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Mr. Dustin Armstrong, Project Officer
Environmental Cleanup Program
Pennsylvania Department of Environmental Protection
Southeastern Regional Office
Lee Park, Suite 6010
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Conshohocken, PA 19428

Re: Final Supplemental Soil Characterization Report
Bishop Tube Site
East Whiteland Township, Chester County, Pennsylvania
PADEP Contract No. ME359184
Work Requisition No. 31-116

Dear Mr. Armstrong:

Baker Environmental, Inc. (Baker) is pleased to provide the Pennsylvania Department of Environmental Protection (PADEP) with the Final version of the Supplemental Soil Characterization Letter Report. The report outlines the field procedures and analytical results for the additional investigative activities performed to evaluate the concentrations of chlorinated solvents contained in the subsurface materials at the Bishop Tube site. Recommendations regarding options for remediating the chlorinated solvents contained in the soils underlying the site are also presented for consideration.

1.0 BACKGROUND

1.1 Site Location and Setting

The Bishop Tube site is located along the east side of Malin Road approximately ¼ of a mile south of U.S. Route 30, in Frazer, East Whiteland Township, Chester County, Pennsylvania. The site can be located on the Malvern, Pennsylvania USGS 7.5-Minute Quadrangle Topographic Map at north 40° 02' 24" latitude and west 75° 32' 13" longitude (see Figure 1). The Central and Western Chester County Development Authority (CWCCDA) currently owns the site. The CWCCDA acquired the property from Christiana Metals in late 2002.

Survey mapping indicates that the current property is approximately 13.7 acres in size. The Bishop Tube site is situated in a suburban area that is mainly served by public water. Some local residents and businesses, however, still rely upon private wells for their water supply needs. According to the United States 2000 Census report for Chester County Pennsylvania, 9,333 people were listed as residing within the East Whiteland Township, Pennsylvania area (United States Census Bureau, 2000).

The Bishop Tube site is situated within a southwest-northeast trending valley locally referred to as the Chester Valley area. This valley is mainly underlain by easily eroded rocks comprised of limestone and dolomite. The northwestern edge of Chester Valley is flanked by resistant quartzites that form the North Valley Hills. The southeastern edge of the valley is bordered by a combination of resistant phyllites and schists, and is locally referred to as the South Valley Hills. The main trunk streams draining the valley are Little Valley Creek and Valley Creek. The headwaters of Little Valley Creek originate along the upper portion of the hillside immediately east of the Bishop Tube site.

The Bishop Tube facility was formerly used to process precious metals and to fabricate stainless steel specialty items, namely tubing and piping products. The site includes two large out-of-service rectangular-shaped one-story concrete block buildings that cover approximately 3.2 acres of surface area. These two buildings are connected to one another and are referred to as Building #5 and Building #8. A considerable amount of cutting and filling has occurred at the site to construct the buildings and parking areas. Building #5 was constructed in 1950 and Building #8 was built in 1959. The remainder of the property primarily consists of paved and gravel-covered storage/parking areas, with a smaller amount of undeveloped grassy areas. An 8-foot high chain-link fence currently borders the northern, southern, and western edges of the property (see Figure 2).

A transformer pad is located next to a loading dock at the southern side of Building #5. The former boiler room for Building #5 is located just east of the transformer pad and loading dock. Two underground storage tanks (UST) used to store No. 2 and No. 6 fuel oils are believed to exist along the western and southern sides of this boiler room. Each of these two USTs is reportedly 5,000 gallons in capacity. A third UST (20,000 gallon capacity) used to store fuel oil for the boiler room of Building #8 is believed to exist in the middle of the plant complex between Buildings #5 and #8.

During the former plant operations, stainless steel was first cleaned prior to fabrication by passing the raw materials through several pickle tanks (i.e., acid). The former pickle tank area is located in the eastern portion of Building #8. An 8-inch raised concrete pad currently overlies the area where the pickling operations were conducted. Rinse waters from the pickling process were reportedly mixed/aerated with the sanitary wastes generated by the plant facility and discharged to an underground sanitary cesspool located between the east end of Building #5 and the concrete "acid" aboveground storage tank (AST) pad.

Immediately east of Building #5 is a concrete-covered area formally used to store drums of solvents and chemicals associated with the plant operations. A raised concrete berm surrounds the eastern portion of the former drum storage area. Several rectangular-shaped concrete pads exist within the bermed enclosure. According to plant records, several aboveground storage tanks were housed in this area for the storage of nitric acid (4,000-gallon capacity), hydrofluoric acid (5,100-gallon capacity), used acids (4,000-gallon capacity), and acid rinse waters (two tanks, each 5,600-gallon capacity). These acids and waste fluids were apparently associated with the former pickling operations performed at the site.

Along the northern edge of Building #8 are two 4 feet by 4 feet concrete-covered areas. According to plant records, a 4,000-gallon capacity aboveground storage tank rested on support pillars in this area for the storage of trichloroethylene (TCE). TCE was transferred from the aboveground storage tank to the vapor degreaser located within Building #8 via a 1¼-inch carbon steel underground pipe.

At the west end of Building #8 is a cooling tower. During the time period from June 2001 through December 2003, groundwater from several springs was observed emerging through cracks in the asphalt pavement of the parking area situated east of the cooling tower. Hydrophytic vegetation (i.e., cattails) is

well established and reddish-brown iron staining is present on the surface of the asphalt pavement adjacent to the points where groundwater emerges from the subsurface and along the downslope runoff areas. Thin films (i.e., sheens) were observed floating on top of the water discharging from these springs. In addition, odors resembling weathered hydrocarbon compounds were observed in this area. It should be noted that the Mobil Oil Corporation, Inc. currently operates a bulk oil terminal on the property situated immediately west of Malin Road adjacent to the Bishop Tube site. A review of aerial photographs (Baker, 2002a, and Baker, 2002b) suggests that the petroleum products have been stored in aboveground storage tanks at this facility since at least 1947. Information furnished by the PADEP indicates that hydrocarbon compounds have been released into the environment at the Mobil bulk oil terminal. A quarterly groundwater sampling report, dated January 2000, prepared by Handex, Inc. on behalf of Mobil shows that the groundwater underlying the Mobil bulk oil terminal flows to the north-northeast in the direction of the Bishop Tube site. The analytical results for the groundwater samples collected from the monitoring wells at the Mobil bulk oil terminal during the period from October through December 1999 show that the groundwater locally contains concentrations of hydrocarbon compounds (i.e., benzene, toluene, ethylbenzene, methyl tertiary butyl ether, cumene, and naphthalene) exceeding the PADEP Statewide Health-based Standards. Separate phase liquid hydrocarbons were reported by Handex, Inc. to be floating on top of the groundwater contained in several monitoring wells at the Mobil bulk oil terminal. In December 1999, removal of liquid hydrocarbon compounds via pneumatically operated skimmer pumps was actively being performed at the Mobil bulk oil terminal from monitoring wells MW-1, MW-2, and MW-3 (Handex, 2000).

The northern and southern edges of the Bishop Tube property are bordered by railroad tracks maintained by Norfolk Southern and Amtrak, respectively. Malin Road borders the western edge of the site. A bulk fuel oil terminal, operated by the Mobil Oil Corporation, is situated along the western side of Malin Road next to the Bishop Tube site (see Figures 1 and 2).

Topography decreases from a high of approximately 500 feet above mean sea level near the Amtrak railroad tracks at the southern boundary of the Bishop Tube site to a low of 370 feet above mean sea level along Little Valley Creek situated at the northeast corner of the property. Based upon these topographical differences, surface water runoff is in a north-northeasterly direction across the site. Little Valley Creek receives surface water runoff from the parking areas situated along the east side of the manufacturing building. A drainage channel is present immediately north of Building #8 adjacent to the Norfolk Southern railroad tracks. This drainage channel receives runoff from the rooftop and parking areas surrounding Building #8, and ultimately conveys this surface water to Little Valley Creek situated along the eastern edge of the property.

1.2 Site History

Prior to the construction of the plant buildings, land use of the Bishop Tube property was primarily agricultural in nature. Manufacturing operations began at the site under the name of the "J. Bishop and Company, Platinum Works" in 1951. Little is known about the early manufacturing work performed at the site. Industrial operations are believed to have included the processing of platinum and other precious metals.

In 1967, the plant was sold to Matthey Bishop and Company. At this time, the industrial operations performed at the site were changed to encompass the manufacturing of special seamless stainless steel tubing. Under these new operations, the plant was classified as a redraw mill, where stainless steel pipe

was reduced to specific diameters and wall gauges by successive redraws and heat treatment. Matthey Bishop and Company sold the plant in 1969 to the Whittaker Corporation.

In 1974, the Christiana Metals Corporation purchased the manufacturing plant. Christiana Metals continued to operate the stainless steel tube manufacturing business at the site until the early 1990's, when the building and facilities were sold to the Marcegaglia Group, USA-Damascus Division. The plant operated under the name of the Damascus-Bishop Tube Company, Inc. from early 1990's to the closure of the business in 1999. The site is currently owned by the Central and Western Chester County Development Authority and is non-operational.

Manufacturing operations performed at the Bishop Tube facility included the cleaning, pointing, shaping (i.e., drawing), welding, degreasing, annealing, straightening, sandblasting, polishing, and painting of stainless steel and specialty metals into tubes (i.e., pipes) and other various metal products. The plant reportedly used a wide variety of materials, including nitric acid, hydrofluoric acid, caustic materials (water treatment), motor oil (20W40), gear oils, specialty drawing lubricants, degreasing solvents (TCE), anhydrous ammonia, coolants, polishing compounds, metal alloys, and paints. The processing procedures included a cleaning/pickling operation to prepare metals for fabrication (source of acidic and caustic solutions/sludges containing heavy metals); drawing operations (introduction of lubricants); trimming operations (source of heavy metal cuttings and dusts); a degreasing/cleaning operation (source of chlorinated solvents and waste oils); an annealing/heat treatment and subsequent cooling operation (source of heavy metal scales); a trim, ream, and deburr operation (source of heavy metal cuttings and dusts); and finally a polishing operation for finished metals (source of metal dusts).

An engineering report dated April 9, 1973, identified the following industrial wastewater sources generated by the manufacturing operations at the Bishop Tube facility:

- Furnace and degreaser cooling waters.
- "A"-furnace cooling water.
- Compressor and after cooler cooling water.
- Pickle rinse water and floor drains.
- Boiler blow down.

Prior to the installation of a public sewer system in the area, plant sanitary wastes were apparently directed to an aeration tower and pit where the sewage was circulated for treatment. A waste acceptance firm pumped out the sludges that settled to the bottom of the pit approximately once every six months. The treated liquid effluent flowed by gravity to a holding tank where it was then pumped to an underground cesspool for disposal. This underground cesspool is believed to be in the area between the east end of Building #5 and the concrete "acid" aboveground storage tank (AST) pad.

The cooling water waste streams (i.e., furnace and degreaser cooling waters, "A"-furnace cooling water, and compressor and after cooler cooling water) were combined into two discharges to Little Valley Creek. The furnace and degreaser cooling water was apparently directed from the manufacturing complex to Little Valley Creek via a 12-inch diameter asphalt-coated corrugated metal pipe. The non-contact cooling water (approximately 60 gallons per minute) from the heat exchangers was discharged to Little Valley Creek under a National Pollutant Discharge Elimination System (NPDES) Permit (No. PA0013641). The "A"-furnace cooling water and compressor and after cooler cooling water were combined and discharged to the drainage swale along the Norfolk Southern Railway line north of Building #8.

Liquid overflow wastes originating from the pickle acid-rinse tanks and floor drains were discharged into a holding tank where they were reportedly mixed with the sanitary effluent from the aeration tower. The mixed liquid wastes contained in the holding tank were reportedly pumped to the underground cesspool located at the east end of Building #5 for disposal. Samples of the pickle acid rinse stream collected in 1973 showed that this liquid waste was acidic (pH of 2.0), and contained high concentrations of nitrates and fluorides, reflecting the characteristics of the nitric-hydrofluoric acid pickle liquor. In addition, the pickle acid rinse stream also contained elevated concentrations of iron (89.9 mg/l), nickel (12.5 mg/l), and total chromium (17.2 mg/l).

Blow down of the two low-pressure boilers was reportedly conducted once or twice a day, depending upon the concentration of the dissolved solids. The boiler blow down discharges were directed to a small pit/impoundment under the driveway. This water apparently then overflowed onto the driveway and evaporated. The location of this pit/impoundment is believed to have been located under the asphalt driveway east of Building #8. Field notes, recorded by an inspector from the Pennsylvania Department of Environmental Resources (PADER – now the PADEP), suggest that this underground pit/impoundment may have also received overflow discharges from the sanitary cesspool, pickle area floor drains, and furnace and degreaser cooling waters. Fluids contained in the underground pit/impoundment may have been pumped to a second cesspool area located within the alcove east of the boiler room in Building #5. Overflow from this second cesspool was conveyed by a stormwater drainpipe to Little Valley Creek east of the site. Bishop Tube closed the pit/impoundment and cesspool areas in 1979. Closure reportedly involved filling these impoundments with limestone and covering the waste disposal areas with concrete.

1.3 Previous Investigations

Previous environmental investigations conducted at the site on behalf of the former property owners have identified impacts to soils and groundwater related to the past manufacturing operations. Specifically, elevated concentrations of chlorinated solvents (i.e., trichloroethylene, 1,1,1-trichloroethane, tetrachloroethylene) and fluoride have been detected in the soils and groundwater at the site that exceed the PADEP Statewide Health-based Standards. In addition, surface water and sediment samples collected from Little Valley Creek have also been found to contain elevated concentrations of chlorinated solvents and fluoride that exceed the established regulatory standards.

In 1972, elevated concentrations of fluoride were detected in surface water samples collected from Little Valley Creek by the PADER. These samples were collected as part of a regional study to evaluate the quality of water within the Little Valley Creek drainage basin. The source for the fluoride was traced to a 12-inch diameter discharge pipe located just east of the Bishop Tube site. Additional water quality studies performed in the early 1980's confirmed the presence of elevated concentrations of fluoride in Little Valley Creek. To evaluate the groundwater conditions at the Bishop Tube site, Betz, Converse, and Murdoch (BCM), Inc., on behalf of Christiana Metals, drilled four monitoring wells (MW01 through MW04) at the site. The results of this investigation determined that the groundwater in the vicinity of MW04 (drilled adjacent to the pit/impoundment east of Building #8) contained an elevated concentration (23.1 mg/l) of fluoride. This finding suggested that the discharge of groundwater via baseflow from the fractured bedrock aquifer underlying the Bishop Tube site might be the source of the fluoride in Little Valley Creek. To address this concern, BCM, Inc. recommended that groundwater samples be collected from the monitoring wells on a periodic basis to monitor the concentrations of fluoride.

On June 10, 1981, nitric and hydrofluoric acid were inadvertently mixed causing a release of an acid mist at the Bishop Tube facility. The acid mist drifted offsite and resulted in the evacuation of approximately

500 residents of the nearby General Warren Village housing development (see Figure 2). Sixteen people were treated at a local hospital for respiratory problems associated with the release of the acid vapors.

In 1984, fluoride was detected in groundwater that had infiltrated through cracks into a concrete-lined sump within the manufacturing plant. Due to an inadvertent connection between the sump and the effluent pipe for non-contact cooling water, fluoride was discharged to Little Valley Creek. The concentration of fluoride dissolved in the effluent water exceeded the permitted average monthly limit of 10 mg/l, and was in violation of Bishop Tube's NPDES permit. To correct the situation, the sump water was transferred to a temporary storage tank for treatment/disposal at an offsite permitted facility.

In 1987, BCM/Smith, Inc., on behalf of Christiana Metals Corporation, conducted an investigation to update the 1981 groundwater study, and to evaluate potential impacts from degreasing agents (i.e., chlorinated solvents) historically used at the plant. The investigation included the drilling of five additional groundwater monitoring wells (MW05 through MW09), the collection of groundwater samples from the monitoring well network, the drilling of five borings and collection of soil samples, and the collection of three surface water samples from Little Valley Creek. The results of this investigation indicated the presence of volatile organic compounds (VOCs), primarily trichloroethylene (TCE) and 1,1,1-trichloroethane (1,1,1-TCA) in the groundwater underlying the site. Heavy metals were also detected in the soil and groundwater samples collected during the investigation (BCM/Smith, 1988).

On July 26, 1988, a meeting was conducted between the PADER, BCM/Smith, Inc. and Christiana Metals Corporation to discuss the environmental concerns at the Bishop Tube site. At this meeting BCM/Smith presented the PADER with a work plan for performing further investigative work to delineate the extent of VOCs (i.e., TCE and 1,1,1-TCA) dissolved in the groundwater underlying the site. The PADER requested that quarterly groundwater monitoring also be performed in the vicinity of the east end of the manufacturing plant where cooling water was being discharged to Little Valley Creek. This monitoring was apparently requested to document the concentrations of fluoride in groundwater that were formerly predicted to decrease with time as a result of improvements made in the plant's pickle liquor handling practices. In October 1988, prior to the submission of a revised work plan, a soil vapor survey (SVS) was conducted along the north side of the manufacturing building. The results of the soil vapor survey showed low concentrations of TCE, tetrachloroethylene (PCE), and trans-1,2-dichloroethylene (trans-1,2-DCE) in the soils underlying the former TCE aboveground storage tank (AST), loading dock area, and concrete storage pad. A final groundwater remediation work plan was submitted to the PADER in June 1989.

In 1989, BCM/Smith, on behalf of Christiana Metals Corporation, drilled and installed seven additional monitoring wells (MW10 through MW16) at the Bishop Tube site. This work included five shallow monitoring wells and two deep monitoring wells. To evaluate the concentrations of VOCs contained in the soils where the SVS was performed, BCM/Smith drilled eight borings at the site. Five of these soil borings were drilled along the north side of Building #8, and three soil borings were drilled inside Building #8 in the vicinity of the vapor degreaser. The soil samples collected from the borings drilled in the vicinity of the vapor degreaser showed that the subsurface materials contained elevated concentrations (up to 3,280 mg/kg) of TCE (O'Brien and Gere, 1998).

Groundwater samples were collected from the monitoring wells at the Bishop Tube facility in 1989. The sampling results were presented to the Christiana Metals Corporation in a report prepared by BCM/Smith titled: *Results of Implementation of Groundwater Remediation Work Plan, Phase I*, dated January 1990. This report characterized the water quality conditions in the underlying bedrock aquifer and the direction of groundwater flow at the site. The sampling results indicated that groundwater in the underlying

bedrock aquifer contained elevated concentrations of chlorinated solvents (namely TCE). Moreover, the indoor vapor degreaser area was suspected as the principle source for the VOCs contained in the groundwater, with the outdoor former TCE AST being a potential secondary source.

In 1995, BCM/Smith on behalf of the Christiana Metals Corporation drilled four additional monitoring wells (i.e., MW17, MW18, MW19, and MW20) to evaluate the water quality conditions at the Bishop Tube facility. These wells included two lower (i.e., deep) bedrock monitoring wells (i.e., MW17 offsite and MW19 onsite), one onsite upper bedrock monitoring well (MW18), and one onsite shallow overburden well (MW20). During the drilling of the borehole for MW19, continuous rock cores were collected from the interval between 300 feet to 500 feet below grade. The investigation also included downhole video surveys in monitoring wells MW17 and MW19 (i.e., deep wells), packer testing and the collection of depth discrete groundwater samples in monitoring wells MW17 and MW19, slug testing within the packer test interval in monitoring wells MW17 and MW19, and a 30 hour aquifer test in monitoring well MW19. The results of the investigation indicated that high yielding fracture zones occur within the upper portion of the bedrock aquifer within 100 feet of the ground surface. The concentrations of TCE detected in the groundwater samples collected from deeper intervals of MW17 and MW19 were similar to the shallow groundwater samples. The groundwater samples collected from monitoring wells MW17 and MW19 were found to contain concentrations of TCE ranging between 44 mg/l and 680 mg/l. These concentrations are equivalent to 4% to 62% of the pure phase aqueous solubility limit of TCE. This information suggests that dense non-aqueous phase liquids (DNAPLs) may be present within the upper portion of the bedrock aquifer underlying the site (O'Brien and Gere, 1998).

In 1996, Smith Environmental (formerly BCM) collected surface water samples from Little Valley Creek in the vicinity of the Bishop Tube site. The sampling data for these surface water samples were presented in the 1998 *Site Characterization and Interim Remedial Action Plan* report, prepared by O'Brien and Gere, Inc. following the bankruptcy of Smith Environmental. These surface water samples were analyzed for fluoride and VOCs. The analytical results show that TCE was detected in the surface water of Little Valley Creek at concentrations of 0.075 mg/l and 0.01 mg/l. These concentrations exceed the Surface Water Quality, Human Health-based Standard for TCE of 0.003 mg/l.

In January of 1996, Smith Environmental collected a groundwater sample from a domestic water supply well, CH1985, located at 54 Conestoga Road. This well is reportedly 225 feet deep with 20 feet of casing. The groundwater samples collected from this well were found to contain concentrations of the following VOCs: TCE at 0.053 mg/l, 1,1,1-TCA at 0.0081 mg/l, and 1,1-DCA at 0.0011 mg/l. The sampling data show that the concentration of TCE exceeded the Act 2 Statewide Health-based Groundwater Standard of 0.005 mg/l. In 1999, a whole-house carbon filtration system was installed in this home at the expense of the Christiana Metals Corporation.

In 1998, O'Brien and Gere, on the behalf of the Christiana Metals Corporation, completed a *Site Characterization and Interim Remedial Action Plan* report outlining a planned interim remedial action program to address the groundwater quality conditions at the Bishop Tube site. This report was prepared using the information compiled from previous investigations performed by other consultants at the site. The interim remedial action program proposed extracting groundwater from the north and east plant areas in an attempt to limit the offsite migration of the TCE plume. The final number and locations of the extraction wells were to be based upon a pilot testing program and the performance data of the initial phase-in implementation program. The conceptual interim remediation plan included the extraction of groundwater from two vertically oriented pumping wells. One extraction well would be located in the vicinity of well cluster MW02/MW03/MW19 and pumped at a rate of 30 to 60 gallon per minute (gpm).

A second extraction well would be located along the eastern side of Building #8 and pumped at a rate of 30 gpm. The plan also included the possibility of using a horizontally oriented well to extract groundwater within the upper portion of the overburden/shallow bedrock. The groundwater extracted from the pumping wells was proposed to be treated onsite using an air stripper. The treated effluent would ultimately be discharged to the local publicly owned treatment works (POTW). A catalytic oxidizer with a caustic scrubber was proposed to reduce the concentrations of VOCs in the off-gas generated by the air stripper. This interim remedial action plan was never implemented.

During the period of June through October 2001, a Site Characterization was performed by Baker on behalf of the PADEP to determine the concentrations of organic and inorganic compounds contained in the soils, sediments, surface water, and shallow groundwater at the Bishop Tube site (Baker, 2002a). The results of this investigation were used to evaluate potential risks to human health and the environment. A total of 87 soil borings were drilled inside and around the perimeter of the plant building to evaluate the horizontal and vertical extent of organic and inorganic compounds contained in the soils. To assess potential impacts resulting from the past disposal of waste materials at the site, eight sets of surface water and sediment samples were collected from selected locations along Little Valley Creek as well as the drainage swale situated north of Building #8. Elevated concentrations of chlorinated solvents (trichloroethylene, tetrachloroethylene, 1,1-dichloroethene, 1,2-dichloroethene, 1,1,1-trichloroethane, 1,1,2-trichloroethane, 1,2-dichloropropane, and vinyl chloride); hydrocarbon compounds (MTBE, benzene, toluene); polynuclear aromatic hydrocarbon compounds (anthracene, benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, chrysene, and pyrene); polychlorinated biphenyls (aroclor 1260); and heavy metals (antimony, arsenic, barium, beryllium, cadmium, chromium, copper, lead, mercury, nickel, silver, thallium, vanadium and zinc) exceeding the PADEP Health-based Standards were detected in the soils, sediments, surface water, and shallow groundwater at the site. The results of the Phase I Site Characterization were used by the PADEP to develop a Scope of Work for further investigating the impacts to the groundwater underlying the Bishop Tube site.

During the period from December 2001 through June 2002, Baker performed a Groundwater Investigation at the Bishop Tube site on behalf of the PADEP (Baker, 2002b). This investigation included the following work: 1) the collection of groundwater samples from selected private water supply wells and springs believed to be situated hydraulically downgradient to the direction of groundwater flow from the Bishop Tube site; 2) the performance of geophysical well logging techniques to log the boreholes of monitoring wells MW09, MW17, and MW19; 3) the completion of a seismic refraction geophysical survey to map the elevation of the top of bedrock for selected areas at the site; 4) the installation of four new monitoring wells (MW21, MW22, MW23, and MW24); 5) the collection of one round of groundwater samples from the monitoring well network to assess the concentrations of organic and inorganic compounds contained in the underlying fractured bedrock aquifer; and 6) the performance of a 24-hour constant rate pumping aquifer test to evaluate the hydraulic properties of the shallow groundwater flow system.

The results of the seismic refraction geophysical survey showed that the surface of the bedrock underlying the former vapor degreaser area in Building #8 and the former drum storage area is pinnacled. The elevation changes exhibited by the surface of the bedrock were postulated to be providing a path for the migration of DNAPLs in the subsurface. A trough/depression was identified in the southeast corner of Building #8 by the geophysical survey. This trough/depression was suspected to represent the location of the former waste disposal lagoon.

The results for the geophysical logging responses recorded abrupt increases in the specific conductance of the groundwater with respect to depth in the boreholes for former deep monitoring wells MW17 and MW19. This information suggested that DNAPLs may be present in the deeper portions of the fractured bedrock aquifer underlying the site.

The data collected during the 24-hour constant rate aquifer test showed that the average hydraulic conductivity of the weathered bedrock/saprolite interval is approximately 2.06×10^{-2} ft/min. The average hydraulic conductivity value estimated for the fractured bedrock interval is 4.19×10^{-3} ft/min. In addition, the aquifer testing results showed that groundwater flow within both the saprolite/weathered bedrock and the fractured bedrock intervals underlying the Bishop Tube site is anisotropic. Specifically, the hydraulic conductivity within these intervals was found to be 1.5 times greater parallel to the strike of the rock beds than perpendicular to strike.

The analytical results for the groundwater samples collected from the offsite residential wells and springs showed that elevated concentrations of TCE (37 $\mu\text{g/l}$) and PCE (5.8 $\mu\text{g/l}$) exceeding the PADEP Statewide Health-based Groundwater Standards were detected in well CH1985 (54 Conestoga Road) and the spring at sample point No. SP-49 (10 Winding Way), respectively. The source of the TCE and PCE detected in well CH1985 and the spring at sample point No. SP-49 is unknown. Based upon published groundwater flow maps for the Chester Valley, Pennsylvania area, well CH1985 is believed to be situated hydraulically downgradient to the direction of groundwater flow from the Bishop Tube site. The spring at sample point SP-49 is situated lateral to the direction of groundwater flow from the Bishop Tube site.

The groundwater samples collected from the monitoring wells in February 2002 were found to contain concentrations of the following VOCs that exceeded the PADEP Statewide Health-based Groundwater Standards: 1,1-DCE, 1,2-DCE, methylene chloride, PCE, 1,1,1-TCA, TCE, and vinyl chloride. The concentrations of TCE were found to exceed the PADEP Statewide Health-based Groundwater Standard in each monitoring well at the Bishop Tube site with the exception of the samples collected from monitoring wells MW01 (upgradient) and MW24. The highest concentration of TCE (i.e., 45,000 $\mu\text{g/l}$) was detected in the groundwater sample collected from monitoring well MW22. Monitoring well MW22 is currently the deepest well at the Bishop Tube site. Because the concentrations of TCE detected in the groundwater samples collected from monitoring well MW22 are greater than 10% of the pure phase solubility limit for TCE, DNAPLs are suspected to be present in the fractured bedrock aquifer underlying this area of the site. The results of the Phase II Groundwater Investigation were used by the PADEP to develop a Scope of Work for further investigating the impacts to the soils and groundwater underlying the Bishop Tube site.

1.4 Purpose and Objective

The purpose of the Supplemental Soil Characterization was to more fully assess the following issues: 1) determine changes in the elevation of the bedrock surface in uncharacterized areas at the site (potential DNAPL accumulation points and/or migration conduits); 2) define the lateral limits of the VOCs contained in the subsurface materials underlying the former vapor degreaser area #2 in Building #5, the former vapor degreaser area #1 in Building #8, and in the former drum storage area; 3) characterize the concentrations of organic and inorganic compounds contained in the subsurface materials overlying the depression occurring within the top of bedrock situated at the southeast corner of Building #8 (suspected former waste disposal lagoon area); and 4) determine the presence or absence of free-phase DNAPLs occurring within the soils and weathered bedrock materials underlying the site. The additional information provided by the Supplemental Soil Characterization was evaluated with the environmental

data collected during previous investigations to assess various remediation techniques for cleaning up the elevated concentrations of chlorinated solvents contained within the soils at the site.

2.0 SITE ASSESSMENT

The scope of the field procedures performed during the Supplemental Soil Characterization is outlined in the following sections.

2.1 Site Scoping Meeting and Historical Information Review

Baker received a letter from the PADEP on June 13, 2002, to prepare a Work Plan and Cost Proposal (i.e., Change Order #9) for performing supplemental investigation activities associated with further characterizing the soils and groundwater at the Bishop Tube site. The supplemental investigative activities requested by the PADEP for further characterizing the soils included: performing additional geophysical survey studies in uncharacterized areas at the site; the drilling of additional soil borings using membrane interface probe (MIP) technology; the collection of confirmatory soil samples using direct push technology to verify the concentrations of VOCs contained in the subsurface materials; and the deployment of Flexible Liner Underground Technologies, Ltd. Company (FLUTE[®]) non-aqueous phase liquids (NAPL) liners in selected borings to determine the presence of free-phase DNAPLs contained in the soils. It should be noted that Baker is conducting the investigation of the groundwater contained in the fractured bedrock aquifer underlying the Bishop Tube site under a separate phase of the work proposed under Change Order #9. The Work Plan and Cost Proposal for Change Order #9 were prepared as part of the project planning task of the Work Order. In addition, Baker also prepared an addendum to the original site-specific Health and Safety Plan (HASP) dated June 5, 2001.

Copies of the draft version of the Work Plan and Cost Proposal for Change Order #9 were submitted to the PADEP Southeastern Office for review on July 24, 2002. The final versions of the Work Plan and Cost Proposal for Change Order #9 were submitted to the PADEP on August 23, 2002. The PADEP issued authorization (i.e., "Notice to Proceed") for Baker to begin the Supplemental Site Characterization activities included in Change Order #9 on September 18, 2002.

The fieldwork activities for the supplemental characterization of the soils at the Bishop Tube site pursuant to Change Order #9 were performed during the period from September 2002 through November 2002.

2.2 Field Procedures

The various field procedures, operations, and methods used by Baker to complete the project task objectives outlined in the Scope of Work for Change Order #9 are presented in the following sections.

2.2.1 Introduction

An intrusive field investigation was performed to define the lateral extent and to further characterize the concentrations of the VOCs contained in the soils at the site. The field investigative procedures for each project task are outlined in the following sections. Representatives from the PADEP Southeastern Regional Office were present during a portion of the field investigation activities. Decisions regarding the sampling locations and the necessary analytical parameters for the soil samples were made collaboratively by Baker and the PADEP representatives, taking into consideration the project objectives and field conditions.

2.2.2 Supplemental Geophysical Survey Activities

To identify areas where DNAPLs may be pooled in the subsurface, Baker retained the services of Enviroscan, Inc. to perform a supplemental geophysical survey at the Bishop Tube site. Traditional seismic refraction and uphole seismic refraction techniques were used to map the elevation of the top of bedrock as part of the Phase II investigation procedures performed in January 2002 (Baker 2002b). For the Supplemental Soil Characterization, these same geophysical techniques were used to expand the survey area for gathering additional information from uncharacterized parts of the site. The additional areas surveyed using seismic refraction and uphole seismic refraction techniques during the Supplemental Soil Characterization included: 1) the northeastern section of Building #8, 2) the area located north of Building #8; 3) the uncharacterized area east of Building #8; and 4) the uncharacterized area south of Building #5. These survey areas are shown on Figure 1 contained in Appendix A.

Seismic refraction techniques were used to perform a profile of subsurface density contrasts (i.e., top-of-bedrock). This involved measuring the travel times of shock waves from a surface source or shot point down to the top-of-bedrock (or other density contrast) and back to an array of ground motion sensors or geophones at the surface. Due to the presence of extensive paving and concrete, traditional seismic refraction was used only as a secondary option since using a surficial seismic source (e.g. airless jackhammer with a tamper plate) on concrete or paving creates plate-wave interference in the seismic data. Such interference is not present in uphole seismic survey data due to the source being located beneath the concrete/paving surface.

For the traditional seismic refraction survey technique, a Geometrics Smartseis 24-channel seismograph was used to record seismic travel times at linear arrays of Mark Products 4.5 Hertz geophones spaced at constant 10-foot intervals along each of the lines. Travel times were recorded for shot points located at the end of each line and at 40-foot intervals along each line to provide multi-fold, reversed seismic data capable of resolving potentially undulating density contrasts. At each shot point, repeated blows of a 27-pound airless jackhammer generated the seismic waves. The seismic waveform data for individual geophones were summed or stacked during each blow to enhance the signal-to-noise ratio. Waveform data were recorded on the internal hard drive of the seismograph.

For the uphole seismic refraction technique, a Geometrics Smartseis 24-channel seismograph was used to record seismic travel times at linear arrays of Mark Products 4.5 Hertz geophones spaced at constant 10-foot intervals along each of the lines. Travel times were recorded for shot points located at depth in each accessible monitoring well to provide multi-fold, reversed seismic data capable of resolving potentially undulating density contrasts. Rather than using an airless jackhammer to generate the seismic waves, a Bolt Airgun was used during the uphole seismic survey. This apparatus was chosen to eliminate potential plate-wave interferences typically generated by airless jackhammers on concrete or paving. The airgun produces seismic energy by releasing an instantaneous burst of compressed air, creating a hydrostatic pressure pulse. For the uphole seismic survey performed at the Bishop Tube site, the airgun was lowered into each accessible monitoring well located along the profiles. At each shot point, repeated pulses of compressed air through the airgun generated the seismic waves. The seismic waveform data for individual geophones were summed or stacked during each pulse to enhance the signal-to-noise ratio.

The seismic refraction field data were analyzed using the following software packages: SIP by Rimrock Geophysical, and SeisOPTPro by Optim Software. First arrival travel times or first breaks were selected on the waveform data using the automatic picking routine SIPIK (with occasional manual adjustment) to ensure consistent and objective selections. From the first arrival times and geophone locations, T-X

graphs (see Appendix A) were compiled for each line using the routine SIPIN. The T-X data were subjected to a mathematical inversion using SeisOPTPro to determine the statistically best-fitting velocity distribution beneath each seismic line.

The location of each seismic shot point was surveyed using a Trimble Pathfinder global positioning system (GPS) receiver. Shot point elevations were surveyed using a rod and transit. The GPS data were differentially corrected in real time using data from a fixed-position U.S. Coast Guard beacon to provide differential GPS (DGPS) positioning with an accuracy of less than two feet.

The geophysical survey was performed using OSHA Level D PPE. A representative from Baker was present during the geophysical surveying activities to direct Enviroscan, Inc. personnel to the survey locations and to ensure compliance with the site specific Health and Safety Plan.

The geophysical data collected during the Supplemental Soil Characterization was included with the results obtained during the Phase II investigation (i.e., January 2002) to create one composite bedrock elevation map of the area. The composite bedrock elevation map and seismic velocity profiles recorded during the supplementary geophysical survey are included in Appendix A.

2.2.3 MIP Drilling Program

To further evaluate the horizontal and vertical extent of VOCs contained in the soils at the site, a total of 53 borings were drilled during the investigation using Membrane Interface Probe (MIP) technology. These borings were drilled at the site during the period from October 21 through October 28, 2002. The drilling locations for the MIP borings were selected to further evaluate the soils underlying the following areas of concern at the Bishop Tube site:

- The former vapor degreaser area #2 in Building #5;
- The former vapor degreaser area #1 in Building #8; and,
- The former drum storage area.

These areas of concern were chosen for further study based upon the elevated concentration of VOCs detected in the soil samples collected from the borings drilled at the site during the Phase I Site Characterization (Baker 2002a), as well as the geophysical survey results. In addition, real time results regarding the relative concentrations of VOCs provided by the MIP instrumentation were used to assess the lateral limits of chlorinated solvents contained in the soils underlying these areas of concern and to chose the drilling locations for the confirmatory direct push soil borings. The locations of the MIP borings drilled during the soil investigation at the site are shown on Figure 2.

Baker retained the services of Vironex, Inc. (Vironex), located in Glen Burnie, Maryland, to drill the MIP borings. These borings were drilled using both truck-mounted and track-mounted hydraulic push drilling rigs. A Baker representative was onsite during the drilling operations to supervise the installation of each test hole.

Borings were drilled using MIP technology for collection of vapor samples to characterize the relative concentration of the VOCs (i.e., chlorinated solvents) contained in the soils and shallow groundwater.

Each boring was drilled to the point of refusal (i.e., assumed top of bedrock). The depth of the MIP borings ranged from 2.5 feet (WDL-MIP06) to 31.5 feet (DSA-MIP05) below the ground surface.

To detect the VOCs in the subsurface, the MIP uses a heated membrane to raise the temperature of the soils/groundwater in the immediate vicinity of the sonde. This heating promotes the volatilization of light molecular weight organic compounds. Vapors collected by the MIP sonde are transferred to the surface via an inert carrier gas (i.e., nitrogen) and introduced into an electron capture detector (ECD), a flame ionization detector (FID), and a photoionization detector (PID) to determine the relative concentration of the VOC species. For this investigation, the MIP provided information regarding the relative concentrations of VOCs contained in both vadose and saturated zones. To maintain quality control, the MIP was calibrated prior to each boring location by conducting a response check using a 100 microgram per liter ($\mu\text{g/l}$) tetrachloroethylene (PCE) standard. To prevent false background readings from the exhaust of the ancillary equipment, the air discharges from the truck and electric generator were directed down wind of the boring locations using a 10-foot section of flexible corrugated hose.

An electronic soil conductivity probe was also used in conjunction with the MIP sonde for providing real time and continuous information regarding the lithology of the subsurface materials, probe depth, penetration rate, and membrane temperature. The MIP and soil conductivity results were plotted electronically on a drilling log for each boring. Information regarding the lithology of the subsurface materials and the ECD/PID reading recorded during the drilling of the MIP borings are outlined on the drilling logs presented in Appendix B.

To prevent cross contamination, all non-dedicated (i.e., reusable) sampling equipment was decontaminated between sample runs using an AlconoxTM soap wash and a deionized water rinse. The wash fluids generated during the decontamination procedures were temporarily containerized in a 55-gallon capacity steel drum and stored at the designated onsite staging area located south of the loading dock of Building #5. These decontamination fluids were treated onsite by passing the raw influent through a 1,000-pound liquid-phase carbon adsorber during the drilling of the monitoring wells at the site in December 2002 (i.e., second phase of the investigative activities associated with Change Order #9). The treated effluent was ultimately discharged to the ground surface.

The MIP drilling activities were conducted using Level D personal protective equipment (PPE). Conditions in the ambient atmosphere were monitored using a PID and a Combustible Gas Indicator (CGI) for detection of potentially explosive gases. Disposable latex gloves were used to protect workers from direct contact with the subsurface materials during the MIP testing procedures.

2.2.4 Collection of Soil Samples

Based on the screening results obtained from the MIP investigation, a total of 18 confirmatory borings were drilled at the site to verify the concentrations of VOCs contained in the soils. Two confirmatory soil samples were collected from each boring, for a total of 36 soil samples. The confirmatory borings were drilled at the site during the period from October 29 through October 30, 2002. The analytical results for the confirmatory borings were intended to be used to document the lateral and vertical extent of the VOCs contained in the soils surrounding the former vapor degreaser area #2 in Building #5, the former vapor degreaser area #1 in Building #8; and, the former drum storage area. In general, the confirmatory borings were drilled along the perimeter of these three areas of concern where the MIP screening results (i.e., registered by the ECD, FID, and PID instruments) showed a decrease in the relative concentration of

VOCs in the subsurface materials. From each boring, the confirmatory soil samples were collected from the intervals that exhibited the highest ECD, FID, and/or PID responses.

In addition, a total of two borings were drilled in the area of the bedrock depression (i.e., suspected location of the former waste disposal lagoon) situated in the southeast corner of Building #8 to characterize the concentrations of VOCs and metals contained in the soils. Two soil samples were collected from each boring for a total of 4 soil samples. These characterization-related borings were drilled at the site on November 4, 2002.

A total of three borings were drilled at the site during the investigation to evaluate the physical characteristics of the soils/weathered bedrock materials. One soil sample was collected from each physical testing boring drilled at the following areas of concern: the former vapor degreaser area #2 in Building #5, the former vapor degreaser area #1 in Building #8; and, the former drum storage area. The physical testing borings were drilled at the site on October 29, 2002.

A truck-mounted hydraulic push drilling rig (i.e., Geoprobe[®]) was chosen to drill the soil borings at the Bishop Tube site. This drilling apparatus was selected to drill the borings because: 1) the Geoprobe[®] is relatively more mobile than a conventional drilling rig; 2) the Geoprobe[®] generates virtually no cuttings, reducing the need for waste disposal; 3) the Geoprobe[®] operates more quickly and is typically more cost effective than a conventional drilling rig; 4) the relatively small size of the drilling rig (i.e., van) allowed entry into Building #5 and Building #8; and 5) the borehole produced by the Geoprobe[®] is only two inches in diameter, greatly reducing the amount of material needed for hole abandonment.

Each boring was drilled to either the point of refusal (i.e., to the top of bedrock) or to the point where the target sampling depth was encountered (i.e., based upon the MIP testing results). The locations of the borings drilled during the Supplemental Soil Characterization at the site are shown on Figure 2.

Baker retained the services of Vironex to drill the soil borings at the Bishop Tube site. A Baker representative was onsite during the drilling operations to supervise the installation of each test hole. It should be noted that dual tube drilling and discrete depth sampling techniques were used to collect the soil samples from the borings drilled in the vicinity of the former vapor degreaser area #2 in Building #5, the former vapor degreaser area #1 in Building #8, the former drum storage area, and the suspected waste disposal lagoon area. Accordingly, no detailed logs of these boreholes were prepared as part of the investigation. Information regarding the characteristics of the subsurface materials and changes in the relative concentration of VOCs with respect to depth in the boreholes drilled at the site during the investigation is presented on the MIP drilling logs included in Appendix B.

Drilling and Soil Collection Procedures for Confirmatory Borings

The drilling locations for the confirmatory borings installed along the perimeter of the former vapor degreaser area #2 in Building #5, the former vapor degreaser area #1 in Building #8, and the former drum storage area were selected based upon the MIP testing results. At each location, the soil samples were collected from the confirmatory boring using dual tube sampling techniques. Dual tube sampling involves using two sets of rods to collect cores of the subsurface materials. The outer rods or casing receive the driving force from the Geoprobe[®] drilling machine and are used to drill the boring to the target depth. These outer casing rods provide a sealed hole for the recovery of discrete interval soil samples, reducing the risk of potential cross contamination or hole cave-in. In addition, this technology generally allows

discrete interval soil samples to be collected at a more efficient rate than using continuous coring methods.

At each confirmatory boring location, a 1.5-inch diameter sampler assembly with a bottom cap/bumper was placed inside the 2.125-inch diameter outer casing. The outer casing holding the inner sampler assembly was then driven to the top of the selected sample interval. Upon reaching the target depth, the inner rods and sampler assembly were retracted to remove the bottom cap/bumper. The inner sampling assembly was reinserted into the outer casing and driven into the soil materials exposed at the bottom of the borehole. The inner rods were then retracted from the borehole and the acetate liner holding the soil materials was removed from the sampler assembly. A PID was used to scan the soil materials contained in the sample tube for volatile organic vapors. To prevent the loss of VOCs, representative portions of the sample sleeve were immediately placed into EnCore[®] sampling tubes. The collection of the soil samples for volatile organic compounds was performed in accordance with U.S. EPA methodology 5035. The drilling of the confirmatory borings and the collection of the soil samples were performed using Level D PPE. Disposable nitrile gloves were used to protect workers from direct contact with the subsurface materials during the sampling procedures.

Upon the completion of the drilling and sampling procedures, the outer casing materials were removed and the boreholes filled with bentonite. The boreholes were capped at the surface with a pre-mixed concrete grout or cold patch asphalt mix.

Following the collection of the confirmatory soil samples, the sample containers were immediately placed into coolers and stored at 4°C for delivery to Lionville Laboratory, Inc., the PADEP contract laboratory for this phase of the project.

Drilling and Soil Collection Procedures for Borings Installed in the Suspected Waste Disposal Lagoon Area

During the installation of each boring drilled in the suspected waste disposal lagoon area, soil samples were collected at discrete sampling intervals based on visual observations of the soil profile and the MIP testing results. At each location, the soil samples were collected from the boring using dual tube sampling techniques, following the same procedures outlined above.

Prior to sample collection, a PID was used to scan the soil materials contained in the sample sleeve for volatile organic vapors. To prevent the loss of VOCs, representative portions of the sample sleeve were immediately placed into EnCore[®] sampling tubes. The collection of the soil samples for volatile organic compounds from the borings drilled in the suspected waste disposal lagoon area was performed in accordance with U.S. EPA methodology 5035. The drilling of the borings and the collection of the soil samples were performed using Level D PPE. Disposable nitrile gloves were used to protect workers from direct contact with the subsurface materials during the sampling procedures.

Upon the completion of the drilling and sampling procedures, the outer casing materials were removed and the boreholes filled with bentonite. The boreholes were capped at the surface with a pre-mixed concrete grout or a cold patch asphalt mix.

Following the collection of the soil samples, the sample containers were immediately placed into coolers and stored at 4°C for delivery to Lionville Laboratory, Inc., the PADEP contract laboratory for this phase of the project.

Drilling and Soil Collection Procedures for Physical Testing Borings

During the investigation, three borings were drilled at the site to collect samples for characterizing the physical properties of the soil and weathered bedrock materials. One boring was installed in each of the following areas of concern at the site: the former vapor degreaser area #2 in Building #5, the former vapor degreaser area #1 in Building #8, and the former drum storage area. The drilling locations for the physical testing borings were randomly selected in each area of concern and are shown on Figure 2. At each location, the physical testing soil samples were collected from the borings using dual tube sampling techniques, following the same procedures outlined above.

Upon extraction of the sampler assembly from each borehole, the top and bottom ends of the acetate liner were capped without disturbing the soil materials contained within the sample tube. Duct tape was then wrapped around the ends of the liner to hold the caps in place. An indelible marker was used to mark the top and bottom ends of the soil core. The drilling of the physical testing borings and the collection of the undisturbed soil samples were performed using Level D PPE. Disposable nitrile gloves were used to protect workers from direct contact with the subsurface materials during the sampling procedures.

Upon the completion of the drilling and sampling procedures, the outer casing materials were removed and the boreholes filled with bentonite. The boreholes were capped at the surface with a pre-mixed concrete grout.

Following the collection of the undisturbed physical testing soil samples, the sample containers were placed into a cardboard mail tube for delivery to F.T. Kitlinski and Associates, Inc., Harrisburg, Pennsylvania (i.e., approved physical testing and analysis subcontractor).

2.2.5 Deployment of FLUTE® NAPL Liners in Soils

Upon completing the collection of the soil samples from the confirmatory borings, additional boreholes were drilled in selected locations for the deployment of FLUTE® NAPL liners. The drilling of the boreholes and the deployment of the FLUTE® NAPL liners was performed during the period from October 31 through November 5, 2003. These liners were used to identify the presence or absence of free-phase chlorinated solvents within the soils and weathered bedrock materials underlying the site. The locations for deploying the FLUTE® NAPL liners at the Bishop Tube site were chosen based upon: 1) the previous soil sampling results (Baker 2002a); 2) the top of bedrock elevation data provided by the January 2002 and October 2002 geophysical surveys; and 3) the results obtained from the borings drilled using the MIP.

A total of seven FLUTE® NAPL liners were deployed at the site during the investigation. For characterizing the subsurface conditions, FLUTE® NAPL liners were deployed at the following locations: the former vapor degreaser area #1 in Building #8 (four FLUTE® NAPL liners); the former vapor degreaser area #2 in Building #5 (one FLUTE® NAPL liner); and the former drum storage area (two FLUTE® NAPL liners). Baker retained the services of Vironex to drill the borings and deploy the FLUTE® NAPL liners. The borings were drilled using the same truck-mounted Geoprobe drilling apparatus as used for installing the MIP and confirmatory soil borings.

The borings for deploying the FLUTE® NAPL liners were drilled using 2.125-inch diameter casing fitted with a disposable drive point tip. For each boring, the casing was drilled to the top of bedrock. Upon encountering refusal, the FLUTE® NAPL liners were inserted inside the outer casing to the bottom of the borehole. The excess liner material was trimmed at the surface, approximately 2 feet above the top of the

casing. A FLUTE[®] injector system was used to fill the inside portion of the NAPL liner with clean, potable water. The outer casing was then raised one rod length, allowing the NAPL liner to come in contact with the soil materials at the bottom portion of the borehole. The inner portion of the NAPL liner was then refilled with clean potable water to anchor the liner in the borehole. The procedure of extracting rods and refilling the inner portion of the NAPL liner with clean potable water was repeated until the entire string of casing was removed from the borehole. Upon extracting the casing from the borehole, the NAPL liners were allowed to sit in each borehole between 2 to 3 hours. This waiting period is deemed necessary for any NAPLs to settle against the reactive covering of the liner.

Following the waiting period, the tether cord attached to the bottom of the NAPL liner was pulled upward to invert and extract the liner from the hole. Upon complete recovery at the ground surface, the liner was laid out on a clean piece of polyethylene sheet plastic. The reactive liner was then peeled off of the protective cover by sliding and re-inverting the liner over the exposed flexible tubing. An indelible marker was used to immediately mark the top and bottom of the portions of the liner. The liner was then split lengthwise using a knife/scissors and spread out on the polyethylene plastic for further inspection. Indications regarding the presence of free-phase NAPLs show up on the liners as dark spots (i.e., staining) and/or a bleed through of the reactive dye on the outside cover of the Tyvek[®] material. To determine the depth of the NAPL fluids in the subsurface, a measuring tape was used to gauge the distance between the top of the liner (i.e., reference point at the ground surface) and the occurrence of the staining. These measurements were recorded in the notebook of the Baker field technician at the site. Following the inspection work, the liner was rolled up, placed in a clean plastic zip-lock bag, and labeled for future reference.

2.2.6 Supplemental Site Survey

Baker retained the services of a Pennsylvania Registered Land Surveyor (i.e., Dawood Engineering, Inc.) to perform a supplemental survey of the site. The information gathered during the supplemental site survey work was used to prepare an inclusive site map of the Bishop Tube site.

The supplemental site survey work was performed on November 14, 2002 to establish the locations and ground elevations for the 53 MIP boreholes, eighteen confirmatory soil boring locations, the two borings drilled in the location of the suspected waste disposal lagoon, the three borings drilled to collect the physical testing samples, and the seven borings used to deploy the FLUTE[®] NAPL liners. For these boring locations, the reference elevations were established at the ground surface.

The elevation measurements recorded by the subcontractor were tied into a control point in the vicinity of the site for equating the data to mean sea level (i.e., North Geodetic Vertical Datum 1929). This control point consists of a nail set in B.T. CO utility pole #5 (elevation 390.5 feet) located in the northeast corner of the Bishop Tube property (see Figure 2). Representatives from Baker were present during the surveying activities to show the survey subcontractor the points and features to be mapped at the site.

The soil boring locations established during the supplementary site survey were incorporated into the existing survey database to create one composite map of the area. The site map included the following information: pertinent site features (i.e., buildings, fencing, gravel covered areas, asphalt covered areas, property boundaries, new monitoring wells, sampling locations, and surface topography). The electronic data produced from the survey activities were used to develop a site map using AutoCAD[™] Version No. 2000 software.

2.2.7 Management of IDW Materials

Investigation Derived Waste (IDW) materials generated during the investigation activities were managed appropriately to minimize exposure to potential contaminants and impacts to human health and the environment. To minimize the volume of IDW produced during the investigation, the excess soil/rock materials generated during the drilling of the borings were used to backfill each test hole. Liquid IDW generated from the decontamination of sampling equipment during the investigation was temporarily containerized in a 55-gallon capacity steel drum and stored at the designated onsite staging area located next to the loading dock south of Building #5. These liquid IDW fluids were treated onsite along with groundwater generated during the drilling of the additional monitoring wells (i.e., second phase of work under Change Order #9) by passing the raw influent through a 1,000-pound liquid-phase activated carbon adsorber. The treated water was ultimately discharged to the ground surface at the site. Accordingly, no solid or liquid IDW materials were generated during this phase of the investigation that required offsite treatment and/or disposal.

Contracting arrangements were made for the disposal of the used activated carbon materials and the water/sludges contained in a frac tank (vessel used to containerize the groundwater generated during the well drilling activities) between Baker and Waste Recovery Solutions, Inc., of Myerstown, Pennsylvania. The used carbon IDW materials were vacuumed out of the 1,000-pound carbon adsorber on May 14, 2003 by a separate tank-cleaning subcontractor (i.e., TIER, Inc.). On May 14, 2003, the residual water/sludges contained in the frac tank were also removed by TIER, Inc. The used carbon and water/sludge materials were transported by TIER, Inc. to Waste Recovery Solutions, Inc. (located in Myerstown, Pennsylvania) on May 14, 2003. These waste materials were stabilized by Waste Recovery Solutions, Inc. at their Myerstown, Pennsylvania facility by mixing the used carbon and water/sludge materials with sawdust. Based upon prior approval received from the Department, the stabilized waste materials were transported by Waste Recovery Solutions, Inc. to the Waste Management, Inc., Modern Landfill facility, located in York County, Pennsylvania (PADEP Municipal and Residual Waste Processing Permit No. 100113) for disposal. The transportation and disposal of the stabilized used carbon and water/sludge materials occurred on May 16, 2003.

2.3 Sample Analytical Program

The record keeping procedures and the laboratory testing methods used to analyze the environmental samples collected during the investigation are outlined in the following paragraphs.

2.3.1 Introduction

In accordance with the project objectives, the soil samples collected during the investigation were used to further characterize the concentrations of VOCs contained in subsurface materials underlying the site. The environmental samples collected during the investigation were submitted for analysis to Lionville Laboratory, Inc. of Lionville, Pennsylvania (i.e., PADEP selected state contract laboratory). The testing results for the environmental samples analyzed by Lionville Laboratory, Inc. followed CLP Type III reporting protocols.

Field Quality Assurance/Quality Control (QA/QC) samples were collected for each environmental medium of samples during the investigation. The QA/QC requirements for the selected sample groups were performed in accordance with the guidelines outlined in the Quality Assurance Project Plan (QAPP) developed by Baker prior to initiation of the field investigation activities.

Four QA/QC samples were submitted to Lionville Laboratory, Inc. along with the soil samples collected from the borings drilled at the site during the investigation. These QA/QC samples included two duplicate soil samples, one field blank sample, and one rinsate sample. During transit to the testing laboratory, trip blank samples were placed in each cooler that contained samples for VOC analysis. A total of three trip blank samples were used during the investigation for documenting the sample handling procedures.

In order to identify and accurately track the environmental samples collected during the investigation, including QA/QC samples, a unique number was given to each sample. This number was designed to provide information regarding the sample date, the sample media, sampling location, the depth of the sample (soil samples only), and QA/QC qualifiers. The sample designation format used during the investigation is as follows:

PADEP Site # - Sample Date - Medium-Station # - Depth or QA/QC designation

An explanation of each of these identifiers is given below.

PADEP Site # 116 (for all samples)

Sample Date 110402 November 4, 2002

Medium S – soil

Station # A unique sample number was used to identify the sample location:

Primary Soil Sample Location

DSA	Former Drum Storage Area
SDA	Former Solvent Distillery Area in Building #8
VDP	Former Vapor Degreaser Pipeline Area in Building #8
VD	Former Vapor Degreaser #1 Area in Building #8
VD2	Former Vapor Degreaser #2 Area in Building #5
WDL	Suspected Waste Disposal Lagoon Area in Building #8

Secondary Soil Boring Number

CB01	Soil sample collected from confirmatory boring No. 1
CB02	Soil sample collected from confirmatory boring No. 2
CB03	Soil sample collected from confirmatory boring No. 3
CB04	Soil sample collected from confirmatory boring No. 4
PTP01	Soil sample collected from physical testing parameters boring No. 1.

Depth Indicators were used for the soil samples referencing the depth interval of the sample. For example:

01	= ground surface to 1 foot below ground surface (bgs)
13	= 1 to 3 feet bgs
35	= 3 to 5 feet bgs
57	= 5 to 7 feet bgs
812	= 8 to 12 feet bgs
1011	= 10 to 11 feet bgs

QA/QC The following designations were used for the QA/QC samples collected during the investigation:

D = Duplicate Sample
EB = Equipment Blanks (Rinsate Samples)
FB = Field Blank Samples
TB = Trip Blanks

Using this sample designation format the sample number 116-110402-S-WDL-CB02-812D refers to:

<u>116</u> -110402-S-WDL-CB02-812D	PADEP Site # for Bishop Tube Site
116- <u>110402</u> -S-WDL-CB02-812D	Date collected – November 4, 2002
116-110402- <u>S</u> -WDL-CB02-812D	Sample Type – Soil
116-110402-S- <u>WDL</u> -CB02-812D	Soil sample location – Waste Disposal Lagoon Area
116-110402-S-WDL- <u>CB02</u> -812D	Soil Boring Number – Confirmatory Boring No. 2
116-110402-S-WDL-CB02- <u>812D</u>	Depth of Soil Sample – 8 to 12 feet bgs
116-110402-S-WDL-CB02-812 <u>D</u>	QA/QC Designation – Duplicate Sample

2.3.2 Analysis of Soil Samples Collected from Borings

To further characterize the concentrations of VOCs contained in the soils at the site, a total of eighteen confirmatory borings were drilled during the investigation. These confirmatory borings were drilled around the perimeter of the former vapor degreaser area #2 in Building #5, the former vapor degreaser area #1 in Building #8, and the former drum storage area to characterize the vertical and lateral extent of VOCs contained in the soils. The soil samples collected from the confirmatory borings were collected directly from the materials inside the acetate macro-core sample and immediately placed into Encore® sample containers following EPA Method 5035. To preserve the integrity of the soil samples, the containers were stored in coolers at 4°C until delivered to Lionville Laboratory, Inc. for analysis. A total of 36 soil samples (two samples from each boring) were collected from the confirmatory borings drilled at the site during the investigation. These soil samples were submitted for analysis of TCL VOCs. In addition, one duplicate soil sample was collected from the confirmatory borings drilled during the investigation. A summary of the analytical methods used to analyze the soil samples collected from the confirmatory borings is outlined in Table 1.

Two additional borings were drilled in the area of the suspected waste disposal lagoon (southeastern corner of Building #8) to characterize the concentrations of VOCs and heavy metals contained in the soils. A total of four soil samples (two samples from each boring) were submitted to Lionville Laboratory, Inc. for analysis of TCL VOCs and TAL metals. In addition, one duplicate soil sample was collected from the borings drilled in the suspected waste disposal lagoon area during the investigation. The soil samples that were targeted for analysis of VOCs were collected directly from the materials inside the acetate macro-core sample sleeve and immediately placed into EnCore® sample tubes following EPA Method 5035. The soil samples collected for analysis of TAL metals were collected from representative materials contained inside the acetate macro-core sample sleeve and placed in pre-cleaned 4 oz. and 8 oz. clear glass jars with Teflon®-lined lids. To preserve the integrity of the soil samples, the containers were stored in coolers at 4°C until delivered to Lionville Laboratories, Inc. for analysis. A summary of the analytical methods used to analyze the soil samples collected from the borings drilled in the area of the suspected waste disposal lagoon is outlined in Table 1.

During the investigation three borings were drilled at the site to collect samples for characterizing the physical properties of the soil and weathered bedrock materials. One sample was collected from a separate boring drilled in each of the following areas of concern at the site: the former vapor degreaser area #2 in Building #5, the former vapor degreaser area #1 in Building #8, and the former drum storage area. An undisturbed soil sample was collected using the Geoprobe® hydraulic push machine from each borehole. The physical testing samples were submitted to F.T. Kitlinski and Associates, Inc., Harrisburg, Pennsylvania (i.e., approved physical testing laboratory subcontractor) for analysis of the following parameters: wet bulk density (ASTM D1556), dry bulk density (ASTM D1556), natural moisture content (ASTM D2216), water filled porosity (calculation by testing laboratory), grain size sieve analysis (ASTM D442), and total organic carbon content (Walker-Black method). A summary of the analytical methods used to analyze the soil samples collected from the physical testing borings is outlined in Table 1.

3.0 SITE CHARACTERIZATION RESULTS

The results of the Supplemental Soil Characterization of the soils at the Bishop Tube site are presented in the following sections.

3.1 Geophysical Survey Results

The analytical results for the soil samples collected from the borings drilled at the Bishop Tube site during the Phase I Site Characterization (Baker, 2002a) show that the subsurface materials underlying the following areas of concern contain elevated concentrations of VOCs: the former vapor degreaser area #1 in Building #8; the former vapor degreaser area #2 in Building #5; and the former drum storage area. Locally, the concentrations of TCE contained in the soils underlying these three areas of concern were found to exceed 1,000,000 µg/kg. The relatively high concentrations of TCE detected in the soils underlying these areas suggest that they are functioning as residual sources for the chlorinated solvents dissolved in the groundwater at the site. Groundwater samples collected from borings drilled in the vicinity of the Building #8 vapor degreaser area were found to contain elevated concentrations (i.e., +1,000,000 µg/l) of TCE. Because the concentrations of TCE detected in the groundwater are greater than 1% of the pure phase aqueous solubility limit for TCE (i.e., 11,000 µg/l), dense non-aqueous phase liquids (DNAPLs) are suspected to be present in the subsurface.

A geophysical survey was performed at the Bishop Tube site as part of the Phase II Groundwater Investigation (Baker, 2002b). The results of the geophysical investigation showed that the upper surface of the bedrock underlying the site is locally pinnacled. These differences in the elevation of the top of bedrock are believed to be influencing the migration of DNAPLs in the subsurface. To more fully evaluate the configuration of the upper bedrock surface at the site, additional geophysical testing was performed as part of the Supplemental Soil Characterization. The additional geophysical survey information was incorporated with the Phase I geophysical data to produce a composite top of bedrock map. This information was ultimately used to assess the areas where DNAPLs may be pooled in the subsurface and to select the drilling locations for the MIP, confirmatory soil borings, and the deployment of the FLUTE NAPL liners.

To evaluate topographical changes in the surface of the underlying bedrock, the geophysical survey included the completion of traditional seismic refraction and uphole seismic refraction techniques. A copy of the report completed by Enviroscan, Inc. outlining the results of the Phase II geophysical survey performed at the Bishop Tube site is included in Appendix A.

The geophysical survey completed by Enviroscan, Inc. provided further information regarding the physical characteristics of the subsurface materials and the depth of bedrock underlying the three areas of concern. This information is depicted graphically on Figures 2 and 3 included in Appendix A.

The seismic refraction responses recorded in the vicinity of the former vapor degreaser area #1 in Building #8 suggest that the surface of the bedrock underlying this section of the site exhibits several high and low features (see Figure 3 included in Appendix A). Specifically, two large bedrock highs border the southern and western edges of the former vapor degreaser area #1 in Building #8. A smaller bedrock high borders this area along its eastern edge. Based upon the seismic refraction measurements, the bedrock may be depressed in a trough located northeast of MW20. The orientation of this trough and elevation changes of the bedrock surface suggest that residual DNAPLs, if present, may be migrating from the former Building #8 vapor degreaser area in a north-northeastward direction toward monitoring wells MW02 and MW03. North of monitoring wells MW02 and MW03, the bedrock continues to slope in a northward direction to another bedrock trough. The configuration of the bedrock surface north of the Norfolk Southern railroad tracks is unconstrained.

The geophysical testing results suggest that a trough exists in the top of bedrock underlying the central portion of Building #5 (see Figure 3 included in Appendix A). The deepest portion of this trough is centered approximately 10 feet south-southwest of soil boring VD2-02. A bedrock high bounds the northern and eastern edges of the bedrock trough underlying the central portion of Building #5. The southern and western edges of this trough are unconstrained. It should be noted that low concentrations of VOCs were detected in the subsurface materials by MIP testing equipment and in the soil samples collected from the confirmatory soil borings drilled around the perimeter of the bedrock low. This information suggests that the bedrock trough underlying the former vapor degreaser area in Building #5 may be limiting the lateral migration of VOCs in the subsurface.

The results of the geophysical survey performed in the vicinity of the former drum storage area suggest that a bedrock trough occurs in the top of bedrock. This bedrock trough is aligned in a north to south direction between monitoring well MW22 and soil sampling location DSA-11 (see Figure 3 included in Appendix A). The deepest portion of the bedrock low occurs west and southwest of soil sampling point DSA-07. Bedrock highs surround the north, south, east, and west sides of the trough. The analytical results for the soil samples collected from borings drilled in the drum storage area during the Phase I Site Characterization (Baker, 2002a) show that the highest concentrations of VOCs occur in the vicinity of soil sampling point DSA-12 (i.e., 4,179,000 µg/kg near monitoring well MW22). Relatively high concentrations of VOCs (i.e., 13,275 µg/kg and 1,407 µg/kg) were detected in the soil samples collected from borings DSA-03 and DSA-07, respectively. Borings DSA-03 and DSA-07 were drilled in areas exhibiting lower bedrock elevations. These two borings were drilled southeast and south of boring DSA-12. This information suggests that: 1) differences in the elevation of the bedrock may be influencing the lateral migration of VOCs in the subsurface; and/or 2) a supplemental source area may be situated in the vicinity of the DSA-03 and DSA-07 drilling locations.

The geophysical survey results show that a bedrock low occurs in the southeastern corner of Building #8. The center of this trough is situated approximately 10 feet south of the doorway entrance into Building #8. It should be noted that a former waste disposal lagoon was reportedly situated in this area at one time. The exact location of the former waste disposal lagoon is unknown. Architectural and roofline differences suggest that the eastern section of Building #8 may represent a "supplemental" structural addition to the main portion of the industrial complex. An attempt was made to locate the former waste disposal lagoon during the drilling program conducted at the site during the Phase I Site Characterization (Baker, 2002a).

The additional information obtained from the geophysical survey suggests that the former waste disposal lagoon may have been located in the area that currently underlies the southeast corner of Building #8.

3.2 MIP and Confirmatory Soil Sample Results

To better define the lateral and vertical extent of VOCs contained in the soils, a total of 53 borings were drilled for screening purposes using MIP technology during the investigation. The following number of MIP boreholes were drilled to further characterize each area of concern: eight MIP boreholes were drilled around the perimeter of the former vapor degreaser area #2 in Building #5; twenty-two MIP boreholes were drilled around the perimeter of the former vapor degreaser area #1 in Building #8; fifteen MIP boreholes were drilled around the perimeter of the former drum storage area; and eight MIP boreholes were drilled in the area of the suspected waste disposal lagoon situated near the southeast corner of Building #8. The drilling locations for the MIP borings were chosen based upon the historical background information for the site, the analytical results for the soil samples collected from borings during the Phase I Site Characterization (Baker 2002a), and the geophysical survey results. The locations where the MIP borings were drilled at the site during the investigation are displayed on Figure 2. The results provided by the MIP borings were used to select the drilling locations and the sample depths for the collection of confirmatory soil samples to characterize the lateral extent of VOCs contained in the subsurface materials surrounding each area of concern.

To confirm the MIP testing results, 40 soil samples and two duplicate soil samples were collected from 20 confirmatory borings drilled using a Geoprobe® direct-push drilling rig. The drilling locations for the confirmatory borings and the intervals for sample collection were chosen based upon the MIP testing results. The locations where the confirmatory soil borings were drilled at the site are displayed in Figure 2. The confirmatory soil samples were submitted to the state contract laboratory (i.e., Lionville Laboratory, Inc.) for the analysis of TCL VOCs. The analytical results outlining the concentrations of VOCs measured in the confirmatory soil samples are summarized in Tables 2.1 through 2.9. The analytical results for the QA/QC VOC samples are summarized in Table 3.

The soil samples collected from the borings drilled in the area of the suspected waste disposal lagoon were also submitted to the state contract laboratory for the analysis of total TAL metals. The analytical results outlining the concentrations of TAL metals in the soil samples are summarized in Table 4. The QA/QC results for the soil samples analyzed for TAL metals are summarized in Table 5.

Three soil samples were collected during the investigation to characterize the physical characteristics of the subsurface materials. One physical testing parameter soil sample was collected from each of the following areas of concern at the site during the investigation: the former vapor degreaser area #2 in Building #5, the former vapor degreaser area #1 in Building #8, and the former drum storage area. The analytical results for the soil samples collected to determine the physical characteristics exhibited by the subsurface materials are outlined in Table 6.

The testing results provided by the MIP probe were used to assess the relative concentration of chlorinated VOCs contained in the subsurface materials. At each area of concern, the results for individual borings were reviewed to determine the relative concentration and corresponding depth of VOCs. Where relatively elevated ECD, FID, and/or PID readings were observed, an additional MIP boring was drilled at a location farther from the center of the area of concern. This procedure was followed until a decrease in the ECD, FID, and PID readings were observed within the soil column from the ground surface to the point of refusal (i.e., top of bedrock). Confirmatory soil samples were then

collected from separate borings drilled in close proximity to the low level MIP boreholes. At each confirmatory boring location, soil samples were collected from the intervals that exhibited the highest ECD, FID, and/or PID readings.

Soil Sample and FLUTE® NAPL Liner Testing Results, Former Vapor Degreaser #2 Area, Building #5

The analytical results for the soil samples collected from the confirmatory borings drilled in the former vapor degreaser area #2 show that the measured concentrations of 1,1,2-trichloroethane (1,1,2-TCA) exceeded the PADEP Soil to Groundwater Pathway Standard in the following soil samples: VD2-CB01 (4 to 8 feet), VD2-CB02 (8 to 12 feet), and VD2-CB03 (8 to 12 feet). The concentrations of 1,1,2-TCA in these soil samples ranged from a low of 560 µg/kg in boring VD2-CB03 to a high of 5,500 µg/kg in boring VD2-CB01. The PADEP Soil to Groundwater Pathway Standard established for 1,1,2-TCA is 500 µg/kg. The concentrations of the other VOCs measured in the soil samples collected from the confirmatory borings drilled in the former vapor degreaser area #2 were all below the PADEP Soil to Groundwater Pathway Standards.

One FLUTE® NAPL liner was deployed to determine the presence or absence of free-phase DNAPLs in the subsurface materials underlying the former vapor degreaser area #2. The FLUTE® NAPL liner deployed in the former vapor degreaser area #2 did not display any evidence of staining or dispersion of the reactive dye indicating that free phase DNAPLs are not present in the subsurface materials where the NAPL liner was deployed. Importantly, the bottom of the VD2-FLUTE01 NAPL liner did not display evidence of an accumulation of free phase DNAPL fluids in the saturated weathered bedrock materials. This information suggests, that a perched free-phase pool of DNAPL fluids probably does not exist on top of the bedrock surface underlying the former vapor degreaser area #2 in Building #5.

Soil Sample and FLUTE® NAPL Liner Testing Results, Former Vapor Degreaser #1 Area Building #8

The analytical results for the soil samples collected from the confirmatory borings drilled in the former vapor degreaser area #1 show that the measured concentrations of 1,2-dichloroethene (1,2-DCE) were found to exceed the PADEP Soil to Groundwater Pathway Standard in the soil samples collected from the following borings: VD-CB03 (1,100 µg/kg from 0 to 4 feet) and VD-CB03 (770 µg/kg from 4 to 8 feet). The PADEP Soil to Groundwater Pathway Standard established for 1,2-DCE is 700 µg/kg. The measured concentrations of 1,1,2-TCA were found to exceed the PADEP Soil to Groundwater Pathway Standard in the soil samples collected from following borings: VD-CB03 (1,200 µg/kg from 4 to 8 feet) and SDA-CB03 (550 µg/kg from 0 to 4 feet). The PADEP Soil to Groundwater Pathway Standard established for 1,1,2-TCA is 500 µg/kg. The concentrations of the other VOCs measured in the soil samples collected from the confirmatory borings drilled in the former vapor degreaser area #1 were all below the PADEP Soil to Groundwater Pathway Standards.

Four FLUTE® NAPL liners were deployed to determine the presence or absence of free-phase DNAPLs in the subsurface materials underlying the former vapor degreaser area #1. The FLUTE® NAPL liners deployed in borings AST-FLUTE01, SDA-FLUTE01, and VDP-FLUTE01 did not display any evidence of staining or dispersion of the reactive dye indicating that free phase DNAPLs are not present in the subsurface materials where these NAPL liners were deployed. The FLUTE® NAPL liner deployed in boring VDP-FLUTE02, however, was found to display evidence of staining and dispersion of the reactive dye at a depth of four to five feet. It should be noted that a soil sample collected from the same depth in a nearby boring (i.e., VDP03) during the Phase I Site Characterization (Baker, 2002a) was found to contain a concentration of TCE exceeding 10,000,000 µg/kg. This information collectively suggests that residual

DNAPLs occur in the subsurface materials at the VDP-FLUTE02 drilling location. The absence of DNAPL staining on the NAPL liner below a depth of 4 to 5 feet suggests that the residual DNAPL fluids probably exist in the soils as ganglia rather than fully saturated conditions over the entire length of the soil column. Importantly, the bottom of the VDP-FLUTE02 NAPL liner did not display evidence of an accumulation of free phase DNAPL fluids in the saturated weathered bedrock materials. This information suggests, that a perched free-phase pool of DNAPL fluids probably does not exist on top of the bedrock surface underlying the former degreaser area in Building #8.

Soil Sample and FLUTE® NAPL Liner Testing Results, Former Drum Storage Area

The analytical results for the soil samples collected from the confirmatory borings drilled in the former drum storage area show that the measured concentrations of 1,2-DCE were found to exceed the PADEP Soil to Groundwater Pathway Standard in the soil sample collected from boring DSA-CB03 (750 µg/kg from 4 to 8 feet). The PADEP Soil to Groundwater Pathway Standard established for 1,2-DCE is 700 µg/kg. The measured concentrations of 1,1,2-TCA were found to exceed the PADEP Soil to Groundwater Pathway Standard in the soil sample collected from boring DSA-CB02 (600 µg/kg from 4 to 8 feet). The PADEP Soil to Groundwater Pathway Standard established for 1,1,2-TCA is 500 µg/kg. In addition, the soil samples collected from boring DSA-CB03 (4 to 8 Feet) were found to contain a concentration of tetrachloroethylene (PCE) of 830 µg/kg. This measured concentration of PCE exceeded the PADEP Soil to Groundwater Pathway Standard established for this parameter of 500 µg/kg. The concentrations of the other VOCs measured in the soil samples collected from the confirmatory borings drilled in the former drum storage area were all below the PADEP Soil to Groundwater Pathway Standards.

Two FLUTE® NAPL liners were deployed to determine the presence or absence of free-phase DNAPLs in the subsurface materials underlying the former drum storage area. The FLUTE® NAPL liner deployed in boring DSA-FLUTE02 did not display any evidence of staining or dispersion of the reactive dye indicating that free phase DNAPLs are not present in the subsurface materials where this NAPL liner was deployed. The FLUTE® NAPL liner deployed in boring DSA-FLUTE01, however, was found to display evidence of staining and dispersion of the reactive dye at a depth of three to four feet. It should be noted that a soil sample collected from the same depth in a nearby boring (i.e., DSA12) during the Phase I Site Characterization (Baker, 2002a) was found to contain a concentration of TCE exceeding 4,000,000 µg/kg. This information collectively suggests that residual DNAPLs occur in the subsurface materials at the DSA-FLUTE01 drilling location. The absence of DNAPL staining on the NAPL liner below a depth of 3 to 4 feet, suggests that the residual DNAPL fluids probably exist in the soils as ganglia rather than fully saturated conditions over the entire length of the soil column. Importantly, the bottom of the DSA-FLUTE01 NAPL liner did not display evidence of an accumulation of free phase DNAPL fluids in saturated weathered bedrock materials. This information suggests, that a perched free-phase pool of DNAPL fluids probably does not exist on top of the bedrock surface underlying the former drum storage area.

Soil Sample Results, Suspected Waste Disposal Lagoon Area

The analytical results for the soil samples collected from borings WDLCB01 and WDLCB02 drilled in the suspected waste disposal lagoon area (i.e., southeast corner of Building #8) show that the measured concentrations of VOCs and inorganic compounds (i.e., metals) were below the PADEP Soil to Groundwater Pathway Standards (see Tables 2 and 4). The relatively low concentrations of VOCs measured in the soil samples collected from borings WDLCB01 and WDLCB02 suggest that chlorinated solvents were not disposed of in the area underlying the southeast corner of Building #8.

The soil sample collected from boring WDL02 at a depth of 16 to 20 feet was found to contain concentrations of chromium and nickel that are higher than the general background levels of these metals in neighboring borings (see Table 4). It should be noted that relatively high concentrations of heavy metals (nickel and chromium – exceeding general background levels) were also detected in the soil samples collected from borings WDL01, WDL03, and WDL04 drilled at the Bishop Tube site during the Phase I Site Characterization (Baker, 2002a). These borings were drilled approximately 100 feet south-southeast of the southeast corner of Building #8 and are situated hydraulically upgradient from boring WDL02. The shallow soil sample collected from boring WDL04 from a depth of 2 to 3 feet was found to contain concentrations of antimony and lead that exceeded the PADEP Soil to Groundwater Pathway Standards (see Figure 8). The groundwater sample collected from neighboring boring WDL02 was found to contain elevated “total” concentrations of the following heavy metals that exceeded the PADEP Health-based Groundwater Standards: arsenic, barium, beryllium, cadmium, chromium, copper, lead, mercury, nickel, thallium, vanadium, and zinc. Elevated concentrations of chromium, lead, nickel, and fluoride exceeding the PADEP Health-based Groundwater Standards have also been detected in the groundwater samples collected from neighboring monitoring well MW07. The former manufacturing operations performed at the Bishop Tube site included a pickling operation (i.e., use of nitric and hydrofluoric acids) for cleaning the raw stainless steel materials prior to their fabrication into tubing and piping products. The presence of high concentrations of antimony, chromium, lead, and nickel in the soils surrounding borings WDL01, WDL03, and WDL04 suggests that waste products generated during the former manufacturing operations may have been disposed of in this area. This supposition is supported by the elevated concentrations of fluoride contained in the groundwater samples collected from monitoring well MW07.

The review of aerial photographs identified the presence of a disposal pit at the southeast corner of Building #8 as well as the former storage of drums/roll off boxes along the western edge of Little Valley Creek (Baker, 2002a). The discharge of waste waters to the former lagoon, as well as leaks/releases of substances resulting from the storage of waste materials along the western bank of Little Valley Creek are collectively believed to be the source of the heavy metals contained in the soils and shallow groundwater underlying this portion of the site. Importantly, the southernmost limit of the heavy metals contained in the soils upgradient to the drilling locations of WDL01, WDL03, and WDL04 remains unconstrained.

Soil Sample Results, Physical Testing Parameters

Soil samples were collected from each of the three principal areas of concern (i.e., former vapor degreaser area in Building #5, the former vapor degreaser area in Building #8, and the former drum storage area) during the investigation to evaluate the physical characteristics of the subsurface materials. The testing parameters for these soil samples are outlined in Table 1. The physical testing results for each of these three soil samples are summarized in Table 6.

One of the objectives of the Supplemental Soil Characterization was to evaluate the potential presence of free-phase DNAPLs (using the analytical testing data and the principals of equilibrium partitioning) and the total mass of TCE contained in the soils underlying each of the three principal areas of concern (i.e., former vapor degreaser area in Building #5, the former vapor degreaser area in Building #8, and the former drum storage area) at the Bishop Tube site. This information was deemed necessary to evaluate potential remedial options for the soils underlying these three principal areas of concern.

The determination of the potential presence of free-phase DNAPLs (using the analytical testing data and the principals of equilibrium partitioning) contained in the soils underlying the three principal areas of

concern at the Bishop Tube site required information regarding the following physical characteristics exhibited by the soils:

- Effective porosity;
- Volume of gas/volume of total assessable pore space in dry porous media;
- Volume of water/volume of total accessible pore space in dry porous media;
- Bulk density (dry mass of soil/volume of soil); and,
- Total organic carbon content.

The specific physical testing values used in the calculations for determining the potential presence of DNAPLs (based upon the principals of equilibrium partitioning) in the subsurface materials underlying each of the three principal areas of concern at the Bishop Tube site are discussed in Section 4.3 below, and in outlined in Appendix C. The physical testing values determined for the dry bulk density and total organic carbon content of the soils/weathered bedrock materials are similar to values published by Kunkle (1963) for the Glenelg-Manor-Chester Association soils in Chester County, Pennsylvania.

The determination of the total residual mass of TCE contained in the soils underlying the three principal areas of concern at the Bishop Tube site required information regarding the following physical characteristics exhibited by the soils:

- Bulk density (dry mass of soil/volume of soil)

The specific physical testing values used in the calculations for determining the total mass of TCE contained in the subsurface materials underlying each of the three principal areas of concern at the Bishop Tube site are discussed in Section 4.3 below and in outlined in Appendix D.

The physical testing results provided information regarding the characteristics exhibited by the subsurface materials underlying the site. These characteristics are important to understand the retention and migration of the organic and inorganic compounds contained in the soils. The transport of organic and inorganic compounds in the vadose zone can be affected by many factors. Accordingly, a complete understanding of contaminant transport would require knowledge of a multitude of physical and chemical parameters. Permeability testing was not performed as part of the physical testing program for the soil samples collected during the Supplemental Soil Characterization. The values determined for volume of gas/volume of total assessable pore space in dry porous media, volume of water/volume of total accessible pore space in dry porous media, bulk density (dry mass of soil/volume of soil), and total organic carbon content can be used in the future with site specific air and infiltration testing to determine the rate of vapor and fluid migration in the soils (if deemed necessary).

3.3 Discussion of Soil Characterization Results

Lateral Extent of VOCs in the Soils Underlying the Three Areas of Concern

The purpose of the Supplemental Soil Characterization was to more fully evaluate the lateral and vertical extent of the chlorinated solvents contained in the soils along the perimeter of the former vapor degreaser area #1, the former vapor degreaser area #2, and the former drum storage area. The analytical results for the soil samples collected from the confirmatory borings drilled in these three areas of concern show that the lateral limits of TCE have been better constrained. These analytical results were combined with the data collected during the Phase I Site Characterization (Baker, 2002a) to develop contour maps depicting

the concentrations of TCE contained within the shallow and deep portions of the overburden materials (i.e., soils and weathered bedrock) underlying the Bishop Tube site (see Figure 3 and Figure 4, respectively). As shown on Figures 3 and 4, elevated concentrations of TCE and other chlorinated solvents have been identified in the following three areas of concern at the Bishop Tube site: the former vapor degreaser area #1, the former vapor degreaser area #2, and the former drum storage area. Minor areas of impact also occur in the vicinity of borings SSA04 (suspected solvent disposal area – north of building #8), PTA02 (former pickling tank area in the eastern section of Building #8), and WDL05 (drilled along the eastern edge of Building #8).

Although the analytical results for the soil samples collected from the confirmatory borings provided information to better constrain the lateral limits of TCE occurring in the overburden materials underlying the site, several chlorinated solvent compounds were detected in the soils along the edges of the former vapor degreaser area #1, the former vapor degreaser area #2, and the former drum storage area that exceed the PADEP Act 2 Soil to Groundwater Pathway Standards. A graphical presentation of the VOCs occurring at concentrations exceeding the PADEP Act 2 Soil to Groundwater Pathway Standards in the overburden materials underlying these three principle areas of concern are shown in Figures 5, 6, and 7. Specifically, elevated concentrations of 1,2-dichloroethylene (1,2-DCE) and 1,1,2-trichloroethane (1,1,2-TCA) were detected in confirmatory boring VD-CB03 drilled along the western edge of the former AST area (see Figure 5). Elevated concentrations of 1,1,2-TCA were also measured in the soil sample collected from boring SDA-CB03 drilled along the southeastern edge of the former solvent distillery area inside Building #8 (see Figure 5). The soil samples collected from confirmatory borings VD2-CB01, VD2-CB02, and VD2-CB03 drilled along the edges of the former vapor degreaser #2 area inside Building #5 were found to contain elevated concentrations of 1,1,2-TCA that exceeded the PADEP Act 2 Soil to Groundwater Pathway Standards (see Figure 6). Elevated concentrations of 1,1,2-TCA exceeding the PADEP Act 2 Soil to Groundwater Pathway Standards were detected in the soil sample collected from confirmatory boring DSA-CB02 drilled along the south-southeastern edge of the former drum storage area (see Figure 7). Finally, the soil samples collected from confirmatory boring DSA-CB03 drilled along the western edge of the former drum storage area were found to contain concentrations of 1,2-DCE and 1,1,2-TCA that exceeded the regulatory standards (see Figure 7).

Chlorinated solvents exist in a formally oxidized state due to highly electronegative halogen substitutes on the molecules. In the environment, primary and secondary anaerobic abiotic reactions may occur breaking down TCE to 1,2-DCE (Kollig et al., 1990, and McCarty, 1991). Based on this information, the concentrations of 1,2-DCE detected in the soil samples collected from the confirmatory borings drilled along the perimeter of the former vapor degreaser area #1, the former vapor degreaser area #2, and the former drum storage area are believed to represent a breakdown product of more halogenated compounds (i.e., PCE, TCE, 1,1,2-TCA, and 1,1,1-TCA) contained in the soils. This supposition is supported by the elevated concentrations of 1,2-DCE occurring along the outer edges of each area of concern, suggesting that abiotic and possibly biotic reactions are breaking down the PCE, TCE, 1,1,2-TCA, and 1,1,1-TCA parent compounds to 1,2-DCE.

1,2-DCE exhibits a lower solubility in water than TCE. Based upon its higher Henry Law constant ($3.84E-01$), 1,2-DCE will tend to partition itself in soil to a greater degree than that exhibited by TCE. The affinity of a hydrophobic solute to be sorbed by the soil matrix is characterized by the solid-water partition coefficient, K_d . The value of K_d can be expressed by the following equation: $K_d = K_{oc} \cdot f_{oc}$, where: K_d represents the solid-water partition coefficient (in cm^3/g); K_{oc} is the organic carbon-water partition coefficient (in cm^3/g); and f_{oc} represents the fraction of organic carbon contained in the soil (dimensionless). The values of K_{oc} for different total organic fractions have been measured

experimentally and do not vary by a large factor over a wide range of soil types. 1,2-DCE exhibits a lower K_{oc} value than TCE. Based upon this information, 1,2-DCE would tend to be less adsorbed to the soil matrix than TCE.

It should be noted that 1,2-DCE was only locally detected in the soil samples collected from the borings drilled around the perimeter of each of the three principal areas of concern at the Bishop Tube site. Although the lateral limits of 1,2-DCE remain unconstrained in these localized areas, 1,2-DCE exhibits a lower solubility than that of TCE. Importantly, the MIP testing results and the analytical results for the soil samples collected from the borings drilled during the investigative activities indicate that the “bulk mass” of chlorinated VOCs contained in the soils surrounding each of the three principal areas of concern has been better constrained at the site. Importantly, the MIP testing results and the laboratory testing data for the soil samples collected from borings show that a decrease in the concentration of VOCs occurs from the center to the edge of each area of concern. Any residual concentrations of 1,2-DCE remaining in the soils around the perimeter of the three principal areas of concern would be reduced further by a remediation program designed to address the higher levels of TCE contained in the subsurface materials.

The source for the elevated concentrations of 1,1,2-TCA remaining in localized areas along the perimeter of the former vapor degreaser area #1, the former vapor degreaser area #2, and the former drum storage area is unknown. 1,1,2-TCA is used primarily as a solvent and may be present in adhesives and lacquer-based paints. The Air Resources Board (1997) reports that 1,1,2-TCA is used by fabricated metal producers in California. Based upon this information, 1,1,2-TCA may have been used during the former manufacturing operations performed at the Bishop Tube site. 1,1,2-TCA exhibits a higher solubility in water than TCE. Based upon its lower Henry Law constant ($7.40E-04$), 1,1,2-TCA will tend to partition itself in water to a greater degree than that exhibited by TCE. Cohen and Mercer (1993) indicate that the half-life of 1,1,2-TCA in soil and groundwater ranges from 136 to 360 days and 136 to 720 days, respectively. This compares to a half-life of TCE in soil and groundwater of 180 to 360 days and 321 to 1,653 days, respectively. As discussed above, the affinity of a hydrophobic solute to be sorbed by the soil matrix is characterized by the solid-water partition coefficient, K_d . 1,1,2-TCA exhibits a lower K_{oc} value than TCE. Based upon this information, 1,1,2-TCA would tend to be less adsorbed to the soil matrix than TCE.

It should be noted that 1,1,2-TCA was only locally detected in the soil samples collected from the borings drilled around the perimeter of each of these three areas of concern. Although the lateral limits of 1,1,2-TCA remain unconstrained in these localized areas, the higher degradation rates exhibited by this compound suggest that it is more labile than TCE. Importantly, the MIP testing data and the analytical results for the soil samples collected from the borings drilled during the investigative activities indicate that the “bulk mass” of chlorinated VOCs contained in the soils surrounding each of the three principal areas of concern has been better constrained at the site. Importantly, the MIP testing results and the laboratory testing data for the soil samples collected from the borings show that a decrease in the concentration of VOCs occurs from the center to the edge of each area of concern. Any residual concentrations of 1,1,2-TCA remaining in the soils around the perimeter of the three principal areas of concern would be reduced further by a remediation program designed to address the higher levels of TCE contained in the subsurface materials.

Distribution of VOCs with Respect to Depth in the Soil/Weathered Bedrock Materials

The continuous profile data provided by the MIP and the analytical results for the soil samples collected from the borings drilled at the site during the investigative activities indicate that the concentrations of

VOCs contained in the soils underlying each area of concern vary with respect to depth. In general, the concentrations of TCE tend to peak within the shallow to intermediate intervals of the soil/weathered bedrock materials underlying each area of concern. Changes in the concentration of VOCs with respect to depth appear to be dependent upon: 1) the lithology the subsurface materials (i.e., fill materials, residual soils, weathered bedrock); 2) the overall thickness of the overburden section; and 3) seasonal fluctuations in the elevation of the water table surface. The relative changes in the concentration of TCE contained within the shallow and deep portions of the soil/weathered bedrock materials underlying the areas characterized at the Bishop Tube site are shown on Figures 3 and 4, respectively.

The MIP profile data for the borings drilled around the perimeter of the former vapor degreaser area #1 in Building #8 show that the levels of chlorinated compounds (i.e., ECD responses) tend to peak between three and seven feet below the ground surface. The analytical results for the soil samples collected from the borings drilled to characterize this area of concern also show that the subsurface materials contained within the interval between three and seven feet below the ground surface contain the highest concentrations of VOCs. The interval between seven feet and the point of refusal (i.e., top of bedrock) was found to contain lower concentrations of VOCs (based upon MIP responses and the analytical results for discrete interval soil samples). It should be noted that relatively high residual concentrations of TCE and other chlorinated solvents (exceeding the PADEP Soil to Groundwater Pathway Standards) remain in the deeper overburden interval (i.e., seven feet to the top of bedrock) underlying the former vapor degreaser area #1 (see Figure 4). The MIP testing results for boring SDA-MIP02 (see Appendix B) show that very high ECD readings were recorded in the interval between four and nine feet below the ground surface. This boring was drilled along the southern edge of former degreaser area #1 at a location where used chlorinated solvents are believed to have been distilled and recycled. The MIP log for boring SDA-MIP02 shows that elevated concentrations of chlorinated solvents extend from a depth of four feet to the top of bedrock. This information indicates that the residual concentrations of chlorinated solvents remaining in the subsurface materials underlying the former vapor degreaser area #1 are continuing to function as a source for TCE dissolved in the shallow groundwater underlying the site. The vertical distribution of VOCs contained in the subsurface materials underlying the former vapor degreaser area #1 suggests that any future remedial programs should be designed to target the interval situated between three feet and the top of bedrock.

The data provided by the MIP for the borings drilled in the former vapor degreaser area #2 in Building #5 show that the levels of chlorinated solvents (i.e., ECD responses) tend to peak in the shallow soil interval at a depth of four feet and in the deeper soil interval between nine and eleven feet below the ground surface. The analytical results for the soil samples collected from the borings drilled to characterize this area of concern show that the subsurface materials contained within the interval between three and eight feet below the ground surface contain the highest concentrations of VOCs (see Figure 3). The concentrations of VOCs contained within the interval situated between eight feet and the top of bedrock were found to be lower (based upon MIP responses and the analytical results for discrete interval soil samples). It should be noted that locally elevated concentrations of 1,2-DCE and 1,1,2-TCA exceeding the PADEP Soil to Groundwater Pathway Standards were detected in the soil samples collected between eight and twelve feet in borings VD2-CB02 and VD2-CB03. Relatively high levels of TCE were detected in the soil samples collected from a deep interval between a depth of sixteen and twenty-four feet. The vertical distribution of VOCs contained in the subsurface materials underlying the former vapor degreaser area #2 suggests that any future remedial programs should be designed to target the shallow interval situated between three feet and eight feet below the ground surface. The remediation program should also consider addressing the residual concentrations of 1,2-DCE, 1,1,2-TCA, and TCE contained within the deep interval situated between eight feet and the top of bedrock.

The MIP profile data for the borings drilled around the perimeter of the former drum storage area show that the levels of chlorinated solvents (i.e., ECD responses) tend to peak in the shallow soil interval at a depth of four to eight feet and in the deeper soil interval between nine and sixteen feet below the ground surface. The analytical results for the soil samples collected from the borings drilled to characterize this area of concern show that the subsurface materials contained within the interval between four and eight feet below the ground surface contain the highest concentrations of VOCs. The interval between nine feet and the point of refusal (i.e., top of bedrock) was found to contain lower concentrations of VOCs (based upon MIP responses and the analytical results for discrete interval soil samples). It should be noted that relatively high residual concentrations of TCE and other chlorinated solvents (exceeding the PADEP Soil to Groundwater Pathway Standards) remain in the deeper overburden interval (i.e., nine feet to the top of bedrock) underlying the former drum storage area (see Figure 4). Elevated concentrations of 1,2-DCE and 1,1,2-TCA exceeding the PADEP Soil to Groundwater Pathway Standards were locally detected in the soil samples collected between four and eight feet in borings DSA-CB02 and DSA-CB03. The vertical distribution of VOCs contained in the subsurface materials underlying the former drum storage area suggests that any future remedial programs should be designed to target the interval situated between three feet and the top of bedrock.

Residual DNAPLs within the Soils Underlying the Three Areas of Concern

The results provided by the NAPL liner testing showed that perched free-phase pools of DNAPL fluids probably do not exist on top of the bedrock surface underlying the former vapor degreaser area #1, the former vapor degreaser area #2, and the former drum storage area. This finding suggests that the fractures/bedding planes contained in the bedrock underlying each of these three areas have allowed the chlorinated solvents to migrate downward into the underlying fractured bedrock aquifer.

The analytical results for the soil samples collected from selected borings drilled in the three principle areas of concern show that the subsurface materials locally contain elevated concentrations of chlorinated solvents. Feenstra and others (1991) and Pankow and Cherry (1996) present a method to assess the potential presence of DNAPLs using analytical data and the principals of equilibrium partitioning. This method tests the assumption that all of the organic compounds in the subsurface are either dissolved in the groundwater or absorbed to the soils. By using the concentration of organics measured in the soil and the partitioning calculations, an assessment can be made regarding whether or not separate phase DNAPLs exist at a site. If the theoretical pore-water concentration is greater than the measured mass fraction of the organic constituent of interest, free-phase NAPLs may exist in the subsurface. According to Griffin and Watson (2002), the total concentration of a specific organic compound measured in a saturated soil sample C_T (in mg/l total volume) can be expressed in terms of the pore water concentration C_W (mg/l) as:

$$C_T = nS_gC_g + nS_wC_w + \rho_bC_s \quad \text{Equation \#1}$$

Where: C_T = Total concentration of a organic compound measured in a saturated soil sample (mg/l).
 n = porosity.
 S_g = Volume of gas/volume of total assessable pore space in dry porous media.
 C_g = Mass of chemical in gaseous phase at equilibrium (mg/m³).
 S_w = Volume of water/volume of total accessible pore space in dry porous media.
 C_w = pore water concentration (mg/l).
 ρ_b = bulk density (dry mass of soil/volume of soil [kg/m³ or kg/l]).
 C_s = mass of chemical in solid phase equilibrium with liquid phase (mg/kg).

The three terms in Equation #1 represent the mass of the chemical in unit volume in the gaseous, aqueous, and solid phases. Substituting:

$$C_g = HC_w \quad \text{Equation \#1a}$$

Where: H = Henry's Law vapor/aqueous partition coefficient, and

$$C_s = K_D C_w \quad \text{Equation \#1b}$$

Where: $K_D = K_{oc}f_{oc}$ = Solid/aqueous phase partition coefficient (m^3/kg).
 K_{oc} = Organic carbon partition coefficient (m^3/kg).
 f_{oc} = Mass fraction of organic carbon in soil.

Then Equation #1 can be rewritten as:

$$C_T = (nS_gH + nS_w + \rho_b K_D)C_w \quad \text{Equation \#1c}$$

The components of Equation #1c represent the mass of a specific chemical in the gaseous phase (bound to the soil solids) that is in equilibrium with the dissolved concentration. The total concentration per unit mass C_{SOIL} (mg/kg dry weight) is given by:

$$C_{SOIL} = C_T^{NAPL}/\rho_b \quad \text{Equation \#1d}$$

For saturated soils, $S_g = 0$, and $S_w = 1.0$. Accordingly, Equation #1d then reduces to:

$$C_T = (n + \rho_b K_D)C_w \quad \text{Equation \#2}$$

In applying Equation #2, if C_w is set to the solubility limit of a particular chemical $C_{w, SOIL}$, then the measured concentration of the chemical in saturated media exceeding $C_T^{NAPL} = (n + \rho_b K_D)C_{SOIL}$ implies that the chemical is present at a higher mass than is possible without free product being present.

Equation #2 was used to estimate whether or not free phase DNAPLs may exist in the saturated weathered bedrock materials underlying the former vapor degreaser area #1, the former vapor degreaser area #2, and the former drum storage area at the Bishop Tube site. The equations and calculations used to determine C_T^{NAPL} for each of these three areas of concern are presented in Appendix C. A summary of the values determined for C_T^{NAPL} and a comparison of the soil testing results are presented in Table 7.

The comparison of the maximum concentrations of TCE detected in the soils to the calculated C_T^{NAPL} values suggests that free-phase DNAPLs may be present in the saturated soil/weathered bedrock materials underlying the former vapor degreaser area #1 and the former drum storage area. The testing results for the NAPL liners showed that perched free-phase pools of DNAPL fluids probably do not exist on top of the bedrock surface underlying these two locations. This information collectively suggests that the suspected DNAPLs contained in the soils underlying the former vapor degreaser area #1 and the former drum storage area may exist as isolated residual NAPL particles/globules occurring within the pore spaces of the weathered bedrock materials. Importantly, the residual DNAPL particles contained in the soils and weathered bedrock materials underlying these areas will continue to function as a residual source of chlorinated solvents dissolved in the groundwater underlying the site.

Estimate of the Bulk Mass of TCE Remaining in the Soils Underlying the Three Areas of Concern

Groundwater samples collected from the onsite and offsite monitoring well network show that the underlying fractured bedrock aquifer contains elevated concentrations of TCE and other chlorinated solvents. The Department has expressed interest in evaluating technologies for remediating the soils underlying the former vapor degreaser area #1, the former vapor degreaser area #2, and the former drum storage area to reduce the further loading of chlorinated solvents to the underlying fractured bedrock aquifer. To meet this objective, the areas of impact as depicted on the TCE Soil Concentration Maps (i.e., Figure 3 and 4) were used to estimate the “bulk mass” of TCE contained in the soil and weathered bedrock materials underlying each of the three principal areas of concern at the site.

The analytical results for the soil samples collected from the borings drilled at the Bishop Tube site show that the concentration of TCE varies with respect to depth. Based upon this finding, two separate iso-concentration maps (i.e., Figure 3 and Figure 4) were developed to evaluate the lateral limits and relative concentrations of TCE contained within the shallow and deep portions of the overburden materials underlying the site.

The depth to bedrock was found to vary spatially across the site. In general, the depth to bedrock along the south sides of Buildings #5 and #8 was found to be deeper (average 20.9 to 19.7 feet, respectively) than in the borings drilled with and along the north side of Building #8 (average 10.7 feet). These variations in the depth to bedrock are believed to be related to the cutting and filling activities associated with the construction of the plant buildings, as well as the natural differential weathering of the underlying rock materials. Accordingly, for the development of Figures 3 and 4, the overburden section was segregated into “shallow” and “deep” intervals, based upon the relative depth to bedrock underlying each area of concern

Due to the thicker overburden section underlying the former vapor degreaser area #2 and the former drum storage area, the contours depicting the TCE concentrations in the “shallow” overburden interval (i.e., Figure 3) was modeled using the analytical results for the soil samples collected from depths ranging from zero to eight feet. The analytical results for the soil samples collected from the interval between eight feet and the top of bedrock were used to model the TCE concentration contours for the “deep” soil interval (i.e., Figure 4) underlying these two areas of concern. The overburden interval underlying the former vapor degreaser area #1 is much thinner (average thickness of 10.7 feet). Accordingly, the contours depicting the TCE concentrations in the “shallow” overburden interval (i.e., Figure 3) underlying the vapor degreaser area #1 was modeled using the analytical results for the soil samples collected from depths ranging from zero to seven feet. The analytical results for the soil samples collected from the interval between seven feet and the top of bedrock were used to model the TCE concentration contours for the “deep” soil interval (i.e., Figure 4) underlying this area of concern.

The estimation of the bulk mass of TCE underlying the three principal areas of concern involved measuring the surface area of impact for each contour interval depicted on Figures 3 and 4. To determine the volume of the impacted soil materials, the surface area measurements for each contour interval was multiplied by the thickness of the shallow/deep overburden materials underlying each area of concern using Equation #3.

$$\text{VOL}_{\text{IMP}} = \text{SA} \cdot \text{Z}_T \quad \text{Equation \#3}$$

Where: VOL_{IMP} = Volume of the impacted soil materials (m^3).
SA = Surface area of the impacted zone (m^2).
 Z_T = Thickness of the impacted interval (m).

To determine the weight of the impacted materials underlying each contour interval, the volume of the soils determined from Equation #3 was multiplied by the dry bulk density of the soil materials (obtained from the physical testing soil samples collected from each area of concern) using Equation #4.

$$Wt = VOL_{IMP} \cdot \rho_b \quad \text{Equation \#4}$$

Where: Wt = Weight of the impacted soil materials (kg).
 VOL_{IMP} = Volume of the impacted soil materials (m^3).
 ρ_b = Dry bulk density of the soil materials (kg/m^3).

To estimate of the bulk mass of TCE contained in the soil materials underlying each contour interval, the weight of the impacted soil materials determined from Equation #4 was multiplied by the median concentration of TCE for each area using Equation #5.

$$Mass_n = Wt \cdot CONC_{MED_n} \quad \text{Equation \#5}$$

Where: $Mass_n$ = Bulk mass of TCE contained within the “n” contour interval (mg).
Wt = Weight of the impacted soil materials (kg).
 $CONC_{MED_n}$ = Median concentration of TCE contained within the “n” contour interval (mg/kg).

The calculations and assumptions used to estimate the bulk mass of TCE underlying each of the three principal areas of concern are presented in Appendix D. A summary of the input parameters and the estimated bulk mass of TCE underlying the three principal areas of concern are presented in Table 8.

As summarized in Table 8, an estimated volume of 113,265 ft^3 (i.e., 4,195 cubic yards [yds^3]) of soil materials containing 500 ug/kg or more of TCE underlie the former vapor degreaser area #1 in Building #8. Based upon a dry bulk density value of 111.1 pounds per cubic foot (lbs/ft^3 – value obtained from the physical testing soil sample collected from this area), this volume equates to a weight of 12,587,608 pounds (6,294 tons) of impacted soil materials. Approximately 4,505 pounds of TCE is estimated to occur in the soils underlying the former vapor degreaser area #1 (see Table 8 and Appendix D).

An estimated volume of 12,240 ft^3 (i.e., 453 yds^3) of soil materials containing 500 ug/kg or more of TCE underlie the former vapor degreaser area #2 in Building #5. Based upon a dry bulk density value of 112.4 lbs/ft^3 (value obtained from the physical testing soil sample collected from this area), this volume equates to a weight of 1,375,566 pounds (688 tons) of impacted soil materials. Approximately 15 pounds of TCE is estimated to occur in the soils underlying the former vapor degreaser area #2 (see Table 8 and Appendix D).

An estimated volume of 123,076 ft^3 (i.e., 4,558 yds^3) of soil materials containing 500 ug/kg or more of TCE underlie the former drum storage area. Based upon a dry bulk density value of 116.8 lbs/ft^3 (value obtained from the physical testing soil sample collected from this area), this volume equates to a weight

of 14,369,515 pounds (7,185 tons) of impacted soil materials. Approximately 2,911 pounds of TCE is estimated to occur in the soils underlying the former drum storage area (see Table 8 and Appendix D).

The values referenced above for the volume of impacted soil materials and the residual bulk masses of TCE remaining in the soils underlying these three areas of concern are estimated amounts only. The values are presented for the purpose of: 1) estimating remediation costs associated with the excavation of the soil materials; 2) estimating reagent volumes required for enhanced *in situ* remediation technologies; and 3) comparing the effectiveness of various technologies during the remediation process.

3.4 Discussion of Various Remedial Technologies

The findings of the environmental investigations performed at the Bishop Tube site show that elevated concentrations of TCE and related breakdown products are present in the soils underlying the former vapor degreaser area #1, the former vapor degreaser area #2, and the former drum storage area. The highest concentrations of chlorinated solvents are present within the soil and weathered bedrock materials underlying the former vapor degreaser area #1 situated in Building #8 and the former drum storage area. The analytical results for groundwater samples collected from the monitoring wells at the site (Baker, 2002b) show that elevated concentrations of TCE and other chlorinated solvents occur within the underlying fractured bedrock aquifer. It is suspected that the residual concentrations of chlorinated solvents contained within the soils will continue to function as a supplemental source for the TCE dissolved in the groundwater underlying the site.

To circumvent the leaching process and to reduce the potential for the migration of groundwater containing chlorinated solvents offsite, a remediation program will be necessary to address the soils containing elevated concentrations of chlorinated solvents at the site. The targeted zones for remediation of the soils at the Bishop Tube site should include the following areas of concern: the former vapor degreaser area #1, the former vapor degreaser area #2, and the former drum storage area.

The treatment of source zones for chlorinated solvents implies removing the DNAPL mass from the subsurface (i.e., *ex-situ* methods) or destroying it in place (i.e., *in situ* methods). The physical properties exhibited by chlorinated solvents (i.e., high specific gravity; low solubility; and non-uniform occurrence, typically in discontinuous masses and ganglia) collectively provide problems associated with the remediation of these compounds contained in both unsaturated and saturated media. In recent years new and more aggressive *in situ* treatment technologies have been developed to remove/reduce DNAPL source masses in both unsaturated and saturated media.

The benefits of implementing new technologies for aggressively removing/reducing the DNAPL source mass *in situ* include:

1. **Shorter Remedial Time Frames** – By aggressively attacking the source of the DNAPL mass, while managing the dissolved phase groundwater plume, clean up of sites can be achieved in shorter time frames and at lower costs.
2. **Elimination of Long-term Operation and Maintenance Requirements** - If the removal of the source allows the remedial objectives to be achieved in less time, then the costs associated with the operation and maintenance of the remedial system can be reduced. In addition, the institutional controls needed to prevent exposure can be

removed earlier, and the liability associated with groundwater impacts resulting from the chlorinated solvents can be reduced.

Such new remedial technologies for removing/reducing the DNAPL source mass using *in situ* and *ex situ* processes at the Bishop Tube site may include the following: bioremediation/chemical oxidation/surfactant flushing and physical source removal, respectively. It is important to note that these remedial techniques may not function as stand alone approaches at the Bishop Tube site. Researchers have recently advocated an integrated or phased strategy for remediating sites with DNAPL compounds. This phased approach may include aggressive source removal combined with less aggressive alternatives for managing the residual concentrations remaining in the soils. Such an approach is believed to efficiently treat the residual concentrations, accelerating site closeout and reducing life-cycle costs.

The use of *in situ* remedial technologies involves the imposition of physical, chemical, and/or biological changes to the subsurface environment for reducing/removing the source mass. An effective delivery system is required to induce these physical, chemical, and/or biological changes in the subsurface environment. Delivery systems may include: 1) injection of air, carrier gases, water, or solutions; 2) recirculation of air, gases, water, or solutions within the remediation zone; 3) addition of heat; and 4) injection of chemicals and/or specific engineered biological cultures. Effective delivery is absolutely critical for successfully completing a remedial program. Incomplete delivery may result in pockets of persistent intermediate degradation products and may extend the time required to remediate a site.

Summary of Potential Remedial Technologies

A brief discussion of new remedial technologies that may be applicable for removing/reducing the DNAPL source mass *in situ* at the Bishop Tube site is presented in the following paragraphs.

Enhanced In Situ Bioremediation

Enhanced *in situ* bioremediation of chlorinated solvents is a relatively new technology. Microbial populations involved in bioremediation require a source of carbon, an electron donor, an electron acceptor, appropriate nutrients, a suitable temperature and pH range, and other environmental conditions. Enhanced *in situ* bioremediation systems stimulate the biodegradation of chlorinated solvents in the subsurface by manipulating these requirements in the subsurface. Some systems further stimulate biodegradation by adding naturally occurring or engineered microorganisms that are particularly suited for the breakdown of chlorinated solvents. There are several different designs of enhanced *in situ* bioremediation systems for soils and groundwater that use various delivery mechanisms, degradation mechanisms, and nutrient/biological amendments. The appropriateness of a particular type of delivery, degradation, or amendment will be dependant upon the site specific characteristics.

Most enhanced *in situ* bioremediation systems for chlorinated solvents rely upon one or two of the following major degradation mechanisms: 1) reductive anaerobic dechlorination; or 2) aerobic cometabolism.

Reductive Anaerobic Dechlorination

Reductive anaerobic dechlorination systems have proven to be effective at many sites. In most cases these systems are relatively inexpensive to operate and the amendments involved to produce the degradation of

the chlorinated solvents are typically not a concern to regulatory agencies. Some potential problems associated with the operation of reductive anaerobic dechlorination systems include; 1) degradation rates may be slow, especially for less chlorinated ethenes and ethanes; 2) biofouling may cause reduced injection/circulation rates of the liquid amendments; 3) the rate of reductive biodegradation may be reduced due to the presence of high concentrations of naturally occurring electron acceptors such as sulfate; and 4) underground injection control and RCRA regulations/restrictions may apply if fluids/groundwater are re-circulated.

Anaerobic Cometabolism

Aerobic cometabolism systems have also been proven to be effective at many sites. Degradation rates may be quite high in cometabolic systems. The unsaturated/saturated portions of the subsurface environment at most sites are generally aerobic. As a result, less extensive modifications are required to promote the oxidation-reduction reactions. It is often times easier to inject gases rather than liquids. Based on this functionality, aerobic cometabolism systems require less elaborate controls for the delivery of the necessary amendments to the subsurface environment. Potential disadvantages of cometabolic systems include problems with the degradation of highly chlorinated compounds, competitive inhibition between cosubstrates, and the relatively high cost of maintaining aerobic conditions in some subsurface environments (Becvar et al., 1997). Toluene and phenol, which are two of the more common substrate amendments, are also both RCRA regulated compounds.

Enhanced *in situ* bioremediation technologies have been used to remediate the soils at several facilities containing DNAPLs with concentrations similar to those at the Bishop Tube site. A review of the U.S. EPA Clu-in web site (www.clu-in.org) contained the following project listings where reductive anaerobic dechlorination systems have been used to remediate soils at sites containing DNAPLs: Dover Air Force Base, Dover Delaware; Niagara, New York; and Watertown, Massachusetts. Anaerobic cometabolism systems have been used at the following sites to remediate soils containing DNAPLs: Dover Air Force Base, Dover Delaware; Niagara, New York; and Watertown, Massachusetts. The remediation of the VOCs contained in soils at sites where bioremediation has been employed typically ranges from 6 months to 5 years (dependent upon volume of soils, permeability of subsurface materials, and initial VOC concentrations). Cleanup goals may not be attained, however, if the soil matrix prohibits NAPL-microorganism contact. The circulation of water-based solutions through the soil may increase NAPL mobility and necessitate the treatment of the underlying groundwater. The preferential colonization of microbes may occur at the nutrient/water inject ports, causing clogging problems in wells. Preferential flow (i.e., channeling) paths may severely decrease contact between the injected fluids and the residual NAPL compounds contained in the soils. The system should not be used in for remediating NAPLs contained in clay, highly layered soils, or heterogeneous subsurface environments because of oxygen or other electron acceptor transfer limitations. High concentrations of heavy metals, highly chlorinated organics, long chain hydrocarbons, or inorganic salts may be toxic to some microorganisms. Bioremediation slows at low temperatures. A summary of the costs associated with using enhanced *in situ* bioremediation technologies to remediate DNAPLs is presented in Table 9.

In Situ Chemical Oxidation

The remediation of soils and groundwater using *in situ* chemical oxidation involves injecting chemicals (i.e., oxidants) into the source zone. The oxidant chemicals react with the chlorinated solvents, producing innocuous substances such as carbon dioxide, water, and inorganic chloride. *In situ* chemical oxidation offers several advantages over conventional treatment technologies such as pump and treat and soil vapor

extraction. These advantages include: 1) the technology does not generate large volumes of waste materials that must be disposed of and/or treated; and 2) remediation can often times be completed over a much shorter time period. Both of these advantages generally result in savings on material, monitoring, and maintenance. The appropriateness of using *in situ* chemical oxidation is dependant upon matching the oxidant and delivery system to the compounds and subsurface conditions at a site. *In situ* chemical oxidation should not be used at a site where reductive anaerobic dechlorination (i.e., biological treatment) may be chosen as a future remedial option. The use of *in situ* chemical oxidation techniques at such sites may disrupt the natural subsurface geochemical environment, inhibiting reductive anaerobic dechlorination processes. Most *in situ* chemical oxidation systems for chlorinated solvents rely upon one or two of the following oxidizing chemicals: 1) potassium and sodium permanganate; 2) hydrogen peroxide; and 3) ozone.

Permanganate

Permanganate is an oxidizing agent with the unique affinity for oxidizing organic compounds containing carbon-carbon double bonds, aldehyde groups, or hydroxyl groups. This compound has proven to be effective in oxidizing chlorinated solvents at many sites. Important advantages of permanganate include its relatively low cost and speed of reaction. If the precipitation of manganese dioxide in the subsurface is excessive (based upon the amount of naturally occurring amounts of manganese dioxide), the use of permanganate can reduce permeability, limiting the injection of the aqueous oxidant.

Hydrogen Peroxide

The use of hydrogen peroxide as an oxidant involves the generation of free radicals. Organic compounds are oxidized by the liberated free radicals and direct oxidation by the hydrogen peroxide. To achieve the desired reductions in a reasonable amount of time, a metal catalyst is required. Iron is the most commonly used metal catalyst, and when mixed with hydrogen peroxide, the solution is referred to as Fenton's reagent. This compound has proven to be effective in oxidizing chlorinated solvents at many sites. The hydroxyl radicals liberated by the solution serve as a very powerful, effective, and non-specific oxidizing agent. The oxidizing process is relatively fast, taking only days or weeks to occur. The usefulness of hydrogen peroxide may be limited by low permeability of the subsurface materials, subsurface heterogeneities, and highly alkaline subsurface materials where carbonate ions may scavenge the free hydroxyl radicals. In addition, venting or negative pressure reduction systems (i.e., soil vapor extraction) may be required to accommodate off-gases and relieve pressure buildup of organics, especially in paved areas.

Ozone

Ozone is one of the strongest oxidants available for *in situ* chemical oxidation. This compound oxidizes organic compounds in the following two ways: 1) direct oxidation by ozone, and/or 2) by the generation of free hydroxyl radicals. The hydroxyl radicals are non-selective oxidizers that rapidly attach to organic compounds (typically in less than 10 seconds), breaking down their carbon-carbon bonds. Ozone must be generated on site. It can be delivered via horizontal or vertical wells. Venting or negative pressure reduction systems (i.e., soil vapor extraction) may be required to accommodate off-gases and relieve pressure buildup of organics, especially in paved areas.

Chemical oxidation technologies have been used to remediate the soils at several facilities containing DNAPLs with concentrations similar to those at the Bishop Tube site. A review of the U.S. EPA Clu-in web site (www.clu-in.org) contained the following project listings where chemical oxidation technologies systems have been used to remediate soils at sites containing DNAPLs: Portsmouth Gaseous Diffusion

Plant, Piketon, Ohio (hydrogen peroxide); Jim Dandy Cleaners site, Thousand Oaks, California (Ozone); and at a Pennsylvania Bottle Manufacturer site, York, Pennsylvania (hydrogen peroxide and permanganate). The remediation of the VOCs contained in the soils at these sites where chemical oxidation has been employed ranged from 6 to 12 months (dependent upon volume of soils, permeability of subsurface materials, and initial VOC concentrations). Hydrogen peroxide, ozone, and permanganate have been capable of achieving high treatment efficiencies (i.e., greater than 90%) for unsaturated aliphatic (i.e., TCE) and aromatic compounds (i.e., benzene, toluene, ethylbenzene, and xylenes) with very fast reaction rates (i.e., 90% destruction in minutes). Consideration also must be given to the effects of oxidation on the subsurface environment. The three oxidants outlined above can all decrease the pH of the subsurface environment, if not buffered effectively. Other oxidation-induced effects include: the genesis of colloids leading to reduced permeability; the mobilization of redox-sensitive and exchangeable sorbed heavy metals; the possible formation of toxic daughter products; the evolution of heat and gas; and biological perturbation. In addition, the following factors may limit the applicability and effectiveness of chemical oxidation: the requirement for handling large quantities of hazardous oxidizing chemicals; some NAPL compounds are resistant to oxidation; and there is the potential for process-induced detrimental effects (i.e., the destruction of naturally occurring microbial populations). A summary of the costs associated with using chemical oxidation technologies to remediate DNAPLs is presented in Table 9.

Physical Source Removal Techniques- In situ Technologies

Remedial technologies involving the physical *in situ* removal of chlorinated solvents may include: soil vapor extraction, hot air injection, steam enhanced extraction, electrical resistance heating, radio frequency heating, and thermal conduction. These technologies may be used alone (i.e., soil vapor extraction) or combined with other technologies (i.e., soil vapor and groundwater extraction combined with chemical oxidation, surfactant flushing, or thermal heating technologies) for remediating a site.

Soil Vapor Extraction

Soil vapor extraction (SVE) has been applied to many sites that contain chlorinated solvents in the unsaturated zone, including the Tyson's Dump Superfund Site, located in Upper Merion Township, Pennsylvania. This technology, however, is not effective for remediating groundwater. The use of soil vapor extraction technology is relatively simple. A vacuum is created by withdrawing air from a well screened within the vadose zone. The withdrawal of air from the extraction well promotes airflow within the vadose zone. The air moving through the vadose zone picks up VOCs contained within the soils, carrying them to the extraction well. The off-gases generated by the extraction process are treated at the ground surface by passing the air stream through activated carbon, filters, and/or catalytic oxidizers.

SVE is a relatively simple and inexpensive remedial technology. It is often used in combination with other remedial technologies for capturing and reducing VOC concentrations within unsaturated materials. Due to subsurface heterogeneities, airflow within the subsurface materials may be either short-circuited or channelized, leaving isolated pockets of residual DNAPLs. These isolated pockets may extend the length of time required to achieve complete remediation. Factors that may limit the applicability and effectiveness of using SVE to remediate sites containing DNAPLs include: soils that contain a high percentage of fines and a high degree of saturation will require higher vacuum pressures, increasing set up and operation/maintenance costs; fine-grained materials may also hinder the operation of the system; soils that contain high amounts of organics or are extremely dry exhibit a high sorption capacity for VOCs, reducing removal rates; vapors generated during the operation of SVE systems often require treatment prior to discharge to meet local air quality standards; as a result of off-gas treatment, residual liquids may be generated, requiring treatment and disposal; SVE is not effective in the saturated zone; the upwelling

of groundwater with extraction wells (due to high vacuum pressures) may require the lowering the water level via pumping to increase the efficiency of air flow within the subsurface environment. A summary of the costs associated with using soil vapor extraction as a remedial technology is presented in Table 9.

In-Situ Thermal Treatment Technologies

In situ thermal treatment technologies (i.e., hot air injection, steam enhanced extraction, electrical resistance heating, radio frequency heating, and thermal conduction) are relatively new technologies designed to raise the temperature of the subsurface materials, facilitating the more efficient removal of residual DNAPL compounds. The more efficient removal of the residual NAPL compounds in the subsurface materials may greatly accelerate the cleanup of a site, over that which can be achieved relying upon natural attenuation processes.

The physical properties of NAPL compounds are temperature dependent. As the temperature of the subsurface materials is increased, there is also an increase in the viscosity, vapor pressure, solubility, diffusion rate, and density of the NAPL compounds. Accordingly, the residual NAPL compounds contained in the subsurface materials become more mobile, increasing the efficiency for their removal and recovery. *In situ* thermal operating temperatures vary with the type of system. Lower temperature systems (operated under 40⁰C) seek to take advantage of enhanced metabolic processes by naturally occurring bacteria and microbes to degrade the residual NAPL compounds. Higher temperature systems (operated at or above 100⁰C) intend to remove the residual NAPL compounds by thermally enhancing their mobility in the subsurface.

Hot air injection increases the rate of NAPL removal by increasing the soil temperature through injection wells or injection through a soil auger. This process may dry-out the soils during the heating process, reducing the rate of microbial degradation.

Steam enhanced extraction is an *in situ* technology that increases the temperature of the soil, and also induces a pressure gradient to mobilize the NAPL compounds. Steam is injected into the subsurface to promote the partitioning of the NAPL compounds into the vapor and aqueous phases for removal. This technology is most appropriate where the soils are relatively permeable. Lower permeable zones can be treated if steam can be injected above and below the interval to allow heating by conduction. Steam enhanced extraction can be used to treat both shallow and deep (i.e., greater than 140 feet in depth) impacted soils containing a wide variety of organic compounds. For effectively removing the residual DNAPLs contained in the soils, it is important to evenly heat the subsurface materials (i.e., isolated cold areas may not be remediated). To recover the DNAPLs flushed from the soils, it is generally necessary to operate groundwater and/or soil vapor extraction systems when using this remedial technology. The operation of these secondary systems to collect and remove the DNAPLs may require the use of gas condensers, the treatment of extracted groundwater, and/or the treatment of extracted soil vapors.

Electrical resistance heating (sometimes referred to as three-phase and six-phase heating) increases the temperature of the soil using an array of electrodes inserted into the source area. When an electric current is applied, a voltage differential is created between the electrodes that increases the temperature of the soil materials. As the soil is heated and dried, the permeability of the soils is also increased, resulting in the more efficient removal of the residual DNAPL compounds. The operating temperature of electrical resistance heating systems is approximately 100⁰C (i.e., within the range of steam temperatures). As a general rule of thumb, the energy flux necessary to raise the temperature of one cubic yard of soil to 100⁰C is 100-kilowatt hours. Accordingly, the energy costs needed to treat large impacted areas can be

expensive. Due to depth limitations in setting the electrodes, electrical resistance heating technology is generally restricted for remediating soils 140 feet or less in depth. For effectively removing the residual DNAPLs contained in the soils, it is important to evenly heat the subsurface materials (i.e., isolated cold areas may not be remediated). To recover the DNAPLs flushed from the soils, it is generally necessary to operate groundwater and/or soil vapor extraction systems when using this remedial technology. The operation of these secondary systems to collect and remove the DNAPLs may require the use of gas condensers, the treatment of extracted groundwater, and/or the treatment of extracted soil vapors.

Radio frequency heating is a technology that uses electrodes or antennae powered by a radio frequency generator to heat the subsurface materials. The electrodes are placed either on the surface or in boreholes drilled in the area containing NAPLs. This technology can reportedly create temperatures ranging from 150°C to 200°C that are much higher than those attainable by hot air or steam injection. In addition, radio frequency heating also exhibits the tendency to dry out the subsurface materials during the heating process. This desiccation effect may lower the degradation rates by naturally occurring microbes in the soils. For effectively removing the residual DNAPLs contained in the soils, it is important to evenly heat the subsurface materials (i.e., isolated cold areas may not be remediated). To recover the DNAPLs flushed from the soils, it is generally necessary to operate groundwater and/or soil vapor extraction systems when using this remedial technology. The operation of these secondary systems to collect and remove the DNAPLs may require the use of gas condensers, the treatment of extracted groundwater, and/or the treatment of extracted soil vapors.

Thermal conduction heating uses heaters applied horizontally or vertically on or in the soil. The application of this technology involves the use of heater-only and heater-extraction wells. The application of heat to the subsurface materials destroys the residual NAPLs *in situ*. During the heating process, vapors may be released as off-gases at the ground surface, requiring containment and treatment. The heating elements can operate at temperatures ranging from 750°C to 800°C. Remediation projects involving mainly volatile organic compounds, rather than semi-volatile organic compounds, can generally be operated at lower temperatures.

In situ thermal treatment technologies have been used to remediate the soils at several facilities containing DNAPLs with concentrations similar to those at the Bishop Tube site. A review of the U.S. EPA Clu-in web site (www.clu-in.org) contained the following project listings where *in situ* thermal treatment technologies have been used to remediate the soils at sites containing DNAPLs: North Penn Area #6, Lansdale, Pennsylvania (hot air injection); A.G. Communications site, North Lake, Illinois (steam injection); Dover Air Force Base, Dover, Delaware (electrical resistance – six phase heating); Volk Field Air National Guard Base, Wisconsin (radio frequency heating); Delavan Municipal Well site, Delavan, Wisconsin (thermal conduction heating).

Groundwater and/or soil vapor extraction (SVE) may be required to recover DNAPLs and other fluids flushed from the zone of remediation using thermal treatment technologies. In addition, time will be required for performing the following work: setting up the electrodes/heating elements; arranging for electrical power; installing vapor extraction and groundwater recovery wells; the installation of onsite soil vapor and groundwater extraction equipment, piping, and treatment components; and possibly the acquisition of air and groundwater discharge permits for operation of the treatment components.

In situ thermal treatment technologies have been demonstrated to be very effective in removing DNAPLs from a wide variety of subsurface materials. In addition, the time frames required for remediation (from start up of the systems to shut down) using thermal treatment technologies can be relatively short (i.e., six

to twelve months). Following the application of lower temperature thermal treatment technologies, subsurface conditions may be amendable for applying biodegradation technologies to remediate residual NAPL compounds. Heating, especially radio frequency heating and electrical resistance heating can improve airflow in high moisture soils by evaporating water. Thermal technologies can be operated in outside open areas and underneath existing buildings. The high capital costs associated with using these technologies generally limits their use to large, highly impacted sites. The following factors may limit the applicability and effectiveness of using *in situ* thermal treatment technologies to remediate DNAPL compounds: the presence of debris and other large objects buried in the media can cause operating difficulties; soils comprised of fine-grained materials (i.e., clays) or containing a high moisture content exhibit reduced air permeabilities that may hinder the operation of thermally enhanced SVE and may require more energy input to increase vacuum pressures and temperatures; soils that contain high amounts of organics often exhibit a high sorption capacity of VOCs, which results in reduced NAPL removal rates; vapors extracted from the subsurface during the remedial process will require treatment prior to discharge for meeting local air quality standards; and hot air injection has limitations attributable to the low heat capacity of air. A summary of the costs associated with using *in situ* thermal treatment technologies to remediate DNAPLs is presented in Table 9.

In situ Surfactant and Cosolvent Flushing Technologies

In situ flushing is a relatively new innovative technology for remediating soils and groundwater containing residual amounts of NAPLs. The process involves the injection of an aqueous solution into the vadose zone, commonly through either horizontal or vertical wells. The solution flows through the soil materials, and the effluent is extracted via pumping wells hydraulically downgradient of the inject point. The extracted groundwater is treated and discharged or re-injected into the ground surface. The aqueous solution used to remove the NAPL compounds commonly contains surfactants, cosolvents, or treated groundwater.

The removal of NAPL compounds is frequently inefficient and expensive using conventional technologies, due to the low solubilities and rates of volatilization of NAPL compounds. The goal of *in situ* flushing is to enhance the recovery of sorbed NAPLs by increasing the effective aqueous solubility and reducing the interfacial tension between the soil/groundwater and NAPL phases. The increased recovery of the NAPL compounds from the subsurface materials accelerates the remediation process. This technology has been most often applied at sites where the groundwater has been impacted by chlorinated solvents. More recently, *in situ* flushing has been used to recover DNAPLs from soils.

In situ flushing is commonly applied to sites using surfactants or cosolvents as the primary flushing agents. Surfactants (surface-acting-agents) are chemical compounds frequently used as detergents and food products that alter the properties of solution interfaces. Cosolvent flushing involves the injection of alcohols such as methanol, ethanol, and propanols as the primary flushing agent. Similar to surfactant flushing, cosolvent flushing can also enhance the solubility of many NAPL compounds through what is referred to as the cosolvent effect. The alcohols used in cosolvent flushing are mutually miscible in both water and NAPL, and when added to the flushing system, can produce a change in the bulk properties of the subsurface materials. When larger amounts of alcohol are used, the alcohol will partition into both the NAPL and water phases, reducing the NAPL-water interfacial tension. This reduction in the NAPL-water interfacial tension facilitates de-sorption of the NAPL compounds from the subsurface materials.

A review of the U.S. EPA Clu-in web site (www.clu-in.org) contained the following project listings where *in situ* flushing has been used to remediate the soils at sites containing DNAPLs: Dover Air Force

Base, Dover, Delaware (cosolvent solubilization); and Hill Air Force Base Operable Unit #2, Layton, Utah (surfactant flood).

In situ flushing has been demonstrated to be very effective in removing DNAPLs in both soil and groundwater. In addition, the time frames required for remediation (from start up of the systems to shut down) using *in situ* flushing range between four to seventeen months. This short operating time frame eliminates the need for long-term operating and maintenance costs typically associated with conventional treatment systems. Under appropriate site conditions, NAPL removal rates of 80% or higher can be expected with surfactant/cosolvent flushing. Rates as high as 99% for the removal of the original DNAPL mass have been demonstrated at some sites. The following factors may limit the applicability and effectiveness of using *in situ* flushing techniques to remediate DNAPL compounds contained in soils: Low permeability or heterogeneous soils are difficult to treat; surfactants can adhere to soil and reduce the effective porosity; reactions of flushing fluids through the soils can reduce NAPL mobility; the potential of washing NAPL compounds beyond the capture zone and introducing surfactants to the subsurface may be a concern to regulatory agencies; the technology should only be used where the flushed NAPL compounds can be contained and recaptured; and the aboveground separation and treatment costs can drive the economics of the process. A summary of the costs associated with using *in situ* flushing techniques to remediate DNAPLs is presented in Table 9.

Physical Source Removal Techniques- Ex situ Technologies

The selection of a remedial technology for reducing the concentrations of VOCs contained in the soils and weathered bedrock materials underlying the source areas at the Bishop Tube site will need to consider the future redevelopment plans for the property. The former vapor degreaser area #1 and the former vapor degreaser area #2 are located within Buildings #8 and #5, respectively. Estimates regarding the volume of impacted soil materials underlying the former vapor degreaser area #1 and the former vapor degreaser area #2 are presented in Table 8. Based upon the relatively large volumes of impacted soil materials underlying these two areas of concern, excavation of the soils within the two existing buildings may be cost prohibitive and impractical. If the future development plans for the property include the removal of Buildings #5 and #8, excavation and disposal may become a cost effective option for removing impacted soils underlying the former vapor degreaser area #1 and the former vapor degreaser area #2, as well as the former drum storage area at the site.

Excavation and disposal of the impacted soils from the Bishop Tube site may be an attractive option for remediating the source areas because remediation could be completed in a shorter amount of time than using *in situ* technologies. This may be an important consideration, based upon the schedule for the redevelopment of the site. Conversely, the costs associated with the disposal of the impacted soils may be higher than using *in situ* technologies. This later point may be important if the soil materials are deemed hazardous, based upon the concentrations of the VOCs. In addition, soil samples collected from the more deeply buried weathered bedrock materials underlying the former vapor degreaser area #1 and the former drum storage areas have been identified to contain elevated concentrations of VOCs. Based upon the site conditions (i.e., water table and the indurated character of the weathered bedrock materials) excavation may be unable to remove all the impacted soil and weathered bedrock materials. Accordingly, one or more supplemental technologies may have to be implemented to further reduce the residual levels of VOCs remaining in the weathered and shallow bedrock intervals following excavation and disposal.

Excavation and offsite disposal is a well proven and readily implementable technology. The excavation rate depends upon the number of available operating loaders and trucks. The excavation of 20,000 tons

(12,345 yds³) of impacted soil would typically require two months to complete. There is an estimated 9,200 yds³ of impacted soils at the Bishop Tube site (i.e., three principal source areas – see amounts listed in Table 8). Based upon this estimated volume, the excavation and disposal of the impacted soil materials could probably be completed in a period of time ranging from 1.5 to 2 months. If deemed hazardous, disposal of the impacted soils would be dependent upon the availability of adequate containers to transport the soils to a permitted hazardous waste disposal facility. This remedial technology is applicable to a wide range of organic and inorganic compounds. The following factors may limit the applicability and effectiveness of using excavation techniques to remove the soils containing DNAPLs from the Bishop Tube site: the generation of fugitive emissions may be a problem during operations; the distance between the site and the nearest disposal facility will affect costs; the depth and composition of the media requiring excavation may also affect costs; and the transportation of the soils through populated areas may be a public concern. A summary of the costs associated with the excavating and disposing impacted soils is presented in Table 9.

4.0 Conclusions

Based upon the review of available information and the results of the Supplemental Soil Characterization, the following conclusions have been determined.

- The geologic horizons beneath the Bishop Tube site can be segregated into three categories: 1) a shallow soil/overburden interval; 2) a weathered bedrock interval; and 3) a deeper unweathered bedrock interval.
- Seismic refraction geophysical techniques were used to further characterize changes in the elevation of the bedrock surface underlying the former vapor degreaser area #1 in Building #8, the former vapor degreaser area #2 in Building #5, and the former drum storage area. The results of the geophysical survey indicate that the surface of the bedrock underlying the site is pinnacled. The surface of the bedrock underlying the former vapor degreaser area #1 in Building #8 was found to slope in a northeasterly direction toward monitoring wells MW02 and MW03. This slope/trough in the bedrock surface underlying the former vapor degreaser area #1 in Building #8 is suspected to be providing a path for the migration of DNAPLs in the subsurface. The geophysical testing results suggest that a trough exists in the top of bedrock underlying the central portion of Building #5. This trough is surrounded by bedrock highs, that and may be limiting the lateral migration of VOCs in the subsurface. The results of the geophysical survey performed in the vicinity of the former drum storage area suggest that a north to south aligned trough occurs within the top of bedrock underlying this area of concern. Differences in the concentration of TCE measured in soil samples collected from the drum storage area suggest that the bedrock trough may be influencing the lateral migration of VOCs in the subsurface. A closed depression was found to occur in the surface of the bedrock underlying the southeast corner of Building #8. This trough/depression is believed to represent the location of the former waste disposal lagoon.
- The instrument responses recorded from the borings drilled using MIP technology show that VOCs extend from near surface sources to the top of bedrock. This information is consistent with the analytical results for the soil samples collected during the Phase I Site Characterization (Baker, 2002a) and suggests that DNAPLs have migrated downward and invaded the underlying fractured bedrock aquifer.

- The real time results provided by the MIP testing instrumentation furnished reliable information to select the drilling locations and sampling depths for the confirmatory borings. Based upon the data obtained from the MIP borings, the lateral limits of TCE contained in the soils surrounding the former vapor degreaser area #1 in Building #8, the former vapor degreaser area #2 in Building #5, and the former drum storage area were better constrained. Importantly, the MIP testing results show that the concentrations of VOCs contained in the soils along the perimeter of the former vapor degreaser area #1 in Building #8, the former vapor degreaser area #2 in Building #5, and the former drum storage area are exhibiting a decreasing trend.
- The analytical results for the soil samples collected from the confirmatory borings drilled in the former vapor degreaser area #1 (i.e., Building #8) show that residual concentrations of 1,2-DCE and 1,1,2-TCA exceeding the PADEP Soil to Groundwater Pathway Standard locally occur in the subsurface materials underlying the northwestern and southeastern edges of this area of concern. Importantly, the testing data show that elevated concentrations of TCE (exceeding the PADEP Soil to Groundwater Pathway Standards) do not extend beyond the boundaries of the confirmatory borings drilled to characterize the former vapor degreaser area #1.
- The MIP profile data for the borings drilled around the perimeter of the former vapor degreaser area #1 in Building #8 show that the levels of chlorinated compounds (i.e., ECD responses) tend to peak between three and seven feet below the ground surface. The analytical results for the soil samples collected from the borings drilled to characterize this area of concern also show that the subsurface materials contained within the interval between three and seven feet below the ground surface contain the highest concentrations of VOCs. The interval between seven feet and the point of refusal (i.e., top of bedrock) was found to contain lower concentrations of VOCs (based upon MIP responses and the analytical results for discrete interval soil samples). It should be noted that relatively high residual concentrations of TCE and other chlorinated solvents (exceeding the PADEP Soil to Groundwater Pathway Standards) remain in the deeper overburden interval (i.e., seven feet to the top of bedrock) underlying the former vapor degreaser area #1. The vertical distribution of VOCs contained in the subsurface materials underlying the former vapor degreaser area #1 suggests that any future remedial programs should be designed to target the interval situated between three feet and the top of bedrock.
- The analytical results for the soil samples collected from the confirmatory borings drilled in the former vapor degreaser area #2 (i.e., Building #5) show that residual concentrations of 1,1,2-TCA exceeding the PADEP Soil to Groundwater Pathway Standard locally occur in the subsurface materials underlying the northeastern, northwestern, and southwestern edges of this area of concern. Importantly, the testing data show that elevated concentrations of TCE (exceeding the PADEP Soil to Groundwater Pathway Standards) do not extend beyond the boundaries of the confirmatory borings drilled to characterize the former vapor degreaser area #2.
- The data provided by the MIP for the borings drilled in the former vapor degreaser area #2 in Building #5 show that the levels of chlorinated solvents (i.e., ECD responses) tend to peak in the shallow soil interval at a depth of four feet and in the deeper soil interval between nine and eleven feet below the ground surface. The analytical results for the soil samples collected

from the borings drilled to characterize this area of concern show that the subsurface materials contained within the interval between three and eight feet below the ground surface contain the highest concentrations of VOCs. In addition, the soil samples collected from the confirmatory borings drilled along the perimeter of this area of concern were found to contain elevated concentrations of 1,2-DCE and 1,1,2-TCA, that exceeded the PADEP Soil to Groundwater Pathway Standards established for these compounds. The vertical distribution of VOCs contained in the subsurface materials underlying the former vapor degreaser area #2 suggests that any future remedial programs should be designed to target the shallow interval situated between three feet and eight feet below the ground surface. The remediation program should also consider addressing the residual concentrations of 1,2-DCE, 1,1,2-TCA, and TCE contained within the deep interval situated between eight feet and the top of bedrock.

- The analytical results for the soil samples collected from the confirmatory borings drilled in the former drum storage area show that residual concentrations of 1,2-DCE, 1,1,2-TCA, and PCE exceeding the PADEP Soil to Groundwater Pathway Standard locally occur in the subsurface materials underlying the western and southeastern edges of this area of concern. Importantly, the testing data show that elevated concentrations of TCE (exceeding the PADEP Soil to Groundwater Pathway Standards) do not extend beyond the boundaries of the confirmatory borings drilled to characterize the former drum storage area.
- The MIP profile data for the borings drilled around the perimeter of the former drum storage area show that the levels of chlorinated solvents (i.e., ECD responses) tend to peak in the shallow soil interval at a depth of four to eight feet and in the deeper soil interval between nine and sixteen feet below the ground surface. The analytical results for the soil samples collected from the borings drilled to characterize this area of concern show that the subsurface materials contained within the interval between four and eight feet below the ground surface contain the highest concentrations of VOCs. The interval between nine feet and the point of refusal (i.e., top of bedrock) was found to contain lower concentrations of VOCs (based upon MIP responses and the analytical results for discrete interval soil samples). It should be noted that relatively high residual concentrations of TCE and other chlorinated solvents (exceeding the PADEP Soil to Groundwater Pathway Standards) remain in the deeper overburden interval (i.e., nine feet to the top of bedrock) underlying the former drum storage area. The vertical distribution of VOCs contained in the subsurface materials underlying the former drum storage area suggests that any future remedial programs should be designed to target the interval situated between three feet and the top of bedrock.
- It should be noted that 1,2-DCE and 1,1,2-TCA were only locally detected in the soil samples collected from the borings drilled around the perimeter of each of the three principal areas of concern at the Bishop Tube site. Importantly, the MIP testing results and the analytical results for the soil samples collected from the borings drilled during the investigative activities indicate that the “bulk mass” of chlorinated VOCs contained in the soils surrounding each of the three principal areas of concern has been fairly well delineated at the site. Any residual concentrations of 1,2-DCE, 1,1,2-TCA, and PCE remaining in the soils around the perimeter of the three principal areas of concern would be reduced further by a remediation program designed to address the higher levels of TCE contained in the subsurface materials.
- The analytical results for the soil samples collected from the borings drilled in the area of the suspected waste disposal lagoon (i.e., southern corner of Building #8) show that the measured

concentrations of VOCs and TAL metals were below the PADEP Soil to Groundwater Pathway Standards. The soil sample collected from boring WDL02 at a depth of 16 to 20 feet was found to contain concentrations of chromium and nickel that are higher than the general background levels of these metals in neighboring borings. It should be noted that relatively high concentrations of heavy metals (nickel and chromium – exceeding general background levels) were also detected in the soil samples collected from borings WDL01, WDL03, and WDL04 drilled at the Bishop Tube site during the Phase I Site Characterization (Baker, 2002a). The former manufacturing operations performed at the Bishop Tube site included a pickling operation (i.e., use of nitric and hydrofluoric acids) for cleaning the raw stainless steel materials prior to their fabrication into tubing and piping products. The presence of high concentrations of antimony, chromium, lead, and nickel in the soils surrounding borings WDL01, WDL03, and WDL04 suggests that waste products generated during the former manufacturing operations may have been disposed of in this area. This supposition is supported by the elevated concentrations of fluoride contained in the groundwater samples collected from monitoring well MW07. The review of aerial photographs identified the presence of a disposal pit at the southeast corner of Building #8, as well as the former storage of drums/roll off boxes along the western edge of Little Valley Creek (Baker, 2002a). The discharge of waste waters to the former lagoon, as well as leaks/releases of substances resulting from the storage of waste materials along the western bank of Little Valley Creek, are collectively believed to be the source of the heavy metals contained in the soils and shallow groundwater underlying this portion of the site. Importantly, the southernmost limit of the heavy metals contained in the soils upgradient to the drilling locations of WDL01, WDL03, and WDL04 remains unconstrained.

- A total of seven FLUTE[®] NAPL liners were installed at selected locations at the site during the investigation. Evidence of staining suggesting the presence of DNAPLs was observed on the NAPL liners deployed in the DSA-FLUTE01 (i.e. drum storage area) and VDP-FLUTE02 (i.e., vapor degreaser #1 area) boreholes. This information confirms the presence of residual DNAPL fluids contained in the soils surrounding these drilling locations. Staining was not observed on the NAPL liners deployed in the following boreholes: AST-FLUTE01, SDA-FLUTE01, VDP-FLUTE01, VD2-FLUTE01, and DSA-FLUTE02.
- The results provided by the NAPL liner testing showed that perched free-phase pools of DNAPL fluids probably do not exist on top of the bedrock surface underlying the former vapor degreaser area #1, the former vapor degreaser area #2, and the former drum storage area. This finding suggests that the fractures contained in the bedrock underlying each of these three areas has allowed the chlorinated solvents to migrate downward into the underlying fractured bedrock aquifer.
- Soil samples were collected from each of the three principal areas of concern (i.e., former vapor degreaser area in Building #5, the former vapor degreaser area in Building #8, and the former drum storage area) during the investigation to evaluate the physical characteristics of the subsurface materials. These testing data were used to evaluate the potential presence of free-phase DNAPLs (using the principals of equilibrium partitioning) and the total mass of TCE contained in the soils underlying each of the three principal areas of concern at the Bishop Tube site. The following physical parameter values were used in the calculations: effective porosity, void volume, water volume, dry bulk density, and total organic carbon content. The site specific values determined for the dry bulk density and total organic carbon

content of the soils/weathered bedrock materials are similar to values published by Kunkle (1963) for the Glenelg-Manor-Chester Association soils in Chester County, Pennsylvania.

- Applying the principals of equilibrium partitioning, calculations were performed to assess the potential presence of DNAPLs using the analytical data for the soil samples collected from the borings previously drilled at the site. The comparison of the maximum concentrations of TCE detected in the soils to the calculated C_T^{NAPL} values suggests that free-phase DNAPLs may be present in the saturated soil/weathered bedrock materials underlying the former vapor degreaser area #1 and the former drum storage area. The testing results for the FLUTE[®] NAPL liners showed that perched free-phase pools of DNAPL fluids probably do not exist on top of the bedrock surface underlying these two locations. This information collectively suggests that the DNAPLs contained in the soils underlying the former vapor degreaser area #1 and the former drum storage area may exist as isolated residual NAPL particles/globules occurring within the pore spaces of the soil/weathered bedrock materials. Importantly, the residual NAPL contained in the soils and weathered bedrock materials underlying these areas will continue to function as a residual source of chlorinated solvents dissolved in the groundwater underlying the site. The comparison of the maximum concentrations of TCE detected in the soils to the calculated C_T^{NAPL} values suggests that free-phase DNAPLs do not exist in the saturated soil/weathered bedrock materials underlying the former vapor degreaser area #2 (i.e., Building #5). This finding is consistent with the testing results for the FLUTE[®] NAPL liner deployed in the former vapor degreaser area #2, showing that DNAPLs probably do not occur in the soils underlying this area of concern.
- An estimated volume of 113,265 ft³ (i.e., 4,195 yds³) of soil materials containing 500 ug/kg or more of TCE underlie the former vapor degreaser area #1 in Building #8. Based upon a dry bulk density value of 111.1 lbs/ft³, this volume of equates to a weight of 12,587,608 pounds (6,294 tons) of impacted soil materials. Approximately 4,505 pounds of TCE is estimated to occur in the soils underlying the former vapor degreaser area #1. An estimated volume of 12,240 ft³ (i.e., 453 yds³) of soil materials containing 500 ug/kg or more of TCE underlie the former vapor degreaser area #2 in Building #5. Based upon a dry bulk density value of 112.4 lbs/ft³, this volume of equates to a weight of 1,375,566 pounds (688 tons) of impacted soil materials. Approximately 15 pounds of TCE is estimated to occur in the soils underlying the former vapor degreaser area #2. An estimated volume of 123,076 ft³ (i.e., 4,558 yds³) of soil materials containing 500 ug/kg or more of TCE underlie the former drum storage area. Based upon a dry bulk density value of 116.8 lbs/ft³, this volume of equates to a weight of 14,369,515 pounds (7,185 tons) of impacted soil materials. Approximately 2,911 pounds of TCE is estimated to occur in the soils underlying the former drum storage area.

5.0 Recommendations

The primary objective of the Supplemental Soil Characterization was to evaluate the subsurface conditions at the Bishop Tube site with respect to defining the lateral limits of the VOCs contained in the subsurface materials underlying the three principal areas of concern at the site (i.e., the former vapor degreaser area #1, the former vapor degreaser area #2, and the former drum storage area) and confirming the presence/absence of free-phase DNAPLs contained within the soils and weathered bedrock materials. The recommendations outlined below stem from the conclusions presented in Section 4.0.

1. The results of the environmental studies conducted previously at the site (Baker, 2002a and 2002b) including the findings of the Supplemental Soil Characterization, show that the soils

underlying the former vapor degreaser area #1 (Building #8), the former vapor degreaser area #2 (Building #5), and the former drum storage area contain elevated concentrations of chlorinated solvents (namely TCE). The concentrations of chlorinated solvents contained in the soils underlying these areas of concern are believed to be functioning as residual sources for the TCE dissolved in the fractured bedrock aquifer underlying the site. Based upon this finding, Baker recommends that the Department consider implementing a Feasibility Study to evaluate different remedial techniques to reduce the concentrations of chlorinated solvents contained in the soils. The Feasibility Study should address the following issues: the high concentrations of chlorinated solvents contained in the soils that may inhibit the use of bioremediation techniques; access problems in regards to delivering chemical oxidants and/or amendments to the subsurface (especially for the areas inside Buildings #5 and #8); compatibility with the future development plans for the site; time constraints on the remediation of the soils underlying each area of concern; and a comparison of costs.

To evaluate the most feasible and cost effective approach for remediating the soils, additional information/data may be necessary, including: 1) the performance of site specific testing to evaluate the hydraulic conductivity (i.e., permeability testing) of the soils/unsaturated bedrock materials underlying the three source areas (this information is needed to evaluate the movement of fluids through the subsurface materials if bioremediation, chemical oxidation, and/or surfactant flushing is/are selected for further consideration as remedial technologies); 2) the performance of site specific testing to evaluate the movement of air through the soil/weathered bedrock materials (this information is needed to evaluate the number and spacing of extraction wells that may be required if soil vapor extraction and/or any thermal heating techniques is/are selected for further consideration as remedial technologies); 3) the collection of supplemental soil samples to evaluate the concentrations of metals, organic constituents, and/or natural moisture content that may inhibit the use of chemical oxidation, bioremediation, or other *in situ* technologies; 4) the collection of supplemental soil samples to determine the type and number of naturally occurring microbes contained in the subsurface materials for evaluating the feasibility of applying bioremediation; 5) conducting bench-scale testing to evaluate the efficacy of using chemical oxidation and/or bioremediation techniques, and 6) performing field scale pilot study(ies) to evaluate the effectiveness of one or more remedial techniques. The data collected by this supplementary testing will be used to assess the feasibility of using physical processes and/or chemical/surfactant/biological amendments to the source areas for remediating the residual concentrations of chlorinated solvents contained in the soils.

2. Baker is currently in the process of performing the Supplemental Groundwater Characterization at the Bishop Tube site. The information provided by this investigation should be used in selecting an appropriate remedial approach for the remediation of the soils at the site.
3. Importantly, the screening and selection of appropriate remedial technologies should consider what impact these techniques may have on the future site development plans.

Mr. Dustin Armstrong
PADEP Project Officer
June 30, 2003
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If you have any questions, please do not hesitate to contact me at (717)-221-2019, or Mr. Raymond Wattras, our GTAC Program Manager, at (412) 269-2016.

Sincerely,

BAKER ENVIRONMENTAL, INC.

A handwritten signature in black ink that reads "Mark B. Ioos". The signature is written in a cursive, flowing style.

Mark B. Ioos, P.G.
Baker Project Manager/Senior Geologist

MBI:jmh

Attachments

cc: Mr. Tim Sheehan – PADEP HSCA Supervisor
Mr. Doug Cordelli – PADEP GTAC 3 Contract Manager

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