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FIRST 2008 SEMIANNUAL MONITORING REPORT

CHEVRON CINCINNATI FACILITY

HOOVEN, OHIO

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1.0 INTRODUCTION

Chevron Environmental Management Company (Chevron) is performing final groundwater corrective measures implementation and monitoring of the remedy performance at the former Gulf Refinery located east of the unincorporated town of Hooven, Ohio. The groundwater remedy was designed to be protective of human health and the environment, with the long-term objective of remediating contaminants to meet cleanup objectives. Achieving the long-term objective will take many years; therefore the following interim objectives have been adopted for the groundwater remedy:

- Monitor soil vapor concentrations and prevent unacceptable migration of volatile petroleum hydrocarbons into indoor air
- Measure the stability of LNAPL and dissolved phase petroleum hydrocarbons
- Remove recoverable LNAPL to agreed upon recovery end-points
- Stabilize the west bank of the Great Miami River to prevent erosion of soils containing petroleum hydrocarbons

Groundwater remediation and monitoring efforts are being conducted in accordance with a November 2006 Administrative Order on Consent (2006 AOC) between Chevron and the United States Environmental Protection Agency (USEPA; Docket No: RCRA-05-2007-0001). The primary components of the groundwater remedy specified in the 2006 AOC include:

- Re-establishment of natural hydraulic conditions beneath the facility, Hooven, and off-site properties to the southwest (commonly referred to as the Southwest Quadrant) through discontinuance of year round groundwater recovery
- Focused LNAPL removal during periods of extreme low water table conditions through high-grade pumping over the next 10-years
- Combined operation of the horizontal soil vapor extraction (HSVE) system beneath Hooven with high-grade recovery
- Continued seasonal operation of the Gulf Park biovent system during low water table conditions

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- Engineered stabilization of the bank of the Great Miami River at the former refinery and Gulf Park to prevent erosion of soil containing petroleum hydrocarbons
- Long-term monitoring of natural source zone attenuation including dissolved and vapor phase biodegradation

A fundamental concept of the final groundwater remedy is the continued stability of the LNAPL and dissolved contaminant plumes. The majority of recoverable LNAPL has been removed from beneath the former refinery and off-site properties over the past two decades. This is especially true in the upper and middle reaches of the smear zone, where LNAPL saturations are low. High-grade recovery is intended to focus on remaining LNAPL removal within the lower reaches of the smear zone and core portions of the plume with the highest remaining LNAPL saturations. However, it is understood that the long-term remedy objective will be accomplished primarily through natural processes that drive contaminant degradation and removal over time.

A detailed discussion of the objectives and activities to be conducted to achieve the groundwater remedy goals, are described in the documents titled, *Remedy Implementation Plan (RIP) for Final Groundwater Remedy, Chevron Cincinnati Facility* (Trihydro 2007a) and *Operation, Maintenance, and Monitoring (OMM) Plan for Final Groundwater Remedy, Chevron Cincinnati Facility* (Trihydro 2007b).

1.1 SITE HISTORY

The former Gulf Oil refinery is located approximately 20 miles west of Cincinnati, Ohio, near the intersection of Ohio State Route 128 and US Highway 50. Refinery operations began in 1931; Chevron acquired Gulf Oil Company in 1985. That same year, an oily sheen was observed on the Great Miami River along the southeast portion of the facility. Hydraulic containment measures were implemented to minimize migration of petroleum hydrocarbons off-site. The refinery ceased production in 1986 and the refinery infrastructure was subsequently dismantled.

Land use surrounding the Chevron facility is residential, commercial, as well as undisturbed upland forest and riparian areas. The site occupies approximately 500 acres bordered on the north, east, and south by the Great Miami River. Commercial retail property is developed along State Route 128, to the southwest of the former refinery. Figure 1-1 shows the location of the facility and surrounding area.

In accordance with the facility description included in the 2006 AOC, the facility includes a closed land treatment unit (LTU) located on a ridge northwest of the main portion of the refinery property. In addition, a former loading dock on

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the Ohio River is included as part of the facility, as well as a products pipeline corridor between the refinery and the barge terminal. Two locations of known past pipeline releases are also included in the facility description, at "the Islands" located directly across the Great Miami River from the former refinery, and at an area known as Gulf Park, in the Village of Cleves, Ohio.

Although the LTU is included within the facility definition, groundwater monitoring is conducted in accordance with the post-closure work plan approved by the Ohio Environmental Protection Agency (OEPA). Maintenance and monitoring conducted at the LTU over the past year have been reported separately within the *2008 Groundwater Monitoring Report, RCRA Land Treatment Unit, Chevron Cincinnati Facility, Hooven, Ohio* (Trihydro 2009).

Corrective measures at the Islands has been previously completed and reported to the USEPA and so no further remediation or monitoring is necessary at that property. Assessment and remedial efforts of the former products pipeline corridor between the refinery and the barge terminal have been conducted through historical voluntary remedial efforts. There are no known groundwater impacts on those properties that require monitoring or remediation under the long-term groundwater remedy, and they are not discussed further in this report.

1.1.1 CORRECTIVE MEASURES

Interim measures performed at the facility since early 1985 focused on hydraulic control of LNAPL and dissolved phase petroleum hydrocarbons by extracting groundwater and creating inward hydraulic gradients. These measures were expanded to include removal of impacted soil at the facility; soil vapor extraction and six-phase heating beneath the Islands; bioventing beneath Gulf Park; and operation of the HSVE system designed to remove hydrocarbons beneath State Route 128 and Hooven. Historic remediation activities completed at the former refinery are summarized in the subsections below.

1.1.1.1 HYDRAULIC CONTROL

Hydraulic control and recovery of petroleum hydrocarbons began in early 1985 using three of the facility's groundwater production wells located in the interior portions of the facility. Chevron installed five additional groundwater and LNAPL production wells (PROD-19 through PROD-23) at the western boundary of the facility, in a north-south transect along State Route 128 between September 1998 and August 2001 (Figure 1-2). These additional production wells were installed as an interim measure to control migration of hydrocarbons down-gradient of the facility, as well as beneath Hooven and Southwest Quadrant. Hydrocarbon recovery efforts were focused along the

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western portion of the site and extending beneath State Route 128, to improve recovery in this area where the LNAPL had a greater potential to be mobile and a higher fraction of volatile constituents compared to other areas of the facility.

Groundwater extraction rates increased over the first 15 years in proportion to the number of production wells brought on-line, with the maximum rate of extraction occurring during the late 1990s. More than two million gallons of groundwater were removed each day in the late 1990s.

Between 2000 and 2006, the rate of hydrocarbon removal began to diminish, especially during high water table conditions when the smear zone was submerged. During this timeframe, hydraulic recovery was focused on periods of low groundwater elevations when LNAPL and soil vapor removal rates were greatest. This focused removal of groundwater during seasonal periods of low groundwater elevations (i.e., high-grade pumping) formed the basis of the final remedy at the facility.

1.1.1.2 LNAPL RECOVERY

More than 3.5 million gallons of LNAPL have been removed via hydraulic recovery since 1985. More than 2.7 million gallons were extracted from the subsurface over the first three years of pumping from three LNAPL recovery wells. The remaining 0.8 million gallons were removed over the remaining 22 years from 11 LNAPL recovery wells. The rate of recovery has strongly diminished through time, indicating that the majority of the recoverable LNAPL within the influence of the production wells has been removed.

The remaining LNAPL is present in the pore spaces between soil particles within an area just above and below the groundwater table known as the smear zone. The thickness of the smear zone generally increases from inches at the plume periphery, to as much as 20 feet in locations of the production wells. The depth to the top of the smear zone varies across the site, from as little as 10 feet near the Great Miami River, to approximately 30 feet across most of the former process areas and tank farms, to about 60 feet under the town of Hooven.

1.1.1.3 HORIZONTAL SOIL VAPOR EXTRACTION

Chevron installed the HSVE system as an interim measure for reducing the hydrocarbon concentrations beneath Hooven (ERM 1999). Pilot testing to determine the effectiveness of soil vapor extraction technology beneath Hooven was conducted in June and November 1998. Based upon the results of the pilot testing and completion of a remedial options analysis in June 1999, it was determined that HSVE presented the best available technology for removing

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hydrocarbons and minimizing disruptions to residents. The HSVE system includes three horizontal vapor extraction wells, installed between 1999 and 2000, which extend approximately 800 feet from the western portion of the Chevron property, underneath State Route 128, westward beneath Brotherhood Avenue, Hooven Avenue, and Ohio Street in Hooven. The horizontal vapor recovery wells were designed to remove soil vapors from approximately five feet above the previously observed 15-year maximum seasonal high water table elevation. The system commenced operation in November 1999 following installation of HSVE Line No. 1. Line No. 2 and Line No. 3 were installed in 2000 and brought online during the first quarter 2001.

1.1.2 ASSESSMENT ACTIVITIES

Assessment activities were initially conducted under the May 13, 1993 AOC (1993 Order). These included a RCRA Facility Investigation to identify the nature and extent of contamination at the facility, Corrective Measures Studies for Soils and Groundwater to evaluate long-term corrective measures, as well as additional assessment activities used to support execution of the 2006 AOC.

The USEPA provided a description of the proposed final groundwater remedy, in the Statement of Basis for Groundwater, issued in April 2006. Following a public meeting and comment period, USEPA issued a Final Decision and Response to Comments on August 30, 2006. The Statement of Basis and Final Decision are the underlying technical basis, which in conjunction with the 2006 AOC, define overall remedy components and goals.

1.2 PURPOSE

Between November 2006 (following execution of the AOC) and January 2008 groundwater operations and monitoring at the former refinery were in a transition period, while new infrastructure to support the final remedy was constructed. In the interim, the first high-grade recovery event was successfully conducted between June and December 2007. Following USEPA approval of the RIP and OMM Plans in a letter dated November 15, 2007, continuous groundwater containment and operation of the biological enhanced granular activated carbon (GAC) water treatment system were ceased in January 2008. The primary purpose of this report is to provide a summary of the operations and monitoring conducted in accordance with the 2006 AOC, RIP (Trihydro 2007a), and OMM Plan (Trihydro 2007b) from January 1, 2008 to June 30, 2008. In addition, this report will provide a summary of the additional infrastructure that was installed in accordance with the RIP (Trihydro 2007a) in support of the groundwater remedy. Finally, this report will provide a summary of the remedy activities conducted between November 2006 and June 2008 during the transition period of the

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facility from interim measures stipulated in the 1993 AOC and long term remedy implementation as outlined in the 2006 AOC. The remainder of this report is organized into the following sections:

- Section 2.0 – Presents the site conceptual model (SCM) for conditions beneath the former refinery, Hooven, and Southwest Quadrant including the nature, extent, fate, and transport of petroleum hydrocarbons in the subsurface.
- Section 3.0 – Describes the infrastructure, methods, and results of groundwater and soil vapor monitoring activities conducted during the first semiannual reporting period in 2008.
- Section 4.0 – Presents the preliminary qualitative and quantitative lines of evidence supporting the efficacy of natural attenuation mechanisms to degrade petroleum hydrocarbons within the smear zone over the course of the remedy.
- Section 5.0 – Provides the result of high-grade recovery operation completed between June and December 2007 including performance of the biologically enhanced GAC and HSVE systems during this event.
- Section 6.0 – Describes the results of biovent system operation and groundwater monitoring conducted in Gulf Park during the interim period between 2006 and 2007.

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2.0 GROUNDWATER CONCEPTUAL MODEL

A conceptual model is a summary of the site-specific conditions affecting the distribution, mobility, and fate of chemicals in the environment used to assess and communicate the potential for human health and environmental risks. The SCM typically includes information about the source, pathways, chemical transport processes, and receptors. It can also include identification of background conditions and/or alternate sources of contaminants. This section describes the SCM for the groundwater beneath the former refinery, as well as to the west and southwest. The groundwater conceptual model was initially provided in the *Groundwater Corrective Measures Study, Chevron Cincinnati Facility* (URS 2001). The model was further developed in the *Conceptual Groundwater Remedy Report, Chevron Cincinnati Facility* (ChevronTexaco Cincinnati Groundwater Task Force 2003), and then updated again within the *Update to Site Conceptual Model and Summary of Remedial Decision Basis, Chevron Cincinnati Facility* (ChevronTexaco Cincinnati Groundwater Task Force 2005), as well as the RIP (Trihydro 2007a). In addition, the nature and extent of impacts along the Great Miami River Bank was further developed in the *Evaluation of Engineering Options along the Great Miami River, Chevron Cincinnati Facility, Hooven, Ohio* (Trihydro 2007c). The SCM will be updated as appropriate with submittal of future routine reports, as ongoing data collection and new information warrant.

2.1 SETTING

The Town of Hooven and the adjacent former refinery site lie in a glacial valley incised into Ordovician-age shale and partially filled with glacial outwash and fluvial deposits of the Great Miami River (Spieker and Durrell 1961, Spieker 1968, Watkins and Spieker 1971). The surficial fluvio-glacial aquifer ranges from approximately 20 to 100 feet thick, and is composed of dominantly coarse sediment, referred to as the Buried Valley Aquifer. An upward fining sequence is present in areas along the riverbank and flood plain on the former refinery. In addition, a clayey-silt layer is exposed at the ground surface in the western portion of Hooven with a thickness of at least 10 feet along the western edge of town. This layer serves as an apparent aquiclude with runoff flowing eastward over the shallow aquiclude before descending towards the groundwater table and joining regional flow.

Groundwater within the Buried Valley Aquifer generally flows from north to south, although episodic flooding tends to result in redirection of the flow to the west for periods ranging from days to weeks dependant on the magnitude of the flood event. Figure 2-1 shows a diagrammatic, SCM for the facility, Hooven and Southwest Quadrant.

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2.2 SOURCE

Hydrocarbons from the former refinery were released as LNAPLs, which migrated down through the subsurface under the influence of gravity until encountering the water table. Due to capillary forces, some fraction of the released LNAPL was retained in pore spaces in the unsaturated zone within the refinery boundary. As some LNAPL reached the capillary fringe it displaced water within the pore spaces. As the volume of LNAPL became sufficient to overcome hydrostatic forces, lateral migration of LNAPL occurred beyond the western boundary of the former refinery, extending beneath the eastern portion of Hooven and into the Southwest Quadrant as shown on Figure 2-1. Refinery operations terminated in 1986 (more than 20 years ago), and the distribution of LNAPL would have stabilized as gravity and capillary forces approached equilibrium. Over time, the elevation of the water table varies seasonally, which results in vertical smearing of the LNAPL, some of which can remain trapped below or above the water table by capillary forces. Typically, the top and bottom of the "smear zone" are roughly coincident with the historic high and low groundwater elevation. Therefore, some smear zone is typically exposed above the water table, even during periods of relatively high groundwater elevation, although the maximum exposure of LNAPL occurs during periods of low water table.

Petroleum hydrocarbon liquids are a mixture of hundreds of individual compounds from many families, including aliphatics, aromatics, paraffins, isoparaffins, olefins, and naphthalenes. Each compound has somewhat different physical, chemical, and toxicological properties, but some are sufficiently volatile and toxic to pose a potential human health risk via dermal contact, ingestion, and inhalation if present at sufficient concentration. In the area adjacent to the distribution of LNAPL, some hydrocarbons dissolve in groundwater and migrate as solutes in the aqueous phase. Volatilization from LNAPL or dissolved phase hydrocarbons can produce vapors in the unsaturated zone immediately above the water table.

2.3 PLUME STABILITY

The LNAPL and dissolved phase petroleum hydrocarbons are thought to be stable beneath the former refinery and off-site properties following two decades of source removal activities. The remaining LNAPL saturations have been reduced such that the feasibility of significant lateral LNAPL migration is not sufficient to warrant a management action even under the lowest water table conditions when separate phase LNAPL can be measured within the monitoring wells situated in the interior portions of the plume.

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Dissolved phase plume stability is expected to continue over the long-term, once ambient hydraulic conditions are reestablished after cessation of continuous groundwater recovery. The primary driver for dissolved phase plume stability is believed to be active biodegradation of dissolved contaminants in the oxygenated groundwater at the periphery of the plume. Most petroleum hydrocarbons are readily degradable by soil microorganisms in the presence of oxygen (O_2), a process referred to as aerobic biodegradation. Petroleum hydrocarbons are also degraded by soil microorganisms in the absence of O_2 via anaerobic respiration, but generally at a lower rate compared with aerobic degradation.

It is anticipated that some re-distribution of dissolved phase hydrocarbons may occur at the down-gradient edge of the plume after discontinuance of continuous year round containment. During 2006 groundwater was sampled at the down-gradient plume edge after an approximately 45-day pumping shut-down test, however, conditions at the down-gradient plume edge have never been sampled under longer-term ambient aquifer conditions. Historical sampling has always measured the extent of dissolved phase constituents when groundwater was being extracted toward pumping centers. The down-gradient distance from the edge of the residual source area (smear zone footprint) required for biodegradative processes to remove dissolved contaminants to below remedial goals could never be measured in the past, as groundwater flow rates and directions at the down-gradient edge have always been under (or recently under) the influence of the pumping. Upon termination of long-term pumping, the dissolved phase contaminants will continue to biodegrade, but have the potential to be detected further down-gradient than they have previously been detected.

In most plumes there is a dissolved phase “halo” that extends several hundred feet down-gradient from the edge of the historical LNAPL plume extent. It is anticipated that the dissolved phase plume will become re-established during the first few year after pumping is discontinued. Thus, the detection of dissolved phase contaminants farther down-gradient than in recent years will not necessarily represent an expansion of the plume footprint relative to its maximum historical extent.

The pathway for migration of petroleum hydrocarbon in soil vapor into structures located in Hooven and the Southwest Quadrant is considered incomplete. Upward diffusion of hydrocarbon vapors from the deep source just above the LNAPL and dissolved phase hydrocarbons toward ground surface is the primary mechanism for vapor migration toward overlying buildings. Soils within the vadose zone are predominantly sand and gravel, which allow water to drain relatively freely; therefore, the pore-spaces are mostly air-filled, which provides a pathway for vapor migration. Along the pathway, the migration of hydrocarbon vapors can be retarded by dissolution into pore moisture, or adsorption to soil particles. Where O_2 is present, soil microbes metabolize hydrocarbon vapors, which reduces the

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concentrations of both hydrocarbons and O_2 resulting in an increase in the concentration of CO_2. Generally speaking, where hydrocarbon vapors are present in sufficient concentrations, the O_2 will be consumed and O_2 concentrations will decrease with depth beneath the ground surface. Microbiological degradation can also occur in the absence of O_2, producing methane. Methane will diffuse upward and be degraded along with other hydrocarbons at shallower intervals where O_2 concentrations are sufficient. O_2 in the atmosphere diffuses down into the unsaturated zone when there is a concentration gradient and is advectively transported via barometric pumping.

Biodegradation is a primary driver not only for stability at the down-gradient plume margin, but also for smear zone mass reduction throughout the plume. Aerobic and anaerobic processes reduce contaminant mass in the dissolved and vapor phase. Whenever O_2 is available, aerobic biodegradation processes predominate. Aerobic degradation processes are the dominant mechanism for reductions in petroleum hydrocarbon concentrations in the plume periphery, outside of the smear zone. Within the interior portions of the plume where dissolved oxygen is depleted, anaerobic biodegradation processes will tend to dominate. These anaerobic processes are expected to continue throughout the entire smear zone, given the relatively consistent supply of petroleum hydrocarbons (i.e., source of carbon) from the smear zone.

Immediately down-gradient of the smear zone, anaerobic processes are expected to continue to some extent, as dissolved organic constituents that partitioned to groundwater within the smear zone are consumed. However, the area immediately down-gradient of the smear zone is considered to be the “transition zone,” because the supply of organic constituents that drive biodegradation processes is consumed at a rate greater than can be replenished. Within this transition zone, dissolved oxygen concentrations are expected to “rebound” as the groundwater moves down-gradient.

2.4 RECEPTOR

Receptors that have the potential to be affected by dissolved and LNAPL petroleum hydrocarbons include residents within Hooven, commercial workers in business situated in the Southwest Quadrant, sensitive ecological communities along the Great Miami River, visitors and workers employed in remedy support and redevelopment activities on the former refinery, and trespassers coming onto the facility property. As the groundwater beneath the facility, Hooven, or Southwest Quadrant is not used for drinking purposes or secondary uses (e.g., irrigation, bathing, etc.) ingestion and dermal contact with dissolved phase petroleum hydrocarbons associated with releases from the former refinery will not occur. Administrative and engineering controls, as well as personal protective equipment will be put in place as appropriate to prevent site workers and visitors from unacceptable levels of exposure to LNAPL or dissolved phase

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petroleum hydrocarbons. Bank stabilization measures along the Great Miami River prevent soil containing petroleum hydrocarbons from eroding into the Great Miami River.

With respect to vapor intrusion, the receptor would be any occupant of a building on the former refinery, in Hooven, or to the southwest if subsurface vapors entered that building at concentrations that pose a potential health risk. If soil vapors diffuse within the "zone of influence" of a structure without degrading, they will become available to be transported into the structure via advection and convection through drains, cracks, utility entrances, sumps, or other permeable discontinuities in the building floor or basement walls. Wind load on the side of a building, barometric pressure changes, HVAC system operation, or temperature differences can all contribute to building depressurization that can drive advection. Most of these processes are reversible, so soil gas generally flows both into and out of buildings under varying conditions. Atmospheric air also enters buildings through doors, windows, and small openings, and the rate of air exchange in buildings typically reduces soil vapor concentrations by a factor of 100 to 10,000 (Johnson 1999), depending on building design, construction, use, maintenance, soil conditions, weather conditions and similar factors. It should be noted that the vapor intrusion pathway in Hooven was demonstrated to be incomplete during the subsurface investigation completed in 2005, through characterization of the contaminant source, soil vapor, and migration pathway. In addition, the soil vapor data collected from the nested monitoring wells from 1997 to 1999 and samples collected following the 2005 subsurface investigation also indicate vapors from the plume are not migrating from the smear zone to indoor air within the residences, businesses, or school at concentrations sufficient to pose an unacceptable excess health risk.

2.5 SECONDARY SOURCES

There are several potential secondary sources of LNAPL and dissolved phase petroleum hydrocarbons within proximity of the former refinery. These include the former service station (currently a non-commercial automotive service center) located directly north of the facility, former operations at the Dravo quarry including several diesel and gasoline underground storage tanks removed in 1991, the Kroger service station, dry wells installed in the Southwest Quadrant, the Whitewater Reclamation (formerly Golsch) construction and demolition landfill, as well as local point sources in Hooven.

Volatile petroleum hydrocarbons are ubiquitous in indoor and outdoor air from industrial and commercial sources, automobiles, combustion sources (e.g., gasoline, fuel oil, natural gas, etc.), combustion byproducts (e.g., diesel, wood, coal, candles, etc.), water treatment chemicals and byproducts, a variety of different consumer products, small power

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tools, tobacco smoke, glues, household cleaners, carpeting, and furniture. Indoor air often contains measurable concentrations of volatile and semivolatile compounds from household activities, consumer products, building materials, furnishings, and outdoor air sources (NJDEP 2005). In addition, urban areas can have shallow releases of hydrocarbons to the subsurface from gasoline powered tools (lawnmowers, chainsaws, trimmers, snow blowers, etc.), vehicles with leaks of oil or gas, runoff from roads, and similar sources. Therefore, it is common to detect low concentrations of hydrocarbon vapors in shallow soil gas samples.

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3.0 MONITORING NETWORK AND RESULTS

The primary component of the groundwater remedy is routine monitoring used to evaluate progress towards meeting the interim and long term remedy objectives. The monitoring network has been established to meet multiple performance and compliance monitoring criteria associated with the final groundwater remedy including collection of data to support remedial system operation; confirmation of high-grade pumping and HSVE system effectiveness; determination of compliance at boundaries where sensitive receptors are present; and evaluation of natural attenuation mechanisms. For the purpose of this report, monitoring has been divided into the following activities:

- Fluid level gauging including continuous monitoring using pressure transducers as well as weekly, monthly and bimonthly manual measurements
- Groundwater sampling to demonstrate dissolved phase plume stability, protection of sensitive receptors, and efficacy of monitored natural attenuation
- ROST™ monitoring to confirm stability of the LNAPL plume at the lateral edge of the smear zone
- River monitoring to track potential releases of smear zone soils into surface water, along the west bank of the Great Miami River
- Vapor monitoring to track the vapor intrusion pathway beneath Hooven and evaluate natural attenuation mechanism in the vadose zone

The following sections describe the results of monitoring conducted to support the groundwater remedy between January 1 and June 30, 2008. A description of the methods used for installation, monitoring, and analysis have been previously described within the RIP (Trihydro 2007a) and OMM Plan (Trihydro 2007b). Additional information pertinent to these activities is described herein when deviations from these plans was necessary.

3.1 FLUID LEVEL MONITORING

Pressure transducers are generally deployed across the monitoring well network listed on Figure 3-1 to evaluate rapid fluctuations in hydraulic conditions across the facility. It should be noted that pressure transducers are relocated as the goals of short term monitoring change such as during flood events or high-grade recovery. Transducers log groundwater elevations on a daily basis. High frequency groundwater elevations data recorded using the pressure transducers are provided in Appendix A.

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Manual fluid level gauging is conducted on a bimonthly basis in each of the monitoring wells located on the facility, as well as in Hooven and the Southwest Quadrant. In addition, fluid levels are gauged monthly in groundwater monitoring wells MW-26R, MW-44S, MW-48S, MW-85S, MW-104S, and river bank gauging point RBGP-44 located along the west bank of the river. Monthly gauging in these wells has been conducted since cessation of continuous groundwater recovery to confirm the stability of LNAPL along the river bank. Monthly fluid level monitoring in these wells will terminate once river bank stabilization measures are constructed along the west bank of the Great Miami River. Future monitoring activities following installation will include visual inspection of the stabilization measures and river surface, manual and automated measurement of fluid levels inboard and outboard of the barrier, collection of samples for natural attenuation indicators, as well as routine monitoring of groundwater, surface water, and hyporheic water quality.

Appendix B provides the manual fluid level gauging data collected during the first half of 2008. Potentiometric surface maps for January, March, and May 2008 generated using data collected during the bimonthly monitoring are provided as Figures 3-2 through 3-4. It should be noted that these potentiometric surface maps represent ambient hydraulic conditions in the aquifer and localized depression of the water table associated with operation of the groundwater production wells are not observed. In January 2008, groundwater flow in the Buried Valley Aquifer was generally to the south which is consistent with historic monitoring events. However, groundwater flow during the March 2008 event was predominantly to the east as groundwater elevations receded following flooding of the Great Miami River. The river stage was reported at 25.85 feet on March 19, 2008, which is the fourth highest stage measured at the USGS gauging station located in Miamitown, Ohio (approximately 5 miles upstream of the facility). Groundwater flow was generally to the south and east during gauging conducted in May 2008 as water levels continued to fall following flooding in March.

3.2 DISSOLVED PHASE MONITORING

Dissolved phase monitoring is conducted at the facility, Hooven, and Southwest Quadrant to monitor the stability of dissolved phase petroleum hydrocarbons along the point of compliance boundary, evaluate natural attenuation within the saturated portions of the smear zone, and measure performance of the final groundwater remedy.

Groundwater samples are analyzed for the constituents of concern including benzene, ethylbenzene, toluene, total xylenes, chlorobenzene, arsenic, and lead. Benzene is the most frequently detected constituent detected above the remedial objectives in groundwater samples collected at the facility, with concentrations as high as 5 milligrams per

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liter (mg/L). Dissolved phase benzene is not generally detected more than a few hundred feet outside the LNAPL smear zone, due to intrinsic biodegradation at the plume periphery. Although as discussed in Section 2.2, it is anticipated that some re-distribution of dissolved phase hydrocarbons may occur at the down-gradient edge of the plume after discontinuance of continuous year round containment.

Groundwater samples are also collected from selected wells for analysis of natural attenuation indicators including alkalinity, total calcium, total chloride, chemical oxygen demand, ferric iron (Fe3+), ferrous iron (2+), total iron, dissolved manganese, total manganese, methane, nitrogen, nitrogen as ammonia, nitrate, nitrite, total potassium, total sodium, sulfate, sulfite, and total organic carbon.

Field forms for groundwater samples collected between January and June 2008 are included in Appendix C. Laboratory analytical reports for groundwater samples collected during the first 2008 semiannual monitoring event are provided in Appendix D-1. Data validation reports for each of the analytical packages provided by the laboratory are provided in Appendix D-2. The following subsections present the results of dissolved phase monitoring conducted between January and June 2008. Interpretation of the dissolved phase analytical results is provided in Section 4.0.

3.2.1 SENTINEL AND POINT OF COMPLIANCE MONITORING

In September 2007, four additional groundwater monitoring wells were installed at the down-gradient limits of the dissolved phase petroleum hydrocarbons in the Southwestern Quadrant. Two sentinel monitoring wells (MW-131 and MW-132) were installed to supplement existing monitoring well MW-35. Two point of compliance monitoring wells (MW-133 and MW-134) were installed to supplement existing monitoring wells MW-37 and MW-120. The sentinel and point of compliance monitoring networks are presented on Figure 3-5. A well log and drilling report (ODNR Form 7802.03) was submitted to the Ohio Department of Natural Resources documenting the well construction details for these four monitoring wells and is provided in Appendix E.

Groundwater samples were collected from the newly installed sentinel and point of compliance monitoring wells between January 30 and 31, 2008. Groundwater samples were collected from the entire sentinel and point of compliance network again in mid-April 2008. Groundwater analytical results for the dissolved phase constituents of concern are provided on Table 3-1. Dissolved arsenic estimated in the sample collected from sentinel well MW-131 in April was the only constituent detected in any of the groundwater samples collected from the sentinel and point of compliance monitoring network in the first half of 2008. As reported in the *Evaluation of Background Metal*

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Concentrations in Ohio Soils (Cox-Colvin & Associates, Inc. 1996), the background concentrations of arsenic are elevated in surface soils across Ohio.

3.2.2 PERIMETER, INTERIOR, AND SUPPLEMENTAL MONITORING

As discussed in the SCM presented in Section 2.0, the LNAPL and dissolve-phase petroleum hydrocarbons are stable over time. Remaining LNAPL in the smear zone is gradually depleted through several mass loss mechanisms including dissolution into groundwater and subsequent dispersion and biodegradation, as well as volatilization and degradation within vadose zone. As such, groundwater samples were collected from three groups of monitoring wells for evaluation of natural attenuation mechanisms within the saturated zone: perimeter, interior plume and supplemental monitoring wells.

- Perimeter groundwater monitoring wells include those wells situated at the margins of the smear zone but are not considered to be compliance boundaries for dissolved phase petroleum hydrocarbons in the saturated zone. Monitoring wells that are included in this network include MW-26R, MW-33, MW-48S, MW-85S, MW-94S, MW-95S, MW-100S, MW-104S, and MW-115S.
- Interior plume monitoring wells are those wells located within the smear zone that will be tracked on a consistent basis over the course of the remedy and include ten wells: MW-10, MW-17, MW-18R, MW-20S, MW-22, MW-58S, MW-81S, MW-85D, and MW-93S. A groundwater sample could not be collected from monitoring well MW-85S during the first semiannual monitoring event due to the presence of LNAPL within the well.
- Supplemental monitoring wells include additional monitoring wells that will be targeted for sampling to support MNA evaluation purposes. The supplemental well network may be modified based upon data gaps identified during previous monitoring events. Supplemental monitoring wells sampled during the first semiannual monitoring event in 2008 include wells L-1RR, L-3R, MW-21, MW-51, MW-64, MW-80, and MW-99. Samples could not be collected from groundwater monitoring wells MW-80 and MW-99 due to the presence of LNAPL during sampling conducted in April 2008.

Groundwater analytical results for the dissolved phase constituents of concern reported in samples collected from the perimeter, interior plume, and supplemental monitoring wells are provided on Table 3-2.

Groundwater samples were also collected from 15 monitoring wells for analysis of natural attenuation indicators during the first semiannual monitoring event including wells L-1RR, MW-18R, MW-20S, MW-33, MW-35, MW-38, MW-51,

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MW-81S, MW-85S, MW-100S, MW-112, MW-114, and MW-115S. Groundwater analytical results for the dissolved phase natural attenuation indicators are included on Table 3-3.

3.3 ROST MONITORING

In September 2007, three ROST monitoring transects (RT-1 through RT-3) were completed perpendicular to the leading edge of the LNAPL plume, as shown in Figure 3-5. ROST technology was identified as the preferred tool for monitoring the potential for LNAPL migration at the leading edge of the plume because it is designed to provide rapid real-time analysis of the physical and chemical characteristics of the distribution of petroleum hydrocarbons to distinguish between soils containing LNAPL and those outside of the smear zone.

Previous efforts to install ROST borings in the Southwest Quadrant experienced difficulties with advancing the tool through large cobbles and boulders, resulting in refusal or deflection of the ROST tool. Therefore, blank polyvinyl chloride casing was installed above the smear at three locations within each transect: an interior location (I) situated at the approximate lateral limit of the smear zone, an intermediate location (M) located 20-feet from the approximate lateral limit of the smear zone, and an outer location (O) installed 40-feet from the approximate lateral limit of the smear zone. ROST technology and installation methodology is presented in greater detail in the RIP (Trihydro 2007a).

Monitoring within the ROST monitoring wells was conducted between June 18 and 19, 2008. The tool was advanced from approximately 5 feet above the water table to approximately 5 feet below the water table in each of the wells. ROST monitoring results are provided in Appendix F. Data collected during the first half of 2008 indicate that the smear zone is stable. There was not an indication of the presence of LNAPL within any of the intermediate or outer ROST monitoring wells based on laser induced fluorescence measurements in the three transects.

3.4 RIVER MONITORING

River monitoring was conducted during the first semiannual monitoring period according to activities required prior to construction of the riverbank stabilization measures as outlined in the OMM Plan (Trihydro 2007b). Groundwater monitoring was conducted in three existing monitoring wells situated along the west bank of the Great Miami River: MW-26R, MW-48S, and MW-85S. These wells are monitored as part of the perimeter monitoring network and dissolved phase analytical results are provided on Table 3-2.

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In addition, surface water samples were collected from locations immediately adjacent to each of these three groundwater monitoring wells. Surface water analytical results are provided on Table 3-4. Concentrations of ethylbenzene and total xylenes were reported in the surface water sample collected from location RMW-48S in April 2008. There were no other reported detections of the dissolved phase constituents of concern in the surface water samples collected from the river during the first semiannual monitoring event.

Observations for hydrocarbon sheening on the river surface were conducted on a weekly basis. Sheen observations are conducted at ten monitoring points established along the Great Miami River based on areas of concern identified during historic monitoring. Starting on June 1, sheen observation frequency increased to daily while the groundwater elevation as measured in well MW-20S was below the 464.8 amsl trigger level, as these are the conditions under which sheening has been observed in the past. Results of sheen observations at the Facility are presented in Table 3-5. A single sheen was noted on the surface water at Monitoring Point No. 10 on May 27, 2008.

LNAPL was not detected in any of the monitoring wells situated on the west bank of the river at a thickness greater than 15% from the previous thickness observed at a similar water table elevation. In addition, LNAPL was not detected in any of the monitoring wells where it has not been previously detected. Therefore, the detection of dissolved phase volatile hydrocarbons in the surface water sample RMW-48S and the single sheen observation reported in Monitoring Point No. 10 did not trigger any remedial actions, as construction of corrective measures along the river bank were already underway.

3.5 VAPOR MONITORING

In March 2008, nested soil vapor monitoring wells VW-18R, VW-20, and VW-21 were constructed within the three grouped media sampling locations situated on Site. These three locations in addition to MW-93/VW-93 represent the group media locations where future monitoring will be conducted to evaluate the various lines of evidence used to track the efficacy of intrinsic biodegradation to meet the remedy goals, as discussed in the RIP (Trihydro 2007a). The location of these vapor monitoring wells is presented on Figure 1-2. The nested monitoring wells were constructed with vapor sampling points at 5-foot intervals from five feet below the ground surface to the depth above the seasonal low water table. Construction diagrams for each of the newly installed nested soil vapor wells are provided in Appendix G.

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Soil vapor samples were collected from the three newly installed soil vapor monitoring wells between April 8 and 10, 2008. Soil vapor samples were collected from each of the existing nested wells located in Hooven between April 18 and April 28, 2008 (VW-93, VW-96, VW-99, and VW-127 through VW-130). Re-sampling of the 5- and 10-foot intervals in nested well VW-18 was performed on May 7, 2008; re-sampling of the 10-foot interval in well VW-21 was conducted on May 21, 2008. Field forms for the vapor monitoring activities conducted in April 2008 are provided as Appendix H. It should be noted that the results of soil vapor monitoring conducted in Hooven in April 2008 indicate that that hydrocarbon vapors from the plume are biodegraded at depth and thus the VI pathway is incomplete, consistent with soil vapor data collected during the previous decade.

3.5.1 STATIC VACUUM/PRESSURE

Prior to initiating sampling activities, the static pressure, or vacuum within the nested soil gas probes was assessed to determine whether there were any pressure gradients that might induce soil gas flow. A majority of the nested soil vapor probes showed no significant static pressure or vacuum during initial measurement prior to pneumatic testing. A summary of the static pressures or vacuums measured in the nested soil gas probes is provided on Table 3-6. In general, the initial static pressure or vacuum measurements were between 0 and 0.025 inches of water, which is in the range that can be produced from wind and barometric pressure. A vacuum of 0.12 inches of water was measured in the 15-foot probe in deep nested monitoring well VW-93 during collection of the replicate sample on April 25, 2008. This measurement was recorded less than 20-hours following collection of the primary sample and the vacuum induced during collection of the primary sample had not fully dissipated.

3.5.2 SOIL GAS PERMEABILITY

Pneumatic testing was performed at each probe by measuring the differential pressure over increasing soil vapor extraction rates. The gas permeability of geologic materials around the nested soil gas probes was estimated using data collected through pneumatic testing and is included on Table 3-6. Soil gas permeability within the nested probes were primarily between 1E-6 to 1E-7 square centimeters (cm^2) with specific capacities (flow rate per unit of vacuum applied) ranging from 15 to 300 cubic centimeters per second per inch of water column (cm^3/sec•in H_2O), which are typical for medium to coarse grained sands. Soil gas permeability calculated in the 20 and 25-foot interval in soil vapor monitoring well VW-96, several intervals within deep nested wells VW-127 and VW-128, as well as the deeper probes in nested wells VW-129 and VW-130 were between 1E-8 to 1E-9 cm^2 with specific capacities between 1.0 and 20 cm^3/sec•in H_2O, which are representative of fine sand. Whereas, soil gas permeability in the 5- and 10-foot intervals in nested vapor monitoring wells VW-18 and VW-21 were estimated between 1E-9 and 1E-10 cm^2 with a specific

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capacity of 0.01 cm^3/sec•in H_2O indicative of silt and clay deposits. It is possible that the screen intervals on these shallow probes may have been covered with bentonite during installation. These four probes will be developed by injecting distilled water and ultra high purity grade nitrogen through the probe to remove drilling fines from the screened interval. Additional pneumatic testing will be conducted following development activities to determine if the low soil gas permeability observed in the shallow intervals in nested wells VW-18 and VW-21 is a result of the compacted fill material in which these probes were installed.

3.5.3 VAPOR DIFFUSION COEFFICIENT

The vapor diffusion coefficient (VDC) is defined as the "ease" at which vapors can move through the vadose zone soils. The VDC is a function of both the soil type and the moisture content of vadose zone soils. Soil vapors are transported more easily through soils with a high VDC. There are two primary approaches for estimating the VDC of vadose zone soils. The first method involves mathematical approximation of the VDC based on the physical properties of the soil. One example of a mathematical solution for estimating the VDC is the Millington-Quirk (1960) equation, which relates the VDC to the soil porosity and moisture content. The second approach includes in-situ estimation of the VDC through tracer gas injection and recovery. A tracer test method was described by Johnson et al. (1998) using sulfur hexafluoride or helium as a tracer gas. This technique was performed by Paul Johnson within the wells in Hooven during monitoring conducted in 1998.

Estimation of the VDC using the Johnson et. al. methodology was performed in each of the soil vapor intervals in nested wells VW-18, VW-20, VW-21, and VW-93 in April 2008. The method involves injection of 300 milliliters of ultra high purity grade helium into the vapor point with an airtight syringe followed by injection of known volume of ambient air. The volume of ambient air injected into each vapor point is equal to the volume of ambient air present in the tubing between the ball valve at the top of the interval and the soil vapor probe at depth, such that the helium is displaced into the formation around the vapor probe.

An instantaneous sample was collected by purging the same volume of ambient air and helium that was injected to the vapor point using the airtight syringe. After purging, 300 milliliters of soil gas were sampled into a 1-liter Tedlar bag and the instantaneous helium concentration was measured. This helium concentration was recorded as the "time zero" concentration. The vapor probe and line were then flushed with 10-liters of ambient air. This procedure was subsequently repeated and helium concentrations recorded over two successive time intervals (approximately 30 and 60 minutes) following injection of the tracer gas.

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The change in helium concentration recorded over the three injection intervals (approximately 0, 30, and 60 minutes) during tracer testing can be used to estimate the VDC of the formation or fill material surrounding the soil vapor probe using the equations provided in Johnson et al. (1998) for a point source. The estimated VDC for each of the intervals in nested monitoring wells VW-18, VW-20, VW-21, and VW-93 are presented in Table 3-6. The VDC values ranged from 2.8 x 10-5 cm^2/s within the 5-foot interval in VW-21 to 2.6 x 10-2 cm^2/s in the 50-foot interval in VW-93, with an average VDC of 5.4 x 10-3 cm^2/s. These values correlate well with the soil gas permeability calculated in these nested vapor wells.

In general, the lowest VDCs were measured within nested wells VW-18 and VW-21, located in the central and northern portion of the Chevron Cincinnati Facility. At both of these locations, fine grained deposits (likely fill) were observed in the upper 10 feet of the vadose zone. The VDC estimates for probes installed in nested wells VW-20 and VW-93 were generally higher, which is consistent with coarser grained sediments observed during installation of these nested vapor wells. In addition, the VDC generally increased with depth in each nested well consistent with the coarsening sequence with depth observed in the Buried Valley Aquifer. The VDC estimated using tracer data collected in April 2008 represent a low value for each probe, as testing was conducted during the "wet" part of the year and some fraction of the pore space in the vadose zone was occupied by rainwater infiltrate.

3.5.4 NESTED SOIL GAS ANALYTICAL RESULTS

Table 3-7 presents a summary of the intervals sampled within each of the deep nested monitoring wells since September 2005, when routine monitoring of the nested wells began in Hooven. Soil vapor samples from the deepest intervals in nested vapor monitoring wells GP-7, VW-18, VW-20, VW-93, VW-96, and VW-99 could not be obtained in April 2008 because the probes were submerged beneath the water table. This was confirmed with fluid level measurements collected from nearby groundwater monitoring wells or by pneumatic test results from the deep probes in the nested well. The deepest probe in VW-130 could not be sampled due to a low soil gas permeability measured in this well. A sample from the 15-foot interval in nested well VW-96 could not be obtained as the tubing connecting this probe to the surface was severed. Finally, the sample collected from 20-foot interval in nested well VW-20 was not analyzed due to contamination of the vapor sample during analytical preparation at the laboratory.

A summary of the soil vapor analytical results for the deep nested monitoring wells is provided on Table 3-8. The target analytes have been divided into four classes on these tables including: (a) constituents commonly found in gasoline, (b) solvents, (c) water treatment and other chemicals, and (d) fixed gases. Soil vapor analytical results are

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provided in Appendix I-1. Tier 3 data validation reviews of the laboratory analytical results are included in Appendix I-2.

3.5.4.1 CONSTITUENTS COMMONLY FOUND IN GASOLINE

Of the 23 constituents commonly found in gasoline that were included on the target analyte list, 14 were detected in soil gas samples collected from one or more of the nested monitoring wells. Beneath Hooven, none of the constituents commonly found in gasoline were measured continuously from the deepest intervals to the shallow soil vapor probes within any of the nested wells. The highest measured concentrations in Hooven were reported in the 55-foot intervals in nested wells VW-96 and VW-99, consistent with previous sampling events. On Site, the concentrations of gasoline related compounds in soil vapor were two orders of magnitude greater in wells VW-18 and VW-21 compared to those measured in the nested wells in Hooven.

The 5-foot interval in nested well VW-127 showed concentrations indicative of a surface source that is unrelated to the dissolved plume. The gasoline related constituents detected in VW-127 were benzene, cyclohexane, hexane, and heptane. These chemicals were either not detected in subsequent depth intervals or were detected at concentrations several orders of magnitude below those observed in the 5-foot interval. It is also important to note that these chemicals have never been observed at these concentrations in any of the previous samples collected from the deep nested well VW-127.

3.5.4.2 SOLVENTS

Acetone, 2-butanone, isopropanol, and methylene chloride were the only four solvents detected in the soil vapor samples collected on Site. These four constituents were also the most frequently detected constituents in the soil gas samples collected from the nested wells in Hooven, with an overall frequency of detection in the primary samples of 67%, 58%, 42%, and 12% respectively. These constituents are considered common laboratory contaminants as they are used for cleaning and preparation of samples within the analytical laboratory.

Carbon tetrachloride, tetrachloroethene, tetrahydrofuran, trichloroethene, and 1,1,1-trichloroethane were also reported in soil gas samples collected from the nested wells located in Hooven, generally at a frequency below 10%. These solvents were detected at a similar frequency and concentration in soil gas samples collected from locations both over and outside of the distribution of petroleum related impacts attributed to the former refinery. None of the solvent

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constituents were detected continuously in samples collected from the deepest intervals up to the shallow soil vapor probes within any of the nested wells.

3.5.4.3 WATER TREATMENT AND OTHER CHEMICALS

Carbon disulfide was reported in a single soil vapor sample collected from the nested monitoring wells on Site. In addition to carbon disulfide, chloroform; 1,2-dichlorobenzene; dichlorodifluoromethane; ethanol; and trichlorofluoromethane were reported in soil vapor samples collected beneath Hooven. Dichlorodifluoromethane was predominantly reported in the soil gas samples collected from deep nested wells VW-129 and VW-130, and trichlorofluoromethane was only reported in samples collected from well VW-129. Nested wells VW-129 and VW-130 are located in the central and western portions of Hooven outside of the distribution of LNAPL and dissolved phase constituents associated with the refinery, suggesting a secondary source for these two constituents.

3.5.4.4 FIXED GASES

Fixed gas concentrations including O_2, CO_2, and methane (CH_4) were measured during purging of the nested probes to determine that both steady state conditions had been achieved prior to the collection of the soil gas sample for laboratory analysis and as a quality assurance/quality control measure of the laboratory analytical results. Field screening results indicated that the fixed gas measurements were generally stable prior to collecting samples from the nested soil vapor wells. The fixed gas measurements are included on the field forms provided in Appendix H.

The O_2 and CO_2 analytical results for the soil gas samples are summarized on Table 3-6. The O_2 and CO_2 concentrations recorded in the field can be compared to the fixed gas results provided by the laboratory as a measure to validate the analytical results. Correlation plots showing the field reported O_2 and CO_2 concentrations and the laboratory analytical data for samples collected from the nested wells are provided as Figure 3-6. In general, O_2 and CO_2 concentrations reported in the field were comparable to the laboratory reported results.

The fixed gas results from the deep nested soil vapor wells situated within the distribution of the LNAPL and dissolved phase petroleum hydrocarbons on Site and in Hooven generally show decreasing O_2 and increasing CO_2 with depth, indicative of aerobic degradation of petroleum hydrocarbon vapors in the unsaturated zone. In areas outside the plume, the O_2 and CO_2 concentrations were generally consistent throughout the vadose zone. CH_4 was detected in each of the samples collected from nested vapor wells VW-18 and VW-21 on Site, as well as the deepest intervals in nested wells VW-20, VW-96, and VW-99 situated over the LNAPL plume.

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CH_4 was also reported at 99.9% during purging and at 32% in the sample submitted to the analytical laboratory in the 5-foot interval collected from nested well VW-127. Concentrations of O_2 were measured at approximately 2% in the field during purging and in the soil gas sample analyzed by the laboratory. A natural gas odor was detected near this nested vapor monitoring well during sampling and elevated concentrations of several target analytes were also reported in the soil gas sample collected from this probe.

3.5.5 OUTDOOR AIR ANALYTICAL RESULTS

Two outdoor ambient air samples were collected each day when soil vapor monitoring was conducted in Hooven. One sample was collected at a fixed location in the center of Hooven and the second ambient air sample was placed in the care of the sample team each day. This second "floating" sample remained secured outdoors and the Summa canister was open, collecting a sample, while the team was engaged in soil vapor monitoring activities. The Summa canister was shut, and not collecting a sample, during transport or when sampling activities were not being conducted.

The ambient air samples were collected using a 6-liter Summa canister suspended approximately five feet above the ground surface using a flow-controller calibrated to collect the sample over an eight hour period. A summary of the fixed and floating outdoor air analytical results by constituent class is included on Table 3-9. A floating outdoor ambient air sample was not collected on April 21, 2008 as sampling activities only spanned a few hours this day and an insufficient volume of ambient air was collected for laboratory analysis. Both gasoline and non-gasoline related constituents were detected at low concentrations in the outdoor air samples. Benzene, 2-butanone, isopropanol, toluene, 1,1,2-trichloroethane, and trichlorofluoromethane were detected in more than half the samples. Acetone, chloromethane, dichlorodifluoromethane, and ethanol were detected in every sample.

The outdoor air constituent concentrations reported for the April 2008 monitoring event were compared to the 50th percentile values from the *Summary of Indoor and Outdoor Levels of Volatile Organic Compounds from Fuel Oil Heated Homes in New York State* (NYDOH 2005). These average outdoor air concentrations are included on Table 3-9. The reported results for the outdoor air samples collected in April 2008 were generally within the range of the average ambient air data with the exception of concentrations of acetone, chloromethane, dichlorodifluoromethane, and trichlorofluoromethane, which were detected at concentrations an order of magnitude greater than the published average outdoor air concentrations. These four compounds are not petroleum related constituents.

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3.5.6 METEOROLOGICAL DATA

Table 3-10 presents the meteorological data collected from the weather station located at the scale house on the facility during each day soil vapor sampling was conducted in April 2008. During the soil vapor monitoring activities, ambient temperatures oscillated daily with the temperature ranging from 42 degrees Fahrenheit (ºF) to 81ºF. There was less than an inch of precipitation recorded during this event with only a slight variation in barometric pressure (29.4 to 30.2 inches of mercury). The wind direction was predominantly from the south and west at an average speed of 3.5 miles per hour.

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4.0 INTERPRETATION

Data collected during the first half of 2008 and included herein demonstrate that the intrinsic processes in the saturated and unsaturated zones are degrading petroleum hydrocarbons in the smear zone. In general, natural attenuation occurs as constituents present in smear zone soil partition to groundwater and soil vapor, where they are biodegraded via aerobic and anaerobic processes. These processes can be inferred from the groundwater and soil vapor data using qualitative and quantitative analyses. Qualitative analyses consider spatial trends in petroleum hydrocarbons and electron acceptors in groundwater and soil gas. Quantitative analyses include temporal analysis of petroleum hydrocarbon concentrations in groundwater and attenuation rate estimates. Several of the qualitative and quantitative lines of evidence provided in the following subsections represent baseline conditions, as this is the first event that data was collected from several components of the monitoring network installed as part of the final groundwater remedy.

The data collected over the first half of 2008 also demonstrates that the groundwater remedy is protective of human health and the environment. This report will provide qualitative and quantitative lines of evidence supporting that the remedy is protective of human health in Hooven and groundwater resources at the point of compliance in the southwest quadrant. Future reports will include evaluation of effectiveness of the bank stabilization measures to protect sensitive ecological receptors within the Great Miami River. Finally, additional engineering and institutional controls will be implemented and monitored to ensure protectiveness of human health and the environment as the site is redeveloped for industrial, commercial, recreational, and passive ecological reuses.

4.1 LINES OF EVIDENCE

Natural attenuation processes generally reduce the mass and concentration of petroleum hydrocarbons within soil and groundwater to varying degrees of effectiveness depending on the nature and volume of hydrocarbon released as well as the physical, chemical, and biological characteristics of the saturated and vadose zone. As described in the USEPA Office of Solid Waste and Emergency Response directive, *Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites* (USEPA 1999), intrinsic natural attenuation processes can reduce the risk posed by petroleum hydrocarbons in the following manner:

1. transformation to less toxic forms through destructive processes
2. reduction of contaminant concentrations whereby potential exposure levels may be reduced
3. reduction of contaminant mobility and bioavailability through sorption onto solid matrices

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There are two general lines of evidence provided herein to support the efficacy of natural attenuation processes to degrade petroleum hydrocarbons at a rate that will achieve remedial goals for groundwater (i.e. maximum contaminant levels [MCLs]) in a timeframe comparable to active remedial measures. The primary lines of evidence include evaluation of smear zone, groundwater, and vapor data that demonstrate the stability of petroleum hydrocarbons in the smear zone beneath the Site and protectiveness of sensitive receptors (Section 4.1.1); as well as meaningful trends of decreasing constituent concentrations over time (Section 4.1.2). The secondary line of evidence, discussed in Section 4.1.3, includes evaluation of hydrogeochemical data that demonstrate indirectly the natural attenuation mechanisms are acting to transform hydrocarbon constituents, reduce concentrations, and inhibit mobility of the LNAPL, dissolved phase, and vapor phase impacts. Data used to support these two lines of evidence have been combined in Section 4.2 to evaluate benzene depletion within the smear zone and establish expectations for future monitoring events.

4.1.1 PLUME STABILITY AND PROTECTIVENESS OF SENSITIVE RECEPTORS

During execution of the final groundwater remedy at the Site, Chevron must continue to demonstrate that the LNAPL and dissolved phase plumes are stable and that sensitive receptors remain protected (USEPA 1999). If the extent of the LNAPL, dissolved, or vapor phase petroleum hydrocarbons are determined to be mobile or impacting sensitive receptors above risk based limits, contingency measures would be employed as outlined in the OMM Plan (Trihydro 2007b).

4.1.1.1 LNAPL

As discussed in the *Update to Site Conceptual Model and Summary of Remedial Decision Basis* (Chevron Cincinnati Groundwater Task Force 2005) the LNAPL and dissolved phase plumes are stable based on the following:

- The LNAPL plume is decades old with releases having occurred between 1931 and 1986. Numerical reservoir modeling suggests that LNAPL movement would cease in less than 10-years following a release at this Site (Chevron Cincinnati Groundwater Task Force 2003).
- LNAPL movement is initiated by the presence of a LNAPL gradient, directly analogous to groundwater flow; in the absence of a gradient, there will be no flow. The LNAPL gradients across the Site have decreased over the last decade with focused pumping of LNAPL during low water table conditions and natural attenuation of the smear zone.

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- The ability of the LNAPL to move through the formation under a gradient is dependent on the transmissivity and conductivity of the formation in relation to the fluid. The LNAPL transmissivity values estimated from recovery records and LNAPL pumping tests are estimated between 10,000 and 1,000,000-times smaller than groundwater transmissivity values. Remedial efforts and natural attenuation of the source have continuously decreased transmissivity acting to further stabilize the plume.
- There has been no new LNAPL encroachment into wells or areas of the site where LNAPL was not present during execution of the RCRA Facility Investigation and subsequent monitoring conducted in the late 1990s based upon review of laser induced fluorescence results, total organic concentrations from soil cores, physical observations during soil boring installation, and fluid level monitoring performed over the last decade.
- Historical petrophysical tests on soil cores collected in the saturated portions of the smear zone indicate two-phase (water-oil) LNAPL residual saturation ranges from about 18 to 25% for the Site. Field testing completed in the late 1990s indicates that the two-phase LNAPL saturations in the majority of the plume was below these residual values (i.e., immobilized).
- The relative ability for LNAPL to move while above residual saturations in the presence of water is governed by the relative permeability of the fluid within the formation. Site laboratory measurements show an exponential decrease in the ability of LNAPL to migrate in the presence of water at saturations less than 20 to 25%. This is reflected at the Site where decreasing recoverability and LNAPL transmissivity have been observed over the last decade.
- The LNAPL plume is “thick” in the center and thin at the edges, which is the characteristic morphology of a stable plume anticipated by the multiphase mechanics and site modeling (Chevron Cincinnati Groundwater Task Force 2003). A mobile LNAPL body will have a thicker down-gradient imprint. Since the LNAPL was released before hydraulic containment began, it can be inferred that this morphology is predominantly the result of ambient plume spreading and ultimately of stabilization processes.
- The benzene content of the LNAPL varies as a function of the spatial morphology. LNAPL analytic data suggest that benzene has been preferentially depleted at the LNAPL/soil vapor interface and the LNAPL/groundwater interface. This outside-in weathering indicates the LNAPL plume is stable. If the LNAPL were mobile, then there would be a chemical bias toward benzene replenishment at the leading edge of the plume.

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Data collected during the first half of 2008 indicate that the smear zone is stable. The LNAPL plume has not expanded at the down-gradient limits based on the laser induced fluorescence measurements in the three ROST monitoring transects conducted between June 18 and 19, 2008. Additionally, LNAPL was not measured in any of the sentinel or point of compliance monitoring wells installed in the southwest quadrant or in any of the wells located beyond the smear zone extent in Hooven during gauging events conducted in January, March, and May 2008. Fluid level gauging within the performance monitoring network installed along the west bank of the Great Miami River will begin during the first quarter 2009 to confirm the stability of the smear zone along the restored river bank.

4.1.1.2 DISSOLVED PHASE

Based on data collected during the first semiannual monitoring event and on overall historical monitoring results, the dissolved phase petroleum hydrocarbons are thought to be stable along the down-gradient limits of the plume. Dissolved phase concentrations were not measured in any of the groundwater samples collected from the sentinel or point of compliance monitoring wells in the Southwest Quadrant during the January or April 2008 sampling events. In addition, dissolved phase constituents were not reported in samples collected from any of the monitoring wells installed beyond the distribution of petroleum hydrocarbons in Hooven or on Site. Figure 4-1 shows the distribution of dissolved phase total benzene, toluene, ethylbenzene, and xylenes (BTEX) and total petroleum hydrocarbon (TPH) concentrations measured across the site.

It should be noted that there has been a confirmed detection of benzene in the sentinel monitoring well MW-35 subsequent to the monitoring period discussed in this report. This could represent re-equilibration of the dissolved phase halo subsequent to termination of the year-round hydraulic containment conducted as the interim remedy at the facility, or could also relate to potential alternate sources of contaminants in the area around the well. Overall, it is not thought to indicate significant dissolved phase plume mobility. Additional sampling and analysis has been initiated to further evaluate the groundwater conditions and behavior of the dissolved phase plume at the down-gradient edge and will be discussed in future monitoring reports.

Dissolved phase concentrations will also be monitored using the performance monitoring network installed along the stabilized bank of the Great Miami River beginning in the first quarter 2009. Hyporheic and surface water quality results will be compared to Ohio surface water quality standards to demonstrate that the barrier wall and stabilized riverbank are protective of sensitive ecological receptors within the Great Miami River.

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4.1.1.3 VAPOR PHASE

In order to evaluate protectiveness of human health from migration of deep soil vapors into structures located in Hooven, the data from the nested wells is compared to the conservative risk based screening standards. Screening standards are concentrations that are sufficiently low that any results below these can safely be considered to pose no significant risk. Screening standards are developed with consideration for uncertainty, and are designed to be overly protective; therefore, concentrations above the screening levels do not necessarily pose an unacceptable risk.

Table 4-1a through 4-1c provide the screening level evaluation for the deep soil gas samples for gasoline related, solvent related, and water treatment related and other constituents, respectively. The screening values provided in Table 3b-SG of the *Draft Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway from Groundwater and Soils* (OSWER Draft VI Guidance, USEPA 2002) were used to conservatively determine if any of the constituents identified in the deep soil vapor monitoring points posed a potential risk to human health. The screening values selected from Table 3b-SG are based on a target risk of 1E-5 for carcinogenic constituents and a Hazard Quotient of 1 for non-carcinogenic constituents, using semi-site specific attenuation factors from Figure 3a of the OSWER Draft VI Guidance. Screening levels published within the OSWER Draft VI Guidance are based on statistical comparison of concentration ratios for non-biodegradable or recalcitrant chlorinated hydrocarbon compounds measured in subsurface soil vapor and indoor air. The resultant attenuation factors (concentration of constituent in indoor air compared to the concentration in soil vapor) are used as a conservative screening step to identify where vapor intrusion may be possible based on the presence of contaminants of concern in soil gas. Application of these screening attenuation factors are extremely conservative for this evaluation, since they do not account for attenuation due to aerobic biodegradation, which is the chief mechanism limiting vapor transport beneath the Site.

The screening level evaluation was applied to the deep soil vapor samples collected 20 feet below ground surface (ft-bgs) or greater. The data collected from the shallow probes was not evaluated because vapor concentrations at depths less than 20 ft-bgs have been shown to be indistinguishable between locations over hydrocarbons from the former refinery and locations that were outside of the area of groundwater and LNAPL impacts. Based on Figure 3a of the OSWER Draft VI Guidance, an attenuation factor of 0.002 was applied to samples collected from depths of 20 ft-bgs, 0.001 was used to screen soil vapor data from greater than 20 ft-bgs to 35 ft-bgs, and an attenuation factor of 0.0007 was used to screen data greater than 35 ft-bgs. Note that the attenuation factors shown on Figure 3a of the OSWER Draft VI Guidance correspond to the depth below the foundation. For this evaluation the depth of the basement was assumed to be 5 ft-bgs; therefore, a sample depth of 20 ft-bgs corresponds to a depth of 15 feet as shown on Figure 3a.

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All of the detected constituents reported in the soil vapor samples collected from the 20 to 55 ft-bgs intervals in Hooven were below the screening levels during the April 2008 monitoring event. The reporting limits for 1,2-dibromomethane; 1,3-butadiene; and hexachlorobutadiene were occasionally reported above the screening levels in the deep intervals in nested wells VW-96, VW-99, and VW-130. However, none of the detection limits were greater than the screening values in samples collected above 45 ft-bgs in nested wells VW-96 and VW-99 and above 30 ft-bgs in nested well VW-130. The screening level evaluation demonstrates that there is not a completed pathway for constituents present in the deep soil vapor to depths directly beneath building foundations in Hooven. This is consistent with the results reported within the *Subsurface Investigation Field Activities Report and Human Health Risk Assessment* (Trihydro and GeoSyntec 2005) and the 10-Year Soil Vapor Retrospective Report (Trihydro and GeoSyntec 2008).

Results from soil vapor samples collected within the refinery indicate benzene and hexane measured in the 20-foot interval in nested monitoring well VW-21 exceeded the deep soil gas screening standards for a residential scenario. The reporting limits for several constituents found in gasoline, solvent, and water treatment chemicals were measured above the residential screening standard in this well. It should be noted that nested vapor well VW-21 was installed in the north tank farm on the former refinery property. There are not any structures located in the north tank farm at this time. In addition, this portion of the facility is slated for commercial and industrial reuses only following implementation of engineered and institutional controls to protect future workers.

4.1.2 CONSTITUENT TRENDS

It is expected that the data collected over the course of the remedy will show a meaningful trend of decreasing hydrocarbon mass and/or constituent concentrations over time. Analyses that may be used in evaluating the progress of the long term remedy in meeting groundwater remedial goals (i.e., USEPA MCLs) include evaluation of temporal trends in contaminant concentrations, LNAPL mass, or LNAPL saturations; comparisons of observed contaminant distributions with predictions; as well as comparison of calculated attenuation rates with those necessary to meet remedial goals within the required time frame. These analyses can be complicated as a result of variation in the petroleum hydrocarbon distribution across the site, temporal fluctuations related to seasonal and longer term trends, heterogeneity in the vadose and saturated zones across the plume footprint, along with measurement variability. These complications necessitate the use of multiple lines of evidence and expanded monitoring networks to reduce uncertainty.

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4.1.2.1 LNAPL CONSTITUENT TRENDS

Figure 4-2 shows the mole fraction of benzene in LNAPL samples collected in 1997, 1999, and 2005 from four sets of wells (MW-1R/PROD_20, MW-58/PROD_12, PROD_15, and MW-96S) on a logarithmic-linear scale. This figure also shows the decline in the average mole fraction of benzene for all the LNAPL samples collected over this timeframe. The trends presented on this figure depict a first order degradation rate for benzene in the LNAPL since 1997. Additional LNAPL samples will be collected to track changes in the mole fraction of constituents of concern in LNAPL over the course of the final remedy, with primary emphasis on benzene.

It is expected that, as the LNAPL saturation and transmissivity decrease in the smear zone over time, it may become infeasible to collect LNAPL samples for laboratory analysis. As a result, soil cores will also be collected for LNAPL fingerprinting at three depth intervals vertically across the smear zone (e.g. near the top, middle, and bottom of smear zone) at multiple locations within the LNAPL plume. The soil cores will be analyzed directly for the constituents of concern and modified total petroleum hydrocarbons. Heterogeneity of the LNAPL distribution in the soil cores will be minimized by collecting as many as four cores from each monitoring location and averaging the analytical results. The results will be converted to mole fraction for each constituent of concern. The degradation rates estimated using the soil core analytical results collected periodically over the course of the remedy will be compared to those estimated utilizing LNAPL analytical data. The attenuation of constituents in LNAPL is expected to take many years to demonstrate meaningful trends; samples will generally be collected on five year intervals.

4.1.2.2 DISSOLVED PHASE CONSTITUENT TRENDS

The distribution of dissolved phase BTEX in groundwater is displayed on Figure 4-1. A benzene isopleth map has also been prepared as Figure 4-3. Based on the generalized groundwater flow, there are two areas up-gradient of the smear zone, the first north of the facility property and the second to the west along the Buried Valley Aquifer-bedrock interface in Hooven.

The dissolved phase BTEX concentrations are indicative of ongoing natural attenuation processes. Dissolved phase constituents were not reported in groundwater samples collected from monitoring wells located in the two up-gradient areas while the average concentration of dissolved phase BTEX within the smear zone was 1.56 mg/L. Down-gradient of the smear zone, BTEX constituents were not detected in the groundwater samples, indicating attenuation processes such as dispersion, sorption, and biodegradation reduce the dissolved phase concentration, reduce mobility of the plume, and/or transform BTEX constituents as the plume exits the smear zone.

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Temporal trends observed in the dissolved constituent concentrations collected from individual wells can be essential indicators of plume stability and progress toward meeting remedial goals. In the absence of remedial efforts, (i.e. HSVE system operation), decreasing dissolved phase concentrations over time within the plume area indicate that natural attenuation processes are acting to reduce contaminant mass and concentrations. Trend analyses should be conducted in monitoring locations situated throughout the distribution of petroleum hydrocarbons to assess the range of dominant intrinsic processes acting on the plume. Temporal trend in individual wells may also indicate changes in climatic, hydrogeochemical, contaminant release, site reuse, or other conditions unrelated to attenuation processes and need to be evaluated in context of other lines of evidence.

Historically, groundwater samples have not been collected from the interior plume monitoring wells due to the presence of LNAPL during sampling. For the purpose of this analysis, trends are inferred for wells that have groundwater data from at least three monitoring events. Of the ten interior plume wells, eight (MW-10R, MW-17, MW-18R, MW-20S, MW-22, MW-58S, MW-88, and MW-96S) do not have data for at least three monitoring events. Constituent of concern concentrations reported in the samples collected from interior monitoring well MW-85D were all reported below the remedial goals, which is expected as this well is screened in the deeper portions of the Buried Valley Aquifer, well below the vertical distribution of dissolved phase petroleum hydrocarbons. Dissolved phase trends for the one remaining interior plume monitoring well (MW-81S) is provided on Figure 4-4. This monitoring well was installed in the southwest limit of Hooven adjacent to State Route 128. Dissolved phase constituent concentrations in this well show a clear decreasing trend between 1996 and 2008. This trend is likely associated with startup of the groundwater production, LNAPL recovery, and HSVE systems between 1999 and 2000, focused on remediation of petroleum hydrocarbons beneath Hooven.

Similar to data limitations observed with trend analyses using the interior plume monitoring wells, of the eight supplemental groundwater monitoring wells (L-1RR, L-3R, MW-21, MW-33, MW-51, MW-64, MW-80, and MW-99) only wells MW-21 and MW-33 had sufficient data (i.e., results from at least three monitoring events) to complete a trend analysis. The dissolved phase results for the constituents of concern reported in samples collected from well MW-33 have remained below MCLs over time. As presented on Figure 4-5, dissolved phase benzene and ethylbenzene concentrations reported in supplemental monitoring well MW-21 showed a first order degradation rate over time. This well is situated outside the footprint of remedial measures at the facility and these decreasing trends are indicative of natural attenuation processes.

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Temporal analysis of the dissolved phase results can be performed for three additional monitoring wells (MW- 85S, MW-93S, and MW-115S) located within the distribution of hydrocarbons at the Site, as these wells have a sufficient monitoring history with concentrations above remedial goals. Figures 4-6 through 4-8, show decreasing trends in dissolved phase benzene concentrations over time in these three monitoring wells. Monitoring wells MW-85S and MW-115S are located outside the influence of historic remedial efforts along the Great Miami River and in the southwest quadrant, respectively. Trends within these two wells are considered indicative of natural attenuation processes. Well MW-93S is located in Hooven and the trends observed in the groundwater analytical results from this well most likely have been influenced by hydraulic and vapor recovery efforts since 1999.

The average first order degradation rate estimated using the dissolved phase analytical results from these six monitoring wells (MW-21, MW-81S, MW- 85S, MW-93S, and MW-115S) is approximately 8.0×10^{-4} per day. This compares well with previously estimated first order decay rates for the benzene mole fraction in LNAPL. The average estimated first order decay rate for benzene in LNAPL, based on samples collected between 1997 and 2005, was 7.8×10^{-4} per day.

As the Site transitions into a long-term passive remedy and additional dissolved phase data is collected, it will be possible to make meaningful decisions regarding the temporal trends across the distribution of hydrocarbons. Attenuation rates will be compared over time within individual wells installed across the plume and progress towards meeting the remedial goals will be considered.

4.1.2.3 VAPOR PHASE CONSTITUENT TRENDS

As with temporal analysis of the dissolved constituents of concern, soil vapor results from samples collected above the LNAPL plume (i.e., vapor source) should be considered as a line of evidence to demonstrate the effectiveness of natural attenuation mechanisms to degrade the smear zone over time. Vapor source trend analyses will be conducted using data collected from soil vapor monitoring wells installed across the distribution of petroleum hydrocarbons to assess the rate of attenuation in various portions of the plume. The trends observed in the vapor source should be evaluated in the context of the other lines of evidence to identify secondary causes of variation such as seasonal fluid level fluctuations or longer term cyclical events such as droughts.

For the purpose of this analysis, trends are inferred for wells that have source vapor data for at least three monitoring events. Monitoring wells VW-93, VW-96, and VW-99 have a sufficient monitoring history to complete temporal

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analyses and are located over the smear zone. Figures 4-9a through 4-9c show the concentration of benzene and total petroleum hydrocarbons reported in the vapor source in nested wells VW-93, VW-96, and VW-99 over the past decade. A first order degradation rate is observed in the vapor source concentration since 1997, with a two to five order of magnitude decrease in benzene and total petroleum hydrocarbon concentrations. This rapid decrease in concentrations is attributable primarily to startup of groundwater, LNAPL, and soil vapor recovery systems in Hooven between 1999 and 2000.

4.1.3 GEOCHEMICAL INDICATORS OF NATURAL ATTENUATION

Characterization of geochemical variations in the vadose and saturated zones provides evidence of the types of biodegradation processes that are thought to be attenuating petroleum hydrocarbons in the smear zone. Many of the processes attenuating hydrocarbons in the smear zone cannot be measured directly (e.g., biological transformation of contaminants). However, the processes may cause changes in geochemical parameters, leaving an observable "footprint" that can be related qualitatively and quantitatively to the natural attenuation processes (National Research Council 2000). In general, geochemical species serve as electron acceptors and are reduced during microbial degradation (i.e., oxidation) of petroleum hydrocarbons.

4.1.3.1 DISSOLVED PHASE CONSTITUENTS

During microbial degradation of petroleum impacts, the dissolved oxygen concentrations steadily decrease until anaerobic conditions prevail. Once anaerobic conditions exist and multiple potential electron acceptors are available, microorganisms preferentially use the electron acceptor that is thermodynamically most favorable. The general order of preference for anaerobic hydrocarbon biodegradation based on the Gibb's energy of the reaction is:

- Denitrification (reduction of nitrate), with the eventual production of molecular nitrogen
- Reduction of manganese from Mn4+ to Mn2+
- Reduction of ferric iron (Fe3+) to ferrous iron (Fe2+)
- Sulfate reduction, with eventual production of sulfide
- Reduction of carbon dioxide and generation of methane

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These microbial processes generally segregate into distinct zones dominated by oxygen, nitrate, ferric iron (Fe3+), sulfate, and carbon dioxide reduction. Furthermore, given the different electron acceptors consumed and final products produced it is theoretically possible to differentiate the "zones" of microbial processes across the smear zone.

If dissolved oxygen is present in groundwater above 0.5 mg/L, then aerobic biodegradation of petroleum hydrocarbons is the dominant process. If dissolved oxygen concentrations are less than 0.5 mg/L, but nitrate concentrations exceed 1.0 mg/L, then denitrification dominates. Because nitrite is an unstable intermediate product of denitrification, the presence of measurable nitrite concentrations is indicative of nitrate reduction. If groundwater is deprived of dissolved oxygen, nitrate, and nitrite; but concentrations of ferrous iron are greater than 0.5 mg/L then iron reduction will be the dominant biodegradation process. If ground water is depleted in ferrous iron but contains concentrations of sulfate above 1 mg/L and hydrogen sulfide above 0.05 mg/L, then sulfate reduction will be the predominant process. Finally, if the groundwater is depleted in all the electron acceptors and byproducts, with the exception of methane greater than 0.2 mg/L, then methanogenesis is the predominant process degrading petroleum hydrocarbons. When applied at a field scale this differentiation of microbial zones commonly encounters uncertainties. Many of the byproducts of microbial metabolism (such as ferric iron, hydrogen sulfide, and methane) are readily transported down-gradient. Where groundwater flow is substantial as observed at the Site, it is difficult to determine the exact reduction-oxidation zone. In these cases, direct measurement of dissolved hydrogen can be used to identify reduction-oxidation conditions (USEPA 2003).

The spatial distribution of electron acceptors and byproducts in groundwater is displayed in Figures 4-10 and 4-11, respectively and summarized in Table 4-2. The nitrate and sulfate trends depicted in Figure 4-10 are indicative of denitrification and sulfate reduction. Both nitrate and sulfate concentrations were higher up-gradient of the smear zone compared to within the smear zone. Specifically, average nitrate and sulfate concentrations in up-gradient groundwater were 4.77 and 67.4 mg/L, respectively. Sulfate enriched water enters the smear zone with groundwater flowing from the north of the Site and the bedrock-aquifer interface in the western portions of Hooven. Groundwater flowing from the west in Hooven also contains elevated nitrate. The average sulfate concentration within the smear zone was 15.4 mg/L, and nitrate was not detected above the reporting limit (0.04 mg/L). Sulfate and nitrate rebound down-gradient of the plume with reported concentrations in well MW-35 of 33.5 and 0.47 mg/L, respectively indicating a low oxidant demand for nitrate and sulfate down-gradient of the smear zone. These trends are indicative of a stable or shrinking dissolved phase hydrocarbon plume.

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The dissolved iron, manganese, and methane trends depicted in Figure 4-11 are also secondary indicators of intrinsic natural attenuation processes. The concentration of each of these oxidation byproducts was higher within the smear zone compared to up-gradient and down-gradient conditions. Average dissolved iron, manganese, and methane concentrations up-gradient of the smear zone were 0.014, 0.026, and 0.037 mg/L, respectively. Average dissolved iron, manganese, and methane concentrations within the smear zone were 9.95, 0.70, and 5.38 mg/L, respectively. This significant increase in the concentrations of these dissolved phase products indicates iron and manganese reduction of dissolved phase petroleum hydrocarbons, as well as methanogenic processes that transform dissolved hydrocarbons to methane. Down-gradient of the smear zone, dissolved iron, manganese, and methane concentrations decrease rapidly to 0.004, 0.056, and 0.15 mg/L, respectively. These decreasing trends in microbial activity at the edges of the dissolved phase plume are indicative of a stable or shrinking hydrocarbon plume.

4.1.3.2 VAPOR PHASE CONSTITUENTS

Aerobic degradation of hydrocarbon vapors occurs (often in a relatively thin zone) where the concentrations of O_2 and volatile constituents in the soil vapor are optimal for the growth of petrophyllic bacteria. Aerobic degradation has the potential to reduce soil gas concentrations by several orders of magnitude, as long as the supply of O_2 is not rate limiting (Roggemans et al. 2001). CO_2 is produced as a result of the biodegradation of hydrocarbons. The expected vertical profiles of O_2 and CO_2 concentrations in the presence of aerobic biodegradation tend to be mirror images.

Depth profiles of petroleum related constituent, O_2, and CO_2 concentrations provide qualitative evidence of the occurrence of aerobic biodegradation in the vadose zone.

- For cases where there is little or no hydrocarbon source at depth, the hydrocarbon vapor profiles will show results at or near the reporting limit (i.e., background or non-detectable concentrations) from the deepest to the shallowest portions of the vadose zone. The concentration of O_2 will be nearly constant throughout the unsaturated zone and CO_2 concentrations will be very low or not detectable.
- If there is a significant hydrocarbon source at depth and aerobic biodegradation is not significant, the hydrocarbon vapor profile would show a linear decrease in vapor concentration with increasing distance above the source. In other words, the steady-state soil vapor profile due to diffusion will be linear with the highest concentration at the water table and the lowest concentration at the ground surface assuming the contaminant source is within groundwater and the overlying geology is relatively uniform. Degradation occurs whenever there are hydrocarbon

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vapors and O_2 is available, so this condition would only occur where O_2 is either prevented from entering the subsurface, or consumed completely at a rate faster than oxygen can be supplied.

- Where there is a significant hydrocarbon source at depth and aerobic biodegradation is significant, the hydrocarbon vapor profile will show a decrease in hydrocarbon concentration with increasing distance above the plume that is more rapid than that expected due to diffusion alone. The VOC concentration profile will show three distinct zones. The first zone is from the source to a depth where active aerobic biodegradation occurs. This zone is representative of anoxic conditions where diffusion is the primary transport mechanism and hydrocarbon vapor concentrations decrease in a linear profile, if at all. The second portion of the profile represents the active zone of aerobic biodegradation (which can be relatively thin compared to the thickness of the unsaturated zone), where there is rapid attenuation of hydrocarbon concentrations coinciding with consumption of O_2 and generation of CO_2 (Johnson et al. 1999). It is not uncommon to see O_2 concentrations decrease from atmospheric levels (21%) to 1-2% and CO_2 concentrations increase from less than 1% in the atmosphere to several percent in areas where aerobic degradation is active (DeVaull et al. 1997). In the third zone (above the biologically active layer) hydrocarbon concentrations are typically very low or not detectable and there is generally elevated O_2 and minimal CO_2. These profiles may vary if there are significant stratigraphic layers of different geologic materials, but this is not the case beneath the former refinery or Hooven.

Petroleum hydrocarbon constituent, O_2, and CO_2 profiles were created for each of the deep nested wells for the April 2008 monitoring event, as described in the subsections below. The vertical soil vapor profiles were grouped into four general categories, based on the location of the nested vapor monitoring wells:

1. Overlying undisturbed portions of the LNAPL plume (VW-18 and VW-21)
2. Overlying affected portions of the LNAPL plume (VW-20, VW-93, VW-96, and VW-99)
3. Overlying dissolved phase petroleum hydrocarbons (VW-127 and VW-128)
4. Background areas outside the distribution of petroleum related hydrocarbons attributed to the former refinery (VW-129 and VW-130).

Profiles for Nested Wells Overlying Undisturbed Portions of the LNAPL Plume

Total volatile petroleum hydrocarbon (TVPH) concentration profiles (Figure 4-12a and 4-13a) and benzene concentration profiles (Figure 4-12b and 4-13b) were prepared for samples collected from nested monitoring wells

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VW-18 and VW-21 in April 2008. TVPH is a mixture of petroleum hydrocarbon constituents whose composition can vary significantly both spatially (sample interval in each nest) and temporally (across sample events). TVPH was estimated by summing the mass of the detected volatile hydrocarbon constituents shown in Table 3-8a. For constituents that were reported as "non-detect", half the detection limit was used as a surrogate in the estimation. It should be noted that the benzene and TVPH profile for nested well VW-18 were created using rejected data from the 5 and 10-foot intervals. Fixed gas concentrations do not appear to be significantly affected by the presence of helium in the sample. In addition, the evaluation of the vapor profile is a secondary, qualitative line of evidence for demonstrating intrinsic attenuation processes within the vadose zone.

The profiles for nested vapor wells VW-18 and VW-21 show increasing benzene and TVPH concentrations with depth. Source term vapor concentrations are approximately 5,000 mg/m^3 directly above the saturated portion of the smear zone with a steep decline in vapor concentrations between the 5- and 15-foot intervals. These steep transitions are indicative of significant biodegradation of hydrocarbons in the subsurface. If biodegradation of petroleum hydrocarbons were not occurring the vapor profile would show a linear increase in TVPH concentrations with depth (i.e., diffusion-dominated transport). The steep transitions in these profiles are evidence of a zone where active biodegradation destroys hydrocarbons as they diffuse from the smear zone toward ground surface.

Fixed gas concentrations reported in samples collected from monitoring well VW-18 indicate that aerobic biodegradation is not the primary process for petroleum hydrocarbon attenuation. O_2 concentrations are generally low (approximately 2%) throughout the profile. Anaerobic degradation mechanisms account for the rapid reduction in constituent concentrations observed in this monitoring well with an increase in CH_4 from 8% to 21% between the 5- and 15-foot intervals. Aerobic degradation within nested well VW-18 occurs between 0 and 5 feet below the ground surface with a rapid decrease in O_2 concentrations from atmospheric conditions (20.9%) to approximately 2%. Whereas, a combination of anaerobic and aerobic processes account for TVPH attenuation within nested well VW-21. Between the 5- and 15- foot intervals oxygen concentrations significantly decline with a corresponding increase in CO_2 and CH_4 with depth.

Profiles for Nested Wells Overlying Treated Portions of the LNAPL Plume

TVPH profiles for wells VW-20, VW-93, VW-96, and VW-99 are provided along with O_2 and CO_2 profiles as Figures 4-14a through 4-17a, respectively. The benzene profiles are presented as Figures 4-14b through 4-17b. When historic data was available for a well, the April 2008 profiles were compared to the historic profiles. Generally, TVPH was reported as a single concentration value in the soil gas samples collected prior to 2005.

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The April 2008 TVPH and benzene profiles from nested wells VW-20, VW-96 and VW-99, overlying LNAPL impacts, show a rapid decrease in TVPH and benzene concentrations from the deepest probe to a depth between 20 and 30 ft-bgs. In general, the constituent concentrations above this interval are near background levels. There are surface sources of petroleum related VOCs that can be observed in the 10 ft-bgs samples from well VW-99 and the 20 ft-bgs interval in nested well VW-96. These concentrations are consistent with previous monitoring results and expected background levels in the shallow subsurface in urban areas.

The rapid reduction in VOC concentrations observed in the profiles for wells VW-20, VW-96, and VW-99 also coincide with decreasing O_2 and increasing CO_2 profiles from ground surface to the LNAPL plume at depth. The oxygen and carbon dioxide profiles indicate aerobic biodegradation is the primary process responsible for the observed hydrocarbon concentration decreases observed during the April 2008 monitoring event.

The petroleum hydrocarbon profiles prepared using the analytical results from nested well VW-93 situated over the LNAPL plume show continuously low concentrations from the deepest to the shallowest intervals. The concentration profile for O_2 and CO_2 are relatively constant across the vadose zone. The source vapor concentrations measured in this well have decreased dramatically over the past ten years due to the combined effects of aerobic biodegradation and corrective measures system operation. The TVPH and benzene profiles prepared using data collected from this well between 1997 and 1999 (shown on Figure 4-15a and Figure 4-15b) is representative of a typical aerobic biodegradation profile. The more recent profiles, including the profile for data collected in April 2008, are consistent with a limited hydrocarbon source (i.e., concentrations near background or reporting limits throughout the profile) most likely due to operation of the HSVE system since 2000.

Overall, the hydrocarbon, O_2, and CO_2 profiles are consistent with the results from deep nested soil gas monitoring conducted over the past decade. These profiles are indicative of an active zone of aerobic biodegradation rapidly degrading petroleum hydrocarbon constituents from the source in the deeper portions of the vadose zone beneath Hooven.

Profiles for Nested Wells Overlying Dissolved Phase Plume

Vertical profiles for benzene measured in deep nested wells VW-127 and VW-128 are provided along with O_2 and CO_2 profiles as Figure 4-18 and Figure 4-19, respectively. Soil vapor monitoring has been intermittently conducted at nested wells VW-127 and VW-128 since the Spring 2005 subsurface investigation. Both of these nested vapor monitoring wells are located over the dissolved phase plume but outside the area of LNAPL distribution. The benzene

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screening value is shown on the profiles for reference. Profiles were not constructed for TVPH for these nested wells because the low frequency of detection for nearly all of the TVPH constituents.

The April 2008 vapor profiles for these wells are consistent with cases where there is a limited hydrocarbon source at depth, similar to the recent profiles prepared using data from nested well VW-93. There are consistent, relatively low concentrations of hydrocarbons from near the water table to 10 ft-bgs with a minor reduction in O_2 and slight increase in CO_2 with depth.

The vapor profiles for the April 2008 monitoring event show a reverse gradient from the ground surface to shallow depths caused by detections of benzene in the 5 ft-bgs monitoring interval in these two wells. As previously described herein, a natural gas odor was detected near nested vapor monitoring well VW-127 during sampling and elevated concentrations of several other target analytes were also reported in the soil gas sample collected from this probe. The concentration of benzene reported in the 5 ft-bgs interval in well VW-128 is similar to the background concentrations measured in the shallow subsurface in areas of Hooven located outside of the distribution of petroleum hydrocarbons attributed to the former refinery.

Profiles for Nested Wells Outside of Plume

Routine vapor monitoring has been conducted at least annually using nested well VW-129 since the subsurface investigation in the Spring 2005. Until the April 2008 event, nested vapor monitoring well VW-130 has not been sampled since completion of the subsurface investigation in May 2005. Vertical profiles for benzene, O_2, and CO_2 prepared using soil gas data collected from these two nested wells are presented as Figures 4-20 and 4-21, respectively. There were not any reported detections of benzene within any of the monitoring intervals in these two wells with the exception of the 5-foot sample collected from deep nested well VW-129. The vapor profiles are consistent with there being no source of petroleum hydrocarbons present at depth.

4.2 SMEAR ZONE BENZENE DEPLETION

The dissolved phase benzene concentrations for selected monitoring wells located in the up-gradient (MW-21 and MW-22), interior (L-1RR, L-3R, MW-17, and MW-18R), and down-gradient (MW-48S, MW-94S, and MW-115S) portions of the smear zone are presented on Figure 4-22. Dissolved phase concentrations depicted were reported during the Fall 2002, Fall 2004, and Spring 2008 monitoring events and are averaged for the up-gradient, interior, and down-gradient wells. Irrespective of the well locations, there is a decreasing trend in the dissolved phase benzene

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concentration reported between 2002 and 2008, indicative of benzene depletion from the smear zone. It should be noted that the dissolved phase benzene concentrations are lower at the margins (up-gradient and down-gradient areas) compared to the interior of the smear zone.

The decreasing trends observed in benzene concentrations over time are greater at the margins of the smear zone compared to the interior portion of the plume. At its margins, the smear zone is thinner and LNAPL saturations are lower. Furthermore, groundwater enriched in electron acceptors intercepts the smear zone along the up-gradient margin. Groundwater enriched in electron acceptors flowing from the west along the Buried Valley Aquifer-bedrock interface intercepts the smear zone at the down-gradient margin. This creates a situation whereby petroleum hydrocarbons including benzene are attenuated more quickly along the margins than the interior of the smear zone. These observations are consistent with the expectation of outside-in attenuation of petroleum hydrocarbons within the smear zone.

As the up-gradient portion of the smear zone is depleted of petroleum hydrocarbons, the benzene removal rates from interior portion of the smear zone will increase as outside in weathering continues. It is anticipated that the dissolved phase benzene concentrations reported in monitoring wells L-1RR and MW-17 will show trends similar to those currently observed in wells MW-21 and MW-22. This may then be followed by a similar transition in the dissolved phase benzene trends observed in monitoring wells L-3R and MW-18R. Over time, it is expected that benzene concentrations in groundwater will continue to decrease across the smear zone, eventually approaching remedial goals (i.e., USEPA MCL).

4.3 SUMMARY OF LINES OF EVIDENCE OF NATURAL ATTENUATION

Performance monitoring for any corrective measure is necessary to demonstrate that the remedial action is progressing as anticipated and will meet remedial goals while ensuring that sensitive receptors remain protected. The USEPA has established additional performance monitoring criteria for remedies incorporating intrinsic natural attenuation processes for degradation of residual impacts (USEPA 1999, USEPA 2003). Performance monitoring programs in these cases must be designed to:

1. Demonstrate that natural attenuation is occurring according to expectations
2. Detect changes in environmental conditions (e.g., hydrogeologic, geochemical, microbiological, or other changes) that may reduce the efficacy of any of the natural attenuation processes

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3. Identify any potentially toxic and/or mobile transformation products. (although this process is not typical of biodegradation of petroleum hydrocarbons and have not been observed in samples collected from the Chevron Cincinnati Facility)

4. Verify that the LNAPL or dissolved phase plume is not expanding down-gradient

5. Verify no unacceptable impact to down-gradient receptors

6. Detect new releases of contaminants to the environment that could impact the effectiveness of the natural attenuation remedy

Each of these performance monitoring criteria have been achieved during this first semiannual monitoring event based upon the qualitative and quantitative lines of evidence used to demonstrate the stability of petroleum hydrocarbons in the smear zone, protectiveness of sensitive receptors, transformation of petroleum hydrocarbon constituents via intrinsic processes, as well as decreasing petroleum hydrocarbon constituent concentrations and mass over time. Many of the lines of evidence provided represent a baseline understanding of the processes acting on petroleum hydrocarbons in the smear zone, as this is the first event that data was collected from several components of the monitoring network installed as part of the final groundwater remedy. Refinements to these lines of evidence will be made as data gaps in the conceptual site model are resolved and additional data is available to evaluate short and long term trends and anomalies within the data.

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5.0 HIGH-GRADE RECOVERY

The high-grade pumping component of the groundwater remedy focuses on seasonal source removal of LNAPL from the lower reaches of the smear zone where the LNAPL saturations remain the greatest. The purposes of high-grade recovery are to (1) further reduce LNAPL mobility at the lowest ambient water table conditions and (2) remove additional LNAPL mass from the smear zone. High-grade recovery did not occur during the first half of 2008. A summary of high-grade recovery conducted in 2007 is provided in Section 5.1. Future routine reports will generally focus on results from the reporting period. Discussion regarding the high-grade results from 2007 is presented in this report since it was the first significant high-grade recovery event under the Final Remedy and the results have not previously been formally submitted to the USEPA.

Several million gallons of groundwater containing dissolved-phase petroleum hydrocarbons are generated each day during high-grade pumping. This groundwater is treated within the biologically enhanced GAC and transmitted to the constructed wetlands prior to discharge to the Great Miami River under an OEPA administered NPDES Permit. Operation of the GAC system during 2007 is discussed in Section 5.2.

Additionally, the HSVE system is operated in combination with high-grade recovery to remove volatile petroleum constituents from the vadose zone above the LNAPL plume. The HSVE system did not operate during the first half of 2008. As with the high-grade activities, operations data from the HSVE system recorded in 2007 is presented in Section 5.3. Low water table conditions were prevalent for several months during the latter half of 2007, and so the results represent the first year of recovery under conditions best suited for achieving the goals of the final groundwater remedy.

5.1 2007 HIGH-GRADE SUMMARY

High-grade recovery began on June 20, 2007 after trigger elevations were measured in monitoring well MW-20S (464.8 feet-above mean sea level [ft-amsl]) as stipulated in Table 4-1 of the OMM Plan (Trihydro 2007b) . High-grade recovery was conducted using several production wells over the course of the event as follows:

- PROD_12 - June 20 to July 11, 2007; yielding 341 gallons of LNAPL
- PROD_12 - October 3 to October 15, 2007; yielding 1,117 gallons of LNAPL
- PROD_19 - July 11 to December 14, 2007; yielding 67,999 gallons of LNAPL

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Recovery was also performed using several other production wells including PROD_20, PROD_21, PROD_23, and PROD_24 as wastewater treatment system capacity allowed for supplemental recovery efforts. This supplemental pumping resulted in recovery of an additional 11,278 gallons of LNAPL during the event. Table 5-1 provides a weekly summary of LNAPL recovery by production well. Table 5-2 provides a summary of the pumping rates and fluid levels measured in the primary and supplemental production wells during the 2007 high-grade event.

5.1.1 HIGH-GRADE SYSTEM MODIFICATIONS

Modifications were performed to production well PROD_12 in May 2007 including installation of a high capacity turbine submersible pump; 480-volt, 3-phase electrical line; as well as groundwater transmission pipelines necessary to accommodate increased flow rates. Following completion of these modifications, PROD_12 was selected for operation during the 2007 high-grade event to evaluate the recoverability of LNAPL present in the central area of the plume.

Between October 8 and October 10, 2007, production well PROD_24 was installed by Jackson & Sons Drilling & Pump, Inc. using a bucket auger drilling methodology. Production well PROD_24 was installed in the central portions of Hooven approximately 250 feet east of monitoring well MW-96S. Prior to installation, Chevron obtained necessary permits from the Hamilton County Engineer's Office. Underground utilities were clearly identified via notification to Ohio Utilities Protection Service.

Coarse sand, gravels, cobbles, and boulders were encountered during installation of this well. Large boulders (as much as 3-feet thick) were encountered at 45 and 54 ft-bgs. A 38-inch boring was installed to a total depth of 90 ft-bgs. A 36-inch surface casing was set from 25 ft-bgs to the ground surface to facility advancement of the bucket auger during drilling.

Following completion of the boring to the total depth, an 18-inch continuous wrapped stainless steel screen (0.10-inch slot size) was set from the total boring depth to approximately 50 ft-bgs. Blank 18-inch steel casing was set from the top of the screen to approximately one foot above the ground surface. A No. 3 gravel pack was placed from the bottom of the screen interval to approximately 25 ft-bgs. A concrete-bentonite grout seal was placed above the gravel pack to the ground surface.

The newly installed production well was developed between November 8 and November 9, 2007. Groundwater purged from the well during development was transmitted to the biologically enhanced GAC for treatment. Step testing was

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conducted following development on November 9, 2007. A vertical high capacity turbine pump was installed within production well PROD_24 following development and step testing. The pump intake was set at approximately 81.5 ft-bgs. A well log and drilling report (ODNR Form 7802.03) was submitted to the Ohio Department of Natural Resources documenting the well construction details for production well PROD_24 (Appendix E).

5.1.2 FLUID LEVEL MONITORING

Prior to initiating pumping, transducers were deployed within a monitoring network across the high-grade areas to collect continuous drawdown data. Two categories of monitoring wells, Key Transducer and Select Transducer, were established for the high-grade pumping event and are shown on Figure 5-1. Transducers deployed in the Key Transducer monitoring wells were proximal to production well PROD-19. Transducers deployed in the Select Transducer monitoring wells were typically located farther away from this production well. Transducers generally logged groundwater elevation data on a 10 minute interval. Groundwater elevation data collected from the Key and Select Transducer monitoring wells during the 2007 high-grade event are presented in Appendix J.

During future high-grade events, Chevron is proposing to deploy transducers in Key and Select Transducer wells in both the central and southwest high-grade areas, as shown on Figure 5-2. In addition, the frequency of data logging will be reduced from 10 minute intervals to 4 hour intervals. This 4 hour frequency allows for meaningful evaluation of groundwater elevation and LNAPL thickness trends during high-grade pumping, but reduces the volume of redundant data recorded over a tight logging frequency (i.e., 10 minute intervals).

Manual fluid level gauging is conducted weekly throughout the year to provide data regarding ambient hydraulic conditions and to compare groundwater elevations to trigger levels in key monitoring wells. During high-grade pumping, manual fluid level monitoring is focused upon two groups of monitoring wells, Key Manual and Select Manual, designated as such based on their proximity to the chosen high-grade production well and their monitoring frequencies. Key Manual wells represent a more concentrated cluster of monitoring wells located either proximal to the selected production well or in an area of particular interest, and are considered critical to measuring high-grade performance. Select Manual wells represent a broader area of monitoring wells surrounding the selected production well. Key and Select Manual monitoring wells for the central high-grade area are depicted on Figure 5-3, and Key and Select Manual monitoring wells for the southwestern high-grade area are depicted on Figure 5-4.

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Daily gauging of groundwater and LNAPL levels (if present) began upon start up of high-grade pumping on June 20, 2007 and continued for the first two days of high-grade recovery. Thereafter, Key Manual monitoring wells were gauged an average of twice weekly. If hydraulic conditions persisted for an extended period of time, the monitoring frequency may have been reduced until fluctuations in fluid level conditions warranted bi-weekly monitoring. Likewise, if conditions changed rapidly, monitoring frequencies may have increased. During the Key manual gauging events, groundwater and LNAPL production rates were also measured within the operating production wells. Groundwater and LNAPL extraction rates from the wells were compared weekly against operational logs at the biologically enhanced GAC and recovery volumes measured in Tank No. 291 and Tank No. 50.

Fluid levels in the Select Manual monitoring wells were gauged twice weekly upon start up of high-grade pumping, until equilibration of the system. Thereafter, Select Manual monitoring wells were gauged weekly. Results of manual fluid level gauging of Key and Select Manual monitoring wells in support of 2007 high-grade activities are provided in Appendix K.

5.1.2.1 RECOVERY FROM PRODUCTION WELL PROD_12

The 2007 high-grade event began by initiating recovery using production well PROD_12, located in the central portion of the LNAPL plume on the facility. Flow rates were sustained between 1,920 and 2,400 gallons per minute (gpm) from start up through July 5, 2007. Flow rates were subsequently reduced to between 1,200 and 1,400 gpm until July 11, 2007. The flow rates were reduced in an attempt to minimize entrained LNAPL within the extracted groundwater that was being transmitted to the biologically enhanced GAC. Attempts to utilize the LNAPL skimming system installed within Tank No. 40 as an oil/water separator were unsuccessful.

Approximately 16 gallons of LNAPL were recovered per day from production well PROD_12 during this timeframe; with a cumulative recovery of 341 gallons. Over this same timeframe an average of 2,747,520 gallons of groundwater was recovered daily from production well PROD_12; with a ratio of approximately 169,200 gallons of groundwater removed for every gallon of LNAPL recovered.

Between July 11 and October 3, 2007 recovery was focused on the southwest high-grade area as ambient groundwater elevations decreased across the facility. On October 3, 2007 pumping was resumed in well PROD_12 in the central portion of the smear zone to determine the potential for LNAPL recovery and establish operational targets (i.e., trigger levels, production rates, etc.) under low water table conditions. Groundwater was extracted at a rate of approximately

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805 gpm from production well PROD_12 until October 15, 2007. At the same time, groundwater was extracted from production well PROD_19 at a rate of approximately 1,780 gpm. Approximately 93 gallons of LNAPL were recovered per day from production well PROD_12 during this second test; with a cumulative recovery of 1,117 gallons. There was an average of 1,160,860 gallons of groundwater recovered each day from production well PROD_12 during this second test with a ratio of approximately 12,471 gallons of groundwater removed for every gallon of LNAPL. This second recovery test using production well PROD_12 was terminated on October 15, 2007, due to recurring issues with entrained LNAPL present in groundwater transmitted to the GAC.

Figure 5-5 presents the groundwater elevations and LNAPL thicknesses measured in the Key Manual monitoring wells during the two high-grade recovery tests conducted in production well PROD_12 during 2007. During the brief periods of high-grade operation from this production well, groundwater elevations were depressed by as much as two feet and there was a corresponding increase in LNAPL thicknesses in the Key Manual wells. During pumping in October in the central plume area, groundwater elevations and LNAPL thickness were roughly equivalent to those measured during high-grade recovery in June and July, even though groundwater was extracted at a third of the rate. There was 6 times more LNAPL recovered per day during October and the LNAPL recovery efficiency (gallons of groundwater removed compared to gallons of LNAPL recovered) improved by more than 14 times compared to recovery at the beginning of the test.

Production well and treatment system modifications that may include placement of a packer to separate LNAPL and groundwater within the production well and improvements to oil/water separation systems will be attempted during future events to allow for longer intervals of high-grade recovery at increased flow rates within this well. This will allow for removal of LNAPL from the lower portions of the smear zone in this central high-grade area and reduced LNAPL mobility over the course of the final remedy.

5.1.2.2 RECOVERY FROM PRODUCTION WELL PROD_19

High-grade recovery was conducted continuously in production well PROD_19 between July 11, 2007 until termination of the event on December 14, 2008. During these five months of operation groundwater extraction rates ranged from 1,000 to 2,560 gpm. Approximately 435 gallons of LNAPL were recovered per day from production well PROD_19 during this timeframe; with a cumulative recovery of 67,808 gallons. An average of 2,667,720 gallons of groundwater was recovered daily with a LNAPL removal efficiency of 6,137 gallons of groundwater removed for every gallon of LNAPL recovered.

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It should be noted that pumping was initiated in this well on June 28, 2007 to supplement recovery being performed within production well PROD_12. The flow rates during operation in late-June and early-July were maintained between 900 and 1,500 gpm. A total of 191 gallons of LNAPL were removed during this timeframe with a low removal efficiency of 50,946 gallons of groundwater removed for each gallon of LNAPL.

Figure 5-6 presents the potentiometric surface map for fluid levels measured on October 1, 2008, as this is the date that the lowest groundwater elevations were measured in the Key Manual monitoring wells during pumping in the southwestern high-grade area. As expected, groundwater elevations were lowest around the production well PROD_19; however the groundwater elevations were not depressed uniformly away from the pumping well. Groundwater elevations were lowest in monitoring wells MW-96S and MW-99S situated in the central and northern portions of Hooven. Figure 5-7 presents the drawdown map for October 1, 2007. The drawdown for each well was calculated as the difference in groundwater elevation reported on October 1, 2007 and the ambient groundwater elevations reported prior to high-grade pumping on May 30 and May 31, 2007. The drawdown for each well reported on Figure 5-7 was corrected for the ambient decrease in the water table as measured in monitoring well MW-17 located outside of the radius of influence of high-grade pumping in either area. Drawdown was greatest to the northwest of production well PROD_19 as measured in monitoring wells MW-99S (5.48 feet) and MW-121 (5.47 feet). Similarly, LNAPL accumulations reported on October 1, 2007 were greatest to the west of the pumping center as measured in wells MW-96S (2.70 feet) and MW-99S (2.2 feet), as shown on Figure 5-8.

Operational testing of the newly installed production well PROD_24 began on November 9, 2007. Groundwater was pumped at a rate between 275 and 610 gpm between November 9 and December 14, 2007. Approximately 32 gallons of LNAPL were recovered per day from the new production well situated in Hooven with a cumulative recovery of 1,112 gallons. There was an average of 520,045 gallons of groundwater removed daily from production well PROD_24, which equates to a LNAPL removal efficiency of 16,368 gallons of groundwater for each gallon of LNAPL.

Figure 5-9 presents the potentiometric surface map for fluid levels measured on November 13, 2008 during operation of production wells PROD_19 (2,045 gpm) and PROD_24 (300 gpm). The groundwater elevations were depressed in an area extending around production well PROD_19, extending into Hooven. Figure 5-10 presents the corrected drawdown map for November 13, 2007. The greatest drawdown was measured in monitoring well MW-121 (5.72 feet) located in the northeast limit of Hooven. LNAPL accumulations reported on November 13, 2007 were greatest to the north and west of production well PROD_19 as measured in wells MW-20S (1.33 feet), MW-96S (1.12 feet) and

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MW-121 (1.58 feet), as shown on Figure 5-11. It should be noted that LNAPL was not measured in monitoring well MW-99S on November 13, 2007.

Between mid-November and mid-December 2007 several high intensity precipitation events resulted in a rebound of the groundwater table to an elevation above the 464.8 ft-amsl trigger elevation established for monitoring well MW-20S. As shown on Figure 5-12, LNAPL thicknesses within the Key Manual monitoring wells located in the southwest high-grade area decreased rapidly over this timeframe, and the corresponding LNAPL recovery rates also diminished.

During high-grade operation in the southwest portions of the plume, groundwater elevations were depressed by as much as four feet and there was a corresponding increase of more than 2-feet of LNAPL within the Key Manual wells. There was 14 times more LNAPL recovered per day during high-grade operation using production well PROD_19 and the LNAPL recovery efficiency (gallons of groundwater removed compared to gallons of LNAPL recovered) improved by more than 8 times compared to operation of this well in late-June and early-July when it was pumped to supplement recovery within production well PROD_12. In general, LNAPL removal efficiency at the primary production well PROD_19 or supplemental production wells situated within the pumping center, such as well PROD_21, were several times greater than those located away from the pumping center, such as production wells PROD_20 and PROD_24.

5.1.3 TRIGGER PUMPING ELEVATIONS

LNAPL recovery is undertaken during low water table conditions, based on historical trends and field observations during seasonal dry periods. LNAPL appears in wells and is recoverable as a function of water table elevations (triggers) as they relate to the smear zone. The water table must be low enough to expose the approximate bottom third of the smear zone before LNAPL can be recovered. The goal of high-grade pumping is to use focused groundwater extraction to maximally expose the smear zone and recover LNAPL during intervals of low water table conditions. Maximal exposure of the smear zone occurs when the water table is drawn down below the previous minimum groundwater elevation. Thus, the minimum historical groundwater elevation within a well is used to establish targets for initiating high-grade recovery. With each successful high-grade event, the depth of maximum smear zone exposure will be lowered, thereby establishing new, lower triggers for starting high-grade recovery over subsequent events. The trigger for initiating high-grade recovery is determined via the following equation:

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Pumping Trigger = $PT_i + s_{i,j}$

Where:

PT_i = Pumping target of the ith monitoring well location; value is the historical minimum water table elevation in feet above mean sea level

$s_{i,j}$ = Expected drawdown at the ith monitoring well location caused by high-grade pumping at the production well

As noted by the subscripts in the above equation, pumping triggers are specific to the monitoring location and the production well. Prior to each high-grade event, new pumping triggers will be calculated by analyzing the fluid level data from the preceding event. New triggers will be established at locations where the water table was lowered to a new minimum elevation. Otherwise, triggers from the preceding year will be carried forward. The expected drawdown will be based on fluid level monitoring data collected during previous high-grade pumping events.

Trigger elevations for initiating high-grade pumping using production wells PROD_19 and PROD_20 were determined for the Key Manual wells in the southwest plume areas based on drawdown data collected during testing conducted in 2005 and 2006. Updated triggers for production well PROD_19 have been calculated based upon the fluid level and pumping data collected during the 2007 high-grade event. In addition, trigger levels were established for the Key Manual monitoring wells located in the central production area based on results from initial testing conducted in well PROD_12. Trigger levels for the Key Manual wells in the two high-grade areas associated with operation of specific production wells are provided on Table 5-3.

Trigger levels in the central and southwestern high-grade areas of the plume will continue to be updated following subsequent high-grade events. For the purpose of monitoring groundwater conditions in the central high-grade area during subsequent events, MW-18 will be included as a Key Manual and Key Transducer monitoring well.

5.1.4 SUMMARY OF 2007 HIGH-GRADE RECOVERY

A total of 80,735 gallons of LNAPL were recovered during the 2007 high-grade event. Table 5-4 provides a summary of average daily groundwater and LNAPL recovery rates, LNAPL removal efficiency, maximum groundwater production rate, and maximum drawdown reported in each of the production wells. The maximum drawdown observed in the production well was determined by correcting for ambient decreases in the water table, as well as adjusting for drawdown from concurrent operation of proximal production wells. Specifically, recovery from production well

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PROD_20, PROD_21, and PROD_24 commenced while well PROD_19 was already operating and had measurably depressed the water table. Drawdown in these production wells was adjusted by reducing the observed drawdown in the production well from that observed prior to extracting groundwater from the well. Therefore, the maximum drawdown reported on Table 5-4 for wells PROD_20, PROD_21, and PROD_24 do not include drawdown associated with operation of well PROD_19.

A comparison of the instantaneous groundwater extraction rate versus the corrected groundwater elevation in each of the production wells is presented on Figure 5-13. Drawdown was greatest in production wells PROD_12 (15.0 feet) and PROD_24 (7.5 feet); however the drawdown observed in these wells did not propagate away from these two production wells as shown on Figures 5-5 and 5-12. Additional hydraulic testing and well development may be necessary within these two production wells.

LNAPL recovery was more effective at higher groundwater extraction rates and within those production wells located closest to the pumping center. At least twice as much groundwater was removed per gallon of LNAPL recovered from those production wells operated at lower extraction rates or away from the pumping center. In addition, as production rates were fluctuated within the production wells, the LNAPL thicknesses measured in the surrounding monitoring wells would fluctuate by as much as several feet; potentially inhibiting LNAPL recovery.

Although ambient groundwater levels were much lower during the 2007 high-grade event compared to testing conducted in 2006, the high-grade triggers were not reduced within any of the wells located in the southwestern high-grade recovery area. This is attributed to lower groundwater extraction rates during the 2007 event.

Future events will focus on operation of a single production well operated at higher production rates (up to 3,600 gpm as performed during testing in 2006) to maximize LNAPL recovery and reduce LNAPL mobility in the lower reaches of the smear zone. As LNAPL recovery diminishes within a production well, high-grade operations will be relocated to another well.

5.2 BIOLOGICAL ENHANCED GAC SYSTEM OPERATION

The biologically enhanced GAC is designed to remove dissolved phase petroleum hydrocarbons, primarily BTEX from extracted groundwater. Extracted groundwater is transmitted to the GAC for treatment from one or more of the

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production wells located at the Facility. The GAC treatment process is discussed in further detail in the OMM Plan (Trihydro 2007b).

Following treatment in the GAC, groundwater is transmitted to the sedimentation pond and constructed wetlands prior to discharge to the Great Miami River through the wetlands outfall. Groundwater samples are collected weekly at the wetlands outfall to evaluate compliance with NPDES discharge limits. A composite groundwater sample was collected each week using an automated sampler, which collects a sample aliquot every 45 minutes over a 24-hour period. Composite samples were analyzed by TestAmerica Laboratories located in North Canton, Ohio to evaluate compliance with discharge requirements set forth in the Facility's NPDES permit. Groundwater samples are analyzed for flow rate, pH, biological oxygen demand, total suspended solids, oil and grease, total lead, as well as dissolved phase concentrations of BTEX, total phenols, and 1,2-dichloropropane. Monthly and daily concentration and loading limits are established for these constituents. None of the effluent limits were exceeded in the weekly samples collected from the outfall during the reporting period during the first half of 2008 or during the previous year also discussed herein.

5.3 HSVE SYSTEM OPERATION

The HSVE system removes volatile petroleum constituents from the vadose zone directly above the LNAPL smear zone, contributing to overall mass reduction in the southwest portion of the plume. As documented in the Remedial Action Plan dated June 3, 1999, the HSVE removes hydrocarbon mass and mitigates potential upward migration of vapors beneath off-site residential properties. The HSVE system extracts volatile petroleum hydrocarbons by creating a negative pressure within the three six-inch Schedule 40 carbon steel pipes that extend from the eastern edge of the facility beneath State Route 128 continuing under Hooven, coincident with the distribution of refinery related hydrocarbons. The well screens for each of the lines were installed approximately five feet above the 15 year maximum groundwater elevation (478 ft-amsl for Line Nos. 1 and 2 and 475 ft-amsl for Line No. 3).

Recovered hydrocarbon vapors are destroyed via thermal oxidation (combustion), which converts TVPH to carbon dioxide and water. This process results in the release of a large quantity of energy and the formation of a flame at the combustion zone, destroying recovered vapors with a minimum 98% destruction efficiency in thermal oxidizer mode.

HSVE system operation commenced on July 18, 2007, following soil vapor monitoring in late-June and early-July. Vapor phase recovery using the HSVE began following initiation of high-grade pumping activities in order to remove volatile petroleum hydrocarbons from the vadose zone as the groundwater table was depressed. The system was

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operated by cycling each line from several days and several months. In 2007, Line No.1 was operated for 70 days, Line No. 2 for 17 days, and Line No. 3 for 85 days. Operation of the HSVE system ceased on December 27, 2007, two weeks following termination of high-grade pumping.

5.3.1 SUMMARY OF 2007 HSVE MONITORING DATA

Operational data is collected at each of the process lines during operation of the HSVE system including the rate of airflow and vacuum, as well as the fixed gas concentrations including O_2, CO_2, CH_4, total organic vapors, and the lower explosive limit. Table 5-5 presents a summary of the operational monitoring data recorded at each of the extraction lines.

In addition, combined influent and effluent vapor samples were collected monthly to demonstrate compliance with the Hamilton County Permit to Operate. The compliance monitoring data is compared to permitted operational limits on a quarterly and semiannual basis. Table 5-6 presents a summary of compliance monitoring data collected from the system during operation in 2007, as well as a summary of the calculated organic carbon extraction and emission rates (reported in pounds per hour, pounds per day, and tons per year). Monthly emission rates were below the allowable limits of 6.25 pounds per hour, 40 pounds per day, or 27.38 tons per year. The average emission rate was approximately 0.035 pounds per hour, 0.833 pounds per day, or 0.008 tons per year during operation of the system in 2007.

Approximately 78,850 pounds of organic carbon was recovered via operation of the HSVE system in 2007. The estimated organic carbon removed from the system is calculated based upon the concentration of total petroleum hydrocarbons and methane reported in the influent vapor samples, average flow rate recorded at the wellhead, and hours of operation over the reporting period.

The HSVE system has removed nearly 500,000 pounds of hydrocarbons from beneath Hooven since installation in 1999, and has resulted in significant reductions in the concentrations of benzene over time. As shown on Figure 5-14, the rate of mass removal is dependent on the elevation of the water table as additional smear zone is exposed and the rate of volatilization of petroleum hydrocarbons increases during low groundwater conditions. Groundwater elevations beneath Hooven typically vary by four to ten feet each year. Therefore, the HSVE system operations are optimized to focus effort during the seasonal periods of low groundwater elevations (typically late fall). As reported in the *10-Year Soil Vapor Retrospective Report, Chevron Cincinnati Facility, Hooven, Ohio* (Trihydro and GeoSyntec 2008), the

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HSVE system has been shown to affect soil vapor concentrations in the nested monitoring locations located between 150 and 250 feet from the HSVE lines, demonstrating the influence of the system is extensive beneath the eastern portions of Hooven within the area underlain by LNAPL and dissolved phase petroleum hydrocarbons. Vapors in the deep portions of the vadose zone near nested well VW-93 have been reduced to the point where there are virtually no detectable benzene concentrations and petroleum hydrocarbon impacts are no longer sufficient to cause O_2 depletion at depth, demonstrating a persistent removal of hydrocarbon mass via aerobic degradation and operations of the corrective measures systems.

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6.0 GULF PARK

A former products transfer pipeline, consisting of five 6-inch diameter lines that connected the former refinery with a loading terminal on the Ohio River, passes beneath the Gulf Park property. The pipelines carried three grades of gasoline, kerosene, aviation fuel, diesel, and fuel oil during use between 1930 and the mid-1980s. Hydrocarbon-stained soil was discovered in Gulf Park in January 1993 at approximately 10 to 14 feet below grade. Several subsurface investigations to define soil and groundwater conditions and the extent of petroleum hydrocarbons were conducted between 1993 and 1994.

Based upon the findings of these investigations, a bioventing system was installed in the area that is now the westernmost soccer field at Gulf Park in 1996. It consists of 14 air injection wells designed to deliver approximately 30 to 35 standard cubic feet per minute (scfm) to each injection well, and a rotary blower, which was designed to operate on a manual 8-hour on and 16-hour off cycle. Valve controls for the air injection wells installed in the soccer field area are located in a nearby Valve Control Shed (VCS No.1).

A bioventing system expansion was installed between August and October 2000, consisting of an additional 38 bioventing wells constructed of 2-inch diameter PVC casing and 0.010-inch slotted screen. These bioventing wells were completed below grade and connected to a separate Valve Control Shed (VCS No. 2). Figure 6-1 shows the layout of the two bioventing systems installed at Gulf Park.

Bioventing stimulates intrinsic biodegradation of petroleum hydrocarbons in the vadose zone by injecting air at low flow rates to provide sufficient oxygen to sustain aerobic microbial activity. Airflow is injected at rates designed to maximize oxygen delivery to the subsurface while minimizing volatilization of hydrocarbon constituents, thus eliminating the necessity for vapor intrusion or ambient air pollution control measures.

An automated timer allowed the expanded biovent system to be operated using a phased approach (12-hours on, 12-hours off) with air injected into a maximum of two of the four separate header lines, which connected groups of the bioventing wells to the positive displacement blower. By modifying system balancing valves, air flow to the main supply lines (Line 1 through Line 4) and to individual bioventing wells was adjusted to compensate for changes in the water table elevation. In October 2005, the existing positive displacement blower was replaced with a centrifugal blower with variable speed drive capable of supplying approximately 35 scfm to each of the 52 biovent wells. Subsequent blower operations involved supplying air to all main supply lines simultaneously.

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6.1 BIOVENT SYSTEM PERFORMANCE MONITORING

Startup and shutdown criteria for the biovent system are related to groundwater trigger levels beneath Gulf Park. Historic soil vapor monitoring data indicate that higher respiration rates occur within the lower portions of the smear zone. However, this lower portion of the smear zone is only exposed above the groundwater table during low water table conditions. The groundwater level is typically above the trigger level elevation from January through June and below the trigger level intermittently from June through December. The period of low water table conditions is considered the seasonal bioventing operation period. Figure 6-2 presents the hydrographs from the trigger monitoring wells for 2006, 2007, and the first half of 2008. As shown, groundwater elevations remained above the trigger levels for wells GPW-5S and TH-2 and thus the system was not operated during the first half of 2008.

Each bioventing well has a valve to regulate air flow and a port used for monitoring temperature, pressure, and air flow. This data is gathered for purposes of evaluating system operating efficiencies, and is not directly related to performance metrics associated with the 2006 AOC.

Since this is the first report that has been prepared under the OMM Plan (Trihydro 2007b) and the 2006 AOC, performance monitoring activities conducted in Gulf Park during 2006 and 2007 are included herein as a framework for the future reporting. The system monitoring activities consist of:

- Recording operational parameters (pressure, flow rate, and temperature) periodically at the process blower in order to document blower performance.
- Measuring the air flow parameters in each of the biovent wells periodically in order to document airflow to each injection well.
- Gauging fluid levels within the system “trigger” wells (GPW-5S and TH-2) weekly to determine the schedule for system startup and shutdown.
- Collecting field measurements of soil vapor composition including total organic vapor, pressure, and fixed gas concentrations (O_2, CO_2, and CH_4) to qualitatively evaluate system effectiveness.
- Collecting routine groundwater samples from monitoring wells installed within the shallow and intermediate portions of the aquifer beneath Gulf Park.

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6.1.1 BIOVENT SYSTEM PERFORMANCE RESULTS

During system inspections and each time system air flow adjustments were made, performance parameters for active (i.e., valve not closed) injection wells were monitored within VCS No. 1 (Lines BV-1 through BV-14) and VCS No. 2 (BVW-1 through BVW-38). Biovent wells in VCS No. 1 contain analog, vane-style flow meters, which allow for measuring instantaneous flow rates. Biovent lines located in VCS No. 2 were installed with sensor ports to allow for measurement of pressure, temperature, and differential pressure in order to calculate standard air flow rate.

Pressure in the individual biovent wells in VCS No. 2 was measured using a digital manometer. Injection air temperature measurements for the biovent expansion system were collected from dedicated dial gauge thermometers installed on each vent line. Flow rates measured at individual biovent well lines were measured using a Dwyer flow sensor manufactured to measure differential pressure in a 2-inch diameter pipe. The flow sensor was connected to a digital manometer, and differential pressure values provided by the manometer were recorded. The recorded values were later converted to volumetric flow rates and corrected to standard conditions.

During 2006 and 2007 operations, biovent system control valves were periodically adjusted to deliver a target 35 scfm of air to each biovent well. Supply air was reduced if organic vapors were measured at the ground surface in the area of the corresponding biovent well.

Based upon average flow rates measured at the biovent wells and recorded operation times, approximately 245,000,000 scfm of process air was injected into the expanded biovent system area during the 2006 period of operation. Approximately 441,500,000 scfm of process air was injected into the biovent area during the 2007 period of operation. All recorded 2006 and 2007 biovent well performance parameters, including dates and time of operation, are presented in Appendix L.

6.1.2 SOIL VAPOR MONITORING RESULTS

During operation of the biovent system in 2007, soil vapor conditions including fixed gases (O_2, CO_2, and CH_4), total organic vapor, and pressure were periodically measured within the nested vapor monitoring points (VP-1 through VP-7) installed 25- and 50-feet from the biovent wells associated with the expanded system. Each of the nested vapor monitoring points consists of a monitoring probe installed within the upper portion of the smear zone and a second probe installed in the deeper portions of the smear zone. Soil vapor field measurements were collected beginning in

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October 9, 2007 while the system was active and then 2, 4, 8, 24, 32, and 52 hours following shut down of the biovent system.

Due to the groundwater elevation at the time of measurement, several of the deeper vapor monitoring points could be monitored. Soil vapor within each vapor monitoring point was analyzed for fixed gases and total organic vapors. The ambient pressure or vacuum within each vapor monitoring point (if acquired) were measured using a portable digital manometer with a scale range of approximately 0 to 10 inches of water. Instrumentation was connected to the monitoring points via a ball valve installed at the terminus of each monitoring point. Results of field measurements collected from accessible vapor monitoring points during 2007 are presented in Appendix M.

Figure 6-3 through 6-17 present the results of fixed gas measurement collected from soil vapor monitoring points VP-1 through VP-7 in October 2007. Comparison of the fixed gas concentrations measured during periods when the system was active and following shut down indicates that the system has a measurable impact on subsurface vapor composition within the intended limits of the systems. A significant (>20%) decrease in subsurface O_2 content accompanied with a measureable increase in CO_2 concentrations was observed in nearly each of the soil vapor probes when comparing samples collected during system operation and 48 hours after shut down. Such measurements indicate the biovent system is enhancing aerobic biodegradation of hydrocarbon impacts at these locations.

6.1.3 GROUNDWATER MONITORING RESULTS

Groundwater samples were collected from the shallow monitoring wells (GPW-1S through GPW-5S, TH-1S, TH-2, and TH-3) and intermediate groundwater monitoring wells (GPW-1I, GPW-2I, GPW-3I and TH-1I) in June 2008 for analysis of the dissolved phase constituents of concern. Results for these wells from sampling events in December 2006 and December 2007 are also included for reference. In addition, a groundwater sample was collected from shallow monitoring wells TH-1S and TH-2 in April 2008. Table 6-1 presents a summary of the constituents of concern measured in groundwater samples collected between 2006 and 2008. Concentrations of the volatile constituents of concern were only detected in samples collected from TH-1S and TH-2 during this timeframe. Dissolved phase concentrations of benzene and ethylbenzene exceeded the remedial goals (i.e., USEPA MCLs) in one or more samples collected from these two wells.

A comparison of the reported total dissolved phase BTEX concentration compared to the groundwater elevation over time is provided as Figures 6-18 and 6-19 for monitoring wells TH-1S and TH-2 respectively. An overall decreasing

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trend has been observed in dissolved phase BTEX concentrations measured in well TH-2. This decrease is likely attributed to operation of the biovent system beneath the Park. Concentrations of total BTEX measured in groundwater samples collected from well TH-1S appear to be constant over time and fluctuate in response to changes in the water table. Monitoring well TH-1S is located outside of the influence of the biovent system.

Dissolved phase natural attenuation indicators were not analyzed during the Spring 2008 sampling event, as they are typically collected as part of monitoring conducted in the Fall when lower water table conditions persist in the Buried Valley Aquifer. Table 6-2 summarizes the dissolved phase natural attenuation indicators for groundwater samples collected during historic monitoring events in Gulf Park. Evaluation the efficacy of natural attenuation to degrade dissolved phase petroleum hydrocarbons will be included in future reports, as additional data is collected.

A comparison of total BTEX versus time for groundwater samples collected from shallow monitoring wells GPW-1S through GPW-5S is provided on Figure 6-20. A measureable concentration of total BTEX in groundwater was last reported in any of these wells in November 2007. This decrease in total BTEX concentrations observed in these wells installed across Gulf Park is attributable to a combination of intrinsic biodegradation and historic biovent system operations.

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