	209	na	na
MW-8	12/4/2007	3	< 2 U	< 5 U	< 5 U	13	< 1 U	102	178	182	na	na
MW-8	2/5/2008	7	< 2 U	< 5 U	< 5 U	14	< 1 U	101	163	323 E	na	na
MW-8	3/20/2008	6	< 2 U	< 5 U	< 5 U	12	< 1 U	76	138	252 E	na	na
MW-8	4/15/2008	< 2 U	< 2 U	< 5 U	< 5 U	16	< 1 U	144	211	168	na	na

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Well ID	Date	PCE (µg/L)	TCE (µg/L)	cis-1,2-DCE (µg/L)	trans-1,2-DCE (µg/L)	1,1-DCE (µg/L)	Vinyl Chloride (µg/L)	TCA (µg/L)	DCA (µg/L)	CA (µg/L)	Ethene (ug/L)	Ethane (ug/L)
MW-8 ^b	5/8/2008	4	< 2 U	< 5 U	< 5 U	19	< 1 U	135	180	133	< 0.03	0.15
MW-8	10/16/2009	< 2 U	15	5	< 5 U	15	< 1 U	115	99	< 5 U	na	na
MW-8 ^{a,d}	4/21/2010	< 5	< 5	< 25 U	na	200 B	na	200	94	70	na	na
MW-8	1/31/2011	< 1 U	< 5 U	< 5 U	< 5 U	18.7	< 2 U	220	76.5	30.3	< 10.0	< 10.0
MW-8 ^a	1/31/2011	3.3 J	< 5 U	3 J	na	28	na	230	65	33	na	na
MW-9	Installed 2/23/1998											
MW-9	3/27/1998	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	na	< 1 J	< 1 J	na	na	na
MW-9	6/25/1998	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	< 2 U	na	na
MW-9	6/30/1999	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	na	na
MW-9	9/6/2000	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	na	na
MW-9	8/14/2001	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	< 5 U	na	na
MW-9	12/16/2003	< 5 U	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-9	10/20/2005	10	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-9	10/13/2006	21	< 5 U	< 5 U	< 5 U	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
MW-9	1/9/2007	< 2 U	< 5 U	< 5 U	< 5 U	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
MW-9	2/8/2011	< 1 U	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-10S	Installed 4/13/1999											
MW-10S	4/16/1999	560	4	4	< 1 J	< 1 J	< 1 J	23	1	< 1 J	na	na
MW-10S	7/2/1999	1,200	6	2	< 1 U	< 1 U	< 1 U	20	< 1 U	< 5 U	na	na
MW-10S	9/7/2000	1,700	27	24	< 1 J	< 1 J	< 1 J	73	1	< 1 J	na	na
MW-10S	8/16/2001	4,100	5	3	< 1 U	< 1 U	< 1 U	5	< 1 U	< 5 U	na	na
MW-10S	11/14/2002	1,000	6	< 5 U	< 5 U	< 5 U	< 2 U	6	< 5 U	< 5 U	na	na
MW-10S	12/17/2003	860	2 J	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-10S	12/17/2003	830	2 J	< 5 U	< 5 U	< 5 U	< 2 U	2 J	< 5 U	< 5 U	na	na
MW-10S	4/27/2004	870	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-10S	7/29/2004	520	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-10S	10/21/2004	720	3 J	5 J	< 5 U	< 5 U	< 2 U	2 J	< 5 U	< 5 U	na	na
MW-10S	1/14/2005	510	< 5 U	16	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-10S	4/20/2005	290	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-10S	8/1/2005	290	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-10S	10/20/2005	320	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-10S	1/11/2006	310 E	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-10S	6/6/2006	230	< 5 U	6	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-10S	10/13/2006	271	< 2 U	< 5 U	< 5 U	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
MW-10S	1/9/2007	283	< 2 U	< 5 U	< 5 U	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
MW-10S	5/23/2007	95	< 2 U	< 5 U	< 5 U	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
MW-10S	9/4/2007	241 E	< 2 U	< 5 U	< 5 U	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
MW-10S	10/25/2007	194	< 2 U	< 5 U	< 5 U	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
MW-10S	4/24/2008	209	< 2 U	< 5 U	< 5 U	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
MW-10S	2/3/2011	55.1	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-10M	Installed 4/6/1999											
MW-10M	4/16/1999	4	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	< 5 U	na	na
MW-10M	6/30/1999	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	< 5 U	na	na
MW-10M	9/6/2000	2	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	na	na
MW-10M	8/14/2001	21	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	< 5 U	na	na
MW-10M	11/14/2002	< 5 U	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-10M	11/14/2002	< 5 U	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-10M	12/17/2003	< 5 U	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-10M	10/21/2004	< 5 U	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-10M	10/19/2005	< 5 U	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-10M	2/3/2011	< 1 U	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-11	Installed 5/3/2000											
MW-11	9/6/2000	110	36	130	4 J	4	< 1 J	52	< 1 J	< 1 J	na	na
MW-11	8/15/2001	54	45	110	5	1	< 1 U	62	< 1 U	< 5 U	na	na

Table 9
Groundwater Laboratory Analytical Results for Monitoring Wells
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Well ID	Date	PCE (µg/L)	TCE (µg/L)	cis-1,2-DCE (µg/L)	trans-1,2-DCE (µg/L)	1,1-DCE (µg/L)	Vinyl Chloride (µg/L)	TCA (µg/L)	DCA (µg/L)	CA (µg/L)	Ethene (ug/L)	Ethane (ug/L)
MW-11	8/15/2001	62	29	79	3	1	< 1 U	80	< 1 U	< 5 U	na	na
MW-11	11/14/2002	41	27	44	< 5 U	6	< 2 U	35	< 5 U	< 5 U	na	na
MW-11	12/17/2003	29	7	28	< 5 U	4 J	< 2 U	72	< 5 U	< 5 U	na	na
MW-11	10/21/2004	58	56	87	< 5 U	< 5 U	< 2 U	57	< 5 U	< 5 U	na	na
MW-11	11/4/2005	58	67	81	< 5 U	< 5 U	< 2 U	71	< 5 U	< 5 U	na	na
MW-11	12/11/2006	39	77	72	< 5 U	< 5 U	< 1 U	89	< 5 U	< 5 U	na	na
MW-11	10/25/2007	141	207	88	< 5 U	< 5 U	< 1 U	97	< 5 U	< 5 U	na	na
MW-11	5/29/2008	68	100	64	< 5 U	< 5 U	< 1 U	36	< 5 U	< 5 U	na	na
MW-11	2/3/2011	120	103	11.9	< 5 U	< 5 U	< 2 U	13.3	< 5 U	< 5 U	< 10.0	< 10.0
MW-12	Installed 5/2/2000											
MW-12	9/6/2000	19	10	3	< 1 J	< 5 J	< 1 J	260	14	< 5 J	na	na
MW-12	8/15/2001	36	13	8	< 1 U	16	< 2 U	450	22	< 5 U	na	na
MW-12	11/14/2002	19	11	< 5 U	< 5 U	13	< 2 U	230	31	< 5 U	na	na
MW-12	12/17/2003	2.5 J	6	2 J	< 5 U	9	< 2 U	130	27	< 5 U	na	na
MW-12	10/21/2004	24	13	5 J	< 5 U	18	< 2 U	230	30	< 5 U	na	na
MW-12	10/19/2005	22	14	< 5 U	< 5 U	12	< 2 U	240	33	< 5 U	na	na
MW-12	10/13/2006	38	12	< 5 U	< 5 U	10	< 1 U	208	33	< 5 U	na	na
MW-12	10/25/2007	64	16	< 5 U	< 5 U	21	< 1 U	272	68	< 5 U	na	na
MW-12	2/8/2011	60	9.9	< 5 U	< 5 U	6.0	< 2 U	104	18.3	< 5 U	na	na
MW-13	Installed 4/27/2004											
MW-13	4/27/2004	730	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-13	7/29/2004	340	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-13	10/21/2004	880	2 J	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-13	1/14/2005	450	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-13	4/20/2005	400	< 5 U	12	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-13	8/1/2005	690	< 5 U	9	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-13	10/20/2005	790	2 J	20	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-13	1/11/2006	520	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-13	10/12/2006	768	< 2 U	< 5 U	< 5 U	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
MW-13	10/25/2007	547	< 2 U	28	< 5 U	6	< 1 U	< 5 U	< 5 U	< 5 U	na	na
MW-13	2/5/2008	438 E	< 2 U	< 5 U	< 5 U	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
MW-13	3/20/2008	401 E	< 2 U	< 5 U	< 5 U	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
MW-13 ^u	4/21/2010	200	< 5 U	< 5 U	na	< 20 U	na	< 5 U	< 5 U	8	na	na
MW-13	2/4/2011	217	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	< 10.0	< 10.0
MW-13 ^u	2/4/2011	250	na	na	na	na	na	na	na	na	na	na
MW-14	Installed 4/27/2004											
MW-14	4/27/2004	650	6	< 5 U	< 5 U	< 5 U	< 2 U	9	< 5 U	< 5 U	na	na
MW-14	7/29/2004	1,200	24	< 5 U	< 5 U	< 5 U	< 2 U	28	< 5 U	< 5 U	na	na
MW-14	10/21/2004	1,300	13	< 5 U	< 5 U	< 5 U	< 2 U	15	< 5 U	< 5 U	na	na
MW-14	1/14/2005	980	50	250	< 5 U	< 5 U	< 2 U	11	< 5 U	< 5 U	na	na
MW-14	4/20/2005	620	77	170	< 5 U	< 5 U	< 2 U	6	< 5 U	< 5 U	na	na
MW-14	10/20/2005	270	59	3,400	50	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	< 20	< 20
MW-14	11/16/2005	220	43	3,700	42	< 25 U	< 10 U	< 25 U	< 25 U	< 25 U	na	na
MW-14	11/16/2005	230	44	3,100	47	< 25 U	< 10 U	< 25 U	< 25 U	< 25 U	na	na
MW-14	1/11/2006	140	37	1,600	37	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-14	3/10/2006	120	37	1,000	25	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-14	6/6/2006	110	35	330	9	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-14	6/21/2006	90	45	360	12	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-14	7/11/2006	72	35	210	9	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
MW-14	10/12/2006	94	88	90	< 5 U	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
MW-14	1/9/2007	44	16	2,420	44	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
MW-14	5/23/2007	24	61	337	7	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
MW-14	9/4/2007	46 E	103	730	< 5 U	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
MW-14	10/25/2007	44	120	1,130	30	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
MW-14	2/5/2008	15	10	542 E	34	< 5 U	1	< 5 U	< 5 U	< 5 U	na	na

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Well ID	Date	PCE (µg/L)	TCE (µg/L)	cis-1,2-DCE (µg/L)	trans-1,2-DCE (µg/L)	1,1-DCE (µg/L)	Vinyl Chloride (µg/L)	TCA (µg/L)	DCA (µg/L)	CA (µg/L)	Ethene (ug/L)	Ethane (ug/L)
MW-14	3/20/2008	18	8	435	24	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
MW-14 ^a	4/22/2010	60	10	110	na	4 J	na	< 5 U	< 5 U	< 5 U	na	na
MW-14	2/4/2011	10.4	< 5 U	91.3	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	< 10.0	< 10.0
MW-14 ^a	2/4/2011	13	3.5 J	78	na	na	na	na	na	na	na	na
MW-15	Installed 3/2006											
MW-15	3/15/2006	8	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	71	< 5 U	< 5 U	na	na
MW-15	10/13/2006	29	< 2 U	< 5 U	< 5 U	< 5 U	< 1 U	83	< 5 U	< 5 U	na	na
MW-15	10/25/2007	18	< 2 U	< 5 U	< 5 U	< 5 U	< 1 U	84	< 5 U	< 5 U	na	na
MW-15	2/9/2011	< 1 U	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	24.4	< 5 U	< 5 U	na	na
MW-16	Installed 3/2006											
MW-16	3/15/2006	95	56	27	< 5 U	< 5 U	< 2 U	15	< 5 U	< 5 U	na	na
MW-16	10/13/2006	110	71	20	< 5 U	< 5 U	< 1 U	27	< 5 U	< 5 U	na	na
MW-16	10/25/2007	242	94	10	< 5 U	< 5 U	< 1 U	33	< 5 U	< 5 U	na	na
MW-16	5/29/2008	181	66	14	< 5 U	< 5 U	< 1 U	12	< 5 U	< 5 U	na	na
MW-16	2/9/2011	124	26.1	11.9	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	< 10.0	< 10.0
MW-17	Installed 3/2006											
MW-17	3/15/2006	13	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	33	< 5 U	< 5 U	na	na
MW-17	10/13/2006	66	< 2 U	< 5 U	< 5 U	< 5 U	< 1 U	55	< 5 U	< 5 U	na	na
MW-17	10/25/2007	52	< 2 U	< 5 U	< 5 U	< 5 U	< 1 U	55	< 5 U	< 5 U	na	na
MW-17	2/10/2011	6.4	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	17.4	< 5 U	< 5 U	na	na
MW-18	Installed 3/2006											
MW-18	3/15/2006	2,500	22	19	< 5 U	5	< 2 U	640	< 5 U	< 5 U	na	na
MW-18	4/11/2006	2,000	12	15	< 10 U	4 J	< 4 U	420	< 10 U	< 10 U	na	na
MW-18	6/6/2006	2,500	14 J	21	< 5 U	< 5 U	< 2 U	320	< 5 U	< 5 U	na	na
MW-18	10/13/2006	2,170	16	30	< 5 U	< 5 U	< 1 U	318	< 5 U	< 5 U	na	na
MW-18	1/9/2007	1,580	7	62	< 5 U	< 5 U	< 1 U	309	< 5 U	< 5 U	na	na
MW-18	5/23/2007	1,470	10	11	< 5 U	< 5 U	< 1 U	148	< 5 U	< 5 U	na	na
MW-18	9/4/2007	3,550 E	13	12	< 5 U	< 5 U	< 1 U	269 E	< 5 U	< 5 U	na	na
MW-18	10/26/2007	7,640 E	16	18	< 5 U	7	< 1 U	482 E	< 5 U	< 5 U	na	na
MW-18	4/24/2008	1,820	10	13	< 5 U	< 5 U	< 1 U	294	< 5 U	< 5 U	na	na
MW-18	2/10/2011	1,100	8.9	93	< 5 U	< 5 U	< 2 U	195	7.4	< 5 U	na	na
MW-19	Installed 3/2006											
MW-19	3/15/2006	2,000	< 5 U	60	< 5 U	< 5 U	< 2 U	35	< 5 U	< 5 U	na	na
MW-19	10/12/2006	1,120	5	15	< 5 U	< 5 U	< 1 U	42	< 5 U	< 5 U	na	na
MW-19	10/26/2007	1,230	6	21	< 5 U	< 5 U	< 1 U	39	< 5 U	< 5 U	na	na
MW-19 ^a	4/22/2010	2,000	20	48	na	5	na	10	< 50 U	< 5 U	na	na
MW-19	2/9/2011	806	7.3	8.9	< 5 U	< 5 U	< 2 U	14	< 5 U	< 5 U	< 10.0	< 10.0
MW-19 ^a	2/9/2011	1,300	11.0	8.0	na	na	na	9	na	na	na	na
PBW-1	Installed 6/7/2004											
PBW-1	6/15/2004	610	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	< 10	< 20
PBW-1	8/30/2004	480	51	na	na	na	50	na	na	na	na	na
PBW-1	10/22/2004	1,300	8	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
PBW-1	10/20/2005	24	3	290	24	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	< 20	< 20
PBW-1	11/16/2005	9	< 5 U	270	6	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
PBW-1	1/11/2006	29	5	140	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	< 20	< 20
PBW-1	3/10/2006	11	< 5 U	120	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
PBW-1	4/11/2006	21	< 5 U	120	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
PBW-1	6/6/2006	40	14	300	13	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
PBW-1	6/21/2006	65	22	240	9	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
PBW-1	7/11/2006	68	26	180	8	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
PBW-1	8/11/2006	41	13	260	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
PBW-1	9/6/2006	53	23	470	8	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
PBW-1	10/12/2006	152	34	749	12	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na

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Well ID	Date	PCE (µg/L)	TCE (µg/L)	cis-1,2-DCE (µg/L)	trans-1,2-DCE (µg/L)	1,1-DCE (µg/L)	Vinyl Chloride (µg/L)	TCA (µg/L)	DCA (µg/L)	CA (µg/L)	Ethene (ug/L)	Ethane (ug/L)
PBW-1	11/20/2006	9	< 2 U	997	14	< 5 U	12	< 5 U	< 5 U	< 5 U	na	na
PBW-1R	Installed 12/22/2006											
PBW-1R	1/9/2007	85	12	2,140	< 5 U	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
PBW-1R	2/12/2007	< 2 U	< 2 U	2,220	27	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	0.17	0.12
PBW-1R	5/23/2007	11 J	< 2 J	566	< 5 J	< 5 J	< 1 J	< 5 J	< 5 J	< 5 J	na	na
PBW-1R	6/26/2007	10 J	< 20 U	636	< 50 U	< 50 U	< 10 U	< 50 U	< 50 U	< 50 U	na	na
PBW-1R	7/25/2007	< 5 J	< 5 J	1,100	11 J	< 5 J	< 2 J	< 5 J	< 5 J	< 5 J	na	na
PBW-1R	9/4/2007	< 2 J	< 2 J	1,280 E	16 J	< 5 J	< 1 J	< 5 J	< 5 J	< 5 J	na	na
PBW-1R	9/12/2007	42	< 20 U	734	7 J	< 50 U	< 10 U	< 50 U	< 50 U	< 50 U	na	na
PBW-1R	10/25/2007	3	2	807	12	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
PBW-1R	12/4/2007	2	3	548	17	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
PBW-1R	1/8/2008	< 2 U	124	542	14	< 5 U	3	< 5 U	< 5 U	< 5 U	na	na
PBW-1R	2/5/2008	< 2 U	< 2 U	501 E	15	< 5 U	5	< 5 U	< 5 U	< 5 U	na	na
PBW-1R	3/20/2008	5	6	261	11	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
PBW-1R	5/8/2008	11	10	236 E	13	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
PBW-1R	2/4/2011	< 1 U	< 5 U	34.9	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
PBW-2	Installed 6/7/2004											
PBW-2	6/15/2004	940	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	14	< 20
PBW-2	9/15/2004	1,200	< 5 U	< 5 U	na	na	< 2 U	na	na	na	na	na
PBW-2	10/7/2004	1,300	8	< 5 U	< 5 U	< 5 U	< 2 U	6	< 5 U	< 5 U	na	na
PBW-2	10/22/2004	1,400	7	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
PBW-2	11/1/2004	1,600	7	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
PBW-2	1/14/2005	1,100	450	3900	7	< 5 U	< 2 U	6	< 5 U	< 5 U	na	na
PBW-2	2/17/2005	250	260	11,000	< 120 U	< 120 U	3 J	< 120 U	< 120 U	< 120 U	na	na
PBW-2	3/29/2005	160	79	6,500	54	8	2	< 5 U	< 5 U	< 5 U	< 20	< 20
PBW-2	4/20/2005	150	88	5,700	45	7	3	< 5 U	< 5 U	< 5 U	< 20	< 20
PBW-2	5/23/2005	180	72	4,200	< 50 U	< 50 U	< 20 U	< 50 U	< 50 U	< 50 U	< 20	< 20
PBW-2	6/28/2005	< 50 U	< 50 U	6,000	53	< 50 U	< 20 U	< 50 U	< 50 U	< 50 U	< 20	< 20
PBW-2	8/1/2005	20	12	4,500	71	6	< 2 U	< 5 U	< 5 U	< 5 U	< 20	< 20
PBW-2	8/29/2005	< 25 U	< 25 U	4,400	53	< 25 U	< 25 U	< 25 U	< 25 U	< 25 U	< 20	< 20
PBW-2	9/23/2005	< 20 U	< 20 U	3,500	52	< 20 U	< 8 U	< 20 U	< 20 U	< 20 U	na	na
PBW-2	10/20/2005	< 5 U	8	4,100	64	4	< 2 U	< 5 U	< 5 U	< 5 U	< 20	< 20
PBW-2	11/16/2005	3 J	8 J	4,000	64	< 25 U	< 10 U	< 25 U	< 25 U	< 25 U	na	na
PBW-2	1/11/2006	< 5 U	< 5 U	1,200	25	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
PBW-2	3/10/2006	11	< 5 U	740	16	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
PBW-2	4/11/2006	< 5 U	< 5 U	280	8	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
PBW-2	6/6/2006	27	12	480	21	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
PBW-2	6/21/2006	18	30	350	14	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
PBW-2	7/11/2006	45	35	180	8	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
PBW-2	8/11/2006	67	31	260	8	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
PBW-2	9/6/2006	110	42	510	11	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
PBW-2	10/12/2006	177	51	872	18	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
PBW-2	11/20/2006	< 2 U	< 2 U	1,960	30	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
PBW-2	12/11/2006	11	13	1,940	15	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
PBW-2	1/9/2007	34	32	1,810	22	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
PBW-2	2/12/2007	< 2 U	26	2,460	33	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	0.16	0.10
PBW-2	3/26/2007	10 J	17 J	2,330	27 J	< 50 U	< 10 U	< 50 U	< 50 U	< 50 U	na	na
PBW-2	5/23/2007	< 2 J	< 2 J	1,910	21 J	< 5 J	< 1 J	< 5 J	< 5 J	< 5 J	na	na
PBW-2	6/26/2007	5	5	1,120	15	< 5 U	2	< 5 U	< 5 U	< 5 U	na	na
PBW-2	7/25/2007	< 5 J	< 5 J	1,650	31 J	< 5 J	< 2 J	< 5 J	< 5 J	< 5 J	na	na
PBW-2	9/4/2007	< 2 U	3	1,050 E	25	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
PBW-2	9/12/2007	11 J	< 20 U	1,380	36 J	< 50 U	< 10 U	< 50 U	< 50 U	< 50 U	na	na
PBW-2	10/25/2007	< 2 U	< 2 U	1,490	55	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
PBW-2	12/4/2007	< 2 U	< 2 U	1,220	47	< 5 U	2	< 5 U	< 5 U	< 5 U	na	na
PBW-2	1/8/2008	< 2 U	< 2 U	1,050	36	< 5 U	2	< 5 U	< 5 U	< 5 U	na	na

Table 9
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Well ID	Date	PCE (µg/L)	TCE (µg/L)	cis-1,2-DCE (µg/L)	trans-1,2-DCE (µg/L)	1,1-DCE (µg/L)	Vinyl Chloride (µg/L)	TCA (µg/L)	DCA (µg/L)	CA (µg/L)	Ethene (ug/L)	Ethane (ug/L)
PBW-2	2/5/2008	< 2 U	< 2 U	608 E	37	< 5 U	2	< 5 U	< 5 U	< 5 U	na	na
PBW-2	3/20/2008	3	5	419	18	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
PBW-2	4/15/2008	< 2 U	6	438	8	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
PBW-2	5/8/2008	9	10	328	12	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
PBW-2	2/4/2011	< 1 U	< 5 U	85.3	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
PBW-3	Installed 7/7/2006											
PBW-3	8/11/2006	< 5 U	< 5 U	< 5 U	< 5 U	13	< 2 U	96	300	480	na	na
PBW-3	9/6/2006	5	< 5 U	9	< 5 U	14	< 2 U	91	270	470	na	na
PBW-3	10/6/2006	< 2 U	< 2 U	12	< 5 U	13	< 1 U	114	220	199	na	na
PBW-3	10/12/2006	3	< 2 U	7	< 5 U	14	< 1 U	117	184	155	na	na
PBW-3	12/11/2006	< 2 U	< 2 U	8	< 5 U	6	< 1 U	47	116	331	na	na
PBW-3	1/9/2007	< 2 U	< 2 U	< 5 U	< 5 U	14	< 1 U	125	200	245	na	na
PBW-3	2/12/2007	13	< 2 U	5	< 5 U	19	< 1 U	144	235	707	na	na
PBW-3	3/26/2007	< 20 U	< 20 U	< 50 U	< 50 U	25 J	< 10 U	230	342	1080	na	na
PBW-3	5/23/2007	< 2 U	< 2 U	< 5 U	< 5 U	12	< 1 U	134	< 5 U	929	na	na
PBW-3	6/26/2007	2	< 2 U	< 5 U	< 5 U	16	< 1 U	146	271	< 5 U	na	na
PBW-3	7/25/2007	< 5 J	< 5 J	< 5 J	< 5 J	17 J	< 2 J	213	266	687	na	na
PBW-3	10/26/2007	5	< 2 U	< 5 U	< 5 U	18	< 1 U	147	247 E	451 E	na	na
PBW-3	12/4/2007	4	< 2 U	< 5 U	< 5 U	16	< 1 U	162	148	355	na	na
PBW-3	2/5/2008	12	< 2 U	< 5 U	< 5 U	15	< 1 U	134	150	509 E	na	na
PBW-3	3/20/2008	6	< 2 U	< 5 U	< 5 U	11	< 1 U	87	137	254	na	na
PBW-3	4/15/2008	< 2 U	< 2 U	< 5 U	< 5 U	< 5	< 1 U	186	139	209	na	na
PBW-3	5/8/2008	5	< 2 U	< 5 U	< 5 U	17	< 1 U	266	158	179	na	na
PBW-3	10/16/2009	< 2 U	< 2 U	< 5 U	< 5 U	17	< 1 U	107	172	< 5 U	na	na
PBW-3 nd	4/21/2010	< 5 U	< 5 U	2 J	na	200 B	na	200	100	< 200 U	na	na
PBW-3	1/31/2011	< 1 U	< 5 U	< 5 U	< 5 U	17.6	< 2 U	204	92.9	70.5	< 10.0	< 10.0
PBW-3 nd	1/31/2011	2.6 J	< 5 U	3 J	na	38	na	170	65	65	na	na
PBW-4	Installed 7/7/2006											
PBW-4	8/11/2006	< 5 U	< 5 U	< 5 U	< 5 U	13	< 2 U	65	210	380	na	na
PBW-4	9/6/2006	< 5 U	< 5 U	8	< 5 U	18	< 2 U	57	120	140	na	na
PBW-4	10/6/2006	< 2 U	< 2 U	19	< 5 U	21	< 1 U	120	135	92	na	na
PBW-4	10/12/2006	< 2 U	< 2 U	< 5 U	< 5 U	14	< 1 U	62	93	53	na	na
PBW-4	12/11/2006	< 2 U	< 2 U	9	< 5 U	11	< 1 U	51	56	74	na	na
PBW-4	1/9/2007	< 2 U	< 2 U	< 5 U	< 5 U	14	< 1 U	88	66	60	na	na
PBW-4	2/12/2007	8	< 2 U	7	< 5 U	18	< 1 U	90	100	163	na	na
PBW-4	3/26/2007	< 2 U	< 2 U	9	< 5 U	8	< 1 U	30	53	207	na	na
PBW-4	5/23/2007	< 2 U	< 2 U	< 5 U	< 5 U	17	< 1 U	111	151	382	na	na
PBW-4	6/26/2007	3	< 2 U	< 5 U	< 5 U	10	< 1 U	47	102	< 5 U	na	na
PBW-4	7/25/2007	< 5 J	< 5 J	< 5 J	< 5 J	18 J	< 2 J	100	198	155	na	na
PBW-4	10/26/2007	5	< 2 U	< 5 U	< 5 U	13	< 1 U	85	83	105	na	na
PBW-4	12/4/2007	4	< 2 U	5	< 5 U	11	< 1 U	86	53	104	na	na
PBW-4	2/5/2008	15	< 2 U	< 5 U	< 5 U	9	< 1 U	71	48	131	na	na
PBW-4	3/20/2008	8	< 2 U	< 5 U	< 5 U	11	< 1 U	82	56	81	na	na
PBW-4	4/15/2008	< 2 U	< 2 U	< 5 U	< 5 U	< 5 U	< 1 U	89	68	52	na	na
PBW-4	5/8/2008	8	< 2 U	< 5 U	< 5 U	16	< 1 U	116	85	58	na	na
PBW-4	10/16/2009	< 2 U	< 2 U	< 5 U	< 5 U	22	< 1 U	150	54	< 5 U	na	na
PBW-4	1/31/2011	< 1 U	< 5 U	527	< 5 U	12.4	< 2 U	92.6	24.7	10.1	na	na
PMW-1	Installed 6/7/2004											
PMW-1	6/15/2004	910	6	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	< 10	< 20
PMW-1	10/22/2004	1,200	6	< 5 U	< 5 U	< 5 U	< 2 U	3 J	< 5 U	< 5 U	na	na
PMW-1	12/2/2004	930	78	1600	< 5 U	< 5 U	< 2 U	7	< 5 U	< 5 U	na	na
PMW-1	1/14/2005	15	8	4600	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
PMW-1	2/17/2005	< 5 U	< 5 U	6,900	< 120 U	< 120 U	5 J	< 120 U	< 120 U	< 120 U	na	na
PMW-1	3/29/2005	< 5 U	< 5 U	8,100	38	8	5	< 5 U	< 5 U	< 5 U	< 20	< 20
PMW-1	4/20/2005	< 5 U	< 5 U	7,000	46	8	6	< 5 U	< 5 U	< 5 U	< 20	< 20

Table 9
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Well ID	Date	PCE (µg/L)	TCE (µg/L)	cis-1,2-DCE (µg/L)	trans-1,2-DCE (µg/L)	1,1-DCE (µg/L)	Vinyl Chloride (µg/L)	TCA (µg/L)	DCA (µg/L)	CA (µg/L)	Ethene (ug/L)	Ethane (ug/L)
PMW-I	5/23/2005	< 50 U	< 50 U	5,200	< 50 U	< 50 U	< 20 U	< 50 U	< 50 U	< 50 U	< 20	< 20
PMW-I	6/28/2005	< 50 U	< 50 U	5,700	< 50 U	< 50 U	< 20 U	< 50 U	< 50 U	< 50 U	< 20	< 20
PMW-I	8/1/2005	< 5 U	< 5 U	3,200	40	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	< 20	< 20
PMW-I	8/29/2005	< 25 U	< 25 U	3,500	44	< 25 U	< 25 U	< 25 U	< 25 U	< 25 U	< 20	< 20
PMW-I	9/23/2005	< 20 U	< 20 U	3,100	40	< 20 U	< 8 U	< 20 U	< 20 U	< 20 U	na	na
PMW-I	10/20/2005	< 5 U	< 5 U	1,300	24	3	< 2 U	< 5 U	< 5 U	< 5 U	< 20	< 20
PMW-I	11/16/2005	< 5 U	< 5 U	970	23	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
PMW-I	1/11/2006	7	< 5 U	310	6	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	< 20	< 20
PMW-I	3/10/2006	6	17	170	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
PMW-I	4/11/2006	79	28	49	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
PMW-I	6/6/2006	280	11	56	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
PMW-I	6/21/2006	380	13	89	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
PMW-I	7/11/2006	520	13	250	11	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
PMW-I	8/11/2006	180	120	680	9	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
PMW-I	9/6/2006	97	140	920	9	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
PMW-I	10/12/2006	10	8	1,150	14	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
PMW-I	11/20/2006	5	< 2 U	1,430	44	< 5 U	9	< 5 U	< 5 U	< 5 U	na	na
PMW-I	12/11/2006	< 2 U	< 2 U	1,980	12	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
PMW-I	1/9/2007	26	< 2 U	2,140	20	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
PMW-I	2/12/2007	< 2 U	< 2 U	1,860	34	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	0.16	0.12
PMW-I	3/26/2007	< 20 U	< 20 U	1,760	21 J	< 50 U	< 10 U	< 50 U	< 50 U	< 50 U	na	na
PMW-I	5/23/2007	< 2 U	< 2 U	1,110	20	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
PMW-I	6/26/2007	< 2 U	< 2 U	1,500	16	< 5 U	1	< 5 U	< 5 U	< 5 U	na	na
PMW-I	7/25/2007	< 5 J	< 5 J	1,750	26 J	< 5 J	< 2 J	< 5 J	< 5 J	< 5 J	na	na
PMW-I	9/4/2007	< 2 U	< 2 U	1,160	25	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
PMW-I	9/12/2007	11 J	< 20 U	759	16 J	< 50 U	< 10 U	< 50 U	< 50 U	< 50 U	na	na
PMW-I	10/25/2007	< 2 U	< 2 U	1,600	46	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
PMW-I	12/4/2007	< 2 U	< 2 U	1,080	26	< 5 U	2	< 5 U	< 5 U	< 5 U	na	na
PMW-I	1/8/2008	< 2 U	< 2 U	963	29	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
PMW-I	2/5/2008	< 2 U	< 2 U	469	20	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
PMW-I	3/20/2008	< 2 U	< 2 U	591	27	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
PMW-I	4/15/2008	< 2 U	< 2 U	457	< 5 U	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
PMW-I ^W	5/8/2008	< 2 U	< 2 U	334	15	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	0.02	< 0.03
PMW-I ^W	4/22/2010	20	< 5 U	160	na	4 J	na	< 5 U	< 5 U	< 5 U	na	na
PMW-I	2/4/2011	< 1 U	< 5 U	142	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	< 10.0	< 10.0
PMW-I ^W	2/4/2011	1.8 J	1.2 J	110	na	na	na	na		na	na	na
PMW-IS	Installed 6/7/2004											
PMW-IS	6/15/2004	1,100	14	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	21	< 20
PMW-IS	1/14/2005	120	250	5,600	14	5	< 2 U	< 5 U	< 5 U	< 5 U	na	na
PMW-IS	3/29/2005	< 5 U	< 5 U	7,100	43	8	4	< 5 U	< 5 U	< 5 U	< 20	< 20
PMW-IS	6/28/2005	< 50 U	< 50 U	4,700	46 J	< 50 U	< 20 U	< 50 U	< 50 U	< 50 U	< 20	< 20
PMW-IS	8/1/2005	190	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
PMW-IS	8/29/2005	< 25 U	< 25 U	1300	< 25 U	< 25 U	< 25 U	< 25 U	< 25 U	< 25 U	< 20	< 20
PMW-IS	9/23/2005	13	< 5 U	590	10	< 20 U	< 2 U	< 20 U	< 20 U	< 20 U	na	na
PMW-IS	10/20/2005	27	3	230	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	< 20	< 20
PMW-IS	1/11/2006	140	17	52	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
PMW-IS	3/10/2006	460	12	41	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
PMW-IS	6/6/2006	540	6	27	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
PMW-IS	6/21/2006	630	9	31	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
PMW-IS	9/6/2006	140	78	740	8	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
PMW-IS	10/12/2006	44	27	1,160	13	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
PMW-IS	11/20/2006	6	< 2 U	4,110	28	8	3	< 5 U	< 5 U	< 5 U	na	na
PMW-IS	12/11/2006	< 2 J	< 2 J	3,220	8	< 5 J	< 1 J	< 5 J	< 5 J	< 5 J	na	na
PMW-IS	1/9/2007	29	< 2 U	1,430	15	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
PMW-IS	2/12/2007	< 2 U	< 2 U	2,650	25	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na

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PMW-IS	3/26/2007	< 100 U	< 100 U	3,050	< 250 U	< 250 U	< 50 U	< 250 U	< 250 U	< 250 U	na	na
PMW-IS	5/23/2007	33	< 2 J	1,530	21 J	< 5 J	< 1 J	< 5 J	< 5 J	< 5 J	na	na
PMW-IS	6/26/2007	< 2 U	< 2 U	1,500	15	< 5 U	1	< 5 U	< 5 U	< 5 U	na	na
PMW-IS	7/25/2007	< 5 J	< 5 J	1,160	< 5 J	< 5 J	< 2 J	< 5 J	< 5 J	< 5 J	na	na
PMW-IS	9/4/2007	< 2 U	< 2 U	872 E	13	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
PMW-IS	9/12/2007	18 J	< 20 U	1,130	18 J	< 50 U	< 10 U	< 50 U	< 50 U	< 50 U	na	na
PMW-IS	10/25/2007	5	< 2 U	1,710	37	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
PMW-IS	12/4/2007	3	< 2 U	314	7	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
PMW-IS	1/8/2008	3	< 2 U	111	< 5 U	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
PMW-IS	2/5/2008	3	< 2 U	117	< 5 U	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
PMW-IS	3/20/2008	< 2 U	< 2 U	570	20	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
PMW-IS	4/15/2008	< 2 U	< 2 U	795	< 5 U	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
PMW-IS	5/8/2008	< 2 U	< 2 U	530	17	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	na	na
PMW-IS	2/4/2011	239	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	na	na
HMW-25	Installed 1995 by HM											
HMW-25 ^(HSA)	9/14/1995	< 5	< 5	< 5 U	< 5 U	< 5 U	< 2 U	10	< 5 U	< 10 U	na	na
HMW-25 ^(HSA)	6/12/1996	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	1.8	< 1 U	< 1 U	na	na
HMW-25 ^(HSA)	11/8/1996	< 1	< 1	< 1 U	< 1 U	< 1 U	< 1 U	5	< 1 U	< 5 U	na	na
HMW-25 ^(HSA)	11/8/1996	< 1	< 1	< 1 U	< 1 U	< 1 U	< 1 U	3.3	< 1 U	< 5 U	na	na
HMW-25 ^(HSA)	2/17/1997	< 1	< 1	< 1 U	< 1 U	< 1 U	< 1 U	5.4	< 1 U	< 5 U	na	na
HMW-25 ^(HSA)	5/28/1997	< 5	< 5	< 5 U	< 5 U	< 5 U	< 2 U	9	< 5 U	< 10 U	na	na
HMW-25 ^(HSA)	9/23/1997	< 1	< 1	< 1 U	< 1 U	< 1 U	< 1 U	18	< 1 U	< 5 U	na	na
HMW-25 ^(HSA)	3/24/1998	< 1	< 1	< 1 U	< 1 U	< 1 U	< 1 U	14	< 1 U	< 5 U	na	na
HMW-25 ^(HSA)	9/22/1998	< 5	< 5	< 5 U	< 5 U	< 5 U	< 2 U	26	< 5 U	< 10 U	na	na
HMW-25 ^(HSA)	3/18/1999	< 1	< 1	< 1 U	< 1 U	< 1 U	< 1 U	9.5	< 1 U	< 5 U	na	na
HMW-25 ^(HSA)	8/30/2000	< 1	< 1	< 1 U	< 1 U	< 1 U	< 1 U	4.1	< 1 U	< 5 U	na	na
HMW-25 ^(HSA)	4/9/2003	1.5	< 1	< 1 U	< 1 U	< 1 U	< 1 U	< 1	< 1 U	< 5 U	na	na
HMW-25 ^(HSA)	12/1/2004	< 1	< 1	< 1 U	< 1 U	< 1 U	< 1 U	2	< 1 U	< 5 U	na	na
HMW-25	11/4/2005	< 5 U	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 10 U	na	na
HMW-25 ^(HSA)	1/10/2007	< 1	< 1	< 1 U	< 1 U	< 1 U	< 1 U	2.3	< 1 U	< 5 U	na	na
HMW-25 ^(HSA)	9/30/2008	< 1	1.5	< 1 U	< 1 U	< 1 U	< 1 U	2.6	< 1 U	< 5 U	na	na
HMW-25 ^(HSA)	9/30/2008	1.6	2.3	< 1 U	< 1 U	< 1 U	< 1 U	2.7	< 1 U	< 5 U	na	na
HMW-31	Installed 1995 by HM											
HMW-31 ^(HSA)	9/14/1995	< 5	6	15	< 5 U	< 5	< 2 U	240	< 5	< 10 U	na	na
HMW-31 ^(HSA)	6/12/1996	< 1 U	3.7	4.4	< 1 U	2.7	< 1 U	83	< 1 U	< 1 U	na	na
HMW-31 ^(HSA)	11/8/1996	< 1	10	37	< 1 U	5	< 1 U	190	< 1	< 5 U	na	na
HMW-31 ^(HSA)	2/17/1997	< 5	5.3	20	< 5 U	< 5	< 2 U	140	< 5	< 10 U	na	na
HMW-31 ^(HSA)	5/28/1997	< 5	7	21	< 5 U	< 5	< 2 U	116	< 5	< 10 U	na	na
HMW-31 ^(HSA)	9/23/1997	< 1	13	27	< 1 U	4.7	< 1 U	210	< 1	< 5 U	na	na
HMW-31 ^(HSA)	3/24/1998	14	< 5	23	< 5 U	< 5	< 2 U	210	< 5	< 10 U	na	na
HMW-31 ^(HSA)	9/22/1998	100	7.2	12	< 5 U	< 5	< 2 U	190	< 5	< 10 U	na	na
HMW-31 ^(HSA)	3/18/1999	16	< 5	16	< 5 U	< 5	< 2 U	200	< 5	< 10 U	na	na
HMW-31 ^(HSA)	8/30/2000	68	< 5	< 5	< 5 U	< 5	< 2 U	150	< 5	< 10 U	na	na
HMW-31 ^(HSA)	4/10/2003	120	10	1.6	< 1 U	< 1	< 1 U	100	< 1	< 5 U	na	na
HMW-31 ^(HSA)	11/30/2004	360	16	3.6	< 1 U	2	< 1 U	150	1.2	< 5 U	na	na
HMW-31 ^(HSA)	11/30/2004	340	17	5.9	< 1 U	1.8	< 1 U	120	1.2	< 5 U	na	na
HMW-31	11/4/2005	760	31	12.0	< 5 U	< 5 U	< 2 U	89	< 5 U	< 5 U	na	na
HMW-31 ^(HSA)	1/10/2007	580	26	7	< 1 U	< 1	< 1 U	50	< 1	< 5 U	na	na
HMW-31 ^(HSA)	9/30/2008	730	34	1.2	< 1 U	< 1	< 1 U	32	< 1	< 5 U	na	na

Table 9
Groundwater Laboratory Analytical Results for Monitoring Wells
 Twigg Manufacturing Facility
 Martinsville, Indiana

Well ID	Date	PCE (µg/L)	TCE (µg/L)	cis-1,2-DCE (µg/L)	trans-1,2-DCE (µg/L)	1,1-DCE (µg/L)	Vinyl Chloride (µg/L)	TCA (µg/L)	DCA (µg/L)	CA (µg/L)	Ethene (ug/L)	Ethane (ug/L)
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Notes

Test Method - SW 8260 and/or EPA 602 (undifferentiated)

PCE = tetrachloroethene

TCE = trichloroethene

c-DCE = cis-1,2-Dichloroethene

t-DCE = trans-1,2-Dichloroethene

1,1-DCE = 1,1-Dichloroethene

TCA = 1,1,1-Trichloroethane

DCA = 1,1-Dichloroethane

CAHs = Chlorinated Aliphatic Hydrocarbons

VC = Vinyl Chloride

CA = Chloroethane

U = not detected at the indicated reporting limit

UI = result migrated to database as ND; reporting limit not confirmed.

J = result or reported detection limit below reporting limit, value estimated

na = not analyzed for the indicated compound

E = result exceeds calibration range, value estimated

/HM = samples collected by Harman-Motive

S1 = Oxygen probe measured value as above saturation limit, recorded as saturated, 10.5 mg/L

S2 = Oxygen probe malfunction, value deleted as unreliable.

⁽¹⁾ Samples filtered in the field and analyzed for total iron - results assumed to be ferrous due to solubility.

a/ Volatile organic compound data from Microseeps, only used for CSIA data analysis because it is not a State certified laboratory and duplicate samples that were sent to both MicroSeeps and the State Certified Laboratory were generally not in agreement.

b/ Ethene and ethane data collected 5/29/2008

c/ Ethene and ethane data collected 5/28/2008

d/ Data collected from PBW-3 and MW-8 on 4/21/10 not used because contamination found in blank and data are from non-state-certified laboratory

Table 10
Groundwater Laboratory Analytical Results for Groundwater Probes
 Twigg Manufacturing Facility
 Martinsville, Indiana

Sampling Location	Sample Date	Easting ⁽¹⁾	Northing ⁽¹⁾	Depth ⁽¹⁾	Top of Screen (ft msl)	Bottom Of Screen (ft msl)	Ground Surface Elevation (ft msl) ⁽¹⁾	PCE (µg/L)	TCE (µg/L)	c-DCE (µg/L)	t-DCE (µg/L)	I,1-DCE (µg/L)	VC (µg/L)	TCA (µg/L)	DCA (µg/L)	CA (µg/L)	Mobile Lab
FP-1	12/4/1996	549416	4363151	16.9	588.6	586.6	603.5	< 1 U	< 1 U	< 1 U	na	na	na	< 1 U	< 1 U	na	x
	12/4/1996	549416	4363151	25.0	580.5	578.5	603.5	< 1 U	< 1 U	9	na	na	na	1,662	7	na	x
	12/4/1996	549416	4363151	35.0	570.5	568.5	603.5	< 1 U	< 1 U	15	na	na	na	3,513	7	na	x
	12/4/1996	549416	4363151	45.0	560.5	558.5	603.5	< 1 U	< 1 U	4	na	na	na	895	5	na	x
	12/4/1996	549416	4363151	15.0	590.5	588.5	603.5	< 2 U	< 2 U	< 2 U	< 2 U	na	na	< 2 U	< 2 U	< 2 U	
	12/4/1996	549416	4363151	25.0	580.5	578.5	603.5	< 2 U	< 2 U	19	< 2 U	na	na	3,100	89	< 2 U	
	12/4/1996	549416	4363151	35.0	570.5	568.5	603.5	< 2 U	< 2 U	44	< 2 U	na	na	8,000	660	< 2 U	
	12/4/1996	549416	4363151	45.0	560.5	558.5	603.5	< 2 U	< 2 U	27	< 2 U	na	na	2,700	700	< 2 U	
	3/3/1999	549416	4363151	56-60	547.5	543.5	603.5	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	27	4,900	26	
	3/3/1999	549416	4363151	71-75	532.5	528.5	603.5	< 1 J	< 1 J	< 1 J	< 1 J	8	< 1 J	< 20 U	< 20 U	< 1 J	
FP-2	3/3/1999	549416	4363151	90-94	513.5	509.5	603.5	< 1 J	< 1 J	< 1 J	< 1 J	6	< 1 J	180	74	< 1 J	
	12/4/1996	549511	4363161	17.4	588.6	586.6	604	< 1 U	< 1 U	< 1 U	na	na	na	< 1 U	< 1 U	na	x
FP-3	12/4/1996	549511	4363161	25.0	581.0	579.0	604	< 1 U	< 1 U	< 1 U	na	na	na	< 1 U	< 1 U	na	x
	12/4/1996	549605	4363162	17.4	588.6	586.6	604	< 1 U	< 1 U	< 1 U	na	na	na	< 1 U	< 1 U	na	x
	12/4/1996	549605	4363162	25.0	581.0	579.0	604	< 1 U	< 1 U	< 1 U	na	na	na	6	< 1 U	na	x
	12/4/1996	549605	4363162	35.0	571.0	569.0	604	< 1 U	0.5 J1	< 1 U	na	na	na	2,754	< 1 U	na	x
	5/3/1999	549605	4363162	65.0	544.0	539.0	604	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	5	< 1 J	< 1 J	
FP-4	5/3/1999	549605	4363162	85.0	524.0	519.0	604	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	
	12/4/1996	549825	4363340	17.1	589.9	587.9	605	< 1 U	< 1 U	< 1 U	na	na	na	< 1 U	< 1 U	na	x
FP-5	12/4/1996	549824	4363382	17.5	589.5	587.5	605	< 1 U	< 1 U	< 1 U	na	na	na	< 1 U	< 1 U	na	x
	12/4/1996	549824	4363382	35.0	572.0	570.0	605	< 1 U	< 1 U	< 1 U	na	na	na	< 1 U	< 1 U	na	x
FP-6	12/4/1996	549412	4363103	35.0	570.0	568.0	603	< 1 U	< 1 U	< 1 U	na	na	na	< 1 U	< 1 U	na	x
	5/3/1999	549412	4363103	93.0	515.0	510.0	603	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	
	5/3/1999	549412	4363103	93.0	515.0	510.0	603	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	
FP-7	12/4/1996	549425	4363200	35.0	571.0	569.0	604	< 1 U	< 1 U	< 1 U	na	na	na	1,320	< 1 U	na	x
FP-8	12/4/1996	549425	4363249	35.0	571.0	569.0	604	< 1 U	< 1 U	< 1 U	na	na	na	< 1 U	< 1 U	na	x
FP-9	12/4/1996	549256	4363111	35.0	571.0	569.0	604	< 1 U	< 1 U	< 1 U	na	na	na	< 1 U	< 1 U	na	x
FP-10	12/4/1996	549256	4363111	45.0	561.0	559.0	604	< 1 U	< 1 U	< 1 U	na	na	na	< 1 U	< 1 U	na	x
FP-11	4/9/1997	549825	4363296	20.0	587.0	585.0	605	< 1 U	< 1 U	< 1 U	na	na	na	7	< 1 U	na	x
	4/9/1997	549825	4363296	20.0	587.0	585.0	605	< 5 U	< 5 U	< 5 U	< 5 U	na	na	19	< 5 U	< 10 U	
FP-11	4/9/1997	549988	4363236	15.0	591.0	589.0	604	3	< 1 U	< 1 U				< 1 U	< 1 U	x	
	4/9/1997	549988	4363236	15.0	591.0	589.0	604	< 5 U	< 5 U	< 5 U	< 5 U	na	na	< 5 U	< 5 U	< 10 U	

Table 10
Groundwater Laboratory Analytical Results for Groundwater Probes
 Twigg Manufacturing Facility
 Martinsville, Indiana

Sampling Location	Sample Date	Eastings ⁽¹⁾	Northing ⁽¹⁾	Depth ⁽¹⁾	Top of Screen (ft msd)	Bottom Of Screen (ft msd)	Ground Surface Elevation (ft msd) ⁽²⁾	PCE (µg/L)	TCE (µg/L)	c-DCE (µg/L)	t-DCE (µg/L)	I,1-DCE (µg/L)	VC (µg/L)	TCA (µg/L)	DCA (µg/L)	CA (µg/L)	Mobil Lab
FP-12	4/9/1997	549213	4363142	25.0	581.3	579.3	604.3	< 1 U	< 1 U	< 1 U	na	na	na	5	< 1 U	na	x
	4/9/1997	549213	4363142	35.0	571.3	569.3	604.3	< 1 U	< 1 U	< 1 U	na	na	na	74	< 1 U	na	x
	4/9/1997	549213	4363142	45.0	561.3	559.3	604.3	< 1 U	< 1 U	< 1 U	na	na	na	109	< 1 U	na	x
	3/4/1999	549213	4363142	57-60	547.3	544.3	604.3	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	8	17	< 1 J	
	3/4/1999	549213	4363142	66-70	538.3	534.3	604.3	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	32	19	< 1 J	
	3/4/1999	549213	4363142	78-80	526.3	524.3	604.3	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	11	13	< 1 J	
	3/4/1999	549213	4363142	78-80 Dup	526.3	524.3	604.3	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	8	7	< 1 J	
FP-12A	5/24/2006	549213	4363141	28 - 32	576.3	572.3	604.3	< 5 U	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	
FP-12B	5/24/2006	549213	4363140	60-64	544.3	540.3	604.3	< 5 U	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	15	17	13	
FP-12B ^d	5/24/2006	549213	4363140	60-64	544.3	540.3	604.3	< 5 U	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	18	21	14	
FP-13	4/9/1997	549208	4363175	35.0	571.0	569.0	604	< 1 U	< 1 U	< 1 U	na	na	na	< 1 U	< 1 U	na	x
FP-14	4/9/1997	549186	4363201	35.0	571.0	569.0	604	< 1 U	< 1 U	< 1 U	na	na	na	< 1 U	< 1 U	na	x
FP-15	4/9/1997	548901	4363051	35.0	570.0	568.0	603	< 1 U	< 1 U	< 1 U	na	na	na	< 1 U	< 1 U	na	x
FP-16	4/9/1997	548902	4363119	35.0	570.0	568.0	603	< 1 U	< 1 U	< 1 U	na	na	na	< 1 U	< 1 U	na	x
FP-17	4/9/1997	548924	4363167	35.0	570.0	568.0	603	< 1 U	< 1 U	< 1 U	na	na	na	< 1 U	< 1 U	na	x
FP-18	4/9/1997	548902	4363011	20.0	585.0	583.0	603	< 1 U	< 1 U	< 1 U	na	na	na	< 1 U	< 1 U	na	x
FP-25	3/4/1999	549896	4363229	11-15	593.5	589.5	604.5	300	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	5	< 1 J	< 1 J	
	3/4/1999	549896	4363229	21-25	583.5	579.5	604.5	80	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	
	3/4/1999	549896	4363229	31-35	573.5	569.5	604.5	65	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	
FP-26	3/4/1999	549904	4363229	11-15	593.5	589.5	604.5	74	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	
FP-27	3/4/1999	549901	4363281	11-15	593.5	589.5	604.5	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	29	< 1 J	< 1 J	
FP-28	3/4/1999	549904	4363236	11-15	593.5	589.5	604.5	8	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	12	< 1 J	< 1 J	
	3/4/1999	549904	4363236	21-25	583.5	569.5	604.5	10	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	
	3/4/1999	549904	4363236	31-35	573.5	569.5	604.5	8	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	
FP-30	5/3/1999	549826	4363266	16-20	589.0	585.0	605	< 1 J	2	< 1 J	< 1 J	2	< 1 J	51	3	< 1 J	
FP-31	5/3/1999	549827	4363252	16-20	589.0	585.0	605	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	2	< 1 J	< 1 J	
FP-32	5/3/1999	549826	4363284	11-15	594.0	590.0	605	< 1 J	13	2	< 1 J	34	< 1 J	550	31	< 1 J	
	5/3/1999	549826	4363284	16-20	589.0	585.0	605	< 1 J	2	< 1 J	< 1 J	4	< 1 J	260	5	< 1 J	
	5/3/1999	549826	4363284	26-30	579.0	575.0	605	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	82	< 1 J	< 1 J	
FP-33	5/3/1999	549734	4363170	58.5-63.5 ^e	546.5	541.5	605	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	

Table 10
Groundwater Laboratory Analytical Results for Groundwater Probes
 Twigg Manufacturing Facility
 Martinsville, Indiana

Sampling Location	Sample Date	Easting ⁽¹⁾	Northing ⁽¹⁾	Depth ⁽¹⁾	Top of Screen (ft ms)	Bottom Of Screen (ft ms)	Ground Surface Elevation (ft ms) ⁽¹⁾	PCE (µg/L)	TCE (µg/L)	c-DCE (µg/L)	t-DCE (µg/L)	I,1-DCE (µg/L)	VC (µg/L)	TCA (µg/L)	DCA (µg/L)	CA (µg/L)	Mobil Lab
FP-34	5/3/1999	549596	4363226	31-35	573.5	569.5	604.5	< 1 J	< 1 J	< 1 J	< 1 J	23	< 1 J	610	3	< 1 J	
FP-35	5/3/1999	549601	4363124	31-35	573.5	569.5	604.5	< 1 J	< 1 J	8	1	24	< 1 J	460	4	< 1 J	
(FP-36 to 38 soil only)																	
FP-39	5/3/1999	549826	4363234	14-17	591.0	588.0	605	22	< 1 J	1	< 1 J	< 1 J	< 1 J	33	< 1 J	< 1 J	
FP-40	5/3/1999	549861	4363235	12-16	593.0	589.0	605	22	< 1 J	< 1 J	< 1 J	< 1 J	< 1 J	87	5	< 1 J	
FP-41	5/3/1999	549880	4363277	11-15	594.3	590.3	605.3	23	3	12	< 1 J	2	< 1 J	110	7	< 1 J	
FP-42	5/3/1999	549794	4363262	16-20	588.5	584.5	604.5	< 1 J	13	5	< 1 J	14	< 1 J	440	19	< 1 J	
FP-43	5/3/1999	549861	4363253	11-15	594.3	590.3	605.3	210	2	2	< 1 U	10	< 1 U	160	< 1 U	< 1 U	
FP-44	5/3/1999	549858	4363276	11-15	594.3	590.3	605.3	1	< 1 U	< 1 U	< 1 U	< 1 U	< 1 U	63	6	< 1 U	
FP-45	5/3/1999	549858	4363271	11-15	594.3	590.3	605.3	17	3	2	< 1 U	1	< 1 U	170	< 1 U	< 1 U	
FP-46	5/24/2006	549216	4363144	30-34	574.5	570.5	604.5	< 5 U	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	
FP-47	5/24/2006	549231	4363176	30-34	574.5	570.5	604.5	< 5 U	< 5 U	< 5 U	< 5 U	< 5 U	< 2 U	< 5 U	< 5 U	< 5 U	
SB-101 16"	12/1/08	549814	4363186	16	593.5	588.5	604.5	297	2.6	< 5 U	< 5 U	< 5 U	< 1 U	18	< 5 U	< 5 U	
SB-101 25"	12/1/08	549814	4363186	25	583.5	579.5	604.5	4,010	11	< 5 U	< 5 U	< 5 U	< 1 U	2180	< 5 U	< 5 U	
SB-101 35"	12/4/08	549814	4363186	35	573.5	569.5	604.5	17.3	23	< 5 U	< 5 U	29	< 1 U	7,320 E	18.4	< 5 U	
SB-101 50"	12/1/08	549814	4363186	50	558.5	554.5	604.5	< 2 U	< 2 U	< 5 U	< 5 U	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	
SB-102 16"	12/1/08	549804	4363207	16	594.0	589.0	605	27.4	< 2 U	< 5 U	< 5 U	< 5 U	< 1 U	8.4	< 5 U	< 5 U	
SB-102 25"	12/1/08	549804	4363207	25	584.0	580.0	605	4.3	< 2 U	< 5 U	< 5 U	< 5 U	< 1 U	22.9	< 5 U	< 5 U	
SB-102 50"	12/1/08	549804	4363207	50	559.0	555.0	605	5.4	< 2 U	< 5 U	< 5 U	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	
SB-103 16"	12/2/08	549786	4363242	16	594.0	589.0	605	263	172	7.7	< 5 U	< 5 U	< 1 U	31	< 5 U	< 5 U	
SB-103 25"	12/2/08	549786	4363242	25	584.0	580.0	605	< 2 U	< 2 U	< 5 U	< 5 U	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	
SB-103 35"	12/2/08	549786	4363242	35	574.0	570.0	605	< 2 U	< 2 U	< 5 U	< 5 U	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	
SB-103 50"	12/2/08	549786	4363242	50	559.0	555.0	605	< 2 U	< 2 U	< 5 U	< 5 U	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	
SB-104 16"	12/2/08	549775	4363274	16	593.5	588.5	604.5	< 2 U	< 2 U	< 5 U	< 5 U	< 5 U	< 1 U	16.8	< 5 U	< 5 U	
SB-104 25"	12/2/08	549775	4363274	25	583.5	579.5	604.5	< 2 U	< 2 U	< 5 U	< 5 U	< 5 U	< 1 U	13.0	< 5 U	< 5 U	
SB-104 50"	12/2/08	549775	4363274	50	558.5	554.5	604.5	< 2 U	< 2 U	< 5 U	< 5 U	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	
SB-105 16"	12/3/08	549826	4363156	16	594.0	589.0	605	1,640	4.4	< 5 U	< 5 U	< 5 U	< 1 U	6.0	< 5 U	< 5 U	
SB-105 35"	12/3/08	549826	4363156	35	574.0	570.0	605	864	4.4	< 5 U	< 5 U	< 5 U	< 1 U	16.2	< 5 U	< 5 U	
SB-105 50"	12/3/08	549826	4363156	50	559.0	555.0	605	43	< 2 U	< 5 U	< 5 U	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	
SB-106 16"	12/3/08	549825	4363302	16	594.0	589.0	605	< 2 U	< 2 U	< 5 U	< 5 U	< 5 U	< 1 U	< 5 U	< 5 U	< 5 U	

Table 10
Groundwater Laboratory Analytical Results for Groundwater Probes
 Twigg Manufacturing Facility
 Martinsville, Indiana

Sampling Location	Sample Date	Easting ⁽¹⁾	Northing ⁽¹⁾	Depth ⁽¹⁾	Top of Screen (ft msd)	Bottom Of Screen (ftmsd)	Ground Surface Elevation (ft msd) ⁽²⁾	PCE (µg/L)	TCE (µg/L)	c-DCE (µg/L)	t-DCE (µg/L)	I,1-DCE (µg/L)	VC (µg/L)	TCA (µg/L)	DCA (µg/L)	CA (µg/L)	Mobil Lab
SB-106 25"	12/3/08	549825	4363302	25	584.0	580.0	605	< 2	U	< 2	U	< 5	U	< 5	U	< 5	U
SB-107 16"	12/3/08	549840	4363129	16	594.0	589.0	605	< 2	U	< 2	U	< 5	U	< 5	U	< 5	U
SB-107 25"	12/3/08	549840	4363129	25	584.0	580.0	605	< 2	U	< 2	U	< 5	U	< 5	U	< 5	U
SB-108 16"	12/4/08	549951	4363174	16	593.0	588.0	604	608	< 2	U	< 5	U	< 5	U	< 5	U	U
SB-108 25"	12/4/08	549951	4363174	25	583.0	579.0	604	185	< 2	U	< 5	U	< 5	U	< 5	U	U
SB-109 16"	12/5/08	549725	4363158	16	594.0	589.0	605	96.5	10	< 5	U	< 5	U	6.4	< 5	U	U
SB-109 25"	12/5/08	549725	4363158	25	584.0	580.0	605	< 2	U	< 2	U	< 5	U	< 5	U	< 5	U
SB-110 16"	12/5/08	549656	4363131	16	593.5	588.5	604.5	< 2	U	< 2	U	< 5	U	< 5	U	< 5	U
SB-110 25"	12/5/08	549656	4363131	25	583.5	579.5	604.5	< 2	U	< 2	U	< 5	U	12.6	< 5	U	U
SB-111 16"	12/5/08	549654	4363164	16	593.5	588.5	604.5	< 2	U	< 2	U	< 5	U	< 5	U	< 5	U
SB-111 25"	12/5/08	549654	4363164	25	583.5	579.5	604.5	< 2	U	< 2	U	< 5	U	5.2	< 5	U	U
SB-112 16"	12/5/08	549653	4363217	16	593.5	588.5	604.5	< 2	U	< 2	U	< 5	U	< 5	U	< 5	U
SB-112 25"	12/5/08	549653	4363217	25	583.5	579.5	604.5	< 2	U	< 2	U	5.0	< 5	< 5	U	< 5	U
SB-113 16"	12/5/08	549653	4363250	16	593.5	588.5	604.5	2.8	< 2	U	< 5	U	< 5	< 5	U	< 5	U
SB-113 25"	12/5/08	549653	4363250	25	583.5	579.5	604.5	< 2	U	< 2	U	< 5	U	< 5	U	< 5	U
SB-114 16"	12/4/08	549962	4363227	16	593.0	588.0	604	< 2	U	< 2	U	< 5	U	< 5	U	< 5	U
SB-114 25"	12/4/08	549962	4363227	25	583.0	579.0	604	< 2	U	< 2	U	< 5	U	< 5	U	< 5	U
SB-115 16"	12/4/08	549952	4363193	16	593.0	588.0	604	< 2	U	< 2	U	< 5	U	< 5	U	< 5	U
SB-115 16" D	12/4/08	549952	4363193	16	593.0	588.0	604	< 2	U	< 2	U	< 5	U	< 5	U	< 5	U
SB-115 25"	12/4/08	549952	4363193	25	583.0	579.0	604	< 2	U	< 2	U	< 5	U	< 5	U	< 5	U
SB-115 25" D	12/4/08	549952	4363193	25	583.0	579.0	604	< 2	U	< 2	U	< 5	U	< 5	U	< 5	U

J1 - Reported as "BMDL", thus value estimated as one-half of the reported DL.

E - Reported value is estimated due to linear range exceedence. Reported concentration estimated from a 20x dilution. Not considered valid.

⁽¹⁾ Easting & Northing based on Google Earth coordinates.

⁽²⁾ Ground surface elevation estimated from nearby monitoring wells.

⁽³⁾ Bottom of screened interval. Screened intervals varied from 2 to 5 feet as indicated and methods included

1" pvc temporary casing and retractable Geoprobe screen.

/d = Duplicate

Table 11
Chlorinated Ethene and Ethane Concentration Trends in Individual Wells*
 Twigg Manufacturing Facility
 Martinsville, Indiana

Well Identification	Installation Date	Concentration Trend for Ethenes	Concentration Trend for Ethanes	Source
Wells with 10 or More Years of Data				
MW-1S	8/9/1994	Decreasing	ND†	Figures 51 and 52
MW-1D	2/24/1998	Decreasing	ND†	Table 9
MW-2	8/10/1994	ID	ID	Table 9
MW-3	8/9/1994	Decreasing	Decreasing	Figure 53
MW-4	12/14/1994	Decreasing	Decreasing	Figures 51 and 52
MW-5	9/29/1997	ND	ND	Table 9
MW-6	9/30/1997	Stable	Decreasing	Figures 51 and 52
MW-6D	2/23/1998	Decreasing/ND‡	Decreasing/ND†	Figures 51 and 52
MW-7	10/1/1997	ND	ND	Table 9
MW-8	10/1/1997	ND/Stable ^a	Stable ^b	Figures 51 and 52
MW-9	2/23/1998	Decreasing/ND	ND	Table 9
MW-10S	4/13/1999	Decreasing	Decreasing/ND	Figure 54
MW-10M	4/6/1999	Decreasing/ND‡	ND	Table 9
MW-11	5/3/2000	Stable	Decreasing	Figure 55
MW-12	5/2/2000	Stable/Increasing ^c	Decreasing	Figure 56
Wells with 7 Years of Data				
MW-13	4/27/2004	Decreasing	ND ^d	Figures 51 and 52
MW-14	4/27/2004	Decreasing	Decreasing/ND ^e	Figures 51 and 52
Wells with 5 Years of Monitoring Data				
MW-15	3/1/2006	Decreasing	Decreasing	Figure 57
MW-16	3/1/2006	Stable	Decreasing	Figure 58
MW-17	3/1/2006	Decreasing	Decreasing	Figure 59
MW-18	3/1/2006	Decreasing	Decreasing	Figure 60
MW-19	3/1/2006	Decreasing	Decreasing	Figure 61

Notes:

* Based on visual inspection of available data.

Does not include wells installed expressly for Bioremediation Pilot Testing Extraction or Injection

ID - Insufficient data.

ND - Chlorinated aliphatic hydrocarbons not detected in this well

† Not Detected Since 1999

‡ Not Detected Since 2002

^a/ Bioremediation pilot testing appears to have released minor amounts of PCE from soil which were then degraded.

One anomalously high (15.3 µg/L) detection of TCE in 10/16/09.

Concentrations of PCE, TCE, and cis-1,2-DCE were all ND in 2011

^b/ Peak total ethane concentrations under "natural" conditions appear to have peaked just before bioremediation pilot testing in this area (6/2006). It is not clear if pilot testing released ethanes from soil in the vicinity of MW-8. TCA concentration appears stable since about July 2007

Additional monitoring will be required to confirm trends in this well.

^c/ Concentrations may have stabilized since October 2007 when anomalously high concentrations were seen Site-wide.

^d/ One detection of 1,1-DCE (6 µg/L) and one detection of CA (8 µg/L). TCA not detected in this well.

^e/ Chlorinated ethanes have not been detected in this well since 4/2005.

Table 12
Compound-Specific Isotope Analytical Results
 Twigg Manufacturing Facility
 Martinsville, Indiana

	Date	Distance Down- gradient from MW- 1S (ft)	Distance From Previous Point (ft)	$\delta^{13}\text{C}$ for PCE (‰)	$\delta^{13}\text{C}$ for TCE (‰)	$\delta^{13}\text{C}$ for <i>cis</i> -1,2- DCE (‰)	$\delta^{13}\text{C}$ for <i>trans</i> - 1,2-DCE (‰)	$\delta^{13}\text{C}$ for 1,1- DCE (‰)	$\delta^{13}\text{C}$ for Vinyl Chloride (‰)	$\delta^{13}\text{C}$ for 1,1,1- TCA (‰)	$\delta^{13}\text{C}$ for 1,1- DCA (‰)	$\delta^{13}\text{C}$ for CA (‰)
MW-1S	2/3/2011	0	0	-36.22	na	na	na	na	na	na	na	na
MW-13	4/21/2010	53	53	-31.97	U	U	na	U	na	U	U	U
MW-13	2/4/2011	53	53	-33.75	na	na	na	na	na	na	na	na
PMW-1	4/22/2010	72	19	-32.45	U	-33.83	na	U	na	U	U	U
PMW-1	2/4/2011	72	19	U	U	-35.46	na	na	na	na	na	na
MW-14	4/22/2010	110	38	-28.67	-27.85	-33.69	na	U	na	U	U	U
MW-14	2/4/2011	110	38	-28.51	-28.12	-33.56	na	na	na	na	na	na
MW-4	4/22/2010	250	140	-31.26	-36.45	-34.88	na	U	na	-27.85	U	U
MW-4	2/10/2011	250	140	-32.66	-36.02	-38.32	na	na	na	-36.55 ^{a/}	na	na
MW-19	4/22/2010	452	207	-29.5	-33.01	-27.15	na	U	na	-29.24	U	U
MW-19	2/9/2011	452	207	-29.85	-31.5	-33.6	na	na	na	-34.35	na	na
MW-6	4/21/2010	1,553	1,101	U	-18.54	-33.65	na	-26.82	na	-28.76	-36.52	U
MW-6	2/10/2011	1,553	1,101	-39.73 ^{a/}	-23.37	-32.75	na	-28	na	-30.86	-37.11	na
PBW-3 ^{c/}	4/21/2010	2204	667	U	U	-22.79	na	-14.76	na	-15.84	-28.74	-17.00
PBW-3	1/31/2011	2204	667	U	U	-21.96	na	-14.73	na	-25.61	-30.71	-14.73
PBW-3 ^{b/}	1/31/2011	2204	667	U	U	U	na	-15.2	na	-26.16	-30.96	-14.84
MW-8 ^{d/}	4/21/2010	2219	15	U	U	-22.79	na	-16.58	na	-18.83	-31.59	-14.64
MW-8	1/31/2011	2219	15	U	U	-23.13	na	-17.2	na	-30.01	-31.01	-15.38

Notes:

For non-detect values the following rules were applied unless otherwise indicated:

- If the compound *was* detected within 2 years of the current sampling event, then 1/2 the detection limit was used for data analysis
- If the compound was *not* detected within 2 years of the current sampling event, then a value of zero (0) was used for data analysis

na = Analyte not analyzed because of historical non-detectable concentrations

‰ = per mil

U = not detected at the indicated reporting limit

a/ Data not used because compound present in non-detectable concentrations in State-certified analytical laboratory sample and because value is anomol

b/ Data not used because isotope data for *cis*-1,2-DCE not available.

c/ A value of 17 was used for 1,1-DCE because this compound was found in the blank and because a similar concentration has been historically observed in this well.

d/ a *cis*-1,2-DCE concentration of 2.5 was used for CSIA data analysis because of historical trends and the high detection limit and a 1,1-DCE concentration of 18 was used based on historical trends because this compound was found in the blank.

PCE = tetrachloroethene

TCE = trichloroethene

c-DCE = *cis*-1,2-Dichloroethene

t-DCE = *trans*-1,2-Dichloroethene

1,1-DCE = 1,1-Dichloroethene

TCA = 1,1,1-Trichloroethane

DCA = 1,1-Dichloroethane

CAHs = Chlorinated Aliphatic Hydrocarbons

VC = Vinyl Chloride

CA = Chloroethane

Table 13

Groundwater Geochemical Data

Twigg Manufacturing Facility
Martinsville, Indiana

Well ID	Date	Dissolved Oxygen (mg/L)	Nitrate and Nitrite (mg/L)	Ferrous Iron ^(II) (mg/L)	Sulfate (mg/L)	Sulfide (mg/L)	Methane (ug/L)	Ethane (ug/L)	Ethene (ug/L)	Temperature		Conductivity (uS/cm)	ORP (mV)	Chloride (mg/L)	Total Organic Carbon (mg/L)	Total Inorganic Carbon (mg/L)	Acetylene (ug/L)	Total Alkalinity (mg/L)
										°C	°F							
MW-1S	8/16/2001	10.5 S1	4.7	0.24	23					17.6	63.6	6.94	-25.3					
	10/21/2004	7.9								18.9	66.0	7.19	-49.1					
	10/20/2005	10.6	10.4	< 0.5	21.0					18.9	66.0	7.72	34					
	1/11/2006	10.5 S1										7.16	6					
	3/15/2006	8.3								13.5	56.3	7.56	67					
	6/6/2006	10.5 S1								14.6	58.3	7.16	280					
	1/9/2007											8.07	21					
	5/23/2007	10.5								13.7	56.7	7.47	364					
	9/4/2007	10.5 S1								18.0	64.3	7.78	545					
	10/26/2007	10.3								13.0	55.4	7.19	65					
MW-1D	2/3/2011	4.8	13.9	< 0.20	44							0.645	94.7	13	1.16	59.1		240
	8/14/2001	3.2	0.2	0.35	23					15.0	59.0	7.14	-113.1					
	10/19/2005	3.2								18.8	65.9	7.35	-2.4					
	10/25/2007	4.0								14.6	58.2	7.33	-130					
	2/3/2011	0.5	< 0.1	1.00	34					14.3	57.7	7.01	-90.3	70	< 1	76.3		220
MW-2	2/8/2011	1.1	8.69	< 0.20	23					14.9	58.8	7.18	183.0	< 5	1.07	52.3		230
MW-3	11/4/2005	1.5								20.2	68.3	7.43	102.9					
	10/13/2006									20.2	68.4	8.09	-14					
	10/25/2007	4.3								19.7	67.4	7.34	130					
	2/8/2011	5.2	16.8	< 0.20	31					11.7	53.1	7.23	169.7	25	2.33	51.8		20
	8/16/2001	S2	5.6	< 0.1	18					14.9	58.8	7.03	-28.9					
	10/19/2005	4.3								16.4	61.4	7.46	153					
	1/11/2006	3.5										7.28	10					
MW-4	3/15/2006	2.7	7.5	< 0.5	25.6					14.4	57.9	7.52	31					
	4/11/2006	3.2										0.482	34					
	6/6/2006	10.5 S1								14.1	57.5	7.00	243					
	10/13/2006									15.7	60.3	8.30	-84					
	1/9/2007											0.567	61					
	5/23/2007	3.4								13.6	56.5	7.42	352					
	9/4/2007	0.5										0.522	333					
	10/26/2007	2.5								16.4	61.5	7.62	-61					
	4/22/2010	8.2										0.317	350					
	2/10/2011	1.9	9.55	< 0.20	25		< 10.0	< 10.0	< 10.0	14.6	58.2	7.58	312.8	16	1.33	52.0		240
MW-5	2/10/2011	1.9	10.2	< 0.20	25		< 10.0	< 10.0	< 10.0	14.6	58.2	7.58	312.8	16	1.45	54.0		230
	8/14/2001	S2								14.3	57.7	6.93	-75.3					
	10/19/2005	2.3								19.4	66.8	7.32	42.7					
MW-6	1/31/2011	0.5	6.77	< 0.20	43					14.8	58.7	6.96	260.1	36	1.8	77.4		330
	8/16/2001	4.7	5.5	< 0.1	22					14.9	58.7	7.01	-40.1					

Table 13
Groundwater Geochemical Data
Twigg Manufacturing Facility
Martinsville, Indiana

Well ID	Date	Dissolved Oxygen (mg/L)	Nitrate and Nitrite (mg/L)	Ferrous Iron ^{II} (mg/L)	Sulfate (mg/L)	Sulfide (mg/L)	Methane (ug/L)	Ethane (ug/L)	Ethene (ug/L)	Temperature		Conductivity (uS/cm)	ORP (mV)	Chloride (mg/L)	Total Organic Carbon (mg/L)	Total Inorganic Carbon (mg/L)	Acetylene (ug/L)	Total Alkalinity (mg/L)
										°C	°F							
	10/19/2005	1.3								17.5	63.5	7.12	0.578	52				
	10/13/2006									15.2	59.4	8.30	0.628	-65				
	10/25/2007	0.9								15.4	59.7	7.48	0.326	-172				
	2/10/2011	0.2	7.24 < 0.20	40			45.4 < 10.0	< 10.0		15.3	59.6	7.46	0.676	310.8	30	1.78	60.7	260
	2/10/2011	0.2	7.21 < 0.20	42			45.5 < 10.0	< 10.0		15.3	59.6	7.46	0.676	310.8	30	1.84	60.9	250
MW-6D	8/14/2001	0.3	0.5	0.14	< 5					14.4	57.9	7.63	0.459	-174.5				
	10/19/2005	1.4								16.6	61.9	7.08	0.578	28				
	4/21/2010	2.3								14.9	58.9	6.89	0.553	-131.7				
	1/31/2011	0.3	< 0.1	2.40	< 15					14.5	58.2	7.26	0.675	-125.5	38	2.79	73.6	300
MW-7	8/14/2001	4.2								14.6	58.2	6.72	0.652	-52.9				
	10/19/2005	5.8								17.0	62.5	7.06	0.630	0.3				
	1/31/2011	2.8	8.27 < 0.20	25						13.8	56.8	7.08	0.759	334.6	40	1.61	75.1	310
MW-8	8/15/2001	0.6	0.1	< 0.1	42					14.8	58.6	7.24	0.670	-102.1				
	10/19/2005	4.8								19.4	66.9	7.38	0.792	44.3				
	3/15/2006	3.5	< 0.5	1.3	50					14.9	58.8	7.18	0.756	-21				
	6/6/2006	S2								15.1	59.1	7.03	0.704	-15				
	9/6/2006											7.29		-176				
	10/6/2006											7.34	0.898	-116				
	10/12/2006									14.9	58.8	8.13	0.899	-154				
	12/11/2006											7.51	0.914	-191				
	1/9/2007											7.60	0.882	-168				
	2/12/2007			2.3	43	< 0.05	18	0.44	0.09			7.36	0.823	-137				
	3/26/2007	0.6										7.29	1.008	-84				
	5/23/2007	0.5		3.2	36	< 0.05				17.2	63.0	7.26	1.000	34				
	6/26/2007	0.0											0.703	-120				
	7/25/2007	0.5										6.79	0.696	62				
	9/12/2007	0.3	< 0.1	27	0.34							7.27	0.696	-187				
	10/26/2007	0.9								14.6	58.3	7.35	0.445	-172				
	12/4/2007		< 0.1	38	0.31													
	2/5/2008	0.4		2.0	33	0.39				14.0	57.3	6.96	0.810	-172				
	4/15/2008			1.1	35	0.60				15.4	59.7	6.48	0.798	-223				
	10/16/2009	1.0																
	4/21/2010	0.3			0.14							7.06	0.339	-222				
	9/8/2010	0.3																
	1/31/2011	0.2	< 0.1	0.21	54		210	< 10.0	< 10.0	13.6	56.4	7.06	1.110	-277.8	178	1.17	74.2	310
MW-9	8/14/2001	8.4	6.6	< 0.1	34					16.5	61.7	7.05	0.451	-10.8				
	10/20/2005	4.9	12.2	< 0.5	42.2					19.3	66.7	7.39	0.518	32				
	2/8/2011	5.0	4.45	< 0.20	< 15					14.1	57.4	7.22	0.473	148.7	< 5	1.31	54.7	240

Table 13

Groundwater Geochemical Data

Twigg Manufacturing Facility
Martinsville, Indiana

Well ID	Date	Dissolved Oxygen (mg/L)	Nitrate and Nitrite (mg/L)	Ferrous Iron ⁽¹⁾ (mg/L)	Sulfate (mg/L)	Sulfide (mg/L)	Methane (ug/L)	Ethane (ug/L)	Ethene (ug/L)	Temperature		Conductivity (uS/cm)	ORP (mV)	Chloride (mg/L)	Total Organic Carbon (mg/L)	Total Inorganic Carbon (mg/L)	Acetylene (ug/L)	Total Alkalinity (mg/L)
										°C	°F							
MW-10S	8/16/2001	S2								19.3	66.7	7.16	-28.3					
	10/20/2005	6.8								20.5	68.9	6.92	-105.4					
	6/6/2006	10.8								17.6	63.8	7.19	275					
	1/9/2007											7.69	58					
	5/23/2007	7.8								17.2	63.0	7.47	241					
MW-10M	9/4/2007	7.9										7.01	-434					
	2/3/2011	6.2	6.6	< 0.20	29					18.5	65.4	7.12	124.5	9	1.79	57.2		240
	8/14/2001	0.7								16.2	61.2	7.42	-81.1					
	10/19/2005	4.6								21.3	70.4	7.39	-41.4					
	2/3/2011	0.5	0.88	0.21	45					16.4	61.6	7.01	8.3	73	< 1	69.2		270
MW-11	8/15/2001	1.4								19.9	67.7	7.18	-46.7					
	11/4/2005	1.3								19.0	66.2	7.39	95.5					
	2/3/2011	1.0	17.5	< 0.20	39		< 10.0	< 10.0	< 10.0	19.5	67.0	7.05	110.2	18	1.43	56.1		240
	8/15/2001	0.7								20.4	68.8	7.20	-51.3					
	10/19/2005	3.1								19.7	67.5	7.46	101.5					
MW-12	10/13/2006									20.2	68.3	8.20	-45					
	10/25/2007	0.7								20.0	68.0	7.49	57					
	2/8/2011	0.7	5.98	< 0.20	31					15.9	60.6	7.07	203.2	39	1.15	65.2		280
	10/20/2005	10.1	11.2	< 0.5	21.0					17.4	63.4	7.64	20					
	1/11/2006	10.5	S1									7.31	-40					
MW-13	8/11/2006														2.4			
	10/12/2006									16.8	62.2	7.96	50					
	2/5/2008	1.4										7.19	33					
	4/21/2010	2.0		< 0.5	35	< 0.05				12.0	53.7	7.07	89					
	2/4/2011	4.1	10.2	< 0.20	35		< 10.0	< 10.0	< 10.0	14.2	57.6	7.28	131.4	13	1.2	52.6		240
MW-14	10/20/2005	1.5	1.39	< 0.5	19.2	< 0.1	5800	< 20	< 20	16.7	62.0	7.55	-144					
	11/16/2005	2.3										7.16	-148					
	1/11/2006	0.8										7.02	-137					
	3/10/2006	2.5										7.06	-114					
	3/15/2006	2.5	0.68	3.2	57.9					13.1	55.6	7.06	0.425					
	6/6/2006	9.4								15.3	59.5	7.19	-48					
	6/21/2006	1.5								15.7	60.3	7.05	6					
	7/11/2006											7.04	216					
	10/12/2006									15.6	60.2	7.85	-95					
	1/9/2007											7.71	-174					
	5/23/2007	0.3								13.1	55.6	7.35	190					
	9/4/2007	0.9										7.15	-179					
	10/25/2007	1.6								16.1	61.0	7.24	-175					

Table 13

Groundwater Geochemical Data

Twigg Manufacturing Facility
Martinsville, Indiana

Well ID	Date	Dissolved Oxygen (mg/L)	Nitrate and Nitrite (mg/L)	Ferrous Iron ^(II) (mg/L)	Sulfate (mg/L)	Sulfide (mg/L)	Methane (ug/L)	Ethane (ug/L)	Ethene (ug/L)	Temperature		Conductivity (uS/cm)	ORP (mV)	Chloride (mg/L)	Total Organic Carbon (mg/L)	Total Inorganic Carbon (mg/L)	Acetylene (ug/L)	Total Alkalinity (mg/L)
										°C	°F							
	2/5/2008	0.6										6.87	-1.79					
	4/22/2010	2.8		0.2	61	< 0.05				12.1	53.8	7.05	-32					
	9/8/2010	2.2								16.0	60.8	7.06	-59					
	2/4/2011	0.3	1.36	0.33	59		11.9	< 10.0	< 10.0	14.3	57.7	7.07	-71.2	14	1.66	62.0		260
MW-15	3/15/2006	1.4								15.2	59.4	7.26	71					
	10/13/2006									16.0	60.9	8.22	-60					
	10/25/2007	0.9								15.9	60.6	7.50	60					
	2/9/2011	0.4	3.39	< 0.20	33					15.9	60.7	7.21	296.0	32	1.07	58.4		240
MW-16	3/15/2006	1.1								16.3	61.3	7.18	-35					
	10/13/2006									17.4	63.4	8.08	-83					
	10/25/2007	0.5								17.2	62.9	7.52	-108					
	2/9/2011	0.4	3.96	< 0.20	38	< 10.0	< 10.0	< 10.0	< 10.0	15.8	60.5	7.24	166.3	49	1.28	63.2		230
MW-17	3/15/2006	4.1								15.4	59.8	7.39	71					
	10/13/2006									16.7	62.0	8.37	-39					
	10/25/2007	1.0								16.7	62.0	7.56	66					
	2/10/2011	0.5	5.32	< 0.20	67					15.4	59.8	7.24	239.4	17	1.32	66.8		240
MW-18	3/15/2006	1.8	10.1	< 0.5	30.3					14.4	58.0	7.35	90					
	4/11/2006	4.1										7.17	68					
	6/6/2006	9.4								13.8	56.9	6.85	272					
	10/13/2006									16.0	60.8	8.23	-18					
MW-19	1/9/2007											7.68	76					
	5/23/2007	1.6								13.2	55.8	7.39	742					
	9/4/2007											5.28	535					
	10/26/2007	1.2								15.6	60.2	7.53	-29					
MW-19	2/10/2011	0.8	9.96	< 0.20	34					14.4	57.8	7.49	287.7	10	2.88	51.8		260
	3/15/2006	2.4								14.4	58.0	7.34	88					
	10/12/2006									16.3	61.3	8.07	-35					
	10/26/2007	3.9								15.9	60.6	7.31	121					
PBW-1	4/22/2010	2.9		< 0.1	29	< 0.05				12.5	54.5	7.07	232					
	9/8/2010	2.7								16.7	62.1	6.82	44.9					
	2/9/2011	0.8	7.65	< 0.20	32		< 10.0	< 10.0	< 10.0	14.0	57.3	7.36	166.7	24	1.66	60.6		230
	6/15/2004						< 20	< 20	< 10									
PBW-1	8/19/2004											6.04	540					
	9/15/2004											6.74	125					
	10/19/2004	6.0											40					
	10/20/2005	3.4	< 0.5	29.8	17.2	9.01	3980	< 20	< 20			5.63	0.954					
	1/16/2005	3.5										6.17	1.768					
	1/11/2006	6.3					2710	< 20	< 20			6.88	1.385					

Table 13
Groundwater Geochemical Data
Twigg Manufacturing Facility
Martinsville, Indiana

Well ID	Date	Dissolved Oxygen (mg/L)	Nitrate and Nitrite (mg/L)	Ferrous Iron ^{II} (mg/L)	Sulfate (mg/L)	Sulfide (mg/L)	Methane (ug/L)	Ethane (ug/L)	Ethene (ug/L)	Temperature		Conductivity (uS/cm)	ORP (mV)	Chloride (mg/L)	Total Organic Carbon (mg/L)	Total Inorganic Carbon (mg/L)	Acetylene (ug/L)	Total Alkalinity (mg/L)
										°C	°F							
	3/10/2006	8.6								13.2	55.8	7.05	5,800	-196				
	4/11/2006	6.5										6.85		-213				
	6/6/2006		S2									6.97						
	6/21/2006	6.3										6.88		-42				
	7/11/2006											5.13		89				
	8/11/2006			58	< 0.1							6.57		-61	81.8			
	9/6/2006											7.15		25				
	10/12/2006											7.40		-117				
	11/20/2006			32	< 15	15.6						8.45		-152				
	12/11/2006											6.64		-275				
PBW-1R	1/9/2007			< 15	< 0.05							7.47	0.979	-158				
	2/12/2007			22.9	< 15	< 0.05	15000	0.12	0.17			6.82	1.18	-164				
	5/23/2007	0.2		< 15	< 0.05							5.74	20.150	-132				
	6/26/2007	0.0											1.584	-155				
	7/25/2007	5.2										5.42	12.200	-441				
	9/4/2007	5.7										6.65	0.830	-163				
	9/12/2007	1.6		6.4	184	6.6						6.87	1.182	-139				
	10/25/2007	3.3										7.00	0.629	-189				
	12/4/2007			0.4	248	5.6												
	1/8/2008	5.7										6.68	1.314	-224				
PBW-2	2/5/2008	5.9		150.0	< 75	6				13.3	55.9	6.64	0.734	-261				
	2/4/2011	0.3	< 0.1	< 0.20	75							7.01	0.699	-216.9	14	6.8	67.1	290
	6/15/2004						< 20	< 20	14									
	8/19/2004											4.94		623				
	9/15/2004											6.80		115				
	10/7/2004	4.3										7.38		46				
	11/18/2004	0.0										7.30		16				
	12/14/2004											7.20		-128				
	1/27/2005	0.0										7.28		-165				
	2/17/2005											7.50		-189				
	3/29/2005	10.5					169	< 20	< 20			7.60		-149				
	4/20/2005	0.0					1390	< 20	< 20			7.01		-186				
	5/23/2005						4200	< 20	< 20									
	6/28/2005	0.4					7490	< 20	< 20			7.30		-232				
	8/1/2005	0.0					3150	< 20	< 20			7.21		-220				
	8/29/2005	0.2					1660	< 20	< 20			7.05		-217				
	9/23/2005	0.0										6.75		-213				
	10/20/2005	1.5	< 0.5	3.2	23.6	< 0.2	6650	< 20	< 20			7.29		-234				
	11/16/2005	2.0										6.99		-212				

Table 13

Groundwater Geochemical Data

Twigg Manufacturing Facility
Martinsville, Indiana

Well ID	Date	Dissolved Oxygen (mg/L)	Nitrate and Nitrite (mg/L)	Ferrous Iron ^(II) (mg/L)	Sulfate (mg/L)	Sulfide (mg/L)	Methane (ug/L)	Ethane (ug/L)	Ethene (ug/L)	Temperature		Conductivity (uS/cm)	ORP (mV)	Chloride (mg/L)	Total Organic Carbon (mg/L)	Total Inorganic Carbon (mg/L)	Acetylene (ug/L)	Total Alkalinity (mg/L)
										°C	°F							
	1/11/2006	4.8										6.92	-169					
	3/10/2006	2.8										6.98	-141					
	4/11/2006	4.0										6.60	-134					
	6/6/2006											7.07	-116					
	6/21/2006	1.1										6.95	-91					
	7/11/2006											7.07	-39					
	8/11/2006				148	< 0.1												
	9/6/2006											7.28	-89					
	10/6/2006											7.05	-53					
	10/12/2006											7.93	-182					
	11/20/2006			73	< 15	0.06						8.40	-143					
	12/11/2006											7.31	-229					
	1/9/2007				< 15	< 0.05						7.38	-165					
	2/12/2007			33.6	< 15	< 0.05	19000	0.10	0.16			7.15	-177					
	3/26/2007											7.27	-8					
	5/23/2007			29.9	182	< 0.05						6.83	22					
	6/26/2007	0.0										6.614	-147					
	7/25/2007	2.4		9.3	930	2.3						6.19	-320					
	9/4/2007	2.7										7.12	-220					
	9/12/2007	2.4		< 0.1	28	0.07						7.14	-165					
	10/25/2007	1.2										7.18	-190					
	12/4/2007	1.3		0.1	46	0.07						6.92	-168					
	1/8/2008	1.3										6.59	-168					
	2/5/2008	0.9		10.3	53	< 0.05						6.86	-187					
	4/15/2008			15.9	34	< 0.05												
	2/4/2011	0.3	< 0.1	0.58	94					13.0	55.4	7.16	-143.5	14	2.13	63.3		270
PBW-3	8/11/2006	3.5										7.10	5					
	9/6/2006											7.24	23					
	10/6/2006											7.41	-93					
	10/12/2006											8.28	-244					
	12/11/2006											7.56	-286					
	1/9/2007											7.49	-191					
	2/12/2007											7.31	-299					
	3/26/2007	0.4										6.66	-143					
	5/23/2007	5.2		1.6	27	2.8						7.17	-69					
	6/26/2007	0.0										0.719	-220					
	7/25/2007	1.8		0.8	30	2.5						6.56	-147					
	10/26/2007	0.6										6.97	-216					
	12/4/2007	0.3		0.6	< 15	9.1						7.23	-270					

Table 13
Groundwater Geochemical Data
Twigg Manufacturing Facility
Martinsville, Indiana

Well ID	Date	Dissolved Oxygen (mg/L)	Nitrate and Nitrite (mg/L)	Ferrous Iron ^(II) (mg/L)	Sulfate (mg/L)	Sulfide (mg/L)	Methane (ug/L)	Ethane (ug/L)	Ethene (ug/L)	Temperature		pH	Conductivity (uS/cm)	ORP (mV)	Chloride (mg/L)	Total Organic Carbon (mg/L)	Total Inorganic Carbon (mg/L)	Acetylene (ug/L)	Total Alkalinity (mg/L)
										°C	°F								
PBW-4	2/5/2008	0.7		2.1	18	2.6						6.78	0.344	-220					
	10/16/2009	1.1										7.12	0.753	-286					
	4/21/2010	0.3		0.8	49	4.7				14.7	58.4	6.86	0.825	-315					
	9/8/2010	0.2								18.0	64.5	6.51	0.797	-350					
	1/31/2011	0.2	< 0.1	0.27	51		3020	< 10.0	< 10.0	13.9	56.9	7.00	1.111	-298.2	163	4.02	76.1		300
	8/11/2006											7.14		-18					
	9/6/2006											6.97		-250					
	10/6/2006											6.97	0.903	-6					
	10/12/2006											8.12	0.905	-163					
	12/11/2006											7.47	0.920	-172					
PMW-1	1/9/2007											7.36	0.889	-73					
	2/12/2007											7.32	0.816	-77					
	3/26/2007	1.3										7.41	0.989	-65					
	5/23/2007	0.8										7.23	0.990	155					
	6/26/2007	0.0											0.706	35					
	7/25/2007	0.6										6.86	0.716	94					
	10/26/2007	3.6										7.32	0.443	-147					
	12/4/2007	0.2		< 0.1	50	< 0.05						7.28	0.508	-133					
	2/5/2008	1.0		2.6	49	< 0.05						6.85	0.346	-128					
	10/16/2009	1.1										10.60	0.758	48					300
PMW-1	1/31/2011	0.3	0.27	< 0.20	59					14.4	57.8	7.04	0.919	217.7	87	1.46	76.4		300
	6/15/2004						< 20	< 20	< 10										
	8/19/2004											5.54		578					
	9/15/2004											7.02		88					
	10/22/2004	1.0												0					
	11/18/2004	0.0										6.50		-93					
	12/14/2004											6.50		-114					
	2/17/2005											7.27		-182					
	3/29/2005	1.1					2520	< 20	< 20			7.50		-153					
	4/20/2005	0.0					7310	< 20	< 20			6.81		-157					
PMW-1	5/23/2005	0.0					8680	< 20	< 20			6.95		-175					
	6/28/2005	1.0					7640	< 20	< 20			6.90		-199					
	8/1/2005						3210	< 20	< 20										
	8/29/2005	0.5					2840	< 20	< 20			6.64		-210					
	9/23/2005	0.0										6.61		-237					
	10/20/2005	2.5	< 0.5	4.5	34.8	< 0.1	8200	< 20	< 20			7.19		-254					
	11/16/2005	2.8										6.90		-234					
	1/11/2006	1.0					713	< 20	< 20			6.95		-186					
	3/10/2006	4.1										7.07		-110					

Table 13
Groundwater Geochemical Data
Twigg Manufacturing Facility
Martinsville, Indiana

Well ID	Date	Dissolved Oxygen (mg/L)	Nitrate and Nitrite (mg/L)	Ferrous Iron ⁽¹⁾ (mg/L)	Sulfate (mg/L)	Sulfide (mg/L)	Methane (ug/L)	Ethane (ug/L)	Ethene (ug/L)	Temperature		Conductivity (uS/cm)	ORP (mV)	Chloride (mg/L)	Total Organic Carbon (mg/L)	Total Inorganic Carbon (mg/L)	Acetylene (ug/L)	Total Alkalinity (mg/L)
										°C	°F							
	4/11/2006	1.2										6.65	-84					
	6/6/2006											7.03	69					
	6/21/2006	2.6										6.70	-108					
	7/11/2006											7.12	-94					
	8/11/2006				1300	< 0.1						6.95	-128					
	9/6/2006											7.06	-8					
	10/6/2006											7.71	-183					
	10/12/2006											8.86	-151					
	11/20/2006			43	< 15	< 0.05						6.91	-227					
	12/11/2006											7.27	-163					
	1/9/2007											6.97	-167					
	2/12/2007			65	< 15	< 0.05	14000	0.12	0.16			7.00	-123					
	3/26/2007	0.6										7.14	46					
	5/23/2007	2.9		17.4								6.69	-132					
	6/26/2007	0.3										6.37	-258					
	7/25/2007	3.1										7.01	-177					
	9/4/2007	5.7		< 0.1	24	< 0.05						7.11	-213					
	9/12/2007	0.6										6.93	-191					
	10/25/2007	0.9		0.2	108	0.05						6.65	-190					
	12/4/2007	0.3										6.77	-214					
	1/8/2008	3.9																
	2/5/2008	2.4		10.5	68	< 0.05												
	4/15/2008			25.3	< 15	< 0.05	14000	< 0.03	0.02									
PMW-1S	5/28/2008							UI		11.7	53.1	6.94	-215				< 0.5	
	4/22/2010	3.1		0.3	92	< 0.1				17.6	63.7	7.06	-166					
	9/8/2010	2.2					80.8	< 10.0	< 10.0	13.0	55.4	7.09	-141.0	12	2.57	57.0		250
	2/4/2011	0.3	< 0.1	1.5	84							5.46	585					
	8/19/2004											7.03	54					
	9/15/2004												10					
	10/19/2004	5.0										7.60	-69					
	11/18/2004	0.0										7.20	-127					
	12/14/2004						87	< 20	< 20			7.60	-174					
	3/29/2005	1.1					84.10	< 20	< 20			7.01	-189					
	6/28/2005						983	< 20	< 20			6.90	-213					
	8/29/2005	1.5										6.99	-229					
	9/23/2005	0.0										7.50	-174					
	10/20/2005	1.4	4.9	< 0.5	25.4	< 0.1	33.40	< 20	< 20			7.12	-75					
	1/11/2006	0.4										7.15	-48					
	3/10/2006	4.3																

Table 13

Groundwater Geochemical Data

Twigg Manufacturing Facility
Martinsville, Indiana

Well ID	Date	Dissolved Oxygen (mg/L)	Nitrate and Nitrite (mg/L)	Ferrous Iron ⁽¹⁾ (mg/L)	Sulfate (mg/L)	Sulfide (mg/L)	Methane (ug/L)	Ethane (ug/L)	Ethene (ug/L)	Temperature		Conductivity (uS/cm)	ORP (mV)	Chloride (mg/L)	Total Organic Carbon (mg/L)	Total Inorganic Carbon (mg/L)	Acetylene (ug/L)	Total Alkalinity (mg/L)
										°C	°F							
	6/6/2006	1.2									7.12		160					
	6/21/2006	1.8									6.85		-57					
	9/6/2006										7.17		-89					
	10/6/2006										7.05	2,266	-85					
	10/12/2006										7.71	1,829	-173					
	11/20/2006			25	< 15	< 0.05					8.56	0.844	-153					
	12/11/2006										6.78	2,748	-245					
	1/9/2007										7.30	1,194	-170					
	2/12/2007			68	< 15	< 0.05					6.90	1,692	-163					
	3/26/2007	0.6									7.02	1,302	-95					
	5/23/2007	2.9									7.20	0.862	-7					
	6/26/2007	0.0										0.555	-162					
	7/25/2007	0.5									6.88	0.541	-181					
	9/4/2007	3.2									6.90	0.886	-200					
	9/12/2007	0.5									7.19	0.772	-180					
	10/25/2007	1.0									7.42	0.300	-216					
	12/4/2007	1.1									7.12	0.307	-208					
	1/8/2008	2.0									6.83	0.407	-196					
	2/5/2008	1.0		9.0	67	< 0.05					6.99	0.285	-213					
	2/4/2011	1.1	11.6	< 0.20	39					13.2	55.8	0.555	-33.2	10	2.61	49.1		210

na = not analyzed for the indicated compound

E = result exceeds calibration range, value estimated

HM = samples collected by Harman-Motive

S1 = Oxygen probe measured value as above saturation limit, recorded as saturated, 10.5 mg/L

S2 = Oxygen probe malfunction, value deleted as unreliable.

⁽¹⁾ Samples filtered in the field and analyzed for total iron - results assumed to be ferrous due to solubility.

Table 14
Microbiological Laboratory Data (cells per milliliter)
 Twigg Manufacturing Facility
 Martinsville, Indiana

Well ID	Dechlorinating Bacteria		Methane Oxidizing Bacteria (MOB)	Functional Genes			
	Date	Dehalococcoides spp. (DHC)	Dehalobacter spp. (DHBt)	Soluble Methane Monooxygenase (sMMO)	tceA Reductase (TCE)	Vinyl Chloride Reductase (VCR)	bvcA Reductase (BVC)
PMW-1	9/8/2010	6.59E+02	1.06E+03	5.20E+05	< 5.00E-01	< 5.00E-01	< 5.00E-01
MW-14	9/8/2010	2.00E+00	3.25E+02	3.57E+05	< 5.00E-01	< 5.00E-01	< 5.00E-01
MW-19	9/8/2010	1.50E+00	< 1.00E+00	4.14E+01	< 5.00E-01	< 5.00E-01	< 5.00E-01
PBW-3	9/8/2010	1.10E+01	7.18E+02	4.53E+05	< 5.00E-01	< 5.00E-01	< 5.00E-01
MW-8	9/8/2010	1.00E-01	< 5.00E-01	7.82E+04	< 3.00E-01	< 3.00E-01	< 3.00E-01

Table 15
Diversity of Bacteria that can Degrade Chlorinated Aliphatic Hydrocarbons*
 Twigg Manufacturing Facility
 Martinsville, Indiana

Isolate or Culture	Closest Phylogenetic Affiliation	Dechlorination Steps Performed	Electron Donor	Reference
Chlorinated Ethenes				
<i>Dehalobacter restrictus</i>	Low G+C Gram positive bacteria	Tetrachloroethylene to cis-1,2-Dichloroethylene	H ₂	Holliger <i>et al.</i> , 1993
<i>Dehalobacter restrictus</i> strain TEA	Gram positive bacteria Low G+C	Tetrachloroethylene to cis-1,2-Dichloroethylene	H ₂	Wild <i>et al.</i> , 1996
<i>Dehalobacter restrictus</i> strain PER-K23		Tetrachloroethylene to cis-1,2-Dichloroethylene	H ₂	Holliger <i>et al.</i> , 1998
<i>Dehalospirillum multivorans</i> , renamed <i>Sulfospirillum multivorans</i>	Proteobacteria, ϵ subdivision	Tetrachloroethylene to cis-1,2-Dichloroethylene	H ₂	Scholz-Muramatsu <i>et al.</i> , 1995
<i>Dehalospirillum multivorans</i> , renamed <i>Sulfospirillum multivorans</i> strain PCE-M2	Proteobacteria, ϵ subdivision	Tetrachloroethylene to cis-1,2-Dichloroethylene	H ₂	Schmidt <i>et al.</i> , 2000
strain MS-1	Enterobacteriaceae	Tetrachloroethylene to cis-1,2-Dichloroethylene	H ₂	Sharma and McCarty 1996
<i>Dehalococcoides ethenogenes</i> strain 195	Green, nonsulfur bacteria	Tetrachloroethylene to ethylene†	H ₂	Maymo-Gatell <i>et al.</i> , 1997
<i>Dehalococcoides</i> sp. strain CBDB1	Dehalococcoides ethenogenes	Tetrachloroethylene to trans-Dichloroethylene	H ₂	Adrian <i>et al.</i> , 2000
<i>Dehalococcoides</i> sp. strain BAV1	Dehalococcoides ethenogenes	cis-1,2-Dichloroethylene to ethylene	H ₂	He <i>et al.</i> , 2003a,b
<i>Dehalococcoides</i> sp. strain FL2	Dehalococcoides ethenogenes	Tetrachloroethylene to ethylene†	H ₂	He <i>et al.</i> , 2005
<i>Dehalococcoides</i> sp. strain VS	Dehalococcoides ethenogenes	Trichloroethylene to ethylene†	H ₂	Cupples <i>et al.</i> , 2004
<i>Dehalococcoides</i> sp. strain KB-1/VC	Dehalococcoides ethenogenes	Trichloroethylene to ethylene	H ₂	Cupples <i>et al.</i> , 2004
<i>Dehalococcoides</i> sp. strain Pinellas	Dehalococcoides ethenogenes	Trichloroethylene to ethylene	H ₂	Cupples <i>et al.</i> , 2004
<i>Dehalococcoides</i> sp. strain GT	Dehalococcoides ethenogenes	Trichloroethylene to ethylene†	H ₂	Sung <i>et al.</i> , 2006
<i>Desulfitobacterium frappieri</i> TCE1	Desulfitobacterium a Gram positive bacterium	Tetrachloroethylene to cis-1,2-Dichloroethylene	H ₂	Gerritse <i>et al.</i> , 1999
<i>Clostridium bifermentans</i> strain DPH-1	Clostridium	Tetrachloroethylene to cis-1,2-Dichloroethylene	H ₂	Chang <i>et al.</i> , 2000
<i>Desulfitobacterium</i> sp. strain PCE1	Desulfitobacterium a Gram positive bacterium: Low G+C	Tetrachloroethylene to TCE	H ₂	Gerritse <i>et al.</i> , 1996

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Diversity of Bacteria that can Degrade Chlorinated Aliphatic Hydrocarbons*
 Twigg Manufacturing Facility
 Martinsville, Indiana

Isolate or Culture	Closest Phylogenetic Affiliation	Dechlorination Steps Performed	Electron Donor	Reference
<i>Desulfotobacterium</i> sp. strain Viet 1	Gram positive bacteria Low G+C	Tetrachloroethylene to TCE	H ₂	Löffler <i>et al.</i> , 1997
<i>Desulfotobacterium</i> sp. strain PCE-S	Desulfotobacterium a Gram positive bacterium	Tetrachloroethylene to cis-1,2-Dichloroethylene	H ₂	Miller <i>et al.</i> , 1997
<i>Desulfotobacterium</i> sp. strain Y51	Desulfotobacterium a Gram positive bacterium	Tetrachloroethylene to cis-1,2-Dichloroethylene	H ₂	Suyama <i>et al.</i> , 2002
<i>Desulfotobacterium metallireducens</i>	Desulfotobacterium a Gram positive bacterium	Tetrachloroethylene to cis-1,2-Dichloroethylene	H ₂	Finneran <i>et al.</i> , 2003
<i>Desulfuromonas chloroethenica</i> strain TT4B	Geobacter	Tetrachloroethylene to cis-1,2-Dichloroethylene	acetate	Krumholz <i>et al.</i> , 1996
<i>Desulfuromonas michiganensis</i> strain FL2		Tetrachloroethylene to cis-1,2-Dichloroethylene	acetate	Sung <i>et al.</i> , 2003
<i>Desulfuromonas michiganensis</i> strain BAV1		Tetrachloroethylene to cis-1,2-Dichloroethylene	acetate	Sung <i>et al.</i> , 2003
Chlorinated Ethanes				
<i>Dehalobacter restrictus</i> strain TCA1	Gram positive bacteria Low G+C	1,1,1-TCA to 1,1-DCA to CA	H ₂	Sun <i>et al.</i> , 2002
Chlorinated Methanes				
Not Applicable for this Site				

* Modified from Major 2003 and USEPA 2006

† VC is the end product of the metabolic reductive dechlorination pathway. Degradation of VC to ethene is cometabolic

‡ VC utilization coupled to growth, not cometabolism