AECOM Environment

Prepared for:
Abbott Laboratories
Abbott Park, IL

Prepared by:
AECOM
Raleigh, NC
60135880.200
April 2010

RECEIVED
APR 27 2010
SUPERFUND SECTION

Supplemental Subsurface Investigation Report

Former Abbott Facility
Solvent Release Remediation
Laurinburg, Scotland County, North Carolina
NCDENR ID No. NCD-000-0040

Prepared By
Matt Allen, P.G.
Senior Project Geologist

Reviewed By
S. Grant Watkins, P.G., RSM
Senior Program Manager

NORTH CAROLINA LICENSED SEAL 1035 GEOLOGIST S. GRANT WATKINS

1.0 Introduction

This report presents the findings of a supplemental subsurface investigation conducted by AECOM North Carolina, Inc. (AECOM) on behalf of Abbott Laboratories (Abbott) at the Former Abbott Laboratories facility located at 16000 Joy Street in Laurinburg, Scotland County, North Carolina (the "Site"). The supplemental investigation was performed from November 2009 through February 2010 on the former waste pit solvent plume at the Site. Field activities during the investigation generally followed the work scope and methods described in the *Work Plan for Supplemental Subsurface Investigation and Remedial Actions, Solvent Release Remediation, Former Abbott Facility* (herein called the "Work Plan") prepared by AECOM (2009), which was approved by the North Carolina Department of Environment and Natural Resources (NCDENR). The 2009 Work Plan provides a detailed summary of the Site history, prior remedial actions, and the contaminants of concern.

1.1 Site Description

The former Abbott facility is located at the intersection of NC Highway 15-501 and NC Highway 401 in Laurinburg. Figure 1 shows the Site location on a regional topographic map. Figure 2 is a partial Site plan that shows the Site property boundaries, Site features including groundwater monitoring wells, and boundaries of surrounding properties.

During their ownership of the Site property that began in 1970, Abbott used the facility to manufacture tubing and adapters that were used in medical and health care equipment. The manufacturing process included injection molding of plastics, plastic parts washing, parts assembly and ethylene oxide sterilization. Abbott also operated a solvent disposal and evaporation pit north of the main plant building from 1970 through 1976. Abbott notified the NCDENR of the pit in 1989, and in 1991 entered into an Administrative Order on Consent (AOC) with the NCDENR to investigate and remediate soil and groundwater contamination associated with the solvent disposal pit (Radian, 1993). Since 1994 Abbott has implemented several remediation technologies to cleanup Site soils and groundwater. The remedy currently in use for groundwater is enhanced anaerobic bioremediation, which was initiated in 2002, combined with monitored natural attenuation (Matrix, 2002).

Abbott closed and donated the Site to Scotland County in 2002. Scotland County then sold the Site to Marketta, LLC. The facility tenant and operator is QualPak, Inc., an operating division of GoJo Products/Marketta. QualPak manufactures and packages Purell® brand alcohol-based hand sanitizers at the facility.

1.2 Objectives

The supplemental investigation focused on two areas described in the 2009 Work Plan: the solvent disposal pit source area in the north (upgradient) part of the volatile organic compound (VOC) plume and the southwestern (downgradient) portion of the VOC plume at the southwest Site property boundary. Figure 3 shows the boundaries of the two areas of the Site property that were investigated.

The primary objectives of the supplemental investigation were to:

- Delineate the remaining areas of high concentration dissolved VOCs in the northern source area and map the aquifer strata that control plume migration;
- Identify and determine the distribution of potential dense non-aqueous phase liquid (DNAPL) VOC mass that remains in and around the former solvent disposal pit source area;
- Determine the microbial profile at the Site and the groundwater geochemical conditions that may be limiting biodegradation of the VOCs; and
- Evaluate the subsurface lithology and the extent of the dissolved VOC plume at the southwestern property boundary to determine if VOCs in groundwater are migrating off-site in this area above the regulatory standards.

Groundwater in the northern source area has been undergoing engineered in-situ bioremediation treatment since 2002. In-situ anaerobic bioremediation was subsequently initiated in the southern plume area in September 2006. Data collected from the supplemental investigation will be used to design a follow-up electron donor substrate injection program to maintain and enhance the ongoing groundwater bioremediation remedy.

2.0 Investigation and Sampling Methods

This section describes the work scope and methods used to complete the supplemental investigation field work from November 2009 through February 2010. The main components of the investigation consisted of the following:

- Direct sensing subsurface screening of groundwater and saturated aquifer media in the solvent source area to identify residual contaminant mass and high concentration zones;
- Free phase product screening evaluation and soil core fluid analyses for saturated soils in the solvent source area to determine the presence of NAPL;
- Multi-depth confirmatory sampling of VOCs in groundwater at the solvent source area (i.e. north area plume) and at the southern (i.e. downgradient) end of the dissolved plume;
- Collection of soil core samples for analysis of residual VOCs in the north source area and to establish subsurface lithology in the southwest plume area;
- Installation and sampling of an on-site groundwater monitoring well at the southwestern end of the dissolved solvent plume; and
- Collection of samples for microbial analyses of dehalogenating bacteria to support a bioaugmentation evaluation.

Figure 4 and Figure 5 show the details of the direct sensing borings and/or sampling locations in the northern and southern study areas, respectively. The soil and groundwater sampling borings were installed on-site using Geoprobe® direct-push technology (DPT) methods. The following sections detail the sampling methods.

2.1 Direct Sensing Soil and Groundwater Screening

Direct sensing methods were used to rapidly screen subsurface conditions and the presence of residual soil and groundwater contamination. Direct sensing methods that were used included Laser Induced Fluorescence (LIF) using an Ultra Violet Optical Screening Tool (UVOST®) for free product screening and Membrane Interface Probe (MIP) equipped with three VOC detectors and an Electrical Conductivity (EC) logger. Results of the direct sensing screening survey were then used to facilitate collection of soil and groundwater samples for laboratory analyses to quantify the VOC impacts.

2.1.1 Free Product Evaluation and LIF Screening

Well MW-101A has historically contained small quantities (<2 inches thick) of floating free-phase product. The Work Plan specified that a sample of free product would be collected from the well and analyzed for fluorescence to ultraviolet (UV) light. During semi-annual groundwater monitoring activities in November 2009 a separate, measurable NAPL layer was not detected with an oil-water interface probe. During the subsequent subsurface investigation activities, a bailer was inserted into the top and bottom of well MW-101A to visually inspect for separate phase product in the well. Although neither of these inspection methods showed a distinct separate layer of free phase product, coalesced oily droplets were observed on the bailer.

An LIF screening survey was attempted with a UVOST® probe in the vicinity of MW-101A on December 2, 2009. The LIF UVOST® probe was advanced to depths of 18 feet bgs at two DPT borings (LIF09-1 and LIF09-2) adjacent to well MW-101A. No responses were measured on the LIF instrument at either location, thereby indicating that either free product was not present in that zone or that the product does not contain sufficient aromatic hydrocarbons to fluoresce under UV light.

As a specified contingency in the Work Plan, additional MIP borings were advanced in the immediate vicinity of well MW-101A after the LIF instrument failed to show a fluorescent response at the two LIF borings (see Section 2.1.2 below). The MIP was used as an alternative to the LIF screening in this area to identify relative high-concentration responses that would indicate the potential presence of NAPL and/or residual matrix saturation of VOCs.

2.1.2 MIP Survey

A MIP screening survey was performed by Columbia Technologies, Inc. in the northern plume area from December 9-11, 2009. The MIP instrument provides qualitative real-time analyses of relative levels of VOCs in soil and groundwater. Additionally, the MIP probe is equipped with instruments to measure soil electrical conductivity (the inverse of resistivity) data, which are indicative of variations in the soil lithology.

A total of 16 MIP borings were advanced in the former waste pit area and up to 200 feet downgradient of the pit (see Figure 4). Borings were advanced with the DPT rig to maximum depths ranging from 55 to 85 feet below ground surface (bgs). Individual MIP logs are included in the MIP survey results report presented in Appendix A.

MIP technology employs the use of three organic VOC detectors: an Electron Capture Detector (ECD), a Photo-ionization Detector (PID), and a Flame Ionization Detector (FID). There is considerable overlap of the concentration ranges and compounds that can be measured by each of these detectors. For example, the ECD responds to most chlorinated VOCs such as trichloroethene (TCE), tetrachloroethene (PCE), and 1,1,1-trichloroethane (TCA) at concentrations as low as 200 micrograms per liter (µg/L) in groundwater. The PID responds primarily to aromatic hydrocarbons (i.e., benzene, toluene, xylenes), but it will also detect most chlorinated ethenes if they are present at much higher concentrations. A PID equipped with a 10.0 electron volt lamp does not detect most chlorinated ethanes or chlorinated methane compounds. The FID is used to measure low levels of straight chain hydrocarbons such as methane but, unlike the PID, it will also respond to elevated concentrations of chlorinated ethanes and chlorinated methanes.

An Electrical Conductivity (EC) dipole array system is also attached to the MIP probing tool to provide soil conductivity logging. The EC dipole array measures the electrical conductance of the soil and its fluids as the MIP probe is advanced through the soil column. In general, higher EC readings are typically produced by fine grained sediments such as silt and clay, while coarse-grained sands and gravels produce low EC responses. Because the relative EC responses in subsurface strata at each site can be affected by unique electrical properties of the groundwater and/or its contaminants, a confirmation soil boring is generally recommended to correlate the EC responses to certain soil types.

2.2 Direct Push Groundwater Sampling

Groundwater samples were collected using Geoprobe® direct push technology (DPT) methods in the northern source area of the VOC plume and in the southwestern portion of the plume. Multi-depth groundwater sampling was performed to provide vertical profiling of VOC concentrations within the aquifer system. Samples were collected using either a direct push retractable screen sampler or by

installation and sampling of small-diameter temporary wells. Temporary wells were removed and the boreholes abandoned with bentonite and grout after sample collection.

In both the northern and southern study areas, selected groundwater samples were initially screened in the field for the presence of total chlorinated ethenes as PCE using a Color-Tec® colorimetric test kit. Groundwater Color-Tec® field screening results were used to facilitate selection of samples for laboratory analyses. Appendix B contains the laboratory reports of VOC analyses for groundwater samples collected in the northern and southern study areas.

2.2.1 Northern Source Area DPT Groundwater Sampling

Results of the MIP screening survey were used to determine the locations and depths of DPT groundwater samples for laboratory analysis of VOCs in the northern source area. Laboratory analysis of the groundwater samples was used to confirm the depths and discrete aquifer strata that contain the highest concentrations of dissolved VOCs and to correlate quantitative VOC analytical results to the relative MIP responses at the same location and depth.

From December 14-16, 2009, a total of fourteen (14) groundwater samples were collected by DPT methods at nine locations (GW09N-10 through GW09N-18) in the northern plume source area. Groundwater samples were collected at depths ranging from 13 ft bgs to 65 ft bgs. A Geoprobe® direct-push retractable screen sampler device was used to collect shallow groundwater samples. In addition to using the retractable screen sampler, most of the deeper groundwater samples were obtained by installing a 1-inch diameter temporary well, which was then sampled with a peristaltic pump and subsequently abandoned. Groundwater samples were screened on-site for the presence of total chlorinated ethenes as PCE using a Color-Tec® field screening kit. Figure 4 shows the DPT sampling locations.

Based on the Color-Tec® screening results and sampling locations, 14 groundwater samples were selected for laboratory analysis of VOCs by EPA Method 8260B. These samples were transferred into laboratory supplied sample containers, placed on ice, and shipped to Abbott Laboratories. Chain-of-custody and sample preservation protocols were observed for shipping the samples. Appendix B contains the laboratory report.

2.2.2 Southern Plume Area Soil Boring and DPT Groundwater Sampling

On December 7, 2009, soil boring SB09-01 was advanced in the southwest plume area to a depth of 55 feet bgs using a Geoprobe® rig. Continuous core sampling was performed with Macro-Core™ samplers through the entire boring depth to obtain soil samples for visual inspection and lithologic descriptions. These results were used to identify lithologic strata that may preferentially control migration of the dissolved VOC plume in this area. The soil boring lithology data were used to target specific depths for DPT groundwater sampling and to provide information useful for construction of one or more new monitoring wells near the southwest Site property boundary. Boring logs and groundwater analytical data from existing nearby wells (i.e., MW-19 well cluster) was also used to support these decisions.

A total of fourteen (14) groundwater samples were collected by DPT methods at nine boring locations (GW09-01 through GW09-09) in the southwest plume area. Two of the shallow groundwater samples were collected on December 2, 2009 and the remaining shallow and deep samples were collected on December 7-8, 2009. Groundwater samples were collected at depths ranging from 12 ft bgs to 75 ft bgs using either a Geoprobe® direct-push retractable screen sampler device or by installing and sampling small diameter temporary wells. Groundwater samples were screened on-site for the

presence of total chlorinated ethenes using a Color-Tec® field screening kit. Figure 5 shows the DPT sampling locations in the southern study area.

Based on the Color-Tec® screening results and sampling locations, twelve groundwater samples were selected for laboratory analysis of VOCs by EPA Method 8260B. These samples were transferred into laboratory supplied sample containers, placed on ice, and shipped to Abbott Laboratories. Chain-of-custody and sample preservation protocols were observed for shipping the samples. Appendix B contains the laboratory report.

2.3 Soil Borings and Soil Core Testing

Three soil borings (SB09N-01 through SB09N-03) were advanced by DPT methods to obtain soil cores in the northern plume study area on December 14-15, 2009. The soil cores were collected at locations and depths where elevated ECD and/or PID responses were observed during the MIP survey and where residual NAPL saturation in soil was most likely to occur. The soil cores were also used to visually confirm the soil type as a correlation to the EC readings obtained from these zones during the MIP survey. Figure 4 shows the soil boring locations.

Five-foot continuous MacroCore™ samplers with sectioned stainless steel liners were used to collect undisturbed samples for free product testing and VOC analyses. Three of the soil core samples were submitted to Pace Analytical Services for VOC analysis by Method 8260, including SB09N-01(23-24), SB09N-02(41-46), and SB09N-03(19-20). Additionally, two soil core samples SB09N-01(23-24) and SB09N-03(20.5-22) were submitted to PTS Labs for free product mobility testing by method ASTM D425M, which included measurements of NAPL saturation before and after a centrifuge test. Soil physical properties of bulk density, grain density, and total porosity were also measured in the samples using method API RP40.

2.4 Microbial Profile Sampling and Analysis

Analysis of groundwater for dehalogenating bacteria was performed to determine potential microbial limitations to the effectiveness of the ongoing bioremediation remedy. Groundwater samples were collected from five existing site monitoring wells and two DPT borings and analyzed by Census assays for *Dehalococcoides spp.* (DHC) and *Dehalobacter spp.* (DHB) dehalorespiring bacteria as a component of the supplemental investigation. Functional genes (tceA, bvcA, vcrA) of DHC were also analyzed using the Polymerase Chain Reaction (PCR) test for those samples with detections of DHC bacteria.

Groundwater from three source area monitoring wells (MW-100B, MW-101A, and MW-102C) and from two DPT borings (GW09N-10 and GW09N-12) was sampled and analyzed for DHC and DHB bacteria in December 2009. Two additional wells (MW-103B and MW-104B) located mid-plume and downgradient of the main source area were sampled and analyzed for DHC and DHB bacteria on February 17, 2010. Appendix C contains the laboratory reports for the microbial analyses.

2.5 Monitoring Well Installation and Sampling

New monitoring well MW-105C was installed near the southwest fence line of the Site property on February 9, 2010. The well was installed by hollow stem auger drilling methods to a total depth of 64 feet bgs, and it was constructed of polyvinyl chloride (PVC) casings with a 10-foot PVC screen. Figure 5 shows the well location. A well construction record for MW-105C is included in Appendix D.

The MW-105C well location and screened interval depths (nominal 54 to 64 feet bgs) were based on prior results from the DPT groundwater sampling and the soil lithology boring (SB09-01) in this area. This screened interval monitors the upper portion of a fine sand unit that showed the highest VOC concentrations from DPT groundwater samples collected near the southwest property boundary. Screened intervals of the nearby well cluster MW-19B/D are located above and below the screened elevations of MW-105C.

Following construction, well MW-105C was developed by a Whaler® submersible electric pump to remove sediments in the screen and sand pack. Development continued until the water cleared and had no visible turbidity.

Well MW-105C was purged and sampled on February 17, 2010 a week after its installation. A peristaltic pump was used for low flow purging and sampling. During the purging process, groundwater was measured for the parameters of pH, temperature, specific conductance, dissolved oxygen (DO), and oxidation-reduction potential (ORP). The collected groundwater sample, along with a trip blank, was submitted to the Abbott Laboratory for analysis of VOCs by Method 8260B. A library search for Tentatively Identified Compounds (TICs) was also performed. Appendix B contains the laboratory report.

3.0 Supplemental Investigation Results

This section summarizes results of the supplemental investigation performed at the Site from November 2009 through February 2010. Interpretations of findings are also discussed.

3.1 Direct Sensing MIP and LIF Screening Results

3.1.1 MIP Volatile Organic Compound Detectors

Appendix A contains the full MIP results report prepared by Columbia Technologies for this study. This report includes individual MIP logs and graphs that show the ECD, PID, and FID responses mapped in various three dimensional views. Columbia utilized their SmartData Solutions® software to interpret and map the ECD, PID and FID "plumes" for viewing in multiple dimensions.

The MIP survey successfully identified residual VOC hot spots and areas that potentially contain residual NAPL saturation in the soil matrix. The most significant and widespread responses were measured on the ECD, indicating the predominance of chlorinated ethenes and/or chlorinated ethanes in the subsurface. Sporadic detections were obtained on the PID and FID throughout the MIP study area, but the magnitude of these responses was much lower than those measured by the ECD. The exception was MIP boring MIP09-14 located in the former waste pit area, which showed an elevated PID reading in the depth interval of 12 to 22 feet bgs. The sporadic FID detections may represent pockets of methane, which are known to exist in the plume source area groundwater as a byproduct of organic substrate fermentation.

Figure 6 shows a north-south cross section view of the ECD responses (adapted from 'Figure 41' in the Columbia Technologies data report presented in Appendix A) with recent groundwater analytical data from several adjacent monitoring wells and DPT borings superimposed onto the ECD "plume" image. This figure allows a general visual correlation of dissolved VOC concentrations in groundwater compared to the ECD response within the same aquifer zone. It is important to note that the VOC detectors on the MIP probe respond to both the dissolved VOCs in the aqueous phase and to VOCs adsorbed to the soil matrix.

Several distinct features are apparent in the ECD plume interpretation in Figure 6. First, at MIP09-14 located in the former waste pit boundary, the area of shallow soils and groundwater previously treated with the MecTool® is clearly visible. Beneath the former waste pit, however, the ECD response shows that groundwater remains highly impacted with chlorinated ethenes and potentially with aromatic hydrocarbons from a depth of 12 to 41 feet bgs.

Secondly, two distinct bases are seen in the high concentration ECD responses. Directly below the former waste pit the highest ECD responses abruptly end at a depth of 41 feet bgs. Moving south away from the waste pit a well-defined and laterally continuous ECD response base is seen at an average depth of approximately 53 feet bgs. This pattern of ECD responses, which presumably mimics the dissolved chlorinated ethene plume in groundwater, may be caused by one of the following subsurface conditions:

- The elevated ECD response bases are created by one or more low permeability soil units (i.e., silt or clay) that restrict the vertical downward migration of VOCs and potential NAPL. As

a result, the highest concentrations of dissolved VOCs would reside in and preferentially migrate through more permeable strata above the lower-permeability units;

- The highest ECD responses occur in the lower permeability silt and clayey sand units, which have adsorbed and contain the greatest residual mass of VOCs. This sorbed VOC mass is then slowly released into the more permeable strata via matrix diffusion, where it exists in lower aqueous concentrations;
- Combinations of both plume control scenarios listed above occur on a localized basis across the Site. Based on the lithologic borings and EC responses discussed in the sections below, this is the most likely scenario.

And finally, the depths of the greatest VOC impacts increase toward the south (i.e., downgradient). Between MIP09-01 and MIP09-08 shallow groundwater less than 20 feet deep has significantly lower VOC impacts compared to deeper groundwater between depths 30 and 53 feet bgs.

3.1.2 MIP Electrical Conductivity Logging

Appendix A contains the full MIP results report prepared by Columbia Technologies for this study. This report includes individual MIP logs and graphs that include the electrical conductivity (EC) responses recorded in milliSiemens per meter (mS/m) for the Site soils.

Electrical conductance of the Site soils ranged from approximately 0.5 mS/m to a high of 80 mS/m in the MIP study area. These data suggest that the Site soils range from sand (low EC values <5 mS/m) to silt and clay (higher EC values >30 mS/m). Each site produces a unique EC response based on the electrical properties of the soil and groundwater, and for this reason some variability in EC responses for similar geologic media is common. Several soil cores were collected from this area to allow a visual description of the soils that correspond to an EC response at the same location and depth. Soil core lithology showed that for this Site, EC responses between 10-30 mS/m generally represents silty sands to clayey sands and responses greater than 30 mS/m represent sandy silts, silts and clays.

Interpretation of the EC logs indicates three primary stratigraphic units that were laterally continuous within the upper 80 feet of the aquifer. From 0-22 feet bgs EC responses indicate a sandy unit with discontinuous lenses of silt and gravel. EC responses in this upper sandy unit were generally less than 5 mS/m. Below this sandy unit is heterogeneous sandy silt to clayey sand with discontinuous lenses of silty sand and sandy clay that produced EC responses ranging from 10-50 mS/m. The base of the middle stratigraphic unit contains a distinct silt and clay layer that locally produced EC readings up to 80 mS/m. The bottom of the silt and clay layer was found at a relatively consistent depth of between 52-54 feet bgs in the MIP study area. Beneath the middle clayey sand unit, a more coarse-grained silty sand material is again indicated by lower EC readings <10 mS/m.

Figure 7 is a north-south cross section that depicts the generalized subsurface stratigraphy in the plume source area based on EC profiles. Descriptions of soil cores collected during this investigation as well as historical soil boring logs were also used in developing the cross section. Soils in this area are complex and heterogeneous as indicated by the numerous localized spikes in the EC profiles. Interpretation of the primary stratigraphic units shown in Figure 7 is based on the overall trends and ranges of electrical conductivity responses.

3.1.3 LIF Test Borings and Free Product Distribution

As discussed in Section 2.1.1, no responses were measured at two LIF borings (LIF09-1, LIF09-2) installed to 18 feet bgs adjacent to MW-101A. In accordance with the Work Plan, additional MIP borings were installed around well MW-101A as a contingency to investigate for NAPL if the LIF instrument did not respond. Four additional MIP borings (MIP09-09, MIP09-10, MIP09-12, and MIP09-13) were installed to depths of 62 feet bgs in close proximity to well MW-101A to further investigate for potential NAPL. None of these four MIP borings showed significant responses on the ECD, PID, or FID in the upper 18 feet of the surficial aquifer that was also investigated by LIF methods. As a result, the combined LIF and MIP results in the vicinity of well MW-101A confirm that a floating free phase product layer has not accumulated on or near the water table surface in this area.

During the previous semi-annual groundwater monitoring event in November 2009, no free phase product was detected in any of the monitoring wells using an electronic oil-water interface probe for the product inspection. Additionally, inspection with a bailer did not show a distinct, measurable separate NAPL layer in the liquids retrieved from the upper and lower water column in MW-101A. However, the bailer had a coalesced oily coating on it, indicating that the water column in well MW-101A contains NAPL product as an emulsion and/or as small droplets.

Because the top of the well screen for monitoring well MW-101A is positioned approximately fifteen feet below the water table, the free product that has been observed in this well likely resides in a deeper interval of the aquifer. The free phase product does not behave like a floating LNAPL that exists in the aquifer solely at or near the water table surface. It is possible that the chemical composition of the NAPL, which is known to be dynamic based on historical chemical analyses, creates a free product with a density similar to water. In this case, the NAPL mass would neither preferentially sink nor float as a distinct product layer in the water column of the well.

3.2 DPT Groundwater Sampling Results

Fourteen groundwater samples were collected by DPT methods at nine boring locations (GW09-01 through GW09-09) in the southwest plume area. Twelve of these samples were submitted for laboratory analysis of VOCs. Additionally, a total of fourteen groundwater samples were collected at nine DPT boring locations (GW09N-10 through GW09N-18) in the northern plume area, and each of these samples was submitted for laboratory analysis of VOCs.

3.2.1 Northern Plume Source Area

Table 1 summarizes the VOC laboratory analytical results and the Color-Tec® chlorinated ethenes field screening results for groundwater samples collected in the northern source area of the solvent plume. Figure 4 shows the sampling results on a site map.

Seventeen VOCs were detected in groundwater within the northern plume source area. All but three of these compounds (MIBK, O-Xylene, and Freon 113) were present in concentrations above their respective 2L groundwater standard in one or more DPT groundwater samples. The most frequently detected VOCs during the DPT groundwater sampling were cis-1,2-DCE, methylene chloride, TCE, and Freon 113, which were each detected in fifteen or more of the samples. The compound 1,1-DCE was also detected in nine of the samples above the 2L standard.

The highest concentration of TCE detected was 32,000 µg/L at GW09N-18 (44-49'), which was located adjacent to and dowgradient of the MW-101 well cluster. This DPT sampling location also contained the highest Freon 113 concentration at 31,000 µg/L, the highest 1,1,1-TCA concentration at

2,500 µg/L, and an elevated cis-1,2-DCE concentration (34,000 µg/L). Detections of elevated dissolved VOC concentrations in groundwater at locations GW09N-18 and GW09N-12 correlates to the past observations of NAPL in well MW-101A. These sampling results, combined with the ECD results at MIP borings surrounding the MW-101 well cluster, confirm that there is residual VOC mass trapped in the clayey sand unit beneath this part of the Site.

Directly beneath the former waste pit boundary the dissolved VOCs concentrations were highest in shallow groundwater from 16- 40 feet deep. The highest concentrations of acetone, MEK, and methylene chloride were also detected in shallow groundwater beneath the former waste pit at DPT samples GW09N-10(16-20') and GW09N-14(26-30'). These results likely explain the elevated PID responses obtained in shallow groundwater beneath the former waste pit during the MIP survey.

VOC concentrations decreased significantly in shallow groundwater less than 20 feet deep in areas further south (downgradient) of the former waste pit boundary and the concrete ditch (see Figure 4). The highest concentrations of chlorinated VOCs in groundwater were detected between the depths of 41-49 feet bgs during the DPT sampling event. These sampling results correlate well to the ECD responses obtained in this area at similar depths.

3.2.2 Southern Plume Area

Table 2 summarizes the VOC laboratory analytical results and the Color-Tec® chlorinated ethenes field screening results for groundwater samples collected near the southwest Site property boundary at the leading edge of the plume. Figure 5 shows the results on a site map. Sampling results for monitoring wells MW-19B/MW-19D (November 2009) and MW-105C (February 2010) are also shown in Figure 5.

Nine different VOCs were detected in groundwater within the southern plume study area. Only two of these compounds (1,2-DCA and TCE) were present in concentrations above their respective 2L groundwater standard. The most frequently detected VOCs during the DPT sampling were cis-1,2-DCE, MEK, TCE, and Freon 113. The highest concentration of TCE was 28 µg/L at GW09-06 (54').

Overall, the shallow groundwater less than 30 feet bgs contained very few VOCs, the detected concentrations were very low, and no 2L standards were exceeded for any of the detected VOCs. TCE was not detected in shallow groundwater in the southwest study area, but it was detected in deeper groundwater at seven DPT boring locations. The highest concentrations of chlorinated VOCs in groundwater were detected between the depths of 54-68 feet bgs.

3.3 Soil Core NAPL Testing and Analytical Results

Results of the soil core NAPL and physical properties testing on samples SB09N-01 (23-24') and SB09N-03 (20.5-22') are summarized in Table 3 and are shown on Figure 7. Appendix E contains the laboratory reports for the soil core testing.

Bulk density of the soil core samples varied from 1.66 to 1.80 grams per cubic centimeter (g/cc). Total porosity ranged from 37.3 to 31.9 percent of the bulk volume (%Vb). Residual NAPL pore fluid saturation varied from 3.5 percent of pore volume (%Pv) at SB09N-01 (23-24') to 1.9% Pv at sample SB09N-03 (20.5-22'). The NAPL saturation remained unchanged at each core sample before and after the centrifuge test, and no visible separate phase NAPL was produced during the centrifuge process. Water produced from the centrifuge process was described as having a faint yellow color and strong 'hydrocarbon' odor. These results indicate that the two soil cores tested contain a very low volume of residual NAPL that is adsorbed to the soil matrix but the NAPL is not mobile.

Table 4 summarizes the VOC analytical data for the three soil cores tested. Each of the soil cores contained TCE and one or more other VOCs. TCE concentrations varied from 827 micrograms per kilogram (µg/kg) at SB09N-01(23-24) to 26,400 µg/kg at SB09N-03(19-20). Samples SB09N-01(23-24) and SB09N-02(41-46) also contained cis-1,2-DCE and toluene. Methylene chloride was detected in soil at a concentration of 28,300 µg/kg in SB09N-03(19-20).

3.4 Monitoring Well MW-105C Analytical Results

Three VOCs (cis-1,2-DCE, TCE and Freon 113) were detected in the groundwater sample collected from MW-105C in February 2010. None of these VOCs exceeded their respective 2L standards. The TCE concentration was 1.8 µg/L. Table 2 includes the February 2010 sampling results for MW-105C. Analytical data are shown on Figure 5.

The supplemental investigation sampling results indicate that TCE is present in deeper Site groundwater at the southwest Site property boundary. The combined results of DPT groundwater sampling and monitoring well sampling in the southwest study area (see Figure 5) also confirm that the TCE plume has migrated further toward the southwest than has been depicted in previous groundwater monitoring reports. However, the February 2010 analytical results from permanent well MW-105C indicate that the plume has not migrated off-site above the 2L standard in this area.

3.5 Microbial Profiles and Biodegradation Evaluation

Seven samples were submitted for analysis of DHC and DHB dehalogenating microbes. Five of the samples were further analyzed for functional genes of DHC. Results of the microbial analyses are summarized in Table 5.

Microbial data showed that DHC bacteria were present in four of the samples at very low cell population concentrations. Detected DHC concentrations varied from 0.2J cells per milliliter (cells/ML) at MW-102C to 3.1 cells/mL at MW-104B. The DHC bacteria concentrations, while very low throughout the Site groundwater, appeared to be slightly higher in the wells that were less contaminated with VOCs. As expected, groundwater from well MW-104B also showed the highest counts of DHC functional genes, and the vinyl chloride reductase genes were the most abundant in this sample.

DHB dehalogenating bacteria were detected in five of the samples and were more populous and widespread than the DHC bacteria. Concentrations of detected DHB were highly variable, ranging from 2.7 cells/mL at DPT boring GW09N-12(41-46) to a concentration of 4,650 cells/mL at well MW-103B.

3.5.1 Summary of Biodegradation Potential

Anaerobic reductive dechlorination can be facilitated by several classifications of microbes, including methanogenes, sulfate-reducing bacteria, and dechlorinating (dehalorespiring) bacteria. Bacterial cultures containing *Desulfitobacterium*, *Desulfuromonas*, *Dehalobacter restrictus*, *Dehalospirillum multivorans,* and *Dehalococcoides sp.* are all capable of dechlorinating the higher chlorinated ethene compounds such as Tetrachloroethene (PCE) and TCE to the intermediate product of cis-1,2-DCE (AFCEE, 2004). *Dehalobacter* microbes can also dechlorinate 1,1,1-TCA, another VOC contaminant in Site groundwater, but not cis-1,2-DCE or vinyl chloride. Methanogenes and sulfate-reducing microbes are generally present in all subsurface environments. Many of these bacteria can exist even in aerobic environments and then flourish when more suitable anaerobic conditions are established (Chapelle, 1993; Hollinger et al., 1998).

Current research indicates that the types of bacteria that can further reduce cis-1,2-DCE to vinyl chloride and ethene are much more limited and are not ubiquitous to all subsurface environments (He et al., 2003). Some researchers conclude that the capability of complete dechlorination sequence of PCE and TCE to ethene is limited to only a few species of dechlorinating bacteria within the *Dehalococcoides* group, specifically the species *Dehalococcoides ethenogenes* (Maymo-Gatell et al., 1999). Other researchers (Flynn et al., 2000) have demonstrated complete dechlorination of PCE to ethene using mixed cultures of bacteria that did not contain any *Dehalococcoides* species. Under aerobic conditions, several types of bacteria including methanotrophs (methane-oxidizing bacteria) can co-metabolize TCE, cis-1,2-DCE and vinyl chloride.

Results of recent microbial and semi-annual VOC analyses performed on groundwater samples from the Site were discussed in prior recent reports (Excel, 2009; AECOM, 2010). Potential correlations of the microbial profiles, groundwater geochemistry, and historical VOC trends are summarized below:

- DHC bacteria are present in limited areas of the Site groundwater and they occur at very low concentrations where detected. The highest concentrations were found in the mid-plume wells that are moderately impacted by VOCs;
- DHB bacteria are present in Site groundwater at low to moderate concentrations. The highest concentrations occurred in the wells screened less than 45 feet bgs;
- Methanogenic conditions remain in portions of the impacted aquifer, even though groundwater within the plume boundary has become more oxic. Methane concentrations have declined in most of the source area wells during the past year and are near the lower end of the range considered optimal for reductive dechlorination;
- Methane generation began when the groundwater ORP was highly reduced from fermentation of the injected organic substrate (i.e, HRC®). Methane concentrations increased significantly in most of the wells between 2006 and 2007 and peaked in the source area wells in 2008;
- A large percentage of the TCE has been dechlorinated to cis-1,2-DCE and to a lesser extent 1,1-DCE throughout the VOC plume. There appears to be an historical "stalling" effect of the dechlorination sequence at cis-1,2-DCE in many of the source area Site wells;
- Vinyl chloride and ethene are being generated at low concentrations in groundwater at a some wells, demonstrating that complete dechlorination of TCE is occurring in some portions of the dissolved VOC plume;
- Other VOCs present in groundwater such as 1,1,1-TCA, Freon 113 and Methylene Chloride have also been reduced through biological and/or abiotic processes.

The cumulative conditions described above suggest that the existing suite of microbes in Site groundwater have a limited ability to completely dechlorinate the TCE to ethene, as well as the ability to biodegrade many of the other primary VOCs present in groundwater. Metabolic reductions of TCE to cis-1,2-DCE have been consistent, but at a slow rate, within the groundwater plume. The initial reductions were likely dominated by DHB bacteria in early phases of the bioremediation program and to a lesser extent by methanogenic bacteria.

The general absence or low concentrations of *Dehalococcoides sp.* bacteria in Site groundwater, combined with the inability of the detected *Dehalobacter* bacteria to further dechlorinate the remaining cis-1,2-DCE, leaves the possibility that other types of anaerobic microbes and/or abiotic reduction pathways are responsible for the observed low concentrations of vinyl chloride and ethene. Because

the VOC plume still contains low to moderate concentrations of methane and groundwater has become more oxic during the past year, these pathways may include aerobic and anaerobic co-metabolic dechlorination by methanotrophic bacteria. It can not be ruled out that DHC bacteria also exist in other zones of the aquifer that were not represented by the limited sampling data for this group of microbes.

4.0 Conclusions

A supplemental subsurface investigation was performed at the former Abbott facility in accordance with the Work Plan that included the northern plume source area and the southwest Site boundary plume study area. The following conclusions are based on results of the supplemental investigation and also consider the results of recent semi-annual groundwater sampling events:

4.1 Southwest Site Boundary VOC Plume

- Nine different VOCs were detected in groundwater within the southwest plume study area. Only two of these compounds (1,2-DCA and TCE) were detected at concentrations above their respective 2L groundwater standard. The 2L standards exceedances occurred only in the groundwater samples collected by DPT methods.
- TCE was not detected in shallow (<30 feet deep) groundwater in the southwest study area, but it was detected in deeper groundwater at seven DPT boring locations. The highest concentration of TCE detected was 28 µg/L at DPT boring GW09-06 (54').
- Three VOCs (cis-1,2-DCE, TCE and Freon 113) were detected in the groundwater sample collected from monitoring well MW-105C. None of these VOCs exceeded their respective 2L standards. The TCE concentration was 1.8 µg/L at MW-105C.
- Shallow groundwater (<30 feet bgs) contained very few VOCs, the detected concentrations were very low, and no 2L standards were exceeded for any of the detected VOCs. The highest concentrations of chlorinated VOCs were detected at depths of 54-68 feet bgs.

The supplemental investigation sampling results indicate that TCE is present in deeper Site groundwater at the southwest Site property boundary. The combined results of DPT groundwater sampling and monitoring well sampling in the southwest study area also confirm that the TCE plume has migrated further toward the southwest than has been depicted in previous groundwater monitoring reports. However, the February 2010 analytical results from permanent well MW-105C indicate that the plume has not migrated off-site above the 2L standard in this area.

4.2 Northern Source Area VOC Plume

- The largest and most widespread MIP survey VOC detector responses were measured on the ECD, indicating the predominance of chlorinated ethenes and/or chlorinated ethanes in the subsurface. The magnitude of the PID and FID responses was much lower than those measured by the ECD instrument.
- Directly below the former waste pit the elevated ECD responses abruptly end at a depth of 41 feet bgs. Moving south away from the former waste pit a well-defined and laterally continuous ECD response base was seen at an average depth of approximately 53 feet bgs.
- The magnitude of VOC impacts increase with depth toward the south (i.e., downgradient). Between MIP09-01 and MIP09-08 shallow groundwater less than 20 feet deep has much lower VOC impacts compared to deeper groundwater between depths 30-52 feet bgs.
- No LIF responses were measured at two boring installed to 18 feet bgs adjacent to MW-101A. Four additional MIP borings installed in this area also did not show significant

responses on the ECD, PID, or FID in the upper 20 feet of the surficial aquifer. The combined LIF and MIP results in the vicinity of well MW-101A confirm that a floating free phase product layer has not accumulated on or near the water table surface in this area. The impacted soil matrix in the upper 18 feet also does not contain sufficient aromatic hydrocarbons to fluoresce under UV light.

- Electrical conductance of the Site soils ranged from approximately 0.5 mS/m to a high of 80 mS/m in the MIP study area. Site soils range from fine to coarse sands (low EC values <5 mS/m) to silt and clay (EC values >30 mS/m). Soil core inspections indicate that EC responses between 10-30 mS/m generally represents silty sands to clayey sands and responses greater than 30 mS/m correlate to sandy silts, silts and clays for this Site.
- Three soil cores were collected from suspected NAPL-impacted zones where elevated ECD and/or PID responses occurred during the MIP survey. Each soil core contained TCE and one or more other VOCs. Soil TCE concentrations varied from 827 µg/kg to 26,400 µg/kg. Methylene chloride was also detected at a concentration of 28,300 µg/kg in one of the soil cores collected at the base of the former waste pit.
- Residual NAPL pore fluid saturation varied from 3.5 %Pv at soil core SB09N-01 (23-24') to 1.9% Pv at soil core sample SB09N-03 (20.5-22'). The NAPL saturation remained unchanged at each core sample before and after the centrifuge test, and no visible separate phase NAPL was produced during the centrifuge process. These results indicate that the two soil cores contain a very low volume of residual NAPL that is adsorbed to the soil matrix and is not mobile.
- Seventeen VOCs were detected in multi-depth DPT groundwater samples collected from the northern plume source area. All but three of these compounds (MIBK, O-Xylene, and Freon 113) were present in concentrations above their respective 2L groundwater standard in one or more DPT groundwater samples. The most frequently detected VOCs during the DPT groundwater sampling were cis-1,2-DCE, methylene chloride, TCE, and Freon 113.
- Directly beneath the former waste pit boundary the dissolved VOCs concentrations were highest in shallow groundwater from 16-40 feet bgs. The highest concentrations of acetone, MEK, and methylene chloride were also detected in shallow groundwater in this area. These results likely explain the elevated PID responses obtained in shallow groundwater beneath the former waste pit during the MIP survey.
- The highest concentration of TCE detected during DPT groundwater sampling was 32,000 µg/L at a DPT boring located adjacent to the MW-101 well cluster. This DPT sampling location also contained the highest Freon 113 concentration at 31,000 µg/L, the highest 1,1,1-TCA concentration at 2,500 µg/L, and an elevated cis-1,2-DCE concentration (34,000 µg/L).

The MIP survey ECD response patterns, distribution of the dissolved VOC plume, and soil core test results confirm that the largest remaining VOC mass is adsorbed into the lower permeability silty and clayey sand strata beneath the Site. A strong correlation is seen between the elevated ECD responses and the occurrence of the clayey to silty sand and sandy silt stratigraphic unit that occurs from depths of 20-65 feet bgs in the northern study area. Of particular importance is the distinct vertical base of elevated ECD responses that correlates to the maximum depths of a clay layer that averages 53 feet bgs in the northern study area. This 'middle' lower permeability silt- and clay-rich unit is bounded above and below by more sandy units of higher permeability that have much lower VOC concentrations and that lower soil/groundwater ECD responses. VOC mass sorbed to the lower permeability materials is slowly released into the more permeable sandy strata via matrix diffusion, where it exists in lower aqueous concentrations.

4.3 Biodegradation Potential in Site Groundwater

- Microbial data showed that DHC bacteria were present in a few groundwater samples at very low cell population concentrations. DHC concentrations varied from 0.2J cells/ML at well MW-102C to 3.1 cells/mL at MW-104B. The DHC bacteria concentrations, while very low throughout the Site groundwater, appeared to be slightly higher in the wells that were moderately impacted with VOCs.
- DHB dehalogenating bacteria were detected in five groundwater samples and were more populous and widespread than the DHC bacteria. Concentrations of detected DHB were highly variable, ranging from 2.7 cells/mL to 4,650 cells/mL.
- The existing suite of microbes in Site groundwater have a limited ability to completely dechlorinate the TCE to ethene, as well as the ability to biodegrade many of the other primary VOCs present in groundwater. Metabolic reductions of TCE to cis-1, 2-DCE have been consistent, but at a slow rate, within the groundwater plume.
- The initial TCE reductions were likely dominated by DHB bacteria in early phases of the bioremediation program and to a lesser extent by methanogenic bacteria. Later biodegradation pathways at the Site may also include co-metabolic dechlorination by methanotrophic bacteria in the presence of methane generated by the organic substrate fermentation.

Groundwater geochemistry data from the past two semi-annual sampling events also show that Site groundwater is becoming more oxic and the total organic carbon content has significantly decreased to levels that will not sustain continued anaerobic bioremediation of the VOCs. Restoring the Site groundwater geochemistry to more favorable, strongly anaerobic conditions would likely increase the populations of indigenous dehalogenating bacteria.

5.0 References

Chapelle, F.H. 1993. *Groundwater Microbiology and Geochemistry*. New York: John Wily & Sons.

Radian, 1993. *Remedial Investigation Report, Abbott Laboratories, Laurinburg, NC*. Radian Corporation.

Hollinger et al, 1998. *Dehalobacter restrictus* gen. nov. and sp. nov., a Strictly Anaerobic Bacterium that Reductively Dechlorinates Tetra- and Trichloroethene in an Anaerobic Respiration. *Archives of Microbiology*, Vol. 169(4): 313-321.

Maymo-Gatell, et al., 1999. "Reductive dechlorination of chlorinated ethenes and 1,2-dichloroethane by Dehalococcoides ethenogenes 195." *Applied and Environmental Microbiology*, Vol. 65(7): 3108-3113.

Flynn et al., 2000. Microbial Community Changes Associated with a Shift from Reductive Dechlorination of PCE to Reductive Dechlorination of cis-DCE and VC. *Environmental Science and Technology*, Vol. 34(6): 1056-1061.

Matrix, 2002. *Remedial Action Plan Amendment, Abbott Laboratories, Laurinburg, North Carolina*. Matrix Environmental, Inc. June 2002.

He et al., 2003. Detoxification of Vinyl Chloride to Ethene Coupled to Growth of an Anaerobic Bacterium. *Nature*, Vol. 424:62-65.

AFCEE, 2004. *Principles and Practices of Enhanced Anaerobic Bioremediation of Chlorinated Solvents*. Final-August, 2004.

Excel, 2009. *1st and 2nd Quarters 2009 Progress Report-Solvent Release Remediation, Former Abbott Facility, Laurinburg, Scotland County, North Carolina*. Excel Civil & Environmental Associates, PLLC. June 10, 2009.

AECOM, 2009. *Work Plan for Supplemental Subsurface Investigation and Remedial Actions, Solvent Release Remediation, Former Abbott Facility*. AECOM North Carolina, Inc., August 2009.

AECOM, 2010. *Progress Report for 3rd and 4th Quarters 2009: Groundwater Monitoring and Annual Remediation Effectiveness Evaluation, Former Abbott Facility, Solvent Release Remediation*. AECOM North Carolina, Inc., February 2010.