Conceptual Groundwater Remedy Report for the ChevronTexaco Cincinnati Facility

Draft Revision 0

Prepared for:

ChevronTexaco

Chevron Environmental Management Company
P.O. Box 96
North Bend, OH 45052

Prepared by:

ChevronTexaco Cincinnati
Groundwater Task Force

July 2003

Table of Contents

Table of Contents (Continued)

Appendices

List of Figures

Note: Figures are placed at the end of their respective sections.

List of Figures (Continued)

List of Tables

Acronyms and Abbreviations

bgs	below ground surface
BTEX	benzene, toluene, ethylbenzene and xylenes
CAO	Corrective Action Objectives
CAS	Corrective Action Strategy
CCF	ChevronTexaco Cincinnati Facility
CMI	Corrective Measures Implementation
CMS	Corrective Measures Study
COC	Constituent of Concern
Consent Order	Administrative Order on Consent
COPC	Contaminant of Potential Concern
CPT	Cone penetrometer testing
DEHP	bis(2-ethylhexyl)phthalate
EI	environmental indicator
gpm	gallons per minute
GW CMS	Groundwater Corrective Measures Study
HSVE	Horizontal soil vapor extraction
IC	institutional controls
IM	interim measures
kg	kilogram
LIF	laser-induced fluorescence
LNAPL	Light Non-Aqueous Phase Liquid
MCL	maximum contaminant level
MGD	million gallons per day
mg/L	milligrams/Liter
MNA	monitored natural attenuation
msl	mean sea level
Ohio VAP	Ohio Voluntary Action Program
POC	point of compliance
PMW	performance monitoring well
PRG	preliminary remediation goals
RCRA	Resource Conservation and Recovery Act
RFI	RCRA Facility Investigation
RMS	root mean squared
ROST	Rapid Optical Sensor Technology
SR	State Route
SVE	Soil Vapor Extraction
SWMU	Solid Waste Management Unit
SWQ	Southwest Quadrant
T	Transmissivity
TPH	total petroleum hydrocarbons
µg/L	micrograms/Liter
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey

Executive Summary

Background

ChevronTexaco Products Company (Chevron) owns a former petroleum refinery site near Hooven, Ohio. Gulf Oil Corporation constructed and operated the refinery from 1931 to 1985. Chevron acquired and assumed operation of the refinery in 1985, and ceased refining operations in 1986. Since the closure of the refinery, nearly all of the aboveground structures have been demolished and removed from the site; only a few structures related to remediation and maintenance activities remain at the facility. During the period of refinery operation, refined petroleum products, primarily gasoline and diesel, were released to soil and groundwater, resulting in the presence of light non-aqueous phase liquid (LNAPL) in the subsurface. In addition, oily sludges and other solid wastes were also disposed of at the facility.

The presence of LNAPL was discovered beneath the facility in 1985, when an oily sheen was observed seeping into the Great Miami River in the southeast portion of the facility. Since 1985, groundwater pumping and LNAPL removal efforts initiated by Chevron have contained and removed LNAPL and dissolved-phase hydrocarbon. During this time period, remedial activities have taken place under the name of Chevron Products Company, Chevron Environmental Management Company, and ChevronTexaco. For the purposes of this report, these organizations should all be considered to be the same entity. Activities that have taken place in an historical context generally have been referred to as involving "Chevron," whereas current and future activities generally are referred to as involving "ChevronTexaco."

In 1993, Chevron entered into an Administrative Order on Consent (Consent Order) with the United States Environmental Protection Agency (USEPA) Region 5 to perform a Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI) and a Corrective Measures Study (CMS). The RFI was completed and approved by USEPA in 2000. The CMS was divided by media, with one CMS for soils/sludges and one CMS for groundwater (GW CMS). The CMS reports were submitted separately to USEPA Region 5.

The GW CMS selected a remedial alternative of "containment." Containment is currently achieved by controlling hydraulic gradients via groundwater pumping. Because containment of the LNAPL and dissolved-phase plume could be accomplished in a number of ways, the GW CMS also specified that the containment alternative be "optimized" in order to determine the most protective, efficient, and cost-effective method to maintain containment. The optimization has resulted in recommended interim and final remedies for groundwater beneath the facility, which are presented in this report.

Corrective Action Objectives

The GW CMS presents a tiered approach of identifying Corrective Action Objectives (CAO) in the form of Short-Term Protectiveness Goals, Intermediate Performance Goals, and Final Cleanup Goals.

Short-Term Protectiveness Goals

- Ensure that humans are not exposed to unacceptable levels of contamination; and
- Ensure that contaminated groundwater is not migrating at levels of concern beyond its current extent.

The Short-Term Protectiveness Goals have been met and are documented in the Environmental Indicators (EI) reports, both of which were submitted to USEPA in 2001.

Intermediate Performance Goals

- Protect human health and the environment;
- Recover liquid hydrocarbon (LNAPL) to the extent practicable, concentrating in the LNAPL high-grade areas identified in this report;
- Remove the recoverable hydrocarbon under Hooven to the extent practicable, using the Horizontal Soil Vapor Extraction (HSVE) system;
- Maintain containment of the residual LNAPL and the dissolved-phase hydrocarbon plume through natural stabilization and monitored natural attenuation; and
- Return the site to productive use for the surrounding community.

Final Cleanup Goals

- Protect human health and environment;
- Achieve media cleanup objectives established to ensure continued protection; and
- Control the sources of releases to reduce or eliminate, to the extent practicable, further releases of hazardous constituents that may pose a threat to human health and the environment.

The remedies presented in this report are consistent with the Containment Alternative recommended in the Groundwater CMS Report. They are based on more recent technical interpretations that allow a focused and performance-based program such that long-term environmental objectives are eventually met at the facility. A fundamental finding of the CMS report is that there are no current risk-drivers based on the current hydraulic control of the groundwater and current use of the site. The Human Health Environmental Indicators Report (E&E, 2001) and the Groundwater Environmental Indicators Report (CEC, 2001), both of which were submitted to USEPA in 2001, indicate that short-term goals have been met for the current and projected future conditions at the facility. USEPA approved the Groundwater Environmental Indicators Report in June 2002, and the Human Health Environmental Indicators Report is under review. Potential risks associated with the conceptual land use plan will be managed with a combination of engineering and institutional controls that will be developed in conjunction with USEPA. Based on the current acceptable risk profile and a mechanism to address future exposure through controls instituted as part of the proposed redevelopment, the groundwater remediation program can be based on practicability.

The past (since 1985) and current program of pumping and treating large volumes of groundwater with associated LNAPL recovery has served the initial purposes and program objectives of containing plumes and removing hydrocarbon mass but lacks specific endpoints and schedules for phasing out the ongoing and open-ended operations of the LNAPL recovery program. The proposed strategy optimizes the recovery process, sets field-based performance measures of success, and provides the transition strategy to a long-term natural attenuation approach for the remaining LNAPL plume that is not practicably recovered.

This plan is also compatible with beginning the process for redevelopment of the property which is supported by the neighboring community. Returning portions of the property to productive use through phase-out and completion of major groundwater remediation activities in less than a decade is a fundamental cornerstone of the remedy program. The planned land reuse is ultimately linked through both performance and schedule to the groundwater and LNAPL recovery endpoints.

LNAPL will be recovered to the extent practicable by transitioning to a focused recovery approach that takes advantage of seasonal natural low water table conditions. In addition to seasonal-only recovery, the larger footprint of the plume has been delineated into smaller focus areas. These smaller portions have a higher degree of uncertainty than other areas with respect to potential plume mobility. The smaller areas also contain monitoring wells that have more frequent and greater magnitude observations of LNAPL remaining in them. The transition to this focused recovery program will include a field monitoring and verification program to ensure no unacceptable outcomes are present.

Safeguards will be put or left in place long term that will ensure the footprint of remaining groundwater and LNAPL impacts are essentially immobile under natural gradients (i.e., no pumping necessary). A high degree of certainty will be supported by associated monitoring programs of impacted media.

Site Background

Site History

Chevron owns the site of a former fuels and asphalt petroleum refinery near Hooven in Whitewater Township, Ohio, north of the intersection of State Route (SR) 128 and U.S. Highway 50. The site is approximately 20 miles west of Cincinnati, Ohio, and occupies approximately 600 acres. The former refinery is bordered by the Great Miami River to the east, northeast, and southeast, and by the community of Hooven and SR 128 to the west. Islands No. 1 and No. 2 are also part of the site. U.S. Highway 50 runs just south of the site. Refinery operations occurred on approximately 250 acres, consisting of buildings, refinery process equipment, storage tanks, and roads. The remainder of the site consists of tracts of upland and bottomland forest, open brushy areas, and isolated wetlands, which served as an undeveloped zone along the river.

Gulf Oil Corporation constructed and operated the refinery from 1931 to 1985. In 1985, Chevron acquired and assumed operation of the refinery, and ceased refining operations in May 1986. The major products produced at the refinery were gasoline, jet fuels, diesel, home-heating fuels, liquefied petroleum gas, asphalt, and sulfur. Since the refinery closed, nearly all of the aboveground buildings and structures have been demolished and removed from the facility. Only a few structures currently remain on the site. Voluntary removal actions have been conducted at several high priority Solid Waste Management Units (SWMUs) and Areas of Concern (AOCs). The former operating portion of the facility now consists of a variety of lagoons, foundations, land disposal areas, ditches, disturbed open space, and groundwater remediation facilities, largely surrounded by a flood protection berm.

While the refinery was in operation, refined petroleum products were inadvertently released to the surface and subsurface. The petroleum products moved downward through the soil, leaving residual hydrocarbons in the subsurface. Where enough product was released, a layer of petroleum product (LNAPL) accumulated in the water table zone. Water table fluctuations over the years and the history of LNAPL release and movement have resulted in a relatively thick hydrocarbon smear zone in the central areas of the plume, but there is only a thin smear zone in the lateral and distal transport directions, such as in Hooven and the Southwest Quadrant (SWQ) area. The nature of the LNAPL impacts and distribution has lead to three contiguous areas of interest: 1) the northern property plume, underlaying the former refinery property; 2) the Hooven area, comprised of an off-site plume underlying the adjacent community; and 3) the SWQ, the distal downstream portions of the LNAPL plume off site to the south.

The site is underlain by high permeability glacial outwash deposits with hydraulic conductivity ranging from about 100 to 1,300 feet/day. Groundwater and the Great Miami River are in direct hydraulic communication, and groundwater flows in the same general direction as the river (south) in the site vicinity. Groundwater and the river are both controlled by the bedrock structure of the system (URS, 2001b). Despite the high groundwater transmissivity, current site-specific estimates of LNAPL transmissivity are four to seven orders of magnitude smaller, suggesting limited remaining mobility and recoverability.

Remediation History

In early 1985, in a response to an LNAPL sheen emanating from the river bank adjacent to the then Gulf Oil refinery, focused groundwater and initial LNAPL recovery was begun to contain the LNAPL and dissolved-phase plumes. Chevron assumed ownership of the property in late 1985 and continued environmental remediation activities. The past 18 years of groundwater pumping have resulted in about 1 billion gallons per year of groundwater production, and a cumulative LNAPL recovery of about 3.5 million gallons (original losses during operation of the refinery are unknown and occurred over a period nearly 55 years). Seventy-three percent of the cumulative LNAPL recovery occurred during the first three years of pumping at just two to three recovery wells, with the remaining 27% coming in the last 14 years from these three recovery wells, plus several other wells. The LNAPL mass recovered using the soil vapor extraction system installed in 1999 represents only a small fraction of the cumulative amount recovered since 1985.

The LNAPL recovery has strongly diminished over time (asymptotic), indicating both that the recoverable fraction remaining is relatively small and that the inherent mobility of the LNAPL plume has been greatly reduced. Recovery rates over the last few years are only a fraction of initial recovery rates and are strongly linked to seasonal low water tables or periodic drought conditions that expose the lower portion of the smear zone. These conditions allow LNAPL to drain to recovery locations under increased gradients created by pumping large volumes of groundwater. This can be observed in the brief increase in the LNAPL production during the 1999 drought where unusual low water table conditions exposed drainable portions of the smear zone for new recovery. This low water table and recovery relationship will be a significant component of the planned optimized remediation actions.

The significantly diminished LNAPL recovery and associated decrease in LNAPL transmissivity has resulted in a relative increase in the proportion of produced groundwater to LNAPL, and the cost of operating the recovery program has essentially reached a plateau. However, less LNAPL is being recovered (except during drought conditions) with less benefit while, at the same time, estimates of average natural mass loss rates suggest more mass is typically destroyed by degradation in the dissolved and vapor phases than can be recovered by the existing engineered remediation system(s). Theory and calculations that support this statement are included in this report.

Beyond the liquid LNAPL recovery and plume containment program, horizontal soil vapor extraction (HSVE) was implemented beneath the community of Hooven in 1999 to ensure that there was not an unacceptable vapor exposure issue. The HSVE system also serves as an additional mass recovery measure. Like the LNAPL recovery program, the HSVE system has experienced strongly diminished returns as the available vapor has been removed. Only seasonal vapor recovery is possible when the water table is low enough to expose the smear zone beneath Hooven. The HSVE system will be a component of the additional optimized recovery actions proposed herein.

Current Plume State

Because natural porous materials have an ability to retain residual LNAPL, a finite volume of LNAPL released to the subsurface has a corresponding finite area of expansion. Site-specific evaluations that are presented in this report indicate that the remaining LNAPL plume is likely immobilized without pumping groundwater by the combination of natural resistance to LNAPL movement in water-wet sediments, and through the combined remediation and natural mass losses to the body of the plume since refinery operations ceased in the mid-1980s. A static (created by pumping or natural containment) LNAPL footprint also develops steady-state dissolved-phase and vapor-phase halos, and thus presents a static holistic plume footprint amenable to risk management without the threat of future expansion to new receptors. As natural mass loss continues, there will be a diminishment of plume mass and concentration of key contaminants of concern through time, indicating that potential residual risk will also diminish through time. A key facet to the remedy program is verification of plume state and its management, particularly at sensitive areas such as the river interface, Hooven, and the SWQ.

Context of Final Remedy and Land Reuse

ChevronTexaco is currently at a point in time where remaining phases of the long-term remedies related to groundwater and LNAPL need to be identified. To guide this analysis, ChevronTexaco identified the following environmental objectives:

- Prevent adverse human and ecological exposure to site-related contaminants of concern.
- Deplete subsurface hydrocarbons to the extent practical. Chevron has defined practical as the endpoint that can be achieved using the existing cleanup systems (pump-and-treat and/or soil vapor extraction) and expansion thereof in those circumstances where further investments provide tangible benefits.
- Make available for a safe and beneficial reuse the areas of the property that are compatible with the remaining contaminants of concern and the land use plans for the area. The use of engineering controls, such as barriers, will also be evaluated along with appropriate use of institutional controls.

Building on these objectives, this document identifies a path forward for the hydrocarbon-impacted groundwater. Consideration is given to both surface and subsurface issues since they are interrelated. Principle components include the following:

Near Term Restoration of Beneficial Land Use

Make the property available for beneficial reuse. This will most likely begin with those areas where conditions will be compatible with recreational uses. These conditions should be met after the planned soil removal projects are underway or completed – probably within a five-year time frame. The plan currently includes a green belt with trails along the Great Miami River (northern portion of the facility) and an active recreational area in the north central zone. In addition to being an asset to the community, the recreational/open space may enhance the commercial value of the remaining property.

Further Depletion of Released LNAPL

In the southern portion of the property, there appears to be an opportunity to further diminish the potential for subsurface migration of LNAPL via aggressive groundwater pumping with associated LNAPL recovery. This will be accomplished by continuing to shift current production capacity from areas of low potential benefit to areas of high potential benefit as described in the next section.

Alternative Measures for Management of Potential Product Seeps

Recovery of approximately 3.5 million gallons of LNAPL and inward gradients has ensured the prevention of any further release of petroleum liquids to the river. Given a desire to end active pumping along the river, alternative management measures need to be evaluated. Options include a wall that partially penetrates the saturated alluvium, constructed capillary barriers at the river, and/or aggressive depletion of potentially mobile LNAPL near the river. Each option, or combination of options, has advantages and disadvantages. A study involving controlled reductions of pumping at the river is under review and, if feasible, would be reviewed with USEPA before implementation. A field-based study such as this would provide a better basis for selection and design of seep control measures.

Further Restoration of Beneficial Land Use

The proposed land use in the remaining portions of the facility is light industrial and commercial. As active soil and groundwater cleanup activities end in a select portion of the site, it can be made available for reuse. The time frame in which this will occur is constrained by the local real estate markets and the time required to complete active cleanup measures in each area.

Institutional Controls

Institutional controls will be placed on all impacted properties. At a minimum, this will include a prohibition on groundwater production and construction of basements in areas where petroleum liquids have been encountered in the subsurface. Additional measures, such as engineering controls (i.e., slab construction, vapor barriers, utility modifications, etc.), will also be evaluated as property reuse becomes more defined.

Groundwater Monitoring and Plume Verification

Assurances that the selected measures are protective will be provided through subsurface monitoring of appropriate media, such as soil, groundwater, and/or vapor. At a minimum, this involves tracking potential movement of LNAPL and contaminants of concern in groundwater and through fluid level gauging. Monitoring will occur at the point of compliance and at early warning locations. Inclusive with the monitoring plan are contingency plans for plausible adverse conditions. Prior to defining this plan in detail, additional field investigations are proposed to further delineate conditions at the southern end of the facility to assist in placement of sentry wells as a part of the point-of-compliance network.

Through these actions, the potential for adverse exposures will be minimized, the former facility has the potential to become a commercial/recreational asset to the community, and ChevronTexaco will optimally manage the groundwater liabilities associated with historic refining activities at the facility.

Proposed Interim and Final Remedies

Because of the anticipated conditions of reduced recovery and plume mobility, ChevronTexaco rigorously evaluated existing site information in an effort to identify the focused recovery efforts that will result in the maximum benefit (i.e., stabilizing the plume and allowing transition to passive natural containment). As a result of our evaluation, we believe natural processes are currently containing the plume and, during the focused intermediate recovery efforts, additional field data collection will be implemented to verify plume stability.

The proposed intermediate remedy begins with better defining the containment option identified in the GW CMS and setting a more complete conceptual model for LNAPL characterization and distribution. Containment in the context of this report includes an aggressive interim plan to maximize recovery of the remaining drainable LNAPL and diminish any potential residual mobility of the LNAPL plume in localized areas. This intermediate plan essentially brings to a close the practicable LNAPL recovery and also provides additional assurance that there is no remaining LNAPL plume mobility.

The current program of pumping almost every day of the year for hydraulic control of the LNAPL and dissolved-phase plumes with LNAPL recovery occurring only during low water positions has reached diminishing returns and is proposed to be replaced with a new program. The new program takes advantage of the natural stability of the plumes (i.e., containment) and initiates a seasonally-driven recovery program of LNAPL recovery. It also includes a performance monitoring network that supports the planned changes with maintenance of the plume boundaries and groundwater environmental indicators. After two to three key low water table conditions (e.g., 4 to 10 years) that provide maximum recovery opportunities, the intermediate program will phase into a final program where pumping is phased out entirely, and the natural containment and continued natural depletion of hydrocarbon mass is key in protecting human health and the environment and eventually meeting long-term cleanup goals. Estimates have been made that between 110,000 to 210,000 gallons of equivalent volume on average are lost to natural degradation mechanisms in the dissolved and vapor phases on an annual basis.

Institutional and other plume management control options are being evaluated and will be implemented in the land use plan to ensure continued public and environmental health and safety.

Development of Program Milestones and Endpoints

Both the intermediate focused pumping program and the long-term natural conditions programs contain field performance milestones that are developed in this report. The intermediate program is based on strategic focusing of groundwater pumping and LNAPL recovery to carefully selected small areas that have the highest potential for practicable recovery, while simultaneously reducing any remaining LNAPL mobility and increasing the certainty of plume stability. This focused LNAPL recovery program was developed using existing site groundwater and LNAPL records for the past 17 years. These records have helped to identify areas that have either not been significantly influenced by the existing program or are areas that could be further depleted of remaining LNAPL using the existing and new site infrastructure of pumping and/or vapor extraction wells. Areas having higher potential sensitivity, such as near the river or the Hooven area, were also considered in the evaluation with specific field-based performance measures developed as part of the program to protect those sensitive areas. An example of a performance measure may be to reduce the measurable thickness and frequency of occurrence of LNAPL in monitoring wells in these focus areas to a state where it is only observed a relatively small percentage of time (weeks), and then may only occur at a few tenths of a foot. These conditions are quite different, and indicate a significant change in LNAPL plume state, than those observed during the first few years of LNAPL management and recovery.

A critical element of the intermediate plan is development of a water level trigger that signals when seasonal focused LNAPL recovery will start and end. This trigger is based on site records, such as hydrographs, that clearly show when LNAPL begins to enter monitoring wells as a result of lower water tables that expose the smear zone and allow drainage of the LNAPL. The use of seasonal triggers as an indicator for when to initiate remedial activities has been in place and used successfully for several years at the Island, Gulf Park, and Hooven areas for the soil vapor extraction and air injection systems located in those areas. Use of this natural lowering of the water table and the associated access to the drainable portion of the smear zone are fundamental to optimizing the LNAPL recovery. Recent recovery experience suggests that virtually all the LNAPL recovery occurs during these low water table stands.

Specific intermediate milestones are currently conceptual as ongoing groundwater and remediation modeling is completed to better guide our expectations and additional data evaluations. It is generally expected that the cleanup milestones will include an evaluation of expected diminishing returns of LNAPL recovery from the new high grade areas, and diminishment in both the frequency and magnitude of seasonal LNAPL observations in wells. Based on the modeling results and the direction it provides in site-specific evaluations, specific measures of LNAPL recovery completion will be defined.

The groundwater and remediation modeling will also be used to assess when, using existing and new wells, the smaller areas identified in the interim plan can be further depleted of LNAPL and at what pumping rates, with the goal of maximizing recovery over at least two low water table events. Low water table events as characterized for the Cincinnati site are those events associated with very dry weather conditions that result in prolonged periods (30 to 60 days) of a lower than average water table. These drought-like events occur naturally every three to five years. However, annual low water table positions generally allow some LNAPL recovery, and it is these events that will be evaluated with modeling to assess the feasibility of lowering the water table in some additional incremental amount to achieve increased LNAPL recovery.

In addition to modeling, a field investigation effort is planned at the southern portion of the plume to evaluate the LNAPL plume state and its potential for lateral mobility. This effort includes the use of laser-induced fluorescence (LIF) to detect the presence of LNAPL in pore spaces, combined with soil and water sampling activities at two locations near the leading edge of the plume in the SWQ area. This effort would also include scenarios where some high capacity pumping wells are turned off for a period of time in order to monitor for potential plume mobility that may result from reversed gradients. In addition, this investigation will better characterize the LNAPL plume conditions in the subsurface and their likely relationship to the dissolved-phase plume and downstream points of compliance that will be maintained at non-detect levels for perpetuity. Field work is also being considered in the northern portion of the site to evaluate the smear zone in specific areas and near the river bank in the southern portion to evaluate the interaction of groundwater and surface water features.

Intermediate program goals will be phased into long-term goals after two or three focused recovery periods have been achieved in each area of the plume footprint where practicable recovery can be implemented. Historical records and past recovery estimates suggest that most of the attainable LNAPL drainage to a recovery well occurs over the first drainage event, with what little may additionally be recovered during the subsequent drainage event. LNAPL will continue to be measurable in some monitoring wells at various times after completing the intermediate program activities, particularly at low water conditions. However, results of this program are expected to leave most wells without any observable LNAPL much of the year, and less than about 0.5 feet in wells where LNAPL may accumulate during any short-term drought conditions. Water table fluctuations typically submerge much of the remaining observable LNAPL as will be shown through evaluations in the report. When LNAPL is not observed in wells, it is fully immobile. When it is observed in wells, it is locally drainable to the well to some extent, but it does not necessarily imply plume-wide mobility.

Long-term goals recognize this remaining hydrocarbon mass will require management because of the technical impracticability associated with its complete removal and the limited risk benefit to recovery past these practical constraints. The intermediate plan takes the plume to a state where it is essentially immobile with a high degree of certainty, monitors and protects potential receptors, and tracks the ongoing natural depletion of contaminants of concern. Therefore, the long-term goals allow as full a property reuse as possible while plume stability is monitored. Over time, an improvement in water quality, as measured by dissolved-phase compounds, should be observed as well.

1.0 Introduction

1.1 Overview

ChevronTexaco Products Company (Chevron) owns a former refinery site near Hooven, Ohio, 20 miles west of Cincinnati, north of the intersection of State Route (SR) 128 and U.S. Highway 50. The former refinery occupies approximately 600 acres and is bordered by the Great Miami River to the east, northeast, and southeast, and by the community of Hooven and SR 128 to the west (Figure 1-1). The facility operated from 1931 to mid-1986. After the refinery was closed, most of the aboveground structures were removed. While the refinery was in operation, refined petroleum products, primarily gasoline and diesel, were released to soil and groundwater, resulting in the presence of light non-aqueous phase liquid (LNAPL) in the subsurface. In addition, oily sludges and other solid wastes were disposed of at the facility.

In 1993, Chevron entered into an Administrative Order on Consent (Consent Order) with the U.S. Environmental Protection Agency (USEPA) to perform a Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI) and Corrective Measures Study (CMS). The RFI was completed and approved by USEPA in 2000. With USEPA concurrence, the CMS was divided according to media, with one CMS for soils/sludges and the other for groundwater (the Groundwater Corrective Measures Study or GW CMS). The soils/sludges CMS and GW CMS reports were submitted separately to USEPA Region 5.

The GW CMS selected a remedial alternative of "containment." The GW CMS also specified that the selected alternative be "optimized." The purpose of this document is to present the results of the optimization of the selected groundwater remedial alternative, which include descriptions of the proposed interim and final remedies, and an implementation schedule.

Chevron has been involved with remedial activities at this site since 1985. During this time period, remedial activities have taken place under the name of Chevron Products Company, Chevron Environmental Management Company, and ChevronTexaco. For the purposes of this report, these organizations should all be considered to be the same entity. Activities that have taken place in an historical context generally have been referred to as involving “Chevron,” whereas current and future activities generally are referred to as involving “ChevronTexaco.”

1.2 Site History

Gulf Oil Corporation constructed and operated the refinery from 1931 to 1985. In 1985, Chevron acquired and assumed operation of the refinery. The major products produced at the refinery were gasoline, jet fuels, diesel, home-heating fuels, liquefied petroleum gas, asphalt, and sulfur. Since 1986 when the refinery closed, nearly all of the aboveground buildings and structures have been demolished and removed from the facility. Only a few structures remain on the site.

While the refinery was in operation, refined petroleum product was released to the surface and subsurface. The petroleum product moved downward through the soil, leaving residual hydrocarbons in the subsurface. Where enough product was released, a layer of petroleum product (LNAPL) accumulated in the water table zone. Water table fluctuations over the years and the history of LNAPL release and movement have resulted in a relatively thick hydrocarbon smear zone in the central areas of the plume. Only a thin smear zone exists in the lateral and distal transport directions, such as in Hooven and the Southwest Quadrant (SWQ). Hydrocarbon constituents in the LNAPL also have become dissolved in groundwater at the site. Currently, the LNAPL and dissolved-phase plume footprint covers about 250 acres.

Since 1985 when the plume was discovered, several million gallons of LNAPL have been recovered, but some LNAPL remains and periodically appears in wells, particularly at low water table stands. The LNAPL plume generally is composed of about 80% gasoline and 20% diesel, with some other petroleum fractions in local areas. As discussed in the GW CMS, benzene is the primary constituent of concern (COC).

Groundwater Interim Measures (IM) remediation performed at the facility since early 1985 has focused on: 1) hydraulic control of the LNAPL and dissolved-phase hydrocarbons in the groundwater achieved by pumping groundwater and creating an inward hydraulic gradient; 2) LNAPL recovery, especially during low water table conditions when LNAPL is able to drain toward wells; and 3) soil vapor extraction at Islands No. 1 and No. 2 and Hooven (added during the late 1990s).

Ongoing groundwater monitoring is performed under the terms of the Consent Order to verify hydraulic containment and assess changes in LNAPL thickness and dissolved contaminant concentrations over time. Figure 1-2 shows the network of monitoring wells at the site, as well as recovery wells, horizontal soil vapor extraction (HSVE) wells, and other site features.

1.3 Groundwater CMS

On October 29, 2001, ChevronTexaco submitted the *Chevron Cincinnati Facility Groundwater Corrective Measures Study, Revision 0, October 26, 2001* (URS, 2001b) to USEPA Region 5. The GW CMS evaluated a series of remedial alternatives based on Corrective Action Objectives (CAOs) and engineering criteria. The GW CMS is under review by the USEPA.

Corrective Action Objectives

The Groundwater CMS presented a tiered approach of identifying CAOs in the form of Short-Term Protectiveness Goals, Intermediate Performance Goals, and Final Cleanup Goals. These objectives are consistent with the approach outlined in the *Handbook of Groundwater Protection and Cleanup Policies for RCRA Corrective Action* (USEPA, 2000).

The Short-Term Protectiveness Goals are:

1. Ensure that humans are not being exposed to unacceptable levels of contamination; and

2. Ensure that contaminated groundwater is not migrating above levels of concern beyond its current extent.

The Human Health Environmental Indicators Report (E&E, 2001) and the Groundwater Environmental Indicators Report (CEC, 2001), both of which were submitted to USEPA in 2001, indicate that these goals have been met for the current and projected future conditions at the facility. USEPA approved the Groundwater Environmental Indicators Report in June 2002. The Human Health Environmental Indicators Report is under review by USEPA.

The Intermediate Performance Goals are:

1. Protect human health and the environment;
2. Remove recoverable LNAPL to the extent practicable, concentrating in the LNAPL high-grade areas identified in this report;
3. Remove the recoverable hydrocarbon under Hooven, to the extent practicable, using the Horizontal Soil Vapor Extraction (HSVE) system;
4. Maintain containment of the residual LNAPL and the dissolved-phase hydrocarbon plume through natural stabilization and monitored natural attenuation; and
5. Return the site to productive use for the surrounding community.

The Final Cleanup Goals are:

1. Protect human health and the environment;
2. Achieve media cleanup objectives established to ensure protection; and
3. Control the sources of releases to reduce or eliminate, to the extent practicable, further releases of hazardous constituents that may pose a threat to human health and the environment.

Regulatory Strategy

In the GW CMS, part of the regulatory strategy was the negotiation of a new Corrective Measures Implementation (CMI) Order that will have a defined period of 10 to15 years and would focus on the intermediate performance goals presented above. At the end of the 10- to 15-year period, a new consent order focused on long-term monitoring would be negotiated. Based on the results of optimization of the selected remedial alternative, it may be advantageous to the stakeholders to modify this strategy to best accommodate the optimization, e.g., include different time periods for the orders.

Since the submittal of the GW CMS, ChevronTexaco has also investigated other possible regulatory strategies, such as the USEPA Region 6 Corrective Action Strategy (CAS) Program, which may present benefits to the stakeholders not available under a conventional consent order.

Recommended Alternative of Containment

Because even the most aggressive and expensive of the alternatives evaluated in the GW CMS would take at least 100 years to meet the final cleanup goals, the alternative of containment was recommended. The containment alternative includes the following elements:

- Contain the dissolved-phase and LNAPL plumes to prevent contaminant migration.
- Source removal – recover LNAPL to the extent practicable, utilizing the LNAPL recovery wells and the HSVE wells under Hooven.
- Rely on the long-term dissolution of LNAPL constituents and natural attenuation processes to deplete the contaminant mass and prevent the migration of the dissolved-phase plume.
- Implement and monitor institutional controls to prevent the use of contaminated groundwater and prevent the construction of basements on site.

The Short-Term Protectiveness Goals have already been met at the site, as documented by the Environmental Indicators (EI) reports. The containment alternative will meet the Intermediate Performance Goals and Final Cleanup Goals listed above.

Optimization of Recommended Alternative

The goal of containment is to provide long-term maintenance of stable LNAPL and dissolved-phase plumes to allow natural processes to gradually degrade the hydrocarbons and restore groundwater quality to cleanup levels. Because of the long-term nature of this activity, the goal of the optimization is to identify the most efficient (with regard to cost, labor, and future land use issues) methods of containment that are protective of human health and the environment. As discussed in Section 7.3.1 of the GW CMS, containment potentially could be accomplished in a number of ways. As discussed in the GW CMS, options to accomplish containment could include the following:

- Continue the current practice of groundwater pump-and-treat;
- Construct a barrier wall(s);

- Implement a combination of barrier walls and pump-and-treat; and
- Remove LNAPL to the point that it is no longer mobile and then rely on natural attenuation to control the migration of the dissolved-phase plume.

The GW CMS specifies that, if the containment alternative were selected, an options analysis would be conducted to determine the optimum way to implement the containment of the dissolved-phase and LNAPL plumes. The GW CMS also discussed the use of numerical finite-difference groundwater flow model (MODFLOW) to optimize hydraulic containment by determining the minimum pumping rate that could achieve containment, to help optimize LNAPL recovery, and to evaluate the effectiveness of a barrier wall.

This report presents the results of the containment optimization process and describes the proposed Interim and Final Remedy for the groundwater and LNAPL.

1.4 Scope of Work

In order to optimize the containment alternative, the following tasks were completed:

- Evaluate the mobility of the remaining LNAPL beneath the ChevronTexaco Cincinnati Facility (CCF);
- Evaluate both engineered and natural mechanisms for mass reduction of the LNAPL;
- Determine interim remedial activities that would maximize LNAPL immobility;
- Evaluate the effectiveness of natural attenuation of the dissolved-phase hydrocarbon plume under natural hydraulic gradients; and
- Design a long-term monitoring program to ensure the ongoing stability of the hydrocarbon footprint.

These tasks were achieved by the following activities.

Evaluate LNAPL Mobility

The character and extent of the LNAPL at the facility were carefully reviewed, incorporating historical and new data. The typical mechanisms and limiting factors for LNAPL releases and migration applicable to the facility's hydrogeological setting were studied and compared to existing site conditions. Historical LNAPL recovery results and subsequent LNAPL plume shrinkage were also evaluated to determine endpoints at which the LNAPL plume would not migrate under a "no pumping" scenario. LNAPL mass losses from engineered remediation and natural processes were compared to show that active remediation has become progressively less effective with time and that LNAPL mass loss will continue in the absence of active remediation.

In conjunction with the "no pumping" scenario, various configurations of subsurface barrier walls were evaluated to prevent potential seepage of LNAPL into the Great Miami River.

Evaluate Dissolved-Phase Plume Mobility

Evaluation of the dissolved-phase plume included the following elements:

- Groundwater modeling to simulate natural hydraulic gradients and future changes in the extent of the dissolved-phase plume under natural hydraulic gradients using conservative rates of natural attenuation;
- Evaluation of recently acquired (April 2002) groundwater natural attenuation data for the SWQ; and
- Evaluation of results of natural attenuation processes occurring in other areas around the facility, such as the Islands and the Gulf Park.

Develop the Interim and Final Remedies

Based on the evaluation of LNAPL mobility and natural attenuation of the dissolved-phase plume, the containment alternative was developed into the interim and final remedies, which is presented in detail in this report. The Interim and Final Remedies include detailed monitoring plans to ensure that the LNAPL and dissolved-phase plumes will remain stable, will not migrate laterally, and will dissipate over time, and that groundwater cleanup standards eventually will be achieved.

1.5 Summary of the Interim and Final Remedies

Interim Remedy

The proposed intermediate remedy begins with better defining the containment option identified in the GW CMS and setting a more complete conceptual model for LNAPL characterization and distribution. Containment in the context of this report includes an aggressive interim plan to maximize recovery of the remaining drainable LNAPL and diminish any potential residual mobility of the LNAPL plume in localized areas. This intermediate remedy will essentially bring to a close the practicable LNAPL recovery and also provides additional assurance that there is no remaining LNAPL plume mobility.

The current program of pumping almost every day of the year for hydraulic control of the LNAPL and dissolved-phase plumes with LNAPL recovery occurring only during low water positions has reached diminishing returns and is proposed to be replaced with a new program. The new program takes advantage of the natural stability of the plumes (i.e., containment) and initiates a seasonally-driven recovery program of LNAPL recovery. It also includes a performance monitoring network that supports the planned changes with maintenance of the plume boundaries and groundwater environmental indicators.

Final Remedy

After two to three key low water table conditions (e.g., 4 to 10 years) that provide maximum recovery opportunities, the intermediate program will phase into a final program where pumping is phased out entirely and the natural containment and continued natural depletion of hydrocarbon mass is key in protecting human health and the environment and eventually meeting long-term cleanup goals. Estimates have been made that between 110,000 to 210,000 gallons of equivalent LNAPL volume on average are lost to natural degradation mechanisms in the dissolved and vapor phases on an annual basis.

1.6 Organization of this Report

The optimization of the containment alternative has resulted in the recommendation of a two-phase remedy for the CCF: 1) an Interim Remedy consisting of a period of active remediation, and 2) a Final Remedy consisting of monitored natural attenuation. This report is organized as follows:

Section 1 is the introduction, which includes the background and scope of work for this optimization.

Section 2 presents the Current Conceptual Site Model, which is a description of current site conditions, including hydrogeology, nature and extent of contamination, and engineered and natural contaminant mass loss mechanisms.

Section 3 presents the Future Conceptual Site Model, which is a description of anticipated site conditions following the completion of the Interim Remedy (active remediation). This model provides the setting for the monitored natural attenuation of the Final Remedy, which will extend at least 100 years into the future.

Section 4 describes the Interim Remedy.

Section 5 describes the Final Remedy.

Section 6 presents the schedule for implementation of the Interim and Final Remedies.

Figure 1-1. Site Location Map

Figure 1-2. Facility Diagram

2.0 Current Conceptual Site Model

This conceptual site model (CSM) presents an integrated picture of the hydrogeology, contaminant characteristics, and other supporting factors for the current conditions at the CCF site. This CSM serves as a "platform" from which detailed findings regarding the distribution and behavior of LNAPL and dissolved-phase hydrocarbons can be assessed and applied to future actions, and also provides basic features for the application of the groundwater flow model. In Section 3 of this report, this current CSM is transformed into an envisioned future CSM, which represents anticipated site conditions following the completion of active remediation (Interim Remedy), during which the Final Remedy will be implemented as the site gradually evolves to its final environmental end state.

More detailed technical discussions regarding the properties, behavior, and mobility of LNAPL, mechanisms for mass reduction of the LNAPL, and groundwater modeling that evaluates natural attenuation processes are presented in appendices to this report. These discussions are referenced at appropriate places in this report and form the basis for the proposed interim and final remedies.

The following components comprise the CSM:

1. Geologic and hydrogeologic conditions;
2. Extent of LNAPL and dissolved-phase hydrocarbon plumes;
3. Natural processes (geologic and biologic) that are reducing LNAPL and dissolved-phase hydrocarbon mass;
4. Remediation activity; and
5. Potential exposure pathways and future land use.

2.1 Geology

2.1.1 Regional and Local Geology

Geologic, structural, and topographic features of the CCF site form an important component of the CSM and establish the context in which groundwater flow, hydraulic gradients, and contaminant transport can be modeled. For over 15 years, ChevronTexaco has gathered subsurface data that have led to an understanding of the geologic and hydrogeologic features of the site. A detailed presentation of these features is provided in the GW CMS and summarized in the following paragraphs.

The CCF site lies 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 steep-walled valley is approximately 0.5 miles (0.8 km) wide and 100 ft (30 m) deep. The Ordovician shale is consolidated and has a low permeability, but it is locally fractured and jointed, and is interbedded with thin layers of limestone. Overbank silt and sand deposits derived from floods of the Great Miami River overlie coarser-grained sand and gravel derived from glacial outwash.

Figure 2-1 illustrates the surface topography of the CCF site and surrounding area. The land surface area of the CCF is relatively flat with only minor relief near the river. In the vicinity of the CCF, this topographically flat area generally reflects the lateral extent of the outwash/fluvial valley fill. The topographically higher area located east and west of the CCF site represents the emergent sides of the bedrock valley walls. The village of Hooven, which is west of SR 128, is located on an outwash terrace higher than the CCF and is, therefore, underlain by a thicker sequence of alluvial deposits.

The contact between the glacial-alluvial deposits and the bedrock has been delineated through a combination of direct observations from boreholes and wells, and supplemented with data from a site-wide seismic survey. Figure 2-2 is a contour map of the bedrock surface, which ranges between 395 to 445 ft mean sea level (msl) beneath the CCF. Irregular depressions oriented subparallel to parallel to the axis of the valley suggest some minor paleostream scouring in the bedrock. However, these features do not appear to dominate the bedrock surface and are not interpreted to represent preferential groundwater flow pathways.

2.1.2 Aquifer Characteristics

The aquifer consists of two principal zones:

- **Upper Zone:** Surficial alluvial deposits and fill. This upper zone is discontinuous over the site, is typically unsaturated, and is up to 15 ft thick, especially in the southern part of the site. The lower portion of this zone may be temporarily saturated, especially during rising water levels that occur during spring floods.

- **Lower Zone:** Glacial outwash sand and gravel. This lower zone is up to 85 ft. thick at the site and forms the highly transmissive portion of the aquifer. The upper portion of this zone contains a greater proportion of interbedded sand, silt, and gravel, and generally has a lower hydraulic conductivity than the deeper portion of this zone, which contains coarser sand and gravel. Although most of the outwash consists of relatively coarse-grained materials, there is variability in lithology attributable to abrupt changes in depositional conditions characteristic of outwash deposits. Textural heterogeneity is particularly characteristic of the upper portions of the saturated zone in which most of the LNAPL and dissolved constituents are found.

Overall, the aquifer matrix tends to become finer-grained upward across the site, with a corresponding decrease in the hydraulic conductivity of the aquifer materials. The transmissivity of the aquifer, which is the product of the hydraulic conductivity and the thickness of the aquifer, ranges from about 5,000 to 65,000 ft^2/day. The interpreted distribution of transmissivity in the aquifer is shown on Figure 2-3. The highest transmissivity at the CCF (e.g., greater than 50,000 ft^2/day) occurs in an elongated area that trends north-south across the site.

2.2 <u>Groundwater</u>

2.2.1 Groundwater Occurrence and Flow Direction

Groundwater occurs in the alluvial-glacial aquifer but does not occur in significant amounts in the bedrock. At the scale of this study, the bedrock serves as a barrier to groundwater flow. Therefore, groundwater is restricted to the alluvial-glacial deposits, and the base and sides of the bedrock valley can be considered no-flow boundaries at the site.

The direction of groundwater flow at the CCF is from north to south. Typical groundwater elevations across the study area (from north of the CCF to U.S. Highway 50 to the south) range from about 471 to 465 ft during high water table conditions and from about 468 to 461 ft during low water table conditions. Water table contour maps, based on typical seasonal high (Figure 2-4) and low (Figure 2-5) water table conditions, show that the water table elevation decreases from north to south. The relatively uniformly-spaced contour lines are oriented perpendicular to the axis of the valley with minor, if any, redirection at the river. Pumping wells, characterized by "cones of depression" in the potentiometric surface, locally steepen and/or reverse hydraulic gradients near the wells and alter prevailing hydraulic gradients "inward" to the CCF site.

Depending on the relative stage of the Great Miami River and groundwater levels, local groundwater flow may be temporarily redirected to and from the river. As discussed later, groundwater flow within the area of influence of high-capacity groundwater production wells is redirected toward the wells.

Ambient hydraulic gradients at the CCF are typically about 0.0009 ft/ft in areas not influenced by pumping wells. The groundwater velocity, which is dependent on both the hydraulic conductivity and hydraulic gradient, ranges from 2 to 4 ft/day in areas not influenced by pumping.

2.2.2 Water Table Fluctuations

Water table fluctuations reflect changes in groundwater storage due to recharge of precipitation, operation of groundwater production wells, and river level fluctuations. River level fluctuations create the most pronounced and widespread fluctuations in the water table across the CCF site. The amplitude of water table fluctuations has ranged up to 14 ft since the mid-1980s, but typical water table fluctuation is 2 to 5 ft. Flood waves in the river generally range from a week to a month in duration, during which transient positive head differences of 2 to 9 ft may exist between the river and aquifer. Flood events may occur at any time of year but occur most often during the spring.

The seasonal river stage is typically highest in the spring, drops through the summer, and may remain low throughout the fall, occasionally marked by short-term peaks in the river level caused by stormwater runoff. During the fall and other periods of low river stage, groundwater pumping from the production wells is increased to enhance LNAPL recovery. During periods of extreme drought, water levels in the river and aquifer drop even lower, expanding the area of hydraulic influence of the production wells. Figure 2-6 shows water table contours for November 1999, which represent the lowest water levels observed in recent years.

2.3 Hydrocarbon Product (LNAPL)

As discussed in the GW CMS, an LNAPL plume exists under the facility. The petroleum product releases causing the LNAPL plume may have occurred at any time during the 55-year history (1931-1986) of CCF operations. Environmental investigations began in 1985, a year and a half before refining operations ceased. Although details of the releases are unknown, LNAPL chemistry data, product history, and production runs suggest that much of the LNAPL was released in the 1950s and 1960s.

Overall, the LNAPL is a mixture of approximately 80% leaded gasoline and 20% diesel fuel. As discussed in the GW CMS, the LNAPL can be divided into two types based on physical properties: a low viscosity, low density LNAPL and a higher viscosity, higher density LNAPL. The latter LNAPL type is limited to a small area in the eastern portion of the site.

The following subsections present general discussions regarding LNAPL properties, distribution, and hydraulics. The reader is referred to the discussion in Appendix A for a more detailed and technical development of the properties and behavior of the LNAPL at the CCF.

2.3.1 LNAPL Release Characteristics

The LNAPL occurrence at the CCF can be conceptually described in terms of migration following the release, mechanisms reducing the mobility of the LNAPL, and LNAPL mass reduction processes.

LNAPL Migration

The primary principles that explain LNAPL spills and migration are relatively straightforward. LNAPL flows from the location of the initial spill along the LNAPL hydraulic gradient, which in the early stages of the release is often mounded with some components of radial flow, and later more closely corresponds to the water table gradient. The flow is affected by variations in hydraulic conductivity and hydraulic gradient, with the conductivity toward LNAPL depending both on soil permeability and the degree of LNAPL saturation. Initially, the plume migrates downward and then spreads horizontally near the water table, as shown conceptually on Figure 2-7. Then the horizontal plume migration slows exponentially through time as the initial driving gradient dissipates. Figure 2-8 shows the field observations of this exponential slowing at another ChevronTexaco site in Texas (for general information, not a representation of specific conditions at the subject site). With time and incremental migration, the plume occupies a larger soil volume with a corresponding decrease in the LNAPL saturation and conductivity, and with water table variations causes vertical “smearing” of central portions of the plume. Distal portions of the LNAPL plume often do not redistribute vertically with water table variations because there is insufficient LNAPL conductivity in zones of limited saturation.

LNAPL Mobility Reduction

As the LNAPL plume at CCF initially spread, mass was transferred from the central portion of the plume near the release area to more distal areas, and the observable LNAPL plume thinned through time in the central zones as the lateral migration. Groundwater pumping to contain the LNAPL plume and recover LNAPL began in early 1985. This LNAPL recovery has also contributed significantly to the thinning of the LNAPL plume in the central portion of the site. Thinning of the observable product implies a mobility and recoverability reduction. Because the aquifer materials retain residual LNAPL, the smear zone distribution is not fundamentally changed as a result of the recovery and plume thinning.

The soils have an intrinsic capacity to retain a portion of the LNAPL plume as immobilized residual LNAPL. Therefore, the LNAPL plume at CCF left a distinct trail of immobile residual LNAPL in the subsurface along its path of movement; this residual LNAPL is referred to as a smear zone.

As the mass of LNAPL spread into a larger volume of subsurface material, the mobile portion of the LNAPL was continuously reduced by the conversion to the immobile residual LNAPL, by LNAPL recovery operations, and through natural mass losses in vapor, groundwater, and ultimately biodegradation. Natural attenuation has been well-documented at the site as presented in past reports and as discussed subsequently herein. Even without the LNAPL recovery performed at the CCF, the downgradient migration of the LNAPL plume would have slowed and eventually stopped, as will any finite mass of oil. The general LNAPL migration path left a thick LNAPL smear zone in the central portions of the site and a thin smear zone lens in the distal transport areas that reflect these overall transport processes.

LNAPL Mass Depletion

Mass in the LNAPL plume has been continually depleted over time by both engineered (e.g., LNAPL recovery) and natural processes. Even with the cessation of LNAPL recovery operations, the natural mass reduction processes will continue and the plume footprint will continue to contract over time. The engineered and natural processes of LNAPL mass reduction include the following:

Engineered

- LNAPL recovery;
- Dissolved-phase hydrocarbon recovery; and
- Soil vapor extraction.

Natural

- Dissolution and vaporization; and
- Natural attenuation of vapor and dissolved-phase hydrocarbons.

Dissolution and vaporization at CCF control the natural mass loss of the LNAPL. Natural attenuation from the LNAPL to daughter phases depends on the distribution of the LNAPL in the subsurface, its changing chemical composition through time, and the physical, geochemical, and biological characteristics of the aquifer and vadose systems. Figure 2-7 shows a schematic of how the LNAPL partitions through time.

Conceptually, analogous and related geochemical processes in the subsurface affect both dissolved- and vapor-phase LNAPL movement. Partitioning of chemical species from LNAPL to groundwater and subsequent depletion of the LNAPL plume is partly a function of the groundwater flowrate through and beneath the smear zone. In contrast, there generally is not much active ambient vapor flow in the vadose zone. Both transport mechanisms rely in part on the chemical gradient between zones of high and low concentration, and the diffusion factors of the chemicals moving through porous materials. Given the processes above, chemical partitioning and depletion of the LNAPL is expected to occur most rapidly where LNAPL is in contact with other phases (i.e., water and air).

2.3.2 Lateral LNAPL Distribution

The discussion of LNAPL in this report distinguishes between the LNAPL plume and the smear zone as follows:

- **Smear Zone:** The smear zone is the entire volume of subsurface materials containing some LNAPL. This LNAPL can be observed as stained soil in boring logs and/or elevated responses in rapid optical sensor technology (ROST) logs. The top of the smear zone typically coincides with the highest water level known in the area, and the base of the smear zone is the bottom of the impacted zone shown on ROST logs. The smear zone can be subdivided based on thickness and on saturation levels. The smear zone can be subdivided into low saturation and high saturation areas (see discussion "Low/High LNAPL Saturation Zones" in Section 2.3.4). LNAPL in the low saturation areas occurs below the residual saturation threshold level, and the LNAPL is rendered immobile within the soil. In the high saturation areas, the LNAPL has the ability to redistribute and flow into wells.

- **Observable LNAPL Plume:** The observable LNAPL plume is only the area where petroleum hydrocarbon is observable in wells. LNAPL gains the ability to flow into wells when the petroleum hydrocarbon is present above the residual saturation threshold. The LNAPL plume is typically mapped at the facility through observed LNAPL thicknesses measured periodically in wells at the site.

The smear zone and the observable LNAPL plume are clearly related. All the wells that exhibit measurable LNAPL are in the smear zone. However, not all wells in the smear zone necessarily exhibit measurable LNAPL. Based on the geologic and geophysical logs, the observable LNAPL plume through time represents less than 1% of the total smear zone. This approximation is not highly refined as the available continuous logs are relatively sparse in comparison to the plume area, which is a result of difficult sampling conditions documented in prior site characterization reports (Radian, 1999). Any remaining hydraulic recoverability or residual mobility is limited primarily to the observable LNAPL plume.

The perimeter of the LNAPL plume and smear zone, as shown on Figure 2-9, has been defined by a combination of monitoring well gauging history; direct observations of LNAPL and LNAPL-stained soil collected from soil borings; and interpretations of ROST logs. These data provide strong indications of the presence of LNAPL in the subsurface. Based on this information, the area of the smear zone, which includes the LNAPL plume, is estimated to be approximately 250 acres.

2.3.3 Vertical LNAPL Distribution

The vertical distribution of LNAPL in the smear zone can be inferred from ROST data and continuously cored and sampled soil borings. The estimated thickness of the smear zone across the site is shown on Figure 2-10, and the observable thickness, at the historic low water level, is shown on Figure 2-11. Although the presence/absence of LNAPL generates a characteristic response profile in ROST logs, the hydrocarbon saturations cannot be quantified from these profiles, because the fluorescence also depends on factors other than hydrocarbon saturation, such as lithology, hydrocarbon chemistry, and other factors.

Many of the ROST logs at the CCF site show a distinct interval where hydrocarbon is present in the subsurface above background fluorescence. These profiles can be categorized into two smear zone thickness types:

- **Thick Smear Zone – located under and near the original source areas:** Thick zones of LNAPL smear where there was enough LNAPL volume and relatively high vertical soil conductivity to allow the LNAPL to redistribute with water table fluctuations; and

- **Thin Smear Zone – located in distal transport areas further away from the original source areas:** Thin zones of LNAPL smear in areas where there was no apparent LNAPL release at the surface and/or where there is relatively low vertical soil conductivity to retard vertical redistribution under water table fluctuations.

For example, the central portions of the LNAPL plume typically represent the LNAPL profile described as the thick smear zone. This is because the areas closest to the release inherently have thicker LNAPL accumulations and carry the capacity to vertically redistribute. The thickness of the smear zone in these areas reaches more than 20 ft in some locations.

However, the perimeter areas of the LNAPL plume only contain a thin layer of LNAPL (thin smear zone). This suggests a strong thinning of the LNAPL in the perimeter areas in response to initial lateral migration during the early stages of LNAPL release. The conceptual relationship between thick and thin smear zones is discussed in Section 2.3.1, “LNAPL Release Characteristics.”

In either of the LNAPL smear zone types, LNAPL may be present above or below residual saturation, depending on the mass losses experienced from engineered and natural processes, the location relative to the plume source, and the mass loss processes. The inability of the LNAPL in the thin smear zone to redistribute over the full vertical range of the water table indicates limited vertical mobility over the period and conditions of the water table changes. In contrast, the LNAPL smear zone near the former source areas exhibits thicknesses greater than the range of water table variability, indicating enough mass and saturation to respond and redistribute with fluctuations and the displacement conditions of the release(s).

2.3.4 Low/High LNAPL Saturation Zones

Residual saturation reflects the intrinsic capacity of soil materials to retain LNAPL against drainage forces. The residual saturation threshold in the vadose zone (air-water-oil system) is smaller than in the water-saturated zone (water-oil system). The net effect of the two different forms of residual LNAPL saturation is for the LNAPL to drain downward over time, leaving a lower residual LNAPL saturation in the historic vadose zone than at the bottom of the smear zone in the saturated aquifer. There is also some upward redistribution in areas where the LNAPL saturation and hydraulic conductivity are sufficient to respond to a rising water table.

However, the process is discussed to explain the observation of higher relative LNAPL saturations at the base of the smear zone.

The hydrocarbon mass remaining at the bottom of the smear zone is observable as LNAPL in wells only when the water table falls to an elevation equivalent to the position of a high saturation LNAPL zone. This phenomenon, shown in the hydrograph on Figure 2-12, is seen in the averaged conditions for MW-1 through MW-25, the set of wells with the longest monitoring record beneath the facility. The upper line in the figure illustrates the water table level, and the lower line is the observed product thickness in these wells from 1985 to 2000. LNAPL is observed in these wells only when the water table drops below approximately 464 ft msl. It is clear that the water table must reach the elevation of the high saturation zone before LNAPL is observed in wells. This relationship is also consistent with the one-time occurrence of LNAPL in MW-94S that exhibited a thin smear zone in the soil upon installation, but no LNAPL was detected in the well until the November 1999 drought, when the water table reached an historical low elevation.

This higher saturation zone located at the bottom of the smear zone typically has not been exposed to the three-phase vadose system during historic periodic drought stages. This lower interval is taken as the distance between the seasonal low water table and the interpreted base of the LNAPL smear zone indicated by the ROST logs. This potentially drainable fraction of LNAPL that may remain beneath the facility is likely concentrated in these high saturation zones. This concept is discussed in more detail in Appendix A.

2.3.5 Hooven Ditch LNAPL

The Hooven Ditch is a drainage ditch that runs through the southern portion of the CCF. The Hooven Ditch receives stormwater runoff from Hooven and a limited area in the southern portion of the CCF. The Hooven Ditch trends west to east across the CCF, then turns to the south near the former wastewater treatment lagoons (SWMU 10) before discharging into the Great Miami River (see Figure 1-2). The Hooven Ditch is located over the smear zone and the LNAPL plume.

In May 1996, during a prolonged period of high river stage in the Great Miami River, LNAPL was detected in the lower section of the Hooven Ditch. The river stage in the Great Miami River during this period stayed in the 476 ft range for two weeks, resulting in elevated groundwater levels throughout the Hooven Ditch area. Groundwater levels in this area during May ranged between 474 ft and 477.6 ft above msl.

A geologic review, using cone penetrometer testing (CPT) borings, soil boring logs, and laser-induced fluorescence (LIF), was performed to verify the stratigraphy beneath the Hooven Ditch terminus. As noted previously, three general stratigraphic units are present beneath the site: 1) an Upper Zone consisting of fine-grained floodplain sedimentary deposits; 2) a Lower Zone consisting of glacial outwash; and 3) a shale bedrock. The CPT, soil boring, and LIF locations are illustrated on Figure 2-13.

The Upper Zone sediments generally are located from ground surface to approximately 8 ft below ground surface (bgs). The fine-grained sediments consist primarily of silts, silty sand, and fine-grained sand with trace amounts of clay. The Lower Zone sediments typically are composed of fine- to coarse-grained sand and silty gravel. In select areas, it appears that the Hooven Ditch may penetrate the entire thickness of the Upper Zone sediments. The subsurface stratigraphy is graphically illustrated on cross section A-A' shown on Figure 2-14. Figure 2-15 is the same geologic cross section with LIF intensity in shades of blue.

As noted previously, residual hydrocarbon across the site generally is contained within the Lower Zone sediments. The results of the ROST study confirmed that residual hydrocarbons exist beneath the Hooven Ditch. The smear zone is approximately 12 ft thick and ranges in depth from approximately 6 ft bgs to 18 ft bgs. In addition, free-phase hydrocarbon product (LNAPL) has been detected in groundwater monitoring wells in the general vicinity (MW-86 contained 2.16 ft on May 23, 2002).

Under the high water table conditions experienced in May 1996, the base of the Hooven Ditch (475 ft msl) potentially intercepted the groundwater. Where the ditch penetrates the upper silt unit, the ditch and groundwater were in direct communication and LNAPL could enter the ditch.

Based on the elevation of the smear zone, the base of the Hooven Ditch, and the thickness of LNAPL in this area of the site, LNAPL can only enter the ditch when groundwater elevations in the area are at or above 473 ft msl. Given the viscosity of the LNAPL within this area, a prolonged period of high groundwater levels was required to induce vertical displacement of LNAPL upward through the formation and into the Hooven Ditch. The LNAPL only appeared in the Hooven Ditch during the extreme high water table conditions in May 1996. When the water table subsequently dropped, LNAPL was no longer present in the Hooven Ditch.

2.4 LNAPL Mass Reduction

As discussed previously, the LNAPL mass at the CCF has been depleted over time by two general processes: 1) engineered remedial activities such as LNAPL recovery, groundwater pumping, and soil vapor extraction; and 2) natural processes such as dissolution and vaporization. The LNAPL recovery is unrelated to the natural processes, while the groundwater pumping and soil vapor extraction are designed to enhance (e.g., accelerate) the natural processes. The engineered remediation activities inherently target the mobile and drainable fraction of the smear zone (observable LNAPL plume). Those activities have therefore accelerated the reduction in remaining mobility and recoverability through the historic recovery of approximately 3.5 million gallons of LNAPL. This reduction in mobility reduces the likelihood of the recurrence of LNAPL discharge at points of concern, including the river, the Hooven Ditch, and further downstream migration in the southwest quadrant.

Since 1985, hydrocarbon and groundwater extraction and treatment activities have been conducted at the CCF. In 1999, these activities were supplemented with a soil vapor extraction system designed to remove vapors and hydrocarbon mass from under Hooven. Since installation, hydrocarbon mass removal rates from these systems have continuously decreased over time. To maximize mass removal rates, Chevron has undertaken various optimization activities. These include the installation of additional extraction wells, pulsing of pumping wells, and recently, scheduling of groundwater and LNAPL extraction activities during low water table events. However, despite these actions, LNAPL and hydrocarbon mass removal rates continue to decline to the point that extraction of LNAPL, and hydrocarbon mass during above-average water table conditions is providing only limited LNAPL recovery.

In addition to these engineered loss mechanisms, natural LNAPL mass losses also have been occurring. These natural loss mechanisms include dissolution into groundwater and volatilization of hydrocarbons from LNAPL, soil, and groundwater into the vadose zone. Given the properties of the LNAPL and subsurface conditions, volatilization and degradation in the vadose zone will be the predominant natural mass loss mechanism in the future.

While LNAPL mass reduction through engineered means has decreased significantly since system startup in 1985, the rate of natural mass loss has decreased at a lower rate. The decrease in engineered recovery is a function of the decreased transmissivity toward LNAPL as the observable LNAPL plume has thinned and decreased in overall saturation. The continued natural depletion rate depends on the concentration of various compounds in the LNAPL, the associated fluxes in the groundwater, vapor phases, and related degradation. Clearly bulk physical recovery of the LNAPL has no significant effect on the chemical state that controls the natural mass losses. As a consequence, natural mass losses at some point in the life cycle of the CCF remediation will begin to exceed engineered mass losses and, from that point, will become the dominant mass loss/removal mechanism. A more detailed discussion of engineered and natural LNAPL mass reduction is provided in Sections 2.4.1 through 2.4.5.

2.4.1 LNAPL Recovery

A cumulative total of about 3.5 million gallons of LNAPL has been recovered at CCF since 1985. LNAPL recovery rates have significantly decreased with time as shown on Figure 2-16. From 1985 to 1988, large volumes of LNAPL were recovered annually because many zones contained LNAPL above residual saturation. Annual LNAPL recovery after that time declined to baseline levels due to the depletion of LNAPL that readily flowed to wells. Since 1988, LNAPL recovery has varied between 10,000 and 200,000 gallons per year, with higher production rates during low water table stands. The historic trend of recovery data indicates that LNAPL recovery is approaching asymptotic conditions during annual low water table conditions.

2.4.2 Dissolved-Phase Hydrocarbon Recovery

LNAPL recovery takes place mainly during the fall low water table season. At other times, the water level rises high enough to trap and immobilize most of the LNAPL in soil pores. The initial years of pumping began with one to three wells pumping groundwater and since has grown to operate up to nine wells. The amount of groundwater pumped has proportionally increased over the years to reach a maximum in the mid to late 1990s. Since 2000, the groundwater pumping has been reduced during high water table conditions. Recent typical high water table pumping rates are approximately 2.5 million gallons per day (MGD), whereas low water table pumping rates are up to 5 MGD. During 2002, for example, 1.2 billion gallons of groundwater were pumped at the site. The pumped groundwater is treated in the CCF groundwater remediation system before being discharged to the Great Miami River under an NPDES permit. Assuming that the groundwater pump-and-treat system has operated for 16 years with an average influent hydrocarbon concentration of 5 mg/L, groundwater pumping has removed a total of approximately 670,000 lbs of dissolved-phase hydrocarbons, or about 42,000 lbs/year.

2.4.3 Vapor Recovery

A system of three HSVE wells was installed beneath Hooven beginning in 1999, to mitigate potential vapor pathway risks to Hooven (although no unacceptable risk was identified for Hooven residents from soil vapor) and to remove some LNAPL mass. The locations of the three HSVE wells are shown on Figure 1-2. Operation of HSVE Well 1 started in November 1999, with Wells 2 and 3 starting in 2000. The HSVE wells currently are being operated in a seasonally intermittent mode (based on water table elevation)and are monitored routinely to evaluate system performance due to an asymptotic recovery curve.

Influent concentrations to the system have ranged from 34 mg/m^3 to 20,000 mg/m^3 as total petroleum hydrocarbons (TPH) gasoline, with the highest concentrations recorded on startup of the system. Within several months of operation, influent concentrations to the system fell to below 4,000 mg/m^3. However, LNAPL is still present beneath Hooven, and there are no indications of significant LNAPL mass loss from the HSVE operations. Therefore, the decrease in HSVE recovery indicates that site conditions limit the upward flux of vapor from the smear zone into the HSVE system. This type of suggested flux limitation is unlikely to be affected in any significant way by changes in HSVE operations, and recovery will continue to be vaporization rate-limited.

This mass transfer limitation is reflected in system mass removal rates, with influent concentrations reaching near asymptotic levels during continuous operation. Following a system shutdown, concentrations rebounded to elevated levels before rapidly decreasing. This means that there is no shortage of chemical mass in the subsurface and that the volatilization from the mass (i.e., the smear zone) is slowed by geologic and chemical processes. In addition, rising groundwater levels and the resulting partial or complete submergence of the smear zone has resulted in seasonal fluctuations in influent vapor concentrations. As a consequence, Chevron has modified system operations to include the pulsing of individual HSVE wells and shutdown of the system during high water table events.

Through September 2002, the HSVE system has removed approximately 1.26 million lbs of hydrocarbon compounds from the subsurface (approximately 190,000 gallons of LNAPL). While it is simple to convert the pounds recovered into equivalent units of gallons, it is important to note that the vapor recovered consists of volatile and abundant compounds such as benzene. In this context, the HSVE has addressed benzene as a compound of concern preferentially over the remaining less volatile compounds in the LNAPL. A significant fraction of the LNAPL beneath the site is composed of moderate-to-low-volatility materials. The HSVE system is not expected to have effectively treated any of these compounds, except to increase the biodegradation of amenable components.

In general, most of the mass recovered by HSVE (nearly 80%) was removed in the first five months of each well's operation, with existing operations providing continually decreasing returns. In addition, more than half of the mass removed has been due to aerobic respiration as indicated by CO_2 (Goulding, 2002) production in the subsurface, with vapor flux from the LNAPL and smear zone providing continually decreasing contributions to the total mass removed. Cumulative mass removed is summarized for HSVE Wells 1 and 3 on Figures 2-17 and 2-18). Well 2 is slightly downgradient of the main portions of the LNAPL plume and, therefore, recovery has been negligible.

On these figures, hydrocarbon mass removal via three mechanisms is shown:

1. **Hydrocarbon removed as methane:** Under sufficiently reducing conditions, some hydrocarbons are converted to methane, which is removed by the HSVE system during initial operation. As more air is introduced in the subsurface by the HSVE system, methane formation declines and it ceases to be a significant removal mechanism.

2. **Hydrocarbons biooxidized:** The introduction of oxygen into the subsurface by the HSVE system fosters aerobic oxidation of hydrocarbons; the mass thus removed can be estimated from the quantity of carbon dioxide recovered.

3. **Hydrocarbons stripped:** Hydrocarbons partition from the LNAPL into the flow of air induced by the HSVE system and are thus stripped from the subsurface.

In the figures, the LNAPL mass removal caused by these three mechanisms are added to yield a total mass removal induced by the HSVE system.

2.4.4 Natural LNAPL Mass Losses Over Time

The LNAPL plume has lost significant chemical mass since the time of the releases (between 30 and 60 years ago) that created the plume. One of the strongest indicators of this mass loss is the chemical weathering of gasoline-range compounds evident in the LNAPL samples collected in recent years as compared to the likely original chemical composition of the LNAPL. This reduction in mass attributable to chemical weathering is distinct from physical removal of the LNAPL during pumping operations. The latter removes LNAPL mass but does not change the chemical composition of the LNAPL. These natural weathering and mass loss aspects are discussed and quantified below with respect to benzene and other key compounds of concern in gasoline.

As mentioned in Appendix A and in the GW CMS, benzene concentrations from LNAPL samples identified on Figure 2-19 indicate the natural weathering of LNAPL. First, the average percentage of benzene in LNAPL samples across the site today is approximately 0.3%, which is much smaller than the 3 to 3.5% range expected in leaded gasoline from the 1960s. Second, benzene concentrations in samples collected from the margin of the LNAPL plume are much lower than samples collected from locations in the central portion of the plume. Benzene remains relatively concentrated in the plume core areas where the smear zone is thickest, has the greatest remaining mass, and is interior with respect to LNAPL partitioning mechanisms. This relationship suggests that LNAPL weathering and benzene depletion have progressed more rapidly in the thinner, distal portions of the LNAPL plume.

The rate of chemical mass losses through time from the LNAPL release can be estimated by linking the approximate distribution of LNAPL, estimating an initial chemical composition, and calculating mass losses to the groundwater and soil vapor systems (Huntley & Beckett, 1997). These are gross-scale estimates for two primary reasons: 1) the analytical methods used in the calculations, while accounting for the important multiphase, transport, and mass depletion factors, are screening estimates without a high level of precision; and 2) the conditions of the release, composition, timing, and other system variables are not well defined. So, while the underlying mass transfer and chemical fate and transport processes are relatively well known, some site-specific details are uncertain. The following approximations provide some perspective on the natural rates of mass loss through time:

- The mass loss of dissolved and volatile compounds from the LNAPL smear zone is estimated by combining the mass flux components of groundwater flow through and below the LNAPL interval and volatile losses into the vadose zone.

- The general groundwater flow conditions have been discussed previously, and the average groundwater velocity is on the order of 2 to 4 ft/day under an ambient gradient of 0.001 ft/ft.

- The approximate and average dimensions of the significant smear zone are 5,600 ft by 1,370 ft, with an average thickness of about 13 ft; the lower two feet of the smear zone have an average LNAPL saturation of 12%, and the remaining upper portion of the smear has an average LNAPL saturation of 2 to 4 percent.

- The initial benzene concentration is estimated at 3.5% mole fraction in the LNAPL. The other soil and transport properties are taken from the site and literature database for similar materials and settings.

The initial mass losses of benzene were likely on the order of 400,000 lbs/yr over the first year, diminishing as the remaining benzene mass was depleted to a current rate of about 100,000 lbs/yr. These rough estimates are based on the mass loss principles discussed above, and the observation that site benzene concentrations are significantly less than attributable to a "unweathered" leaded gasoline. Although benzene is one of the first compounds depleted because of its relatively high solubility and volatility, other aromatic compounds are also continually depleted. The total benzene, toluene, ethylbenzene, and xylenes (BTEX) aromatic plume losses may have been as high as about 1 million lbs/yr in the early stages of the plume, and are estimated to be on the order of about 400,000 lbs/yr currently, with total hydrocarbon component losses about double this value for a typical gasoline composition. Again, the estimates are consistent with observations but are not well constrained, as the initial LNAPL composition is not known nor is the distribution and volume of the release highly constrained. The approximation is simply the best-estimate available for the known data.

Figure 2-20 shows the estimated cumulative mass loss from benzene and from the total of the selected compounds. In addition, other system attributes, such as barometric pumping in the vadose zone, have not been considered and would provide additional mass loss mechanisms. For the compounds evaluated, something on the order of 90 million lbs is estimated to have been depleted over the natural depletion time frame of roughly 40 years. Again, because half or more of the compounds are not represented in the estimate, the actual depletion is expected to be greater by a comparable amount.

In these natural mass loss estimates, mass from the LNAPL plume is lost to both the groundwater and vadose zone systems. The relative contribution of each depends on the contrast between component solubility and volatility, and on the transport properties of the system. For the groundwater system, mass losses occur from diffusion and the advective flow of groundwater coming into contact with the LNAPL from upstream areas. For the vadose zone system, the mass losses are driven by the chemical gradient (diffusion) in the absence of active airflow.

Vapor-phase loss is likely important in this particular setting and is estimated to be the major mass loss mechanism. A key attribute, and the primary reason that vapor-phase losses are expected to be high, is the surface area of contact for each mass loss mechanism. For groundwater, the mass losses occur across the plume width and to some depth below the plume (typically less than a few feet). In contrast, the area available for vapor contact is the entire surface area of the LNAPL smear zone, which is about 100 times greater in the contact area. The chemical gradient with respect to vapor has been documented in past vapor profiling work, supporting this mass loss mechanism for the smear zone and, indirectly, the observable LNAPL plume when ephemerally exposed under low water table conditions.

Because of the surface area contrast and other factors, vapor-phase losses are estimated to comprise about 90% of the total compound losses from the LNAPL plume. In general, compounds that have a higher vapor pressure and lower dissolved-phase solubility more favorably partition into the vadose zone system. As mentioned, other mass loss mechanisms not considered (e.g., such as barometric pumping and biodegradation supported by the intrusion of atmospheric oxygen) would only further the importance of the vapor-phase loss mechanisms.

On the basis of all the factors involved, it is estimated that the minimum natural mass loss of petroleum hydrocarbons from the LNAPL is currently between 800,000 lbs/yr and 1,400,000 lbs/yr (~110,000 to 210,000 gallons per year equivalent volume). As the more amenable compounds are lost to the natural system, the remaining weathered LNAPL will partition more slowly through time, and the natural mass loss rates are expected to diminish over time. Again, while the mass depletion processes are well known, site-specific estimates are not highly constrained and should be considered order-of-magnitude based on best available information.

2.4.5 Summary of LNAPL Mass Losses

Although Chevron has taken many steps to increase the engineered mass losses, the natural mass losses currently typically exceed the engineered ones. For a comparison of natural mass losses with engineered mass recovery rates, the rate of LNAPL recovery during the last significant drought year (1999) was about 150,200 gallons. The three-year hydraulic recovery average from 1999 to year-end 2001 was 76,300 gallons per year. As noted in previous sections, the rate of engineered mass losses through LNAPL recovery will continue to diminish, even during drought periods. As such, the estimated natural mass losses in the system, on an average annual basis, exceed the remaining mass recovery potential of the existing LNAPL recovery system.

In comparing the engineered mass losses and estimates of natural mass losses at CCF, the following conclusions can be made:

1. Estimated natural mass losses annually exceed the recovery potential of the existing LNAPL recovery system.

2. Natural mass losses from this point on will be the predominant mass loss mechanism from the LNAPL plumes at the site, and the difference between engineered mass losses and natural mass losses will only increase over time.

3. Natural mass losses are significantly changing the chemistry of the LNAPL, with the most volatile and soluble compounds being preferentially removed from the LNAPL. This has resulted in an order-of-magnitude reduction in the benzene molar fractions and a similar reduction in potential vapor-related risks.

As a result, natural mass losses have reached the point in the life cycle of this remediation project where they exceed engineered mass losses. From this point forward, natural processes will become the dominant mass loss/removal mechanism.

2.5 Dissolved-Phase Hydrocarbon Plume

Dissolved-phase hydrocarbons in groundwater at the CCF are focused within and beneath the LNAPL smear zone. This section discusses the contaminants of potential concern (COPCs) and groundwater contamination distribution affecting the dissolved-phase plume.

2.5.1 Contaminants of Potential Concern

The Groundwater EI report (CEC, 2001) identified COPCs for the groundwater as benzene, ethylbenzene, 1,4-dichlorobenzene, acetophenone, bis(2-ethylhexyl)phthalate (DEHP), naphthalene, pyrene, dissolved lead, and total arsenic. Benzene is the most widespread COPC and exceeds regulatory action levels by the highest factor; thus it is utilized as the primary parameter for evaluation of the dissolved-phase hydrocarbon plume.

2.5.2 Benzene Distribution

Multiple groundwater sampling and analytical programs have been conducted at nested monitoring wells screened across different vertical intervals of the alluvial aquifer. Based on these data, the distribution of dissolved benzene is limited to the area of the smear zone, except near groundwater production wells where pumping has steepened vertical gradients and drawn dissolved-phase hydrocarbons deeper into the subsurface. Due to the hydraulic containment that historically has been provided by the groundwater pumping, dissolved benzene (and other dissolved-phase hydrocarbons) usually is not detected outside the area containing residual LNAPL. However, low levels of benzene occasionally have been detected outside the estimated area of the LNAPL smear zone in the southwestern end of the CCF and beneath Hooven. Figure 2-9 shows the extent of the dissolved-phase hydrocarbon plume, which has the same general footprint as the benzene plume, as discussed above.

2.5.3 Natural Attenuation of Dissolved-Phase Plume

Natural attenuation of dissolved-phase hydrocarbons consists of a set of well-documented and naturally-occurring geochemical and biological processes (USEPA, 1999) that reduce the mobility, concentration, and persistence of these compounds. The biodegradation pathway for hydrocarbons is oxidation, using electron acceptors such as oxygen, nitrate, ferric iron, manganese (Mn^{4+}), sulfate, and CO_2. In a natural environment, the supply of electron acceptors generally is the limiting factor determining the reaction rate.

In addition to the body of technical literature that supports the basic principles of natural attenuation, a significant amount of CCF data documents the active role of natural attenuation in influencing the occurrence and concentration of dissolved-phase hydrocarbons.

Islands Natural Attenuation

Monitoring for indicators of natural attenuation (e.g., electron acceptors) has been performed on a semiannual basis for the dissolved-phase hydrocarbon plume beneath the Islands for several years. The source for the Island dissolved-phase plume is separate from the main LNAPL plume at the CCF and consists of a smear zone of LNAPL in the soils at the Islands resulting from a past product pipeline release. The groundwater monitoring has demonstrated that biodegradation and engineered removal activities have actively reduced the dissolved BTEX concentrations in the Island dissolved-phase plume to below laboratory reporting limits.

SWQ Area Natural Attenuation

In April and November 2002, as a further confirmation that biodegradation processes are at work beneath the CCF, groundwater was sampled mainly in the SWQ and Hooven, seeking chemical evidence of natural attenuation (URS, 2003). Most of the locations had not been previously sampled as part of the monitoring program because they were clearly within the "core" plume area. Groundwater was sampled at wells located in the source area (SWQ and East Hooven), the downgradient area near U.S. Highway 50, the transition zone in between the source and downgradient areas, and potential upgradient areas in West Hooven. Additionally, water upgradient of the site was sampled because, under natural hydraulic gradients (i.e., no pumping), it would flow through the site to the SWQ.

The chemical analysis results of the monitored natural attenuation (MNA) sampling clearly indicate that biodegradation of dissolved-phase hydrocarbons is occurring in the plume (see Appendix C). In general, conditions are reducing and the plume is depleted of electron acceptor compounds needed to oxidize petroleum hydrocarbons in the central areas of the plume. Cross-gradient and background locations away from the plume show higher concentrations of these compounds, indicating that they are used in biodegrading hydrocarbons in the plume. In addition, daughter products of hydrocarbon biodegradation (e.g., ferrous iron, methane) were found in the transition zone.

The 2002 groundwater monitoring data show that benzene concentrations decreased from milligrams/liter (mg/L) levels directly under the dissolved-phase hydrocarbon source area at the CCF to less than 5 micrograms/liter (µg/L) downgradient of CCF toward U.S. Highway 50. These data show that the maximum contaminant level (MCL) of 5 µg/L benzene occurs well to the north of U.S. Highway 50, under the current pumping regime.

2.6 Dissolved Arsenic Plume

A plume of dissolved arsenic is located in the southwest portion of the site and in an adjacent portion of Hooven. The extent of the arsenic plume (as defined by the 0.010 mg/L isopleth) is shown on Figure 2-21. A small portion of the arsenic plume in the Hooven area exceeds the current Safe Drinking Water Act MCL of 0.050 mg/L. However, a new arsenic MCL of 0.010 mg/L will become effective in 2006. Additional discussion is provided in Section 4.2 of the CCF RFI Report (ESE, 2000).

The results of RFI soil sampling show an area of elevated soil arsenic in the southwest portion of the facility, possibly associated with the former foundry that existed prior to the refinery. The arsenic groundwater plume and the area of elevated arsenic in soil do not coincide; the heart of the arsenic groundwater plume is located about 700 feet southwest of the elevated arsenic in soil. The historic groundwater gradients in the area are difficult to evaluate, given the varied pumping history.

The two most common forms of arsenic in groundwater are arsenate (valence +5) and arsenite (valence +3). The arsenate is more strongly adsorbed by insoluble ferric hydroxides than arsenite. Since both arsenate and ferric hydroxides are more stable in oxidizing environments, arsenic would not be expected to be mobile in this environment. In a reducing environment with no hydrogen sulfide, both arsenite and soluble ferrous hydroxides would be present and the arsenic would be more mobile. Reducing conditions in the hydrocarbon smear zone may influence the mobility of the arsenic in this area and thus affect the size of the dissolved arsenic plume. The arsenic plume does not extend beyond the hydrocarbon plume. The arsenic plume is currently contained partially by groundwater pumping and (particularly in the SWQ) partially by oxidizing conditions outside the area of active hydrocarbon biodegradation.

2.7 Land Use and Receptors

Risk assessments completed for the CCF site and the off-site areas of Hooven and the SWQ have determined that there are no completed exposure pathways for the LNAPL and dissolved-phase plumes related to the consumptive use of groundwater. Therefore, as long as institutional controls (IC) are in place to prevent future consumptive use of groundwater, the LNAPL and dissolved-phase hydrocarbon plumes do not present a risk through a groundwater consumption exposure pathway.

However, the risk assessment identified completed exposure pathways related to subsurface hydrocarbon vapor resulting primarily from the LNAPL plume, the smear zone, and areas of shallower hydrocarbon-contaminated soils. The exposure pathways include present and future construction workers and subsurface infiltration into structures either through slabs or basements. For the CCF, the risk assessment identified unacceptable risk from subsurface vapor infiltration into basements. Marginally unacceptable risk from subsurface vapor infiltration into basements was identified for the SWQ, and the basement vapor infiltration risk for the Hooven area was deemed to be acceptable. No unacceptable risk was identified for the construction worker or slab infiltration pathways at the Cincinnati Facility.

The current and anticipated future land use for the site includes commercial, light industrial, and recreational uses on site; commercial uses in the SWQ, which is located south of Hooven and west of the CCF; and commercial and residential uses in Hooven (Figure 2-22).

Although there is an indicated unacceptable risk to receptors for vapor intrusion into basements on site, ChevronTexaco can control the future development activities on site and will ensure that no basements are constructed as prescribed in the risk assessment. ChevronTexaco is also working with developers and property owners to restrict basements in the SWQ, to use engineered controls if basements are constructed, and to implement other institutional controls. Therefore, the hydrocarbon vapors do not present unacceptable risks that need to be addressed other than through IC.

2.8 Current Conceptual Site Model Summary

The CSM shown on Figure 2-23 displays several features discussed previously in Section 2 of this report. It shows the overall conceptual model of the entire site, including features such as Hooven, SWQ, the aquifer, and local roads, in addition to the Great Miami River and the Islands.

The hydrocarbon contamination extends off site to the west under Hooven and to the SWQ located south of Hooven. The extent of the hydrocarbon plumes during high and low water tables is shown by the green hatched line on the figure. The thin and thick LNAPL smear zone types previously described are shown in the two detail block inserts in the upper left and right corners of the figure. The block inserts illustrate the CSM of how the LNAPL has interacted with the subsurface soils and changing water tables to create the smear zone. Groundwater flow on the figure is generally from the right to the left.

3.0 Future Conceptual Site Model

The CSM presented in Section 2 characterizes existing site conditions, is used to establish the basic features of the groundwater flow model, and serves as a "platform" from which detailed findings regarding the distribution and behavior of LNAPL and dissolved-phase hydrocarbons can be assessed and applied to future actions. Three critical factors must be considered for the optimization of the recommended alternative of containment:

1. The mobility of the LNAPL plume;
2. Long-term mass reduction of the LNAPL plume by natural processes; and
3. Containment of the dissolved-phase plume by natural attenuation.

The long-term mass reduction of LNAPL by natural processes was established as viable in Section 2. The issue of LNAPL mobility is discussed in detail in Appendix A. In order to maximize the LNAPL immobility, an Interim Remedy of focused LNAPL recovery will be performed. Natural attenuation of the dissolved-phase plume was evaluated by groundwater modeling.

The purpose of this future CSM is to provide a generalized vision of the site during the time period, perhaps hundreds of years, that the Final Remedy will be implemented. This future CSM is based on the following factors under a non-pumping scenario: an immobile LNAPL plume (following Interim Remedy), LNAPL mass reduction by natural processes, and a stable to (ultimately) shrinking dissolved-phase plume controlled by natural attenuation.

As will be discussed in Sections 4 and 5 of this report, the recommended remedy for the site consists of an interim phase and a final phase. The interim phase will allow a transition from the current groundwater remedial activities (as discussed in Section 2 – "Current Conceptual Site Model") to the Final Remedy. For the purposes of the future CSM, the Interim and Final Remedies are only discussed in general conceptual terms in this section. Justification, design details, implementation issues, and monitoring programs are discussed in detail in Sections 4 and 5 of this report.

Some aspects of the current CSM, as discussed in Section 2 of this report, will not differ from the future CSM. These aspects include aquifer characteristics, water table fluctuations, and the extent of the smear zone. The main differences will be in the hydraulic gradients beneath the CCF and, to a lesser extent, the footprint of the dissolved-phase plume.

Interim Remedy Summary

Most of the LNAPL that can be practically removed from the aquifer has been removed over the last 17 years. It is unlikely that the LNAPL would migrate downgradient if the groundwater pumping were discontinued. However, an Interim Remedy will be implemented that consists of an intense focused effort to remove an additional amount of LNAPL. This will ensure that the LNAPL will not be mobile when the groundwater pumping is gradually reduced until groundwater flows beneath the site are totally under the influence of natural hydraulic gradients.

Instead of pumping groundwater from a network of production wells, the focused recovery will occur by pumping from a few strategically placed production wells at a rate that is near the capacity of the groundwater treatment system. This will be done during low water table conditions (e.g., at a specified water table elevation "trigger"), when the increased drawdown due to the higher pumping rate from individual wells will result in greater drawdown of the water table and the recovery of more LNAPL. Modeling indicates that focused LNAPL recovery during these low water table conditions will remove the remaining LNAPL to the extent that is practicable.

As the focused LNAPL recovery proceeds, the overall groundwater pumping will be reduced, which will allow the aquifer to return to natural hydraulic gradients over time. The transition to reduced groundwater pumping rates actually began in 2000, when the CCF began reducing the total groundwater pumping rate approximately 50% during high water table conditions, when virtually no LNAPL recovery occurs and the LNAPL is submerged and is not mobile. Groundwater monitoring performed since 2000 has not indicated the migration of hydrocarbon. The transition to natural hydraulic gradients over time will allow the natural attenuation processes (particularly biodegradation) occurring in the aquifer to adapt to the changing hydraulic conditions. Groundwater monitoring will be conducted to verify that the LNAPL and dissolved-phase plumes remain stable.

As part of the optimization, the construction of a barrier wall adjacent to the Great Miami River in the southern portion of the CCF is being considered in order to prevent the possible migration of LNAPL into the Great Miami River under natural hydraulic gradients. Monitoring during the Interim Remedy, while groundwater pumping rates are gradually reduced, will allow a further evaluation of this potential option to determine if construction of a barrier is needed.

Final Remedy Summary

When the Interim Remedy has been completed, LNAPL will have been recovered to the extent practicable, and the remaining residual LNAPL will not be mobile. The aquifer underlying the CCF will have reverted to natural hydraulic gradients, and natural attenuation processes will have stabilized the dissolved-phase plume. A groundwater monitoring system will be used to monitor both LNAPL and dissolved-phase plumes on a long-term basis.

Over time (greater than 100 years), mass losses will deplete the LNAPL plume, and the dissolved-phase plume will begin to gradually shrink. The remedy will be considered complete when the groundwater quality has met the applicable cleanup standards.

3.1 LNAPL Plume

Following the completion of the focused LNAPL recovery, most of the smear zone will consist of low saturation LNAPL. A thin layer near the bottom of the smear zone will contain high residual LNAPL saturations in some areas; however, these areas are expected to be discontinuous across the entire smear zone and should not migrate laterally to the extent that the footprint of the smear zone will be modified. Localized intra-site migration of LNAPL within some of the thicker smear zone areas may occur, but this localized LNAPL movement should not affect the LNAPL or dissolved-phase plume geometries. The lateral extent of the smear zone should be as it exists presently, as shown on Figure 2-9.

3.2 Hydraulic Gradients

As discussed in Section 2 of this report, the general direction of groundwater flow beneath the CCF is generally from north to south. The natural hydraulic gradients are currently affected by the groundwater pumping that has historically maintained an inward hydraulic gradient at the CCF for the purposes of LNAPL recovery.

Historically, the CCF has pumped from several production wells at rates near the facility treatment system capacity, which is approximately 2,600 gpm during both high and low water table conditions. Starting in 2000, the total pumping rate was reduced by approximately 50% during high water table conditions, when little or no LNAPL is present in the monitoring wells. As previously discussed, during low water table conditions, the pumping rates are increased back to near system capacity. Since 2000, the routine LNAPL and dissolved-phase monitoring has indicated that the LNAPL and dissolved-phase plumes have remained stable. During the Interim Remedy period, the groundwater pumping rate will have gradually been reduced (except during the periods of focused LNAPL recovery) so that the hydraulic gradients will have approached conditions unaffected by pumping.

Natural groundwater flow prior to the initiation of pump-and-treat operations exhibited gradient and flow direction characteristics *regionally* similar to current groundwater flow affected by pumping. Groundwater flows from north to south, entering the CCF site from the north and flowing south parallel to the Great Miami River valley. Because all water-level measurements at the CCF have been made under pumping conditions, MODLFOW-SURFACT was used to simulate no-pumping water level conditions in the aquifer. Figures 3-1 and 3-2 illustrate the simulated natural hydraulic gradients under high and low water table conditions. Although there are no available data at the CCF representing observed conditions without pumping, the simulated potentiometric surface appears to be reasonable, based on the expected configuration of the water table under both high and low water conditions. The simulated potentiometric surface map shows decreasing heads from north to south, with relatively little direct hydraulic communication apparent between the Great Miami River and the aquifer. The simulated hydraulic gradient is approximately 0.001 ft/ft, which shows relatively little variation along the direction of flow, indicating the lack of significant variability in aquifer transmissivity at the CCF.

Figures 3-1 and 3-2 show the estimated location of a barrier wall if it is constructed as part of the Final Remedy to prevent LNAPL from potentially reaching the river. These contour maps do not consider the impact of a barrier wall at this time. However, initial modeling in preparation of this report showed it had minimal effect on groundwater flow due to the high transmissivity of the aquifer.

3.3 Natural Attenuation of the Dissolved-Phase Plume

The extent of the smear zone and dissolved-phase plume under the existing pumping conditions is shown on Figure 2-9. The extent of the smear zone during the beginning of the Final Remedy will be the same as under existing conditions.

This section describes the behavior of the dissolved-hydrocarbon plume at the CCF site and how the implementation of the containment approach will affect the movement and position of that plume. Benzene, as a dominant component of LNAPL and a compound with a low (5 μg/L) MCL, has been modeled as a compound representative of the dissolved-phase plume. This discussion of the dissolved-phase plume stability is supported by references to literature, the site data, and simulations of groundwater flow and hydrocarbon transport using the MODFLOW-SURFACT numerical model.

The overall behavior of dissolved-hydrocarbon plumes is well understood from literature and over 15 years of monitoring at the CCF site. The geometry and mechanics of the dissolved-phase plume are sufficiently understood to develop and implement a final containment approach for hydrocarbons. Section 2 describes the overall geometry and behavior of the dissolved-phase plume, which is generated from the dissolution of the LNAPL smear zone that occurs beneath the CCF and Hooven. Groundwater monitoring at the CCF site has shown that the dissolved-hydrocarbon plume forms a thin “halo” in the saturated zone around the LNAPL smear zone. The pumping operations thus have limited the downgradient movement of the LNAPL and dissolved-phase plumes. It appears that the benefits of the hydraulic control program have been realized to their maximum extent. At this time, natural biodegradation processes and greatly reduced LNAPL mobility due to mass loss are the primary limiting mechanisms of plume movement rather than the groundwater pumping.

Research at numerous LNAPL sites has identified natural hydraulic and geochemical phenomena that influence the movement and behavior of dissolved-phase hydrocarbons in groundwater. Because these natural phenomena have been the subject of detailed research and confirmed in field studies, it is uncommon (and typically unnecessary) to qualify that all of these phenomena are at work at individual sites. At the CCF, natural hydraulic and geochemical phenomena and their likely roles include:

- Advection-dispersion causes the dissolved-phase hydrocarbons to spread laterally and become less concentrated due to the movement of groundwater through the porous material.
- Sorption and volatilization may result in local changes in the concentration of dissolved-phase hydrocarbons but represent an unknown influence on the overall distribution and movement of dissolved-phase hydrocarbons at the site.
- Degradation due to biological and geochemical processes is known to significantly reduce the dissolved-hydrocarbon levels on the Islands, and represents a significant process that controls the downgradient spreading of the plume.
- Water level fluctuations (within smear zone) act to continually vertically redistribute LNAPL and increase the opportunity for continued dissolution of LNAPL by groundwater.
- Hydraulic gradients and groundwater flow velocities, in the absence of engineered modification due to pumping wells, move dissolved constituents downgradient in a direction parallel to the flow of the Great Miami River.

Several of these processes act in opposing fashions, i.e., expanding or limiting the movement of dissolved-phase hydrocarbons in groundwater. However, evidence provided by groundwater monitoring at the CCF and Hooven area strongly suggest that the current configuration of the plume is attributable to the combined influences of the groundwater flow modified by hydraulic control pumping and natural attenuation.

3.4 Simulation of Dissolved-Phase Plume Transport

The MODFLOW-SURFACT model was used to simulate the behavior of the dissolved-phase hydrocarbon plume after the cessation of groundwater pumping. These simulations were performed using the calibrated groundwater flow and transport model. The LNAPL source term was defined based on evaluation of the geometry, vertical distribution, and saturation characteristics of the smear zone. All simulations were run using conservative literature- or site-based parameter values for water chemistry, LNAPL saturations in the smear zone, and biodegradation rates. These simulations are explained in Appendix B and include a term for natural attenuation (degradation) based on a combination of literature values and site experience.

3.4.1 LNAPL Source and Degradation Terms

LNAPL Source

For purposes of the modeling effort, the smear zone was conceptualized as consisting of both a low-saturation LNAPL zone and a high-saturation LNAPL zone. This concept was discussed as part of the current CSM in Section 2 (and in more detail in Appendix A). It is important to consider the geometry and characteristics of the smear zone because it is considered to represent an ongoing and long-term source of benzene to the groundwater flow system downgradient of the CCF. Based on cores retrieved from the smear zone and interpretation of ROST logs, the low-saturation LNAPL zone was defined as a 3% saturation level and the high-saturation LNAPL zone as a 20% saturation level. The LNAPL saturation levels provide a means to distinguish between smear zone types characterized by relatively small amounts of LNAPL that occupy most of the smear zone thickness versus larger quantities of potentially mobile LNAPL accumulated at the base of the smear zone.

The areal distribution and thickness of the low-saturation and high-saturation zones were inferred from direct observations of cores and interpretations of ROST logs. The thickness of the low-saturation zone ranges from over 20 ft, thinning gradually to the southwest, with the boundary of the LNAPL smear zone indicated on Figure 2-10. Similarly, the thickness of the high saturation zone is a maximum of 5 ft and thins toward the west and southwest.

For the simulation of benzene dissolving from these LNAPL saturation zones, it was assumed conservatively that no degradation of the LNAPL occurs where it is thicker than 2 ft. This assumption was made to ensure that the LNAPL was simulated for the entire modeling period with a nearly continuous flux of benzene into the groundwater flow system. The benzene mole fraction in the LNAPL source body was estimated by directly correlating the thickness of the LNAPL body to the concentration of benzene within that body. Results of chemical analysis of LNAPL samples were projected into areas of thinner LNAPL smear zones where no data were collected because of infrequent occurrences and/or absence of LNAPL in wells.

As discussed above, almost all of the groundwater flowing under the site will leave the smear zone at its southern and southwestern boundary, west of the Great Miami River, and under the SWQ. There, as the smear zone thins and LNAPL saturations decrease, natural attenuation will reduce the benzene concentration to low µg/L levels. It is expected that groundwater will enter this natural attenuation zone with all hydrocarbon species at or near saturation relative to their concentrations in the LNAPL. For benzene, this corresponds to an aqueous solubility of approximately 3 mg/L. This expectation is based on the assumption that electron acceptors would be rapidly exhausted after entering the site with the groundwater flow from the north. Consequently, the water should emerge at the southern edge of the site with benzene concentrations at equilibrium with the LNAPL.

Dissolved-Phase Plume Degradation

It was assumed that the biodegradation of benzene and BTEX could be approximated as a first order reaction. Previous biodegradation modeling conducted for Island No. 1 and the Cleves well field resulted in an estimated first order reaction rate coefficient of 3.5% per day (Geosyntec, 1995). In order to be conservative, Chevron Texaco utilized a biodegradation rate of 0.3%, which is an order-of-magnitude lower than the site-specific modeled value. This conservative value provides a “worst-case” scenario for the downgradient limit of the benzene plume in the MODFLOW-SURFACT simulation runs.

3.4.2 Model Simulations

Several MODFLOW-SURFACT simulations, using different combinations of input parameters considered representative (or conservative) of site conditions and of the dissolved-phase hydrocarbon plume, provided a good match for observed conditions in the field. As previously discussed, these simulations treated the LNAPL smear zone as stable and without biodegradation in order to allow the model to consider a sustained loading of benzene to the groundwater flow system. However, once benzene was allowed to partition from the LNAPL body to the groundwater flow system, a range of biodegradation rates (0.3% to 1% per day), developed primarily from literature sources but conservative with respect to CCF data, was used. The simulation that used a biodegradation rate of 0.3% resulted in the furthest downgradient position of the dissolved-plume front.

Figure 3-3 illustrates the results of a 20-year MODFLOW-SURFACT simulation in which LNAPL is assumed to remain a constant source at the CCF, according to the LNAPL smear zone configuration previously shown in Figure 2-9. A 0.3% degradation rate was applied to the dissolved-phase hydrocarbon plume that partitioned out of the LNAPL source. Figure 3-3 illustrates the benzene isopleths simulated for 1-yr, 5-yr, 10-yr, and 20-yr time periods after the cessation of groundwater pumping and re-establishment of natural hydraulic gradients in the aquifer (e.g., beginning at the completion of the interim remedy). The subsurface barrier along the river is included in this simulation. Groundwater flow under natural hydraulic gradients is allowed to transport the dissolved-phase hydrocarbons away from the source. The layer that is modeled corresponds to the screened interval of the shallow monitoring wells.

The results of this simulation indicate that, under conservative conditions, natural attenuation effectively limits the downgradient migration of the plume to just north of U.S. Highway 50 during the simulation period. The model predicts that the plume will be contained and stable, but the limits of the dissolved-phase hydrocarbon plume initially move a short distance downgradient under the opposing influences of continuous generation and transport of dissolved-phase hydrocarbons from the LNAPL source, coupled with the conservative 0.3% decay rate. If the decay rate were to be higher than 0.3% (which is likely for the CCF), the model predicts that biodegradation processes would overwhelm advective transport, and the downgradient limit of the benzene plume would be stationary, eventually retreating upgradient toward the LNAPL source area.

These time-series benzene plume concentration maps show that the limits of the plume would not change much over the 20-yr modeling period under the most conservative decay rate. However, MODFLOW-SURFACT predicts that there would be approximately a 50% reduction in the concentration levels in the center of the plume (e.g., refer to concentrations around PW-12) between the 1-yr and 20-yr simulations. This reduction in the benzene concentration level would be attributable to the dissolution of benzene from the LNAPL mass and loss of benzene in the LNAPL body over time, coupled with the continuous flushing of groundwater in the aquifer.

3.5 Future Conceptual Site Model Summary

The future CSM shown in Figure 3-4 displays several features discussed previously in Section 3 of this report. It shows the overall conceptual model of the entire site as it will look 50 to 100 years from now after the Interim Remedy is complete and while the Final Remedy is in place. The figure includes features such as Hooven, SWQ, the aquifer, and local roads, in addition to the Great Miami River and the Islands.

The hydrocarbon contamination extends off site to the west under Hooven and to the SWQ located south of Hooven. The green hatched line shows the extent of the hydrocarbon plumes during high and low water tables on the figure. The LNAPL smear zone types previously described are shown in the two detail block inserts in the upper left and right corners of the figure. Groundwater flow on the figure is generally from the right to the left.

Several features can be noticed on this figure that have changed from the current CSM (Figure 2-23):

- The Interim Remedy has been completed, which includes removing LNAPL to the extent practicable.
- Natural hydraulic gradients have been restored, and pumping is no longer creating an inward hydraulic gradient to the site.

- The dissolved-phase plume has stabilized as a result of natural attenuation processes.
- The LNAPL mass has reduced site-wide.
- Footprints of the LNAPL and dissolved-phase plumes have begun to decrease in overall size.
- The POC monitoring well program is active.
- The site is being redeveloped according to the land use plan.

The newest features on this figure show that pumping has ceased and there are no longer any drawdown cones created by the pumping wells. A barrier wall is shown as an optional feature to the Final Remedy. The pink POC boundary is placed around the site, and the orange buildings represent new development on the site according to the land use plan.

4.0 Interim Groundwater and LNAPL Management Strategy

The optimization of the containment alternative recommended in the GW CMS has resulted in a proposed remedy that has an interim component and a final component. The GW CMS specified CAOs that include Short-Term Protectiveness Goals, Intermediate Performance Goals, and Final Cleanup Goals. The short-term goals were met by the Groundwater EI Report. The Interim Remedy presented in this section will address the Intermediate Performance Goals, and the Final Remedy presented in Section 5 will address the Final Cleanup Goals.

The Intermediate Performance Goals are to:

1. Protect human health and the environment;
2. Remove recoverable LNAPL to the extent practicable, concentrating in the LNAPL high-grade areas identified in this report;
3. Remove the recoverable hydrocarbon under Hooven, to the extent practicable, using the HSVE system;
4. Maintain containment of the residual LNAPL and the dissolved-phase hydrocarbon plume through natural stabilization and monitored natural attenuation; and
5. Return the site to productive use for the surrounding community.

4.1 Interim Remedy Strategy

The Intermediate Performance Goals will be met utilizing the following strategies.

Focused LNAPL Removal

Although it appears that the LNAPL plume is immobile on a site-wide basis, focused LNAPL recovery will be performed in key areas (including SR 128 and Hooven areas) where the reduction of the remaining drainable LNAPL will lessen the possibility of LNAPL migrating beyond its current footprint and reduce LNAPL mass. This will also reduce the life span of the plume, although it will still take potentially over 100 years to reach cleanup levels.

As discussed in Section 2, there has been a significant mass reduction of LNAPL since 1985 from engineered and natural mass loss mechanisms. The estimated minimum mass loss by natural processes is currently between 770,000 lbs/yr and 1,400,000 lbs/yr (110,000 gal/yr and 210,000 gal/yr). The rate of LNAPL recovery from engineered remediation has ranged between 10,000 and 200,000 gal/yr since 1988, and has asymptotically declined since the initial high recovery rate. When the focused LNAPL recovery has been completed and active remediation ceases, natural processes will continue to result in LNAPL mass reduction. As the more degradable LNAPL compounds are removed by natural processes, the remaining LNAPL will partition more slowly, and the natural mass loss rates will diminish over time (see Figure 2-20).

Restore Natural Hydraulic Gradients

The site will be returned to natural hydraulic gradients by means of a step-wise reduction in groundwater pumping rates. Groundwater and LNAPL monitoring will be performed throughout and following the transition to natural gradients to ensure the LNAPL and dissolved-phase plumes remain contained. The transition period will allow time for the biodegradation processes to adapt to the new groundwater conditions and will ensure the efficient continuation of the natural degradation of the dissolved-phase plume.

LNAPL Gradients Near the River

LNAPL and smear zone hydrocarbons exist adjacent to the Great Miami River south of the Hooven Ditch and extend across the northern portion of the southwest quadrant (see Figure 2-9). Since 1985, the operation of groundwater extraction systems has sustained a hydraulic gradient away from the river so that LNAPL will not discharge to the river. As discussed in Appendix A, most of the areas near the river have experienced significant water table fluctuation because of the river's influence, and one of the LNAPL recovery wells (PROD_15) is located near the river. Prior to the installation of PROD_15, LNAPL was previously recovered from the Dravo production well, which was also located near the river. These activities have reduced LNAPL saturations to near residual amounts in the area near the river.

During the Interim Remedy period and prior to the cessation of groundwater pumping, additional studies will be conducted to better define the location of the smear zone with respect to the river, evaluate the potential threat of LNAPL seepage to the river, and determine the best way of addressing it if there is a problem.

The LNAPL in the Hooven Ditch area is more viscous and has lower solubility than LNAPL in most other areas of the site, and the soils in the Hooven Ditch area are finer-grained, which limits the mobility of the LNAPL in this area. Options for addressing the LNAPL in this area will be further evaluated during the Interim Remedy.

Prepare Site for Future Reuse

The transition from the Interim Remedy (active remediation) to the Final Remedy (monitored natural attenuation) will enable the site to begin preparations for the planned future reuse in the reasonably near future.

4.2 Interim Remedy Components

The components of the interim LNAPL program include:

1. Concentrating on focused recovery of hydrocarbon during low water table conditions over the next several years;

2. Restoring hydraulic conditions to natural gradients and monitoring to ensure that natural processes to continue to contain and deplete the plume;

3. Evaluating the LNAPL gradients near the river and ways of mitigating any identified problems;

4. Addressing the Hooven Ditch area LNAPL occurrence; and

5. Implementing an interim LNAPL/dissolved-phase monitoring program to verify the absence or presence of any lateral migration of LNAPL.

On-site LNAPL recovery actions will be comprised primarily of pumping modifications to the existing pump & treat system, combined with HSVE in the Hooven area. This may include installation of new wells, changes in pumping regimes, and other optimization actions that will drive the system to an endpoint that meets the objectives stated above.

Hooven presents a unique challenge to LNAPL recovery because it is a residential community outside the direct environmental management control of ChevronTexaco. As a continued good-faith effort over the next several years, ChevronTexaco proposes to focus LNAPL recovery on the Hooven area as well as focused areas within the CCF.

4.2.1 Focused Hydrocarbon Mass Recovery

The focused hydrocarbon recovery will include LNAPL recovery pumping and HSVE. The LNAPL recovery system will be designed to recover LNAPL from specific areas still containing drainable LNAPL during low water table conditions. The site's groundwater pumping capacity (approximately 2,600 gpm) will be focused on these specific areas rather than diffused across the site. This will allow higher pumping rates and greater drawdown which will maximize the recovery of the remaining LNAPL when done during low water table conditions. The HSVE system will be operated in conjunction with the groundwater recovery system to remove additional LNAPL mass from beneath Hooven. The various aspects of this component of the Interim Remedy are discussed in greater detail in the following sections.

It is anticipated that two to three low water tables conditions occurring over 6 to 10 years will provide maximum focused LNAPL recovery opportunities, after which the intermediate program will phase into the final remedy. Experience suggests that most of the attainable LNAPL drainage to a recovery well will occur during the first seasonal pumping drainage event. What little may additionally be recovered will drain to a recovery well during the subsequent drainage event. The results of this recovery program are expected to leave most wells without any measurable LNAPL much of the year, and less than 0.5 feet in wells where LNAPL may accumulate during short-term drought conditions. Under these conditions, the LNAPL is expected to be naturally contained and will not require active management.

Concentrated High-Grade Pumping Area

According to the CAOs, the locations on which recovery efforts will be focused are along SR 128 and under Hooven. However, several indicators define a potential focused LNAPL recovery ("high-grade") area. When used collectively, these indicators provide significant insight and identify areas that can be exploited for the greatest return. The following indicators have been evaluated to identify potential focused recovery areas across the site:

- Water level triggers for recovery;
- Groundwater and LNAPL hydrographs;
- Hydraulic conductivity toward groundwater and LNAPL;
- Apparent thickness of the higher saturation smear zone; and
- LNAPL viscosity.

Figure 4-1 shows estimates of the two areas where ChevronTexaco will focus recovery ("high-grade area"), based on current information, i.e., the Hooven and SR 128 area and in the interior of the CCF site. Evaluation of the high-grade area was based on the extent and thickness of the smear zone (Figure 2-10), the LNAPL plume (Figure 2-11), and its characteristics (Figure A-12). Note that these areas generally coincide with the areas containing the most drainable LNAPL based on hydrographs as shown on Figure A-12 ("Hydrograph Evaluation Map") in Appendix A. The optimum well locations and pumping rates will be determined by subsequent use of the MODFLOW-SURFACT groundwater model coupled with multiphase estimates in the design phase of this program. The model can also consider the attributes of HSVE under changed hydraulic conditions within certain assumption constraints.

Water Elevation Triggers

Low water table conditions expose submerged, potentially drainable LNAPL in the smear zone, thus promoting vertical LNAPL drainage and movement along hydraulic gradients to enhance local LNAPL recovery. The high transmissivity of the aquifer makes it more difficult for pumping systems to generate enough drawdown to expose submerged LNAPL. Therefore, the optimum time for efficient, accelerated LNAPL recovery is at naturally recurring low groundwater table stands.

A focused recovery of LNAPL will be implemented during times of low groundwater levels. Given the transient phenomenon of fluctuating water levels at the CCF site, ChevronTexaco anticipates that the LNAPL recovery program will operate on a cyclical basis to take full advantage of system capacity and seasonal water levels.

The rationale for a water level trigger is discussed in Appendix A. It is suggested in Section A.2.4 that monitoring well MW-20S would be a suitable trigger point well for the SR 128/Hooven area. If necessary, trigger points will be designated for other areas of the site (based on the final design of the focused LNAPL recovery program).

The LNAPL recovery pumping wells will be turned on when the water table drops below a trigger point of 464 ft msl in MW-20S or other suitable trigger point well. The pumping wells will operate for a minimum of 30 days once the water level trigger is reached and maintained, which will allow the groundwater pumping to induce and maintain adequate drawdown, and allow LNAPL time to flow to the recovery wells. After the minimum duration has been reached, the wells will remain in operation until LNAPL recovery has tailed off.

Pumping and Drawdown

The MODFLOW model combined with multiphase estimates will be used to design the focused LNAPL recovery system, and will look at various pumping scenarios to maximize the LNAPL recovery. During the design phase of the Interim Remedy, a preliminary simulation was run to illustrate a typical LNAPL scenario, and is presented here as an example of a possible recovery system.

The MODFLOW model was used to simulate several focused groundwater pumping scenarios at four current wells (PW-19, PW-20, PW-21, and PW-23) along SR 128 during low water table conditions. The total system-wide pumping rate was set at approximately 3,300 gpm (current treatment system capacity is approximately 2,600 gpm) and portioned among the wells. The modeling scenario with the greatest drawdown across the high-grade pumping area is shown on Figure 4-2.

It is estimated that focused groundwater pumping along SR 128 near Hooven will result in approximately 3 to 7 ft drawdown below the LNAPL trigger level under Hooven after about 30 days of a low water table, as shown on Figure 4-2. This would also induce a local recovery gradient and expose some of the smear zone to the HSVE system for additional mass recovery.

Horizontal Soil Vapor Extraction

The existing HSVE will be operated during the same time that the LNAPL recovery system is in operation. Operating the HSVE system during low water tables and high drawdown would increase the hydrocarbon mass recovered from the site.

Despite efforts to optimize the HSVE system, the operation of this system will continue to be limited by the rate of vapor flux from the smear zone and LNAPL to the capture zone of the HSVE wells. Continued operation of the system will provide low mass removal rates and some benefit in terms of LNAPL removal. In addition, most of the mass being removed comprises biodegradation products from the natural degradation of hydrocarbons. Therefore, while the HSVE system will not be considered the primary means of LNAPL removal, ChevronTexaco will continue to operate this system under Hooven as a supplemental effort to the focused LNAPL recovery program. Operation of the HSVE system will be evaluated at the conclusion of LNAPL high-grade recovery efforts, and if appropriate, operation of the HSVE system will be terminated.

Recovery Expectations

Hydrocarbon mass is expected to be removed through the use of both the recovery systems. A reduction in the measurable thickness of LNAPL in wells and in the number of wells containing LNAPL will be expected. The exact amount of recovery with respect to free product and HSVE cannot be predicted. However, overall LNAPL recovery has already reached an asymptotic level, as discussed in Section 2, and the additional recovery during this high-grade period is expected to follow the same trend of diminishing returns.

Given the past recovery history, the nature of the LNAPL occurrence, and the observed sensitivity to water level, the proposed strategy will make the best use of the available recovery methods and optimum recovery conditions.

4.2.2 Restore Natural Hydraulic Conditions

ChevronTexaco proposes that natural attenuation processes be the primary site-wide interim and final action for dissolved-phase plume management. As discussed in the future CSM in Section 3, groundwater modeling demonstrates that natural attenuation will effectively control the dissolved-phase plume under natural hydraulic gradients using conservative assumptions. ChevronTexaco will monitor the ongoing natural attenuation processes to verify that the dissolved-phase plume does not migrate.

The site will be restored to natural hydraulic gradients in incremental steps during the Interim Remedy. This gradual transition actually began in 2000, when the groundwater pumping rate was reduced by 50% during high water table conditions when the LNAPL is mostly submerged and trapped below the water table. During the focused LNAPL recovery, high-grade groundwater pumping will be activated during low water table conditions. However, during the high water periods, the pumping rate will be reduced in incremental steps until the pumps are eventually turned off and ambient water table conditions are reached. Depending on the final design and results of the LNAPL recovery program, groundwater pumping will be reduced stepwise during low water table conditions that do not merit LNAPL recovery operations. Anticipated natural hydraulic gradients at typical high water table levels are shown on Figure 3-1, and typical low water table levels are shown on Figure 3-2.

As discussed in Section 2, when the water table rises, the LNAPL becomes trapped in the subsurface beneath the water table. The LNAPL is residual or immobile in a two-phase (saturated zone) system. It is expected that LNAPL will redistribute vertically at some locations within the LNAPL footprint and be detected at measurable amounts in some wells even when the focused LNAPL recovery is completed. However, no lateral migration is expected to occur along the periphery of the existing LNAPL plume and, therefore, the lateral extent of the smear zone will not change. The Interim Monitoring Plan discussed at the end of this section is designed to monitor any lateral movement of the LNAPL after the natural hydraulic gradients are restored.

4.2.3 Hooven Ditch Area LNAPL Occurrence

As detailed in Section 2, LNAPL is known to have entered the Hooven Ditch during one extremely high water table condition. The LNAPL in the Hooven ditch area is more persistent and occurs under more water table conditions than in areas south of the Hooven Ditch (see Figure A-11 in Appendix A). Because of the higher viscosity of the LNAPL and fine-grained soils in the Hooven Ditch area, efforts to recover the LNAPL have attained limited success.

In general, the mobility of residual LNAPL in this area of the site is limited by these facts:

1. Residual LNAPL is comprised of predominantly high viscosity, heavy molecular weight hydrocarbons;
2. A competent silt unit extends to approximately 10 ft bgs, with a minimum of 3 ft of silty soil underlying the base of the ditch; and
3. Relatively low residual LNAPL saturations above and below the water table reduce the potential for both horizontal and vertical LNAPL mobility.

While the risk of vertical product migration into the Hooven Ditch is limited, under extreme high water table events (as experienced in May 1996), groundwater and floating LNAPL could potentially intercept the Hooven Ditch. As a consequence, the following remedial actions will be further evaluated during the Interim Remedy to mitigate potential risks:

1. When the Corrective Measures remedy for sludges and contaminated soils has been completed (excavation and off-site consolidation), SWMU 10 will have been removed, the portion of the Hooven Ditch that trends north-south can be backfilled, and that portion of the Hooven Ditch can be relocated to run directly east to the river through the SWMU 10 location.
2. Excavation of impacted soils within the smear zone immediately adjacent to the Hooven Ditch.
3. Enhanced product recovery activities (vacuum-enhanced product recovery) in the vicinity immediately adjacent to the Hooven Ditch to generate a buffer zone.
4. Line the Hooven Ditch to eliminate communication between the Hooven Ditch and the underlying groundwater table.

4.2.4 Potential LNAPL Discharge to the River

The smear zone is very close if not adjacent to the river bank in the southeast area of the site. As shown on Figure 3-1, the natural groundwater gradients in this area are parallel with the river. However, river flooding and precipitation events cause groundwater levels near the river to rise and, following the flooding/precipitation events, groundwater will temporarily flow into the river as the river level drops. During these periods, there could be an increased potential of hydrocarbon sheens appearing in the river. This potential will be further evaluated during the Interim Remedy through a detailed field investigation.

One option that has been considered for addressing the potential sheens is to construct a barrier wall along the river that would extend through the smear zone that prevents LNAPL from entering the river during these out-of-bank flow conditions. The ideal location of a barrier would be at the river's edge to prevent any potential seeps from the smear zone into the river. However, construction of a barrier at the river's edge would be very challenging if not impossible. It would also significantly disturb the existing riparian habitat along this section of the river. A barrier wall could be constructed along the location shown on Figure 3-1; however, it could potentially leave a 20-ft to 50-ft rind of smear zone between the river and the barrier wall, thus, not solving any long-term management issues. The barrier wall could effectively isolate the rest of the smear zone from impacting the river but would not address the portion of the smear zone in the 20-ft to 50-ft rind.

A barrier wall could also disrupt natural hydraulic gradients and adversely affect the equilibrium of the aerobic zone below the river and along the river bank area, which is likely contributing to the natural attenuation of any dissolved-phase plume in the river bank area.

During the Interim Remedy period, additional studies will be conducted to determine the location of the smear zone with respect to the river, the potential threat of a sheen along this portion of the river, and the best way of addressing it. The modeling and studies to date have indicated that a barrier wall could be effective hydraulically, as located on Figure 3-1, but it is not yet known if a barrier wall would be the optimum solution.

4.3 Interim Monitoring Program

The Interim Monitoring Program consists of a Point-of-Compliance Monitoring Program, an LNAPL Monitoring Program, and River Monitoring. The interim dissolved-phase monitoring program is identical to the final dissolved-phase monitoring program and is discussed in Section 5.

4.3.1 LNAPL Monitoring Program

A final element of the Interim Remedy is the LNAPL monitoring program. LNAPL may vertically redistribute within the center portions of the plume as water levels fluctuate. Therefore, any increase or decrease in the thickness of LNAPL in monitoring wells within the plume is not indicative of any plume-wide lateral mobility. The purpose of the interim LNAPL monitoring program is to monitor the periphery of the LNAPL footprint for any lateral movement of LNAPL beyond the current smear zone boundaries.

ROST has been chosen as the primary tool for determining the LNAPL location for the interim monitoring plan. Figure 4-3 shows a site map of the SWQ and three proposed areas for the LNAPL monitoring program. ROST technology will be used since it shows the presence or absence of LNAPL and also is not dependent on water table levels. This plan will be implemented concurrently with the interim high-grade recovery actions. The focus area for this interim LNAPL monitoring program will be the edge of the smear zone in the Southwest Quadrant, located southwest of the main CCF site.

The following actions will be performed as part of the interim LNAPL monitoring program:

1. Initially, ROST technology will be used to estimate the smear zone boundary in the SWQ downgradient areas.

2. ROST will be used on a periodic basis to evaluate any lateral migration of the LNAPL. A protective frequency of LNAPL monitoring will be determined by factors, including the findings of the initial ROST investigation (e.g., smear zone thickness and saturations) and other analytical techniques such as modeling.

Although LNAPL is not expected to migrate during the Interim Remedy period, the possibility for LNAPL lateral migration would be highest during the lowest water table conditions. However, the interim high-grade recovery plan will begin recovery operations when the water reaches the low water table trigger elevation. Therefore, since pumping will be active and the hydraulic gradient would be toward the pumping wells within the center of the plume, the interim activities will further mitigate the small possibility of lateral LNAPL migration.

By the time the Interim Remedy has been completed, the site will have returned to natural hydraulic gradients. Since the potential for lateral migration still exists during this time, ROST will continue to be used to verify the edge of the LNAPL plume for approximately 10 years following the end of the high-grade LNAPL recovery operations.

As part of the initial effort, ROST will be used to determine the general areas of the LNAPL smear zone. As shown on Figure 4-4, once the edge of the smear zone has been estimated, one ROST location will be in the LNAPL smear zone and two "clean" ROST locations will be downgradient of the smear zone, each spaced 20 ft apart. The exact location of the edge of the smear zone will be somewhere between the location in the smear zone and the first location outside the smear zone. Therefore, both locations outside the smear zone will be monitored.

If at any point LNAPL is found to have moved beyond the second "clean" ROST location, response actions will be taken as discussed in Section 4.4.

Previous efforts using ROST in these areas have run into difficulties with the tool encountering large cobbles in the subsurface, causing refusal or deflection of the ROST tool. To address this issue, this plan proposes to auger a hole from the surface down to approximately 5 ft above the potential smear zone elevation. A 2-inch diameter steel casing will be installed in the borehole, allowing the ROST tool to bypass the cobbled areas. The casing will be left in place and protected with a flush-mounted vault, allowing repeated measurements at the same location. The ROST tool, as shown on Figure 4-5, will enter through the casing and begin readings from the bottom of the hole down through the potential smear zone elevations to detect any presence of

LNAPL. This method will allow the ROST tool to be used in a specific elevation range, not the entire depth from the surface.

The LNAPL in the interior of the LNAPL plume will also be monitored during and after the Interim Remedy in order to track the anticipated LNAPL thickness reduction and the reduction of BTEX in the LNAPL over time. The expected frequency of LNAPL thickness monitoring is annually (during low water table conditions), and the expected frequency of LNAPL sampling for BTEX content is approximately every three to five years. These data will be used to confirm and calibrate the initial estimates of LNAPL mass loss rates.

4.3.2 Point-of-Compliance Monitoring Program

Point-of-compliance (POC) monitoring of the site is a component of the recommended Final Remedy; however, the wells will be installed and monitoring will begin during the Interim Remedy. The POC monitoring system will consist of a series of groundwater monitoring wells located along the specified POC boundaries. The purpose of the POC monitoring is to ensure that hydrocarbon does not migrate past the POC. The POC monitoring system is discussed in detail as part of the Final Remedy in Section 5.

In conjunction with the POC monitoring system, a series of performance monitoring wells (PMW) will be located upgradient of the POC boundaries just outside the limits of the existing plume. As discussed in Section 5.3, the PMWs will be constructed at various locations in the LNAPL plume, in the dissolved phase plume, and downgradient of the dissolved phase plume. The PMWs will be used to confirm and evaluate natural attenuation processes, and will allow monitoring of the dissolved phase plume upgradient of the POC wells.

4.3.3 River Monitoring Plan

The Great Miami River will be examined for evidence of LNAPL seepage into the river on a regular basis during the Interim Remedy and for the initial 10 years of the Final Remedy. During the Interim Remedy, the river will be examined for evidence of LNAPL seepage (e.g., an oily slick on the water in the river) on a weekly basis during low water table conditions and on a monthly basis during high water table conditions.

As discussed in Section 4.2.4, additional studies are planned during the interim period to evaluate the location of the smear zone with respect to the river. Based on the results of this evaluation, a series of piezometers will be placed near the river bank, as close to the river's edge as possible. The piezometers will be placed in arrays perpendicular to the river in order to evaluate hydraulic gradients between the aquifer and the river.

In order to monitor the potential for dissolved-phase hydrocarbons to migrate into the river, areas of groundwater discharge into the river will be monitored using passive aqueous diffusion (PAD) or passive vapor diffusion (PVD) sampling devices. PAD/PVD samplers can be constructed in various configurations and operate on the principal that the water or air in the sampler will equilibrate with the VOCs in the groundwater via diffusion through a water/vapor-permeable membrane. The time of equilibration varies with the VOC, soil type, sampler type, and temperature. The PAD/PVD samplers will be buried in the river bed near the riverbank smear zone areas at times of groundwater discharge to the river. The data generated by the piezometer arrays will be used to determine periods and areas of groundwater discharge.

A specific PAD/PVD sampling program will be designed based on data obtained from the riverbank piezometers and additional groundwater monitoring in order to identify the appropriate areas and times of groundwater discharge.

4.4 Contingency Plan

The contingency plan addresses three possible events:

1. Sampling of performance wells or POC wells indicates the presence of dissolved-phase hydrocarbon;
2. The LNAPL monitoring wells indicate that LNAPL is migrating laterally; and
3. Evidence of LNAPL seeping into the Great Miami River is observed.

4.4.1 Dissolved-Phase Encroachment

The purpose of the performance monitoring wells is to provide information regarding the behavior of the dissolved-phase plume upgradient of the POC wells. Performance monitoring wells located in the smear zone may experience variations in hydrocarbon concentrations because of water level fluctuations. If monitoring of the performance wells does indicate that the dissolved-phase plume may intercept the POC, USEPA will be notified, and mitigative measures such as activating the groundwater pumping system will be considered. ChevronTexaco believes, and data indicate, that natural attenuation occurs in the dissolved-phase plume and stabilizes it.

4.4.2 LNAPL Plume Migration

The potential for LNAPL migration outside the smear zone footprint would be highest at the downgradient edge of the smear zone in the SWQ, although the potential for migration there is considered to be very low because of the thin (approximately 1 ft thick) smear zone and low LNAPL saturations. If the LNAPL monitoring program shows that the LNAPL plume is migrating beyond the initial footprint of the smear zone, USEPA will be notified, and the groundwater pumping system will be activated.

4.4.3 LNAPL Seepage into Great Miami River

If the river monitoring shows that LNAPL is seeping into the Great Miami River, USEPA and other relevant regulatory agencies will be notified and production well PW-15, which is located near the river and the historical river seepage area, will be activated. An investigation of the LNAPL conditions in the area of the seepage will be performed and a mitigation plan will be presented to USEPA. Based on the results of the investigation, remedial activities such as construction of a barrier wall or additional focused LNAPL recovery will be conducted to mitigate LNAPL seepage into the river.

Issues associated with the construction of a barrier wall and LNAPL seepage into the river are discussed in Section 4.2.4 of this report. These issues and the feasibility of a barrier wall will be reevaluated in case LNAPL seepage into the river actually occurs.

5.0 Final Groundwater and LNAPL Management Strategy

As previously discussed, the recommended remedy for contaminated groundwater at the CCF has an interim component and a final component. The Interim Remedy, which is addressed in detail in Section 4 of this report, consists of focused LNAPL recovery to the extent practicable. During this multiple-year period, pumping rates will be reduced in steps, resulting in a transition from engineered hydraulic gradients to natural hydraulic gradients at the CCF. The Interim Remedy will address the intermediate performance goals specified in the GW CMS.

The Final Remedy will address the following final cleanup goals, as specified in the GW CMS:

1. Protect human health and the environment;
2. Achieve media cleanup standards established to ensure protection; and
3. Control the sources of releases so as to reduce or eliminate, to the extent practicable, further releases of hazardous constituents that may pose a threat to human health and the environment.

5.1 Final Remedy Strategy

The Final Remedy is based on the following conditions that will exist following the completion of the Interim Remedy:

- The LNAPL will be immobile on a site-wide basis under natural hydraulic gradients;
- Natural attenuation processes are actively degrading the hydrocarbon in the groundwater and soil vapor and will contain the dissolved-phase plume under natural hydraulic gradients; and
- LNAPL mass reduction is continuing to occur by natural processes.

The future conceptual site model presented in Section 3 of this report shows the anticipated site conditions following the completion of the Interim Remedy. The future conceptual site model includes detailed discussions regarding ChevronTexaco's investigations of natural hydraulic gradients, natural attenuation, and LNAPL mass reduction.

Natural Attenuation

At the conclusion of the Interim Remedy, the site will have returned to natural hydraulic gradients. Natural attenuation processes will continue to deplete the hydrocarbon in the groundwater over time, and will contain the dissolved-phase plume.

Prevent LNAPL Seepage into the Great Miami River

Monitoring the Great Miami River for evidence of LNAPL seepage will continue throughout the first 10 years of the Final Remedy and will be an integral part of the long-term monitoring program.

Institutional Controls

Because it will take many years to reach the final cleanup levels, institutional controls will be implemented to protect the people using the property from potential exposure to groundwater or soil vapor.

Point of Compliance Monitoring

A POC will be established around the facility, and a POC monitoring system will be utilized to ensure that the dissolved-phase hydrocarbon plume will remain inside the POC.

5.2 Final Remedy Components

Containment of the LNAPL and dissolved-phase hydrocarbon plume in groundwater will be achieved by a combination of:

1. Restoration of natural hydraulic gradients;
2. Monitored natural attenuation;
3. Institutional controls; and
4. A final performance groundwater monitoring program, which will include performance monitoring wells and POC monitoring wells.

5.2.1 Restoration of Natural Hydraulic Conditions

For nearly 20 years, groundwater has been pumped at the CCF site to facilitate the recovery of LNAPL in wells and to manipulate hydraulic gradients to prevent further expansion of the LNAPL plume. As discussed in detail in previous sections, the effectiveness of these pumping operations in recovering LNAPL has diminished over time. The combination of LNAPL plume immobility and the increasing effectiveness of natural attenuation as an LNAPL removal mechanism renders the current pumping approach impractical. Therefore, a key component of the final plume management strategy is allowing natural hydraulic gradients to redevelop across the site. As previously discussed, natural gradients will actually be gradually re-established during the Interim Remedy, concurrently with the focused LNAPL recovery activities.

5.2.2 Natural Attenuation

Natural attenuation occurs whether or not groundwater pumping operations are underway. However, the final dissolved-phase plume management strategy will allow natural attenuation to proceed in the context of natural hydraulic gradients being restored to pre-pumping conditions. The MODFLOW-SURFACT simulations, presented in the future conceptual site model in Section 3, show that natural attenuation will be effective in containing the dissolved-phase plume under natural hydraulic gradients. The simulations predict that the limits of the dissolved-phase hydrocarbon plume will either move slightly downgradient or will remain essentially stationary over the long term. This range of predictions is influenced by the combination of a gradual depletion of the LNAPL source from natural decay and ChevronTexaco recovery operations, as well as the biodecay of the dissolved-phase hydrocarbon plume. These geochemical phenomena are discussed in detail in the conceptual site model in Section 2.

5.2.3 Institutional Controls

Institutional Controls (IC) will be implemented to help protect the people using the site from potential exposure to contaminated groundwater or soil vapor. ICs will be implemented both on the former refinery site and on adjacent properties not owned by ChevronTexaco.

ChevronTexaco is currently working with the law firm of Squire, Sanders and Dempsey, L.L.P. and the State of Ohio to identify the appropriate ICs and the mechanisms for implementing and monitoring the ICs. The first step in this process it to identify the objectives to be accomplished with the use of ICs. The objectives vary, depending on land ownership, impacted media, and potential exposure pathways. Objectives have been identified for four different areas as defined below.

Southwest Quadrant (SWQ)

This is an area of approximately 40 acres to the southwest of the former refinery that is privately owned and is currently undergoing commercial/industrial development. The subsurface contamination includes both groundwater contamination and the associated hydrocarbon-impacted soil at depths of 20 to 25 ft. The subsurface contamination also releases vapors to the subsurface that could pose potential problems to deep excavations in the area. The objectives of the ICs are:

- **Ensure health and safety during subsurface construction activities:** ChevronTexaco would be notified of any excavations greater than five feet deep to ensure proper precautions are taken during the excavation activities.

- **Prevent groundwater withdrawal:** This would prevent contact with contaminated groundwater and potential vapors that could be released from the water if it were used.

- **Restrict the development to commercial/industrial activities:** This would prevent residential development or activities that would attract sensitive populations (e.g., children, elderly, etc.).

- **Prohibit construction of basements or other deep excavations:** This would prevent deep excavations that would increase potential exposure to vapors.

- **Require compliance with the recommended stormwater management system:** The "default" method of managing stormwater is to install infiltration wells into the shallow aquifer. These infiltration wells can increase the potential exposure to vapors from the subsurface contamination. The recommended stormwater management system relies on surface drainage and storm sewers to avoid this potential vapor exposure.

- **Require recognition of the presence of subsurface vapors for any required subsurface construction such as utility installation:** Some temporary subsurface construction will be required with the development of the property. This is a mechanism to put the owners and contractors on notice that subsurface vapors could be encountered, and they should take the appropriate precautions.

- **Require that the owners allow ChevronTexaco access to existing monitoring wells.**

- **Indemnification for property owners for subsurface contamination emanating from the former refinery.**

Village of Hooven

This is an established neighborhood directly west of the former refinery. Approximately 40 to 50 residences and commercial properties in the eastern portion of Hooven are underlain with subsurface contamination that includes groundwater and the associated hydrocarbon-impacted soil. The depth (50 to 60 ft) to contamination in Hooven is deeper than in the SWQ, so there are not as many potential issues to address here. The objective of the ICs is:

- **Prevent groundwater withdrawal:** This would prevent contact with contaminated groundwater.

State Highway Department and Utility Companies

The State Highway Department and various utility companies (e.g., water, sanitary sewer, cable, electric, telephone, etc.) may need to excavate in areas containing hydrocarbon soil vapors, both on and off the ChevronTexaco property. Some mechanism should be available to inform them of the potential contact with hydrocarbon vapors in these excavations.

Former Refinery Site

The former refinery site is currently owned by ChevronTexaco and is planned for a mixed-use development that could include commercial, industrial, and recreational uses. As long as ChevronTexaco owns the land, it will have considerable control over the development. However, if ChevronTexaco sells the property, it will have to address many of the same issues as in the SWQ through the use of ICs. The objectives of the ICs would be:

- **Prevent exposure to contaminated groundwater:** This would prevent contact with contaminated groundwater and potential vapors that could be released from the water if it were used.

- **Restrict the development to commercial/industrial activities:** This would prevent residential development or activities that would attract sensitive populations (children, elderly, etc.).

- **Prohibit construction of basements or other deep excavations:** This would prevent deep excavations that would increase the potential exposure to vapors.

- **Require the installation of passive vapor control systems under building slabs (where applicable):** This would address the potential buildup of vapors under buildings.

- **Require compliance with the recommended stormwater management system:** The recommended storm water management system relies on surface drainage and storm drains to avoid the potential vapor exposure.

- **Require recognition of the presence of subsurface vapors for any required subsurface construction such as utility installation:** Some temporary subsurface construction will be required with the development of the property. This is a mechanism to put the owners and contractors on notice that subsurface vapors could be encountered, and they should take the appropriate precautions.

- **Require that the owners allow ChevronTexaco access for operation and maintenance of remediation systems and monitoring wells.**

ChevronTexaco will continue to identify the appropriate ICs and the mechanism for implementing and monitoring those controls. ChevronTexaco will work closely with USEPA throughout this process to ensure that the ICs and mechanism for implementing and monitoring them are acceptable to USEPA.

5.2.4 Point of Compliance

The POC for groundwater is where ChevronTexaco will monitor groundwater quality to demonstrate that MNA is successful in containing the dissolved-phase hydrocarbon plume and ensuring that action levels for the COPCs are not exceeded. The POC is shown on Figure 5-1 and will include monitoring wells capable of detecting dissolved hydrocarbons originating from the LNAPL plume.

The proposed POC for groundwater has been defined using information specific to the local geohydrologic conditions around the CCF site; the characteristics and distribution of LNAPL and dissolved-phase hydrocarbons; and the simulated size and position of the hydrocarbon plume in the future. Most of this section addresses the monitoring of groundwater downgradient and southwest of the CCF site. The POC was established based on the following factors:

- The physical boundaries and limits of the aquifer;
- The prevailing direction and magnitude of groundwater flow in the alluvial aquifer under natural hydraulic gradients;
- The occurrence and characteristics of the LNAPL plume and dissolved-phase plume of hydrocarbons; and
- The simulated configuration of the dissolved-phase plume under anticipated natural hydraulic gradients and site-specific geochemical conditions.

The POC components will consist of:

- Visual monitoring of the portion of the Great Miami River along the southeast portion of the CCF that received LNAPL seepage in 1985;
- POC monitoring wells downgradient of the plume that are monitored to ensure compliance with action levels; and
- PMWs located within and near the margin of the dissolved plume to confirm that natural attenuation and the plume management approach is working as intended.

5.3 Point-of-Compliance Monitoring Program

The groundwater monitoring program will include two types of monitoring wells to provide a comprehensive evaluation of the progress and performance of the dissolved-phase plume management strategy. PMWs will be used to evaluate groundwater conditions at the LNAPL source area, within the dissolved plume itself, and at the downgradient margin of the dissolved plume. These PMWs will be used to confirm that natural attenuation is containing the dissolved plume in general agreement with the results of MODFLOW-SURFACT simulations. As such, the analytical suite that will be proposed for these wells will consist of parameters indicative of natural attenuation as well as COPCs.

POC monitoring wells will be located at or near the POC to evaluate whether the plume is migrating to or beyond the POC. Accordingly, the analytical suite proposed for the POC monitoring wells will be limited to the COPCs.

As previously discussed and illustrated on Figure 3-3, the results of the groundwater modeling simulations indicate that the downgradient limit of the dissolved benzene plume will migrate slightly downgradient or remain essentially stationary (using conservative assumptions). Therefore, the POC groundwater monitoring program will consist of several components for field-checking the validity of these simulations and ensuring that the LNAPL and dissolved-phase hydrocarbon plume does not migrate to the POC.

PMWs will be located at the distal margins of the dissolved-phase plume and monitored for evidence of plume migration (i.e., increasing or decreasing concentration trends at specific locations). POC monitoring wells will be located further downgradient, near U.S. Highway 50. Groundwater samples collected from POC wells and PMWs will be analyzed for COPCs identified in the GW CMS and summarized in Table 5-1.

Table 5-1
Contaminants of Potential Concern (COPC) for POC Monitoring

Chemical Contaminant	Action Levels
Benzene (µg/L)	5[1]
Ethylbenzene (µg/L)	700[1]
1,4-DCB (µg/L)	75[1]
DEHP[5] (µg/L)	6[1]
Naphthalene (µg/L)	6.2[2]
Pyrene (µg/L)	180[2]
Lead (mg/L)	0.015[3]
Arsenic (mg/L)	0.05[4]

[1] Federal Safe Drinking Water Act Maximum Contaminant Level (MCL).
[2] USEPA Region 9 Preliminary Remediation Goal (PRG).
[3] USEPA Drinking Water Standards and Health Advisories list an action level of 0.015 mg/L.
[4] USEPA has promulgated an MCL of 0.010 mg/L, to become effective in 2006.
[5] Bis (2-ethylhexyl) phthalate.

The GW CMS specified a final cleanup goal for acetophenone of 0.042 µg/L, which is a USEPA Region tap water PRG. However, this PRG should not be used since it is much lower than the laboratory detection limits for that compound. There is no MCL or other drinking water standard for acetophenone. However, the Ohio Voluntary Action Program (Ohio VAP) provides a risk-derived generic unrestricted potable use standard for acetophenone of 1,600 µg/L. The CCF is not currently participating in the Ohio VAP; however, the Ohio VAP risk-derived standard for acetophenone will replace the USEPA Region 9 PRG used in the GW CMS. When comparing the highest detection at the site of 21 µg/L to the Ohio VAP, acetophenone should not be considered a COPC. Therefore, acetophenone has been removed from the COPC list for CCF shown in Table 5-1.

The POC for the CCF extends around the perimeter of the groundwater plume. Because of the variability in the occurrence and characteristics of the hydrocarbon plume and differing hydraulic gradients at the CCF, the POC has been subdivided into four segments. These segments account for these different conditions and facilitate the use of appropriate monitoring strategies. The segments are illustrated on Figure 5-1 and are described below:

- **Segment A:** The SWQ extending from the Great Miami River west along (south) U.S. Highway 50 and then north through Hooven to SR 128;
- **Segment B:** The western portion of the CCF along SR 128 where the alluvial aquifer pinches out at the base of the hills west of the CCF;
- **Segment C:** The northern and eastern portion of the CCF which is hydraulically upgradient and cross-gradient of the LNAPL and dissolved-phase plume; and
- **Segment D:** The southeastern portion of the plume where a hydrocarbon sheen had previously been observed at the Great Miami River before hydraulic control pumping began.

Table 5-2 summarizes the principal features of the POC elements.

Table 5-2
Characteristics of the Groundwater Point-of-Compliance Boundaries

POC Segment	Description	Geologic and Hydrogeologic Features	Gradient Conditions	Monitoring Approach
Segment A	Southwest of CCF. POC segment forms an arc extending from river at U.S. Highway 50 to Hooven at SR 128.	Alluvial aquifer ranges from about 60 to more than 100 ft thick.	Hydraulic gradient to the south-southwest after pumping is discontinued.	Combination of POC monitoring wells and PMWs.
Segment B	West of CCF. North-south line along SR 128 at western boundary of alluvial aquifer.	Alluvial aquifer is absent along this POC segment, which represents the surface boundary between bedrock and alluvial materials.	Groundwater does not occur along this POC in the alluvial aquifer. Groundwater flow is parallel to the POC segment.	No monitoring necessary because of the no-flow conditions at the edge of the alluvial aquifer.
Segment C	Northern and eastern boundaries of CCF bordering the Great Miami River.	Alluvial aquifer thickens toward the river. Groundwater flow is from north to south, perpendicular to the valley axis.	POC segment is upgradient or cross-gradient to groundwater flow.	Combination of POC monitoring wells and PMWs.
Segment D	Southeast boundary of the CCF at the Great Miami River.	LNAPL smear zone in contact with river.	Hydraulic gradient is parallel to subparallel direction of river flow.	Visual observations will be made for LNAPL seepage during low-river stage conditions.

5.3.1 Segment A – Southwest Quadrant and Hooven

The Segment A (Figure 5-1) POC is downgradient of the observed margin of the dissolved-phase hydrocarbon plume. It extends from SR 128 near U.S. Highway 50 west and north in an arc around the plume margin northwestward to Hooven. This segment, representing the downgradient segment through which virtually all groundwater flow at the CCF will pass, was evaluated for groundwater flow velocities, possible preferential groundwater flow pathways, and simulated movement of the benzene plume.

Groundwater Flow Velocity and Preferential Pathways

The MODFLOW-SURFACT model discussed in Section 3 was used to evaluate groundwater flow velocities and estimate the distance that groundwater will flow under ambient (no-pumping) conditions. This evaluation was used to identify appropriate spacing of PMW and POC monitoring wells, and establish the timing of sampling events.

Figure 5-2 illustrates simulated groundwater flowpaths and particle tracks for two layers in the alluvial aquifer. These flowpaths reveal that ambient groundwater flow is to the southwest and the hydraulic conductivity field in the aquifer does not present any obvious preferential zones of groundwater flow. However, the pattern of time markers (particles) for both model layers illustrated suggests that there may be velocity differences within the aquifer near the Great Miami River versus portions of the aquifer farther away from the river (i.e., Hooven area and south of Hooven). Particles on flowpaths near the river are relatively close, indicating that the model is predicting slower groundwater velocities near the river. This zone of slower groundwater flow velocity is adjacent and parallel to the river, and coincides with much of the dissolved-phase hydrocarbon plume. The performance groundwater monitoring plan reflects this difference in apparent groundwater flow velocities in the proposed frequency of groundwater monitoring events.

Proposed Point of Compliance

Segment A POC line is proposed to have five POC wells (red wells on Figure 5-1). Two new wells are proposed to be located just south of U.S. Highway 50, and two additional new wells are proposed along the west POC Segment A. Existing well MW-113 will serve as the location for the last POC well. Four PMWs (green wells) will serve as "early detection" monitoring points upgradient of the POC such that any detection of benzene greater than the Action Levels will trigger actions by ChevronTexaco to prevent further downgradient movement of the dissolved-phase hydrocarbon plume boundary. ChevronTexaco will closely evaluate the other existing monitoring wells (black wells) in the area to verify that the MODFLOW-SURFACT model has reasonably predicted the behavior of the plume.

5.3.2 Segment B – Western Boundary

The western boundary of the CCF at SR 128 coincides with the western limit of the alluvial aquifer. Segment B (Figure 5-1) includes this boundary, which represents the point at which the alluvial aquifer pinches out against the bedrock strata that form the hills west of the CCF and underlie the valley alluvial fill. This contact between the alluvium and bedrock strata is documented from outcrops of bedrock west of SR 128; geologic logs of boreholes and monitoring wells at the CCF; and the results of the seismic refraction survey, which delineated the contact between bedrock and alluvial materials under the CCF. Segment B represents a natural hydrologic (no-flow) boundary that forms a barrier to groundwater flow to the west from the CCF, therefore, no POC monitoring wells are necessary along this POC segment.

5.3.3 Segment C – Northern and Eastern Boundaries

The Segment C POC (Figure 5-1) represents the northern and eastern boundaries of the CCF site that is characterized by groundwater flow from the Great Miami River toward interior portions of the CCF and the hydrocarbon plume. Groundwater flow is either perpendicular to the plume margin (north portion of the segment) or is subparallel to the margin of the plume (east and southeast portion of the segment). Therefore, the margin of the plume is either downgradient or cross-gradient to the direction of groundwater flow. These gradient conditions persist regardless of whether the water table is at high or low conditions. Based on groundwater flow modeling and evaluation of the hydraulic gradients and flow directions in the aquifer, dissolved hydrocarbons will not migrate upgradient or cross-gradient toward the Great Miami River at Segment C.

The hydraulic gradient along portions of Segment C is currently affected by the operation of multiple groundwater production wells. However, gradually during the Interim Remedy, groundwater production wells will stop pumping and hydraulic control will be terminated. Groundwater flow was simulated by MODFLOW-SURFACT under conditions of no pumping to confirm that hydraulic gradients at the POC would not change significantly if pumping were discontinued. The results of these simulations indicate that groundwater flow at this segment would continue to move away from the river toward the interior of the CCF or subparallel to the Great Miami River.

The POC Segment C will consist of four POC monitoring wells located in areas where groundwater flow could possibly be directed from the CCF site to the river under certain rare river stage or groundwater level conditions. These locations are at existing wells MW-109S, MW-105S, MW-55, and MW-44.

5.3.4 Segment D – Southeast Boundary

The POC segment D (Figure 5-1), which extends from the Hooven Ditch to near U.S. Highway 50 along the southeastern side of the CCF at the Great Miami River, incorporates the area where a sheen was observed on the river in 1985. Currently, the potentiometric surface is lowered by extensive pumping away from the river to control the hydraulic gradient so that groundwater does not discharge to the river. Although groundwater pumping has prevented the discharge of hydrocarbons to the river, this area is known to be underlain by a LNAPL smear zone.

During the Interim Remedy and continuing into the Final Remedy, this POC segment will be monitored for evidence of sheens in the river indicating that LNAPL is seeping into the river. As previously discussed, the transition to natural hydraulic gradients will occur gradually during the Interim Remedy, and focused LNAPL recovery will occur during extremely low water table conditions, so it is unlikely that seepage will occur. Contingencies (e.g., activating production well PW-15) will be in place in the event LNAPL seepage is observed.

5.4 Proposed Groundwater Monitoring Program

The groundwater monitoring program is summarized in Table 5-3. Groundwater monitoring will consist of a sampling and analysis program for the POC wells and the PMWs (for Segment A). This program will focus on evaluation of COPCs at the following well networks:

1. **Performance Monitoring Wells:** Located at various positions along a representative groundwater flow path within the dissolved-phase hydrocarbon plume and located just outside the present-day limit of the plume.

2. **POC Monitoring Wells:** Located at the groundwater point of compliance line.

The locations of the POC monitoring program wells are illustrated in Figure 5-1.

Table 5-3
Proposed Groundwater Point-of-Compliance Monitoring Program

POC Segment	Monitoring Program	Analytes		Monitoring Frequency
		POC Wells	PMWs	
Segment A	5 - POC monitoring wells 4 - Performance monitoring wells	• COPCs • LNAPL, water-levels	• COPCs • MNA parameters	Annually Annually
Segment B	No monitoring program required	Not applicable		Not applicable
Segment C	4 - POC monitoring wells	• COPCs • LNAPL and water-level measurements		Annually Annually
Segment D	Visual inspection of the river bank	• LNAPL and water level measurements		At seasonal low-water level stages for Years 1-5, Annually after Year 5

The sampling frequency presented in Table 5-3 starts following the completion of the Interim Remedy, when the facility has reverted to natural hydraulic gradients. As discussed in Section 4, the wells will be sampled on a semi-annual basis during the Interim Remedy. Currently, the monitoring wells in the Interim Measures program are sampled on a semi-annual basis.

Groundwater analytical data generated at the PMWs will be evaluated by comparing the results to previous analytical results and checking the trend of benzene concentrations in wells installed within the limits of the dissolved plume with the general trends anticipated from the MODFLOW-SURFACT simulations. Groundwater data from the four PMWs located just downgradient of the plume will be evaluated for the presence of benzene or other dissolved hydrocarbons that could indicate movement of the dissolved plume downgradient toward the POC.

5.5 Contingency Plan

Groundwater analytical data at the POC monitoring wells will be evaluated as follows:

1. Results will be compared to applicable Action Levels for each of the groundwater COPCs. If the results are lower than the Action Levels, no action will be taken and POC groundwater monitoring will continue.

2. If results at a well are higher than Action Levels, USEPA will be notified and the well will be re-sampled within one week of receipt of the initial data from the chemical analytical laboratory. If the results of the resampling are below the Action Levels, POC monitoring will resume as scheduled.

3. If the results of the resampling are again higher than the Action Levels, ChevronTexaco will notify USEPA and evaluate steps to contain the portion of the plume that appears to be migrating. These steps will be discussed with USEPA before any action is taken.

4. The river will continue to be monitored as described in the Interim Remedy (Section 4) for LNAPL seepage. If a sheen is observed, actions will be taken to remedy the situation.

6.0 Implementation Schedule

ChevronTexaco will submit the final version of the *Conceptual Groundwater Remedy Report* to USEPA within 60 days of receiving comments on the draft report and begin implementation of the Interim Remedy within 60 days of USEPA issuing a Final Decision Response to Comments.

7.0 References

Anderson, Mary P. and William W. Woessner. 1992. Applied Groundwater Modeling. January 1992.

Beckett, G.D. and P.D. Lundegard. 1997. Practically Impractical – The Limits of LNAPL Recovery and Relationship to Risk. Conference Proceedings of the 1997 Petroleum Hydrocarbons and Organic Chemicals in Ground Water: Prevention, Detection and Restoration. Houston, Texas. Sponsored by the National Ground Water Association and American Petroleum Institute.

Civil Environmental Consultants (CEC). 1995. Report of Findings, Bioremediation Treatability Evaluation, Island Investigation, Chevron Cincinnati Facility.

CEC. 1998. Report of Findings, RNA Monitoring Program – Annual Report No. 1, Chevron Cincinnati Facility – Island Investigation.

CEC. 1999. Six Phase Heating Pilot Test – Report of Findings – Chevron Cincinnati Facility – Island No.1, Hooven, Hamilton County, OH.

CEC. 2000. Air Sparging Field Study Gulf Park.

CEC. 2001a. Environmental Indicators Documentation Report, Migration of Contaminated Groundwater Under Control RCRIS Code CA750, Chevron Cincinnati Facility, Hooven, Hamilton County, Ohio. Cincinnati, OH. May 2001.

CEC. 2001b. Report of Findings – Field Test Verification of Drawdown. Chevron Cincinnati Facility, Hooven, Hamilton County, Ohio, May 25, 2001.

CRTC. 2000. Memorandum from M. Moir, dated March 16, 2000.

Doherty, J., L. Brebber, and P. Whyte. 1998. PEST – Model-Independent Parameter Estimation, User's Manual.

Driscoll, Fletcher G. 1986. Groundwater and Wells. 2nd Edition. Johnson Filtration Systems, Inc., St. Paul, Minnesota, 55112. p. 210. 1986.

Ecology & Environment, Inc. (E&E). 1997. Market Analysis and Land Use Plan for the Chevron Cincinnati Facility, Hooven, Ohio.

E&E. 2000. Conceptual Design Report for Groundwater Polishing and Treatment of Storm Water at the Chevron Cincinnati Facility, Hooven, Ohio. Final Version. December 2000.

E&E. 2001. Chevron Cincinnati Facility Documentation of Environmental Indicator Determination (C725) Current Human Exposures Under Control. Revision 0. August 2001.

Environmental Science & Engineering, Inc. (ESE). 2000. RCRA Facility Investigation Report for the Chevron Cincinnati Facility. Four volumes. Miamisburg, OH, April 2000.

Ewing, John E., Richard E. Jackson, and V. Dworankanath. 2001. Remedial Implications of Air Entry Into Water-Saturated Alluvium Contaminated with NAPL. Duke Engineering & Services. 2001.

Fetter, Charles W. 1994. Applied Hydrogeology. January 1994.

GeoSyntec, 1995. Groundwater Flow and Contaminant Fate and Transport Modeling Study, Village of Cleeves Well Field, Hamilton County, Ohio. February 1995.

Goulding, Nigel. 2002. Evaluation of HSVE Performance (PowerPoint) Presentation in Austin, Texas. URS Corporation. February 2002.

Handex. 1996. Pump Test Report, Chevron USA Products Company, Intersection of State Route 128 and Bypass, Hooven, Ohio 45033. January 13, 1996.

Hill, Mary C. 1990. Preconditioned Conjugate Gradient 2 (PCG 2), A Computer Program for Solving Groundwater Flow Equations. USGS. 1990.

Huntley, D. and G.D. Beckett. 1997. The Life and Times of LNAPL Pools. An investigation into the lifespan and time-dependent magnitude of dissolved-phase impacts from free-phase hydrocarbon pools. AEHS West Coast Annual Convention, Oxnard, California. March 1997.

Johnson, Paul. 1998. Arizona State University (ASU), Department of Civil and Environmental Engineering. Subsurface Hydrocarbon Vapor Mitigation Assessment Near the Former Chevron Refinery Facility in the Hooven, Ohio area. November 1998.

Lyverse, M.A. 1991. Analysis of Cincinnati Facility Aquifer Test Data at Well No. 14, December 11-12, 1990. Chevron Research and Technology Company, Richmond, CA. February 1991.

McDonald, M.G. and A.W. Harbaugh. 1988. A Modular Three-Dimensional Finite-Difference Ground-Water Flow Model: U.S. Geological Survey Techniques of Water Resources Investigations, Book 6, Chap. A1, 586 p. 1988.

Obermeyer, Jim. *Draft for Review and Comment, April 24, 2002 Site Reconnaissance, Chevron Cincinnati Facility, Hamilton County, Ohio. Project No. 68-DMRAD053.00 Task 00001*. URS Denver Office. Letter dated June 4, 2002.

Porter, D.W., B.P. Gibbs, W.F. Jones, P.S. Huyakorn, L.L. Hamm, and G.P. Flach. 2000. Data Fusion Modeling for Groundwater Systems, Journal of Contaminant Hydrology, Vol. 42, 303-335.

PTS Laboratories Inc. 1996. Geotechnical Analysis of Soil Borings from Chevron Cincinnati Facility, Hooven, Ohio. Santa Fe Springs, California. July 16, 1996.

Radian International and Duke Engineering Services. 1999. Chevron Cincinnati Facility, Site Characterization Method Selection. Volume IA: Report. Final. Austin, TX. February 1999.

Spieker, A.M. and R.H. Durrell. 1961. A Guide to the Hydrogeology of the Mill Creek and Miami River Valleys, Ohio. In: *Guidebook for Field Trips*, Cincinnati meeting of the Geological Society of America. C 217-237.

Spieker, A.M. 1968. Ground-Water Hydrology and Geology of the Lower Great Miami River Valley Ohio. *Geological Survey Professional Paper 605-A.* United States Government Printing Office, Washington D.C.

URS Corporation (URS) and Duke Engineering Services. 2001. *Hydrogeological Data Report.*

URS. 2000. *Chevron Cincinnati Facility Soils & Sludges Correctives Measures Study, Draft.* May, 2000.

URS. 2001a. *Chevron Cincinnati Facility Soils & Sludges Correctives Measures Study, Final*. September, 2001.

URS. 2001b. *Chevron Cincinnati Facility Groundwater Correctives Measures Study* (GW CMS), *Revision 0.* October 26, 2001.

URS. 2003. Technical Memorandum, "Review of Natural Attenuation Investigation Conducted in 2002." March 2003.

USEPA. 1999. Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites. Final. April 1999.

USEPA. 2001. Handbook of Groundwater Protection and Cleanup Policies for RCRA Corrective Action. Draft Final. April 2001. EPA530-D-00-001.

Watkins, J.S. and A.M. Spieker. 1971. Seismic Refraction Survey of Pleistocene Drainage Channels in the Lower Great Miami River Valley, Ohio. *Geological Survey Professional Paper 605-B.* United States Government Printing Office, Washington D.C.

Wiedemeier T.D., H.S. Rifai, C.J. Newell, and J.T. Wilson. 1999a. *Natural Attenuation of Fuels and Chlorinated Solvents in the Subsurface*. John Wiley and Sons.

Wiedemeier, T.H., J. T. Wilson, D.H. Kampbell, R.N. Miller, and J.E. Hansen. 1999b. Technical Protocol for Implementing Intrinsic Remediation with Long-Term Monitoring for Natural Attenuation of Fuel Contamination Dissolved in Groundwater. U.S. Air Force Center for Environmental Excellence. 1999.