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ENVIRONMENTAL CONSULTANTS

March 25, 2008

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Ashley Holt, P.G., Manager
State Remediation Program
Division of Solid Waste Management
Tennessee Department of Environment and Conservation
5th Floor, L&C Tower
401 Church Street
Nashville, Tennessee 37243-1535

**Re: Report of Additional Solvent Release Investigations
Egyptian Lacquer Manufacturing Company
Franklin, Tennessee
TriAD Project No. 07-ELM01-01**

Dear Ms. Holt:


As required in the *Investigative Workplan* (Workplan) submitted to you on December 20, 2007, TriAD Environmental Consultants, Inc. (TriAD), on behalf of Egyptian Lacquer Manufacturing Company and through its attorneys Stites and Harbison, PLLC, is submitting this *Report of Additional Solvent Release Investigations*. This report documents work done at the site to further define the extent of groundwater contamination and to further characterize the site for natural attenuation of the dissolved phase plume. Other Workplan elements are being performed and will be reported on a separate time frame as approved by the Tennessee Department of Environment and Conservation.

I certify that this document and all attachments were prepared under my direction or supervision to a standard designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my knowledge of the conditions of the property that is the subject of this document and my inquiry of the person or persons who actually planned, managed, and/or performed the investigative and/or remedial activities described herein (except for work previously completed in which neither I nor my firm were involved), I certify that this document and all attachments are true, accurate and complete, and that all relevant site-specific data of which I am aware are presented in this document or have previously been included in documents submitted to the Tennessee Department of Environment and Conservation, Division of Solid Waste Management, State Remediation Program.

Please contact me if you require additional information.

Sincerely,

TriAD Environmental Consultants, Inc.

A handwritten signature in black ink that reads "T. Dwight Hinch". The signature is written in a cursive style with a large, stylized initial "T".

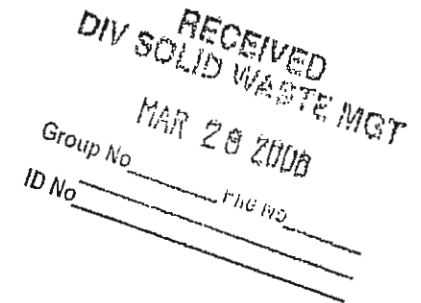
T. Dwight Hinch
Senior Project Manager

Attachment

cc: Bill Penny, Stites and Harbison
Kerry Mattox, ELMCO

**REPORT OF ADDITIONAL
SOLVENT RELEASE INVESTIGATIONS
EGYPTIAN LACQUER MANUFACTURING COMPANY
FRANKLIN, TENNESSEE**

TriAD Project No. 07-ELM01-01



Prepared for:

**EGYPTIAN LACQUER MANUFACTURING COMPANY
113 FORT GRANGER DRIVE
FRANKLIN, TENNESSEE 37064**

Prepared by:

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March 25, 2008

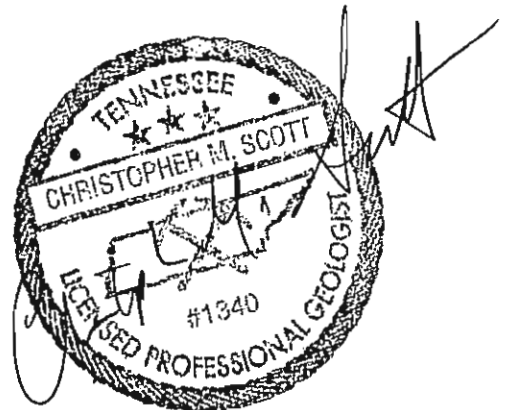


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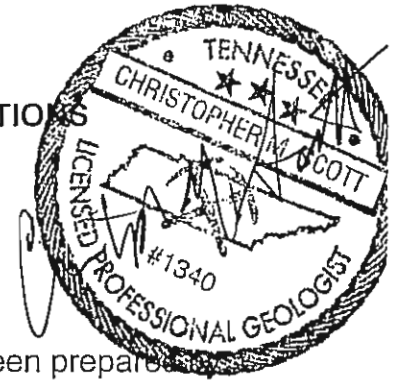
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REPORT OF ADDITIONAL SOLVENT RELEASE INVESTIGATIONS
EGYPTIAN LACQUER MANUFACTURING COMPANY
FRANKLIN, TENNESSEE



1.0 INTRODUCTION

This *Report of Additional Solvent Release Investigations* (Report) has been prepared by TriAD Environmental Consultants, Inc., (TriAD) on behalf of Egyptian Lacquer Manufacturing Company (ELMCO) and through its attorneys Stites and Harbison, PLLC. The Report is being submitted in partial fulfillment of requirements identified in the *Investigative Workplan* (Workplan) dated December 20, 2007, and approved by the Tennessee Division of Solid Waste Management (TDSWM) on January 11, 2008. The Report addresses two of the five tasks identified in the Workplan: 1) further delineation of groundwater contamination, 2) and additional site characterization for natural attenuation. The other three tasks – long-term air monitoring, soil confirmation sampling in the BIOX-treated area, and collection and analysis of soil samples from under the concrete pad of the tank farm – are being performed and reported under different time frames as approved by TDSWM.

This Report is being submitted one month later than originally planned because of delays encountered in obtaining access for installation of the groundwater monitoring well at Battleground Academy (BGA) Lower School. Although ELMCO initiated access agreement discussions with BGA prior to December 20, 2007, agreement could not be reached until January 24, 2008. Further, and as requested by BGA officials, installation of the well was scheduled to coincide with the school's winter break between February 16 and 19. This precluded the completion of sampling, analysis, and evaluation in time to meet the original February 25, 2008, due date for this Report.

2.0 FURTHER DELINEATION OF GROUNDWATER CONTAMINATION

The Workplan called for two steps in further delineation of groundwater contamination: 1) installation of two new groundwater monitoring wells and 2) the sampling and analysis of groundwater from all monitoring wells at the site.

2.1 Additional Groundwater Monitoring Wells

Two additional groundwater monitoring wells were installed at the following locations in February 2008:

- on the west side of Liberty Creek, at the east edge of the parking lot of the BGA Lower School, and
- on the northwest side of the right-of-way of Daniels Drive, in front of the home at 111 Daniels Drive.

Following installation, the two wells were surveyed vertically and horizontally. The locations of the new and previously existing monitoring wells are shown on Figure 1, Site Map. Boring logs, well construction diagrams, and a well development log are presented in Appendix 1.

BGA Well (MW-4)

M&W Drilling of Oak Ridge, Tennessee, mobilized to the BGA location on February 17, 2008, to install well MW-4 under the supervision of TriAD geologist Chris Scott. The borehole was advanced with continuous split-spoon sampling and roller bit drilling through the overburden to refusal on the top of rock at 15.1 feet below ground surface (bgs). The overburden consisted of silty clay, with no water encountered to the top of rock. Retrieved split-spoon samples were screened using an organic vapor meter (OVM) with no organic vapors detected in any sample. As required by TDSWM in their January 11, 2008, approval letter, the soil sample from immediately above the top of rock at 14 to 15.1 feet bgs, was collected into a laboratory-supplied container with zero headspace and submitted to Environmental Science Corporation (ESC) in Mt. Juliet, Tennessee, for analysis of volatile organic compounds (VOCs) by US EPA SW846 Method 8260B. The lab report is included in Appendix 2, and shows no detectable concentrations of VOCs.

Air-rotary drilling continued into limestone bedrock using a cyclone containment system to minimize dust and allow containment of all drill cuttings and groundwater. Several fractures were encountered between depths of 27 and 35 feet bgs. These fractures are located at approximate elevations of 605 to 597 feet above mean sea level (msl). Water was encountered during drilling at approximately 27 feet bgs. The water in the borehole rose to a level of approximately 20 feet bgs, or about 612 feet msl. The elevation of the nearby Liberty Creek Main Seep is approximately 611 feet msl. Thus, the elevation of water in the MW-4 borehole indicated a probable connection with water in Liberty Creek, a condition required under the Workplan for construction of this well. A 2-inch diameter PVC monitoring well was installed in the borehole, screened from 23 to 33 feet bgs. Well MW-4 was completed as shown in the well construction diagram presented in Appendix 1.

On February 19, 2008, TriAD personnel developed MW-4 by bailing to remove sediment remaining from well installation. Ninety-nine gallons of water were removed from the well over a five-hour period, with field measurements of conductivity, pH, and temperature indicating stable conditions had been reached. Maximum drawdown observed during development was less than 3 feet, and the well recovered quickly, indicating a relatively high hydraulic conductivity. The purge water, along with the drill cuttings and water, were contained in closed, labeled, 55-gallon drums, which were removed to the ELMCO facility for proper disposal pending review of analytical results.

Daniels Drive Well (MW-5)

M&W Drilling of Oak Ridge, Tennessee, mobilized to the Daniels Drive location on February 19, 2008, to install MW-5 under the supervision of TriAD geologist Chris Scott. The borehole was advanced with continuous split-spoon sampling and roller bit drilling through the overburden to refusal on the top of rock at 5 feet below ground surface (bgs). The overburden consisted of gravel fill, with no water encountered to the top of rock. Virtually no overburden samples were retrieved from the split spoon due to the presence of gravel, and no organic vapors were detected with the OVM. Because no soil was recovered, no soil sample was submitted for laboratory analysis.

Air-rotary drilling continued into limestone bedrock using a cyclone containment system to minimize dust and allow containment of all drill cuttings and groundwater. Fractures were encountered at depths of 8 and 23 feet bgs, and soft drilling was encountered from 27 to 30 feet bgs. The fracture depths correspond to elevations of approximately 630 feet and 615 feet msl, roughly at or above the lowest water elevation measured in on-site monitoring wells. Drilling was stopped at 31 feet bgs to check the borehole for water, but none accumulated during a 20-minute period. An additional fracture was encountered at 37 feet bgs (approximately 601 feet msl) and a soft zone was encountered at 43.5 feet bgs (approximately 595 feet amsl). No organic vapors were detected during drilling. Drilling was stopped at 40, 45, and 50 feet bgs to check for water, with less than 1 inch accumulating in the borehole during 30-minute breaks at 45 and 50 feet. After discussing the findings with TDEC personnel, it was decided to set a well screened from 37 to 47 feet bgs and to wait to see if water entered the well. Well MW-5 was completed as a flush-mount well as shown in the well construction diagram presented in Appendix 1.

Well MW-5 was checked on February 20 and no water was detected. On February 21, the water level was 38.60 feet below the top of casing (BTOC), or 599.67 feet msl. On February 22, the water level was 33.53 feet BTOC, or 604.74 feet msl, and rising slowly. In 35 minutes, the water level rose to 33.25 feet BTOC, or 605.02 feet msl. After discussing the situation with TDEC personnel, it was decided to collect a sample of groundwater without first developing the well, or allowing the water level to stabilize. The well was sampled on February 22 (see Section 2.2) and was purged dry using a bailer after sampling. On March 12, when the well elevation was surveyed, the water level was not checked but upward pressure on the well cap indicated water was rising. On March 20, 2008, the water level in MW-5 was 20.39 feet BTOC, or 617.88 feet msl.

2.2 Groundwater Sampling and Analysis

In accordance with TDEC's conditions for approval of the Workplan, monitoring wells MW-1, MW-2, MW-4, AR-1 and RW-1 were sampled using low-flow purging with a bladder

pump on February 21 and 22, 2008, with collected samples analyzed by ESC for VOCs by Method 8260B. Groundwater sampling data sheets are included in Appendix 3, and ESC's laboratory reports are included in Appendix 4. Positive analytical results are summarized in comparison to regulatory levels of concern and historical data in Table 1.

Due to the presence of 0.2 foot of free-product solvent (likely toluene) in well MW-3, no sample was collected from that well (the toluene was later removed from the well using an absorbent device, and the well is periodically monitored for free product).

The following paragraphs describe the analytical results from the February sampling event, historical sampling events, and other relevant observations for each monitoring well.

MW-1

The February 21 sampling event was the first event in which VOCs were detected in this monitoring well, which is located approximately 300 feet east of the tank farm, near the manufacturing building. No toluene or acetone was found, but benzene, ethylbenzene, isopropylbenzene, n-propylbenzene, 1,2,3-trimethylbenzene, and 1,2,4-trimethylbenzene were detected. Only benzene was reported at a concentration (0.0086 mg/L) exceeding the drinking water maximum contaminant level (MCL) of 0.005 mg/L. Because samples collected from this well in April and September 2007 contained no detectable VOCs, ELMCO directed that the well be resampled to verify the February results. Resampling was performed on March 12, 2008, again using low-flow purging with a bladder pump. The March sample contained detectable concentrations of benzene and ethylbenzene, both at concentrations below MCLs. No other VOCs were detected. Further discussion of the occurrence of VOCs other than toluene and acetone is included in this Report after the well-by-well discussion.

MW-2

MW-2 is located approximately 60 feet southwest of the contaminant source area at the southern end of ELMCO's tank farm. The sample collected during the February event

contained detectable concentrations of 10 VOCs, including acetone, benzene, ethylbenzene, isopropylbenzene, n-propylbenzene, toluene, xylenes, and 1,2,3-, 1,2,4-, and 1,3,5-trimethylbenzene. Only benzene and toluene were present at concentrations exceeding either the US EPA Region 9 preliminary remediation goal (PRG) (toluene) or the MCL (benzene). The concentration of acetone in the sample was several orders of magnitude less than that reported in the June and September samples from this well, which allowed much lower detection limits for other VOCs.

MW-3

MW-3 is located approximately 120 feet northwest of the contaminant source area at the south end of the tank farm. As noted earlier in this Report, MW-3 was not sampled during the February event due to the presence of approximately 0.2 foot of free product solvent (likely toluene) floating on the water column. This well has previously exhibited free product, although its presence has not been consistent. In October 2007, a sample was collected from the well after free product had been removed using an absorbent device. A thin (0.01-foot) layer of free product was still present during sampling, and the analytical result showed 650 mg/L of toluene, in excess of the water solubility of toluene (about 550 mg/L at 25°C). Because of the high concentration of toluene, no other VOCs were detected in October.

It is important to note that no water was encountered when well MW-3 was drilled. The well was installed in a dry borehole with a stainless-steel screen because a high concentration of solvent vapors was encountered at a depth of about 34 feet bgs (approximately 614 feet msl). One week later, the well was still dry. Water was measured in the well on July 9, 2007, and continued rising through September 2007. Free product was first observed in MW-3 on September 18. As described above, the free product (approximately 0.5 liter) was removed from MW-3 prior to sampling in October. No free product was observed in the well on November 19, 2007; a sheen was observed during microbial sampling on February 12, 2008; and 0.2 foot of product was measured on February 21, 2008. Approximately 0.5 liter was removed by an absorbent device on March

20, 2008. The well is frequently monitored for free product, which is removed as it is observed using absorbent devices.

MW-4

MW-4 is located across Liberty Creek and approximately 930 feet west of the solvent source area. The February event was the first time this well was sampled. Toluene was detected in the sample at 0.17 mg/L, significantly below the MCL or PRG. No other VOCs were detected.

MW-5

MW-5 is located approximately 550 feet north of the solvent source area. The February event was the first time this well was sampled. Seven VOCs were detected, including benzene, ethylbenzene, isopropylbenzene, toluene, xylenes, and 1,2,3- and 1,2,4-trimethylbenzene. Benzene and toluene were present at concentrations exceeding either the MCL (benzene) or PRG (toluene).

As noted previously in this Report, well MW-5 was installed in a borehole that initially produced very little water. In fact, the well was sampled (at the request of TDEC) before the water level had stabilized. Immediately after sampling, the well was bailed dry. On March 20, 2008, the water level in the well was 20.39 feet BTOC, or 617.88 feet msl, and appeared close to being stable. This well produces clear water and no further development of the well is planned.

AR-1

Well AR-1 is located approximately 40 feet west of the solvent source area, in the slight surface depression and corresponding bedrock cutter that apparently directs subsurface groundwater flow toward Liberty Creek. The sample collected during the February sampling event contained detectable concentrations of four VOCs; acetone, ethylbenzene, toluene, and xylenes. Three of these VOCs were present at concentrations exceeding either MCLs (toluene) or PRGs (acetone and xylenes). Although detection limits during the

February event were lower than in the previous events, they were likely still too high (due to the presence of high concentrations of acetone and toluene) to allow detection of other VOCs. The detected concentration of acetone in the February event was significantly lower than in previous events, and the concentration of toluene was similar to that observed in October.

Well AR-1 is cased to a depth of 42 feet bgs, or approximately 621 feet msl. Below the casing was originally an open bore into rock to a depth of about 54 feet bgs, or approximately 609 feet msl. During the February event, however, it was noted that the open bore had apparently collapsed or filled with mud, resulting in a well depth of only about 43 feet bgs. When first drilled, AR-1 contained approximately 1 foot of free product floating on the water surface, within the cased portion. This volume (approximately 4 gallons) was removed via absorbent booms, and no free product has been observed in the well since.

RW-1

Well RW-1 is located just east of well AR-1, approximately 35 feet west of the solvent source area, in the surface depression and corresponding bedrock cutter that apparently directs subsurface groundwater flow toward Liberty Creek. It is the closest well to the source area. The well is screened across the soil-bedrock interface and was planned for use as a recovery well; it was never used as such because free product has never been observed in the well and the well yield is very low. During the February event, six VOCs were detected in the sample, including benzene, di-isopropyl ether, ethylbenzene, isopropylbenzene, toluene, and xylenes. Three of these VOCs are present at concentrations exceeding the MCL (toluene) or PRG (benzene and xylenes). Concentrations of VOCs have fluctuated in this well over the three sampling events (September, October, and February). Acetone, measured at 430 mg/L in October and 3.8 mg/L in September, was not detected in the February event. Toluene, which was measured at 9.1 mg/L in September and 180 mg/L in October, was detected at a concentration of 4.4 mg/L in February. Other VOCs had either not been detected in

previous events, due to higher detection limits, or were present at significantly lower concentrations in the February event.

The low-yield well RW-1 has been purged dry twice in attempts to develop the well. The continued presence of significant sediment in the well indicates that additional development is needed, and this will be done on a periodic basis, using a bailer to surge and purge the well. As with all water removed from on- and off-site monitoring wells, the water from RW-1 is contained for subsequent proper off-site disposal by ELMCO.

2.3 Evaluation of Groundwater Analytical Results

The February 2008 sampling and analysis results showed that the concentrations of acetone and toluene in groundwater have declined in wells MW-2, AR-1, and RW-1 since the inception of monitoring. With new wells MW-4 and MW-5 exhibiting no detectable concentrations of acetone, and toluene concentrations less than the MCL, it appears that the groundwater contaminant plume of acetone and toluene is delineated. However, there are insufficient data to allow determination of definite trends at any of the wells. Continued quarterly groundwater monitoring will provide clearer indications of trends.

Groundwater elevation data are discussed in section 3.3, Groundwater Flow Velocity.

Monitoring data from the contaminated groundwater seeps into Liberty Creek and the Harpeth River (recent seep monitoring results are presented to TDEC in monthly seep monitoring reports) and the wells continue to indicate that acetone and toluene are the principal components of the groundwater contaminant plume. There are, and have always been, other VOCs as minor components of the plume, including methyl ethyl ketone, ethylbenzene, and xylenes. However, the detection during the February event of benzene and several other VOCs (isopropylbenzene, the trimethylbenzenes, n-propylbenzene) not previously detected has introduced new constituents of concern whose presence, for the time being, cannot be fully explained. A number of possibilities have been considered, but the origin of the benzene cannot be determined at this time. The possible explanations for

the presence of these VOCs, particularly benzene, and the evidence for and against each explanation are presented as follows:

- 1) The newly detected VOCs are related to the solvent release at the tank farm. This explanation is supported by the generally higher concentrations of these VOCs detected at RW-1 and MW-2, nearest the source. Most of the detected VOCs are consistent with the types of solvent stored in the tank farm, which included blended solvents. Several of these VOCs have been detected in soil samples from the solvent release area. The presence of the VOCs in samples from MW-2 and RW-1 may have been masked during previous sampling events by the high concentrations of acetone and toluene in the samples, concentrations that have now declined to allow lower detection limits. However, ELMCO has repeatedly stated that they have never used benzene in their solvent mixes, deliberately avoiding use of the chemical. While it is possible that benzene may have been introduced unknowingly as a contaminant in a solvent shipment delivered to ELMCO, there is no firm evidence to support this conclusion. Further, it is important to note that neither acetone nor toluene was detected in the sample from MW-1 and acetone was not detected in the sample from MW-5. Acetone would be expected at the leading edge of a plume as it is the most soluble of the VOCs detected at the site.
- 2) The benzene may be related to one or more gasoline releases somewhere in the area. In fact, trace amounts of benzene, toluene, ethylbenzene, and xylenes were detected in a soil sample collected near an underground storage tank near the ELMCO building. This UST was used to store gasoline in the years before ELMCO purchased the property in 1978. Other gasoline USTs have been and are located at other facilities in the general vicinity of the ELMCO plant. However, ESC personnel were asked to review the lab data from the February event and to provide an opinion regarding the possibility of a gasoline origin for the VOCs. ESC reviewed the chromatographs from the analyses, and determined that they did not show the characteristic "fingerprint" of gasoline. The analytical peaks for the VOCs were isolated, with none of the other many components of gasoline represented.

- 3) Benzene and some other VOCs could have been introduced accidentally to the wells via sampling equipment. Although it is decontaminated prior to use, the bladder pump used for sampling is rented, and prior use at some other site could have been in an aquifer with high concentrations of benzene. Supporting this explanation is the fact that the March resample of MW-1 showed lower concentrations of benzene and ethylbenzene, and no detectable concentrations of other VOCs – a pattern that might be expected if the contamination had been introduced as a one-time event. However, during the February event, MW-4 was sampled before MW-5, and benzene and several other VOCs were absent from the MW-4 sample and present in the MW-5 sample. This pattern would not be expected if the contaminants were introduced from sampling equipment.
- 4) The VOCs were introduced by laboratory error. Although bleed-through from prior, highly contaminated samples is always a possibility in laboratory analysis, it is unlikely in this case. First, the trip blank showed no detectable VOCs, and, as noted above, the sample from MW-4 showed only toluene. Second, two of the samples were re-run, confirming the presence of the reported VOCs.
- 5) There may be some other, previously unknown source of VOCs in the area. No data are currently available to evaluate this possibility.

To summarize, the February groundwater monitoring results have defined a plume of acetone and toluene, but have also shown several VOCs not previously detected in groundwater, including benzene. Benzene was present in samples from MW-1, MW-2, and MW-5 at concentrations exceeding the drinking water MCL, and in the samples from RW-1 and the MW-1 resample at concentrations less than the MCL. However, additional groundwater monitoring data – to be provided by the planned quarterly monitoring of the existing monitoring well system – are needed to confirm concentration trends for the primary constituents, acetone and toluene, and to confirm the presence and significance of benzene and other newly identified VOCs. The additional data may or may not identify the need for additional monitoring wells.

3.0 ADDITIONAL SITE CHARACTERIZATION FOR NATURAL ATTENUATION

Two tasks were performed to provide additional site characterization for evaluation of natural attenuation, or other potential remediation technologies: 1) bioremediation studies, and 2) hydraulic conductivity testing. In addition, using all data available from investigation of the site, estimates of groundwater flow velocity and contaminant mass were produced. The following sections describe these tasks.

3.1 Bioremediation Feasibility Studies

On January 28, 2008, water samples were collected from seeps and surface water along Liberty Creek and the Harpeth River for the purpose of performing microbial analyses. On February 12, 2008, water samples were collected for the same purpose from groundwater monitoring wells using low-flow purge via a bladder pump. Each sample was collected into a 1-liter amber glass bottle with no preservatives and shipped on ice under chain-of-custody procedures to Microbe Inotech Laboratories (MiL) in St. Louis, Missouri for analysis of microbial strains and testing against toluene and acetone to determine whether microbes present in the water are of the type that will degrade the two principal components of the groundwater contaminant plume. MiL also performed chemical analyses on the samples to determine pH, iron, nitrogen ammonia (as N), nitrogen nitrite (as N), nitrogen nitrate (as N), phosphorus orthophosphate (as P), sulfate, and total organic carbon to determine nutrient levels. During sampling activities, field measurements of parameters pH, conductivity, temperature, dissolved oxygen (DO), and oxidation-reduction potential (ORP) were also collected and recorded using portable field instruments. The groundwater sampling data sheets showing these data are included in Appendix 5, along with a table showing field parameter measurements at the surface water and seep locations.

MiL performed total heterotrophic plate counts, bacterial strain identification, and aerobic endpoint assays on each sample. The laboratory reports are included in Appendix 6. Several bacterial strains were identified in one or more of the samples, although their relative presence varied widely. The following is a list of the strains identified and whether

or not they are good degraders of acetone and toluene as determined by the endpoint assays:

<u>Strain</u>	<u>Toluene Degradation</u>	<u>Acetone Degradation</u>
<u>In Surface Water and Seeps</u>		
<i>Granulicatella elagans</i>	Good	Good
<i>Pseudomonas fluorescens</i>	Growth Inhibited	Excellent
<i>Pseudomonas aeruginosa</i>	Excellent	Excellent
<i>Aeromonas sobria</i>	Fair	Growth Inhibited
<i>Brevundimonas diminuta/vesicularis</i>	Growth Inhibited	Growth Inhibited
<i>Staphylococcus intermedius</i>	Excellent	Good
<i>Pseudomonas putida</i>	Excellent	Excellent
<i>Staphylococcus lentus</i>	Excellent	Excellent
<u>In Groundwater</u>		
<i>Sphingomonas paucimobilis</i>	Excellent	Excellent
<i>Sphingomonas paucimobilis</i>	Good	Growth Inhibited
<i>Rhizobium radiobacter</i>	Excellent	Excellent
<i>Pseudomonas mendocina</i>	Excellent	Excellent
<i>Pseudomonas mendocina</i>	Excellent	Excellent
<i>Granulicatella elegans/Kocuria kristinae/</i> <i>Kocuria varins</i>	Excellent	Excellent
<i>Staphylococcus lentus</i>	Excellent	Excellent
<i>Pseudomonas aeruginosa</i>	Excellent	Excellent
<i>Sphingomonas paucimobilis</i>	Excellent	Excellent
<i>Sphingomonas paucimobilis</i>	Excellent	Excellent
<i>Brevundimonas diminuta/vesicularis</i>	Excellent	Excellent

The reason some strains are listed more than once is that morphologies, and therefore functions, of strains can vary within species. This phenomenon is illustrated by the varying

results in the endpoint assay for *Sphingomonas paucimobilis*. Of note in the results for groundwater samples is the lack of strains in the sample from AR-1. The reason for this lack of bacteria is unknown, but, according to laboratory personnel, is unlikely to be related to high concentrations of toluene and acetone.

The lab reports include information on the percentage populations of each strain in each water sample. The following list shows these percentages by sampling point. (For example, 50% of the strains identified in the background surface water sample [Driskill Crossing] were classed as growth inhibited to fair degraders, and 50% classed as good to excellent.)

<u>Sampling Point</u>	<u>% Growth Inhibited/Fair</u>	<u>% Good/Excellent</u>
Driskill Crossing	50	50
Liberty Creek Main Seep	60	40
Liberty Creek Personnel Cross.	75	25
HR-2 (Harpeth River seep)	75	25
MW-1	0	100
MW-2	60 (acetone)	40(acetone)/100 (toluene)
MW-3	0	100
AR-1	none	none

In addition to the samples described above, and in addition to what had been proposed in the Workplan, a sample of the “biological sheen” from water in Liberty Creek was submitted to the lab for a total heterotrophic plate count. This was done to allow identification of microbes responsible for the sheen often observed on the surface of water in Liberty Creek and behind the booms on the Harpeth River. This sheen has been the subject of much speculation and debate as to its origins, and has apparently been mistaken for free-product sheen during the past year. In fact, there has never been a free-product sheen observed on the Harpeth River by TDEC, EPA, TriAD, or Ops Contracting Services personnel. The free-product sheen observed in Liberty Creek during the spring,

summer and, very occasionally, the fall and winter, is distinct from the more frequently observed biological sheen. The two types of sheen can be distinguished by poking them with a stick; the biological sheen breaks into blocky pieces that do not coalesce, and the product sheen does not form blocky pieces and immediately coalesces (similar to a soap sheen). This identifying test is explained in on-line publications from USGS and various state environmental agencies. A sample of the biological sheen was collected on January 28 from the main seep area of Liberty Creek. The total heterotrophic plate count showed the following strains:

<u>Strain</u>	<u>Percentage of Microbes in Sample</u>
Pseudomonas fluorescens	10
Aeromonas hydrophila/caviae	10
Staphylococcus intermedius	5
Unidentified organism	5
Pseudomonas fuscovaginae	70

The principal constituent of the sheen is *Pseudomonas fuscovaginae*, a plant pathogen that is reportedly very effective in breaking down plant cells. The presence of the sheen is likely related to both the presence of VOC constituents dissolved in the water, which provide a food source to some strains and reduce growth of others, and to the vegetation around and in the water, providing a food source to the plant pathogens.

Further evaluation of the biological analytical results will be performed by MiL, particularly regarding the ability of the natural microbial population to degrade the contaminant mass estimated to be present in the groundwater and whether augmentation of the nutrients in the system is needed. This additional information will be presented in the revised Corrective Action Plan to be submitted to TDEC at a later date.

3.2 Hydraulic Conductivity Testing

Single-well slug tests were performed at wells MW-1, MW-2, MW-3, and AR-1 on March 3, 2008, to provide data regarding aquifer hydraulic conductivity. The tests were performed using a decontaminated PVC slug or a disposable polyethylene bailer lowered into or removed from the water column, while monitoring the water level using an In Situ Level Troll 750 pressure transducer. The tests at each well were either rising head or falling head tests, depending on the relationship of water level to well screen. For example, the water level in well MW-3 is within the well screen, so a falling head test would be inappropriate; only a rising head test was performed. In fact, at MW-3 a bailer was used to remove a slug of water from the well because the well configuration prevented a falling head test and the very low yield of the well precluded allowing the water level to stabilize after introducing a slug. At AR-1, there is no well screen, which would allow both rising and falling head tests; however, the hydraulic conductivity was so low as to make performance of both types of tests overly time-consuming, and only a falling head test was performed. Well AR-1 was tested instead of RW-1, which had been proposed in the Workplan, because pumping data obtained during groundwater sampling indicated that AR-1 has a higher yield than RW-1 and would therefore be more representative of the higher range of hydraulic conductivity. TDEC representatives were consulted prior to making the change. Table 2 summarizes the tests performed on each well.

The slug test results were analyzed using the Bouwer and Rice method as facilitated by the AQTESOLV aquifer test software. The Bouwer and Rice method, although applicable to either confined or unconfined aquifers, is not directly applicable to fractured bedrock or karst aquifers of the type found at the site. The method was selected for use because other methods designed specifically for fractured rock aquifers require detailed information regarding the geometry of the fracture system, including fracture aperture, or the ability to monitor hydraulic head changes in multiple wells, which the distance between, and low conductivity of, the site wells precludes. The Bouwer and Rice method assumes uniform flow throughout the saturated section of the aquifer, which is not the case with a fractured or karst system, where flow occurs in small fractures or open conduits in the rock. Using

the method can, therefore, significantly underestimate hydraulic conductivity (van Tonder and Vermeulen, 2005). If it is assumed that the entire saturated thickness of the bedrock aquifer (approximately 60 to 70 feet) contributes flow to the wells, the resulting hydraulic conductivity estimates range from 7.5×10^{-8} ft/sec at MW-3 to 2.6×10^{-4} ft/sec at MW-1 (confined aquifer conditions were assumed at all locations, although the formation as a whole appears to be under semi-confined or leaky conditions).

Drilling and outcrop data from the site indicate that the entire saturated thickness of the bedrock aquifer does not contribute flow to the wells, but that flow occurs along fractures within the rock. In this case, the confined aquifer thickness in the Bouwer and Rice equation was assumed to be an arbitrary value of 1 foot, assuming all groundwater flow into the wells occurs along fractures or conduits totaling only about 1 foot of the total saturated thickness of the formation at the site (wells MW-1, MW-2, and MW-3 are all screened in competent bedrock, while well AR-1 is open to a cutter filled with weathered rock and clay residuum). Drilling logs from these wells provide further evidence that the rock is generally competent, with a few small fractures providing the majority of the groundwater flow. This method yielded hydraulic conductivity values about one order of magnitude higher than using the full thickness of the aquifer, ranging from 6.4×10^{-7} ft/sec at MW-3 to 4.8×10^{-3} ft/sec at MW-1. Test data sheets for both solutions are included in Appendix 7.

Comparing the hydraulic conductivity values estimated from the slug test results to published values of ranges of hydraulic conductivity for karst and limestone/dolomite aquifers (Driscoll, 1986) shows that the wide range of estimated values from the site are close to the published ranges for karst limestone (3.7×10^{-6} ft/sec to 3.8×10^{-2} ft/sec) The estimated value for hydraulic conductivity in the cutter (well AR-1, 1.7×10^{-5} ft/sec) is near the low end of the range for karst limestone.

The data collected during purging of the wells for groundwater sampling provide further evidence of the high variability of hydraulic conductivity at the site. Well MW-1 can sustain

a pumping rate of approximately 0.25 L/min (0.06 gal/min) during low-flow purging with the water level not being drawn down. Although MW-3 was not sampled due to the presence of free product, MW-5 behaves in a similar fashion hydraulically (very slow recovery) and it was sampled using low-flow purging, during which it could barely sustain a flow rate of 0.02 L/min (0.005 gal/min).

Slug tests provide estimates of hydraulic conductivity for the aquifer in the immediate vicinity of the well. Slug tests performed in fractured or karst aquifers are further limited because of the extreme variability of hydraulic conductivities within such aquifers, as shown by the site-specific results and published values reported above. Groundwater flow in the site aquifer is dominated by the presence of conduits or fractures that provide preferential flow paths for both water and contaminants. This phenomenon was observed at the site during construction of the interceptor trench near Liberty Creek. At the interface between weathered and competent bedrock, three discrete points were identified at which water carrying free-product solvent was flowing freely into the trench. These points were apparently where fractures or small conduits in the rock were breached by the excavation, demonstrating that turbulent flow conditions do exist in the aquifer. Whether or not these discrete pathways are open over long distances or represent short segments fed by diffuse flow is unknown. However, it is certain that fracture and/or conduit flow occurs in the aquifer and that hydraulic conductivity along these pathways may be significantly higher, at least for short distances, than the average hydraulic conductivities measured by the slug testing.

3.3 Groundwater Flow Direction and Velocity

A potentiometric map generated from water-level data collected during February and March 2008 (MW-5 water level was not stable until March 20) is presented as Figure 2. As shown on the map, water levels are highest in the area near the solvent release point, which is near the eastern end of a cutter/weathered bedrock feature in which free-product toluene as well as dissolved-phase VOCs are migrating to Liberty Creek. From this high point, groundwater moves to the west through the soil and fractured rock of the cutter as

well as outward in all directions into the bedrock aquifer, working its way along both bedding plane and vertical fractures, where the contaminant plume is dominated by dissolved phase VOCs. Free product solvent has been identified in well MW-3, demonstrating that some free product has worked its way into fractures in the vicinity of the cutter. Well MW-2 is impacted by dissolved-phase contaminants, and February sampling data indicate dissolved-phase contaminants may be impacting MW-1 and MW-5. It is therefore apparent that the cutter is acting as a linear recharge zone for water in the wider vicinity, which discharges into Liberty Creek and the Harpeth River.

Because of the high variability of hydraulic conductivity and porosity in fractured and karst aquifers, estimating groundwater flow velocities based on aquifer testing in these regimes is problematic. However, average flow rates can be estimated and used to help identify the lower range contaminant migration rates. Using data collected from the site and published information, average groundwater flow velocities were calculated for both the fractured bedrock and cutter portions of the aquifer.

The hydraulic gradient (I) in the fractured bedrock portion of the aquifer ranges from 0.01 to 0.05 (from RW-1 to MW-5 or from MW-2 to HR-2, respectively). Using a published value of porosity (n) from the lower end of the value for limestone (1 percent, Driscoll, 1986) and the estimated hydraulic conductivity (K) range of 2.4×10^{-3} ft/sec (MW-1) to 6.4×10^{-7} ft/sec (MW-3), the equation $V = KI/n$ produces the following range of groundwater flow velocity:

$$6 \times 10^{-7} \text{ ft/sec to } 1.2 \times 10^{-2} \text{ ft/sec (roughly 0.05 ft/day to 1,000 ft/day)}$$

The hydraulic gradient in the cutter/weathered bedrock portion of the aquifer is approximately 0.02 (from RW-1 to Liberty Creek Main Seep). Using a published value of porosity from near the upper end of the value for limestone (20 percent in the weathered rock and sandy clay soil of the cutter) and the estimated hydraulic conductivity of 1.7×10^{-5} ft/sec (AR-1), the equation $V=KI/n$ produces the following groundwater velocity:

8×10^{-7} ft/sec (roughly 0.07 ft/day)

Again it must be stressed that these values are averages and may not represent the maximum and minimum velocities that could be encountered at any given point in the aquifer. For example, the velocity calculated for the weathered rock and soil in the cutter does not account for the presence of fracture/conduit flow observed during construction of the interceptor trench. A more realistic approach would be to assume that the higher velocity calculated for the fractured bedrock (1.2×10^{-2} ft/sec) is also more representative of the faster velocities expected in the weathered rock/cutter zone. It is also important to note that although high velocities may be encountered at any given point, these points may or may not be interconnected in a continuous pathway between the source area and the creek or river that would allow such velocities to be maintained over the entire distance.

The only way to confidently measure maximum groundwater flow velocity in a fractured rock/karst aquifer is to perform dye tracing studies. Although considered for this site during 2007, a dye trace was not performed because the extreme drought conditions would likely have produced unrepresentative results. In the absence of dye trace data, the estimates presented above can be used in evaluating remedial alternatives for the site.

3.4 Estimate of Contaminant Mass

To produce an estimate of the dissolved contaminant mass in the affected area as of February 2008, the most recent contaminant distribution, a potentiometric map, and estimated porosities were used. To facilitate the estimation, the aquifer was divided based on the differing hydrogeologic conditions (the larger, fractured bedrock area and the cutter/weathered bedrock zone), with estimates calculated for each.

Contaminant distribution was defined based on the analytical results from the February 2008 groundwater sampling event, the February seep sampling event (reported to TDEC separately), and water samples collected from the central portion of the interceptor trench in December 2007 (included in Appendix 8). The extent of the toluene plume, defined to

the MCL for toluene in drinking water, is shown in Figure 3. Concentrations shown are from the February 2008 sampling event. The wells MW-4 and MW-5 show concentrations less than the 1 mg/L MCL. No toluene or acetone has been detected in MW-1 (the presence of benzene in samples from MW-1 and MW-5 is addressed in Section 2.3). The highest concentration detected in monitoring wells was free product in MW-3. Free product is still being observed at the interceptor trench, indicating the cutter still contains free product. It is also important to note that although the toluene plume has been defined using the MCL, the water in the aquifer is not used as a source of drinking water and there is no completed human exposure pathway by ingestion for the water.

The acetone plume is not shown graphically. There is no MCL for acetone, and no acetone has been detected in wells MW-1, MW-4, or MW-5, and the February event showed none in RW-1 and very little in MW-2. Nevertheless, for the purposes of estimating contaminant mass, the extent of the acetone plume was assumed to be approximately the same area as the toluene plume.

For the cutter/ weathered rock zone between the source area and Liberty Creek, the contaminant mass was calculated using the estimated volume of the zone. This zone is estimated to be 800 feet long, 15 feet wide at the east end, 100 feet wide at the west end, and 5 feet deep. The 5 feet depth is based on the thickness of the weathered rock zone encountered in the borings in the source area (AR-1 and RW-1) and in the excavation at the interceptor trench. Using these dimensions and an estimated porosity of 0.2 (see Section 3.3, above), a groundwater-saturated volume of approximately 4.6×10^4 cubic feet was calculated. An average dissolved concentration of toluene was estimated to be approximately 330 mg/L (the average of the concentration at AR-1 and at the central portion of the interceptor trench). An average concentration of acetone was estimated at 750 mg/L (the average of the concentration at AR-1 and the interceptor trench). Multiplying the saturated volume by the average concentrations and converting the units produce the following estimates of contaminant mass in the cutter/weathered rock zone:

Toluene	948 pounds (130 gallons)
Acetone	2,154 pounds (328 gallons)

For the larger, fractured rock zone of contaminated groundwater, contaminant mass estimates were similarly calculated from estimated saturated volumes and average contaminant concentrations. The cutter/weathered rock zone is considered a source from which solvent constituents migrate to the north and south. This zone effectively bisects the fractured rock zone into northern and southern portions. In the fractured bedrock area, the map of the potentiometric surface was used to estimate the upper limits of the saturated volume of the aquifer. This is overly conservative given that the majority of the saturated portion of the aquifer is under semi-confined conditions, and the potentiometric surface does not represent a water-table condition. The base of the contaminated portion of the aquifer was assumed to be the elevation of the Harpeth River, or roughly 605 feet msl. The volume of aquifer above 605 feet msl was then calculated for the portions of the aquifer north and south of the cutter. These two volumes were then multiplied by 0.01, the estimated porosity of the fractured portion of the aquifer (see Section 3.3, above), to produce an estimated volume of water. These estimated volumes are about 4.7×10^4 cubic feet for the northern and 2.7×10^4 cubic feet for the southern, a total of about 7.4×10^4 cubic feet.

The contaminant concentrations were then estimated for both the northern (north of the cutter) and southern (south of the cutter) portions of the plume. A simple arithmetic mean was used, resulting in an average toluene concentration of 165.5 mg/L to the north (average of 330 mg/L at AR-1 and 1 mg/L at the northern boundary) and 250 mg/L to the south (average of 330 mg/L at AR-1 and 170 mg/L at HR-2). Similar calculations yielded an average acetone concentration of 480.5 mg/L to the north and 710 mg/L to the south. The average concentrations of toluene and acetone were then multiplied by the saturated volume of water of the aquifer portions, which were added together to produce the following estimates of contaminant mass:

Toluene	909 pounds (125 gallons)
Acetone	2,613 pounds (398 gallons)

Adding the estimated masses from the fractured bedrock zone to the estimated masses from the cutter/weathered rock zone produces the following total estimates of dissolved contaminant mass:

Toluene	1,857 pounds (255 gallons)
Acetone	4,767 pounds (726 gallons)

These rough estimates do not include the toluene free product or other VOCs that occur in dissolved phase throughout the plume. The toluene and acetone account for the overwhelming majority of contaminants and are the principal target of any remedial activities performed at the site. Estimates of free-product toluene would be dependent on understanding the specific geometry of the conduits and fractures that allow accumulation of product on a free surface – geometry that is unknown.

References

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