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CORRECTIVE MEASURES STUDY (CMS) FINAL REPORT FOR THE MAIN YARD, EAST YARD, AND CENTRAL YARD CHEVRON PERTH AMBOY REFINERY PERTH AMBOY, NEW JERSEY

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LIST OF ABBREVIATIONS

AOC	Area of Concern
ASARCO	American Smelting and Refining Company
bgs	Below Ground Surface
BTEX	Benzene, Toluene, Ethylbenzene, and Xylene
°C	Degrees Celsius
CA	Chloroethane
CAMU	Corrective Action Management Unit
CEA	Classification Exception Area
CFR	Code of Federal Regulations
cm/s	Centimeters per Second
CM	Corrective Measure
CMS	Corrective Measures Study
COC	Contaminant of Concern
CSIA	Compound Specific Isotope Analysis
CVOC	Chlorinated Volatile Organic Compound
CY	Central Yard
cu yd	Cubic Yard
DAF	Dilution Attenuation Factor
DCA	Dichloroethane
DCE	Dichloroethylene
DNAPL	Dense Non-Aqueous Phase Liquid
DO	Dissolved Oxygen
DOCC	Description of Current Conditions
DPT	Direct Push Technology
DTW	Depth to Water
EAB	Enhanced Aerobic Bioremediation
EDTA	Ethylenediaminetetraacetic Acid
EIB	Enhanced In-situ Bioremediation
EY	East Yard
°F	Degrees Fahrenheit
FS	Feasibility Study
FR	Fenton's Reagent
GC	Gas Chromatograph
GIS	Geographical Information System
GPS	Global Positioning System
gpm	Gallons Per Minute

GWQS	Groundwater Quality Standard
HDPE	High Density Polyethylene
HFO	Hydrous Ferric Oxide
HSWA	Hazardous and Solid Waste Amendments
IRM	Interim Remedial Measure
ISCO	In-Situ Chemical Oxidation
LDR	Land Disposal Restriction
LEL	Lower Exposure Limit
LNAPL	Light Non Aqueous Phase Liquid
LRM	LNAPL Removal Measure
LTTD	Low Temperature Thermal Desorption
MDL	Method Detection Limit
mg/kg	Milligrams per Kilogram (ppm)
MNA	Monitored Natural Attenuation
MPE	Measuring Point Elevation
MPE	Multiphase Extraction
MTBE	Methyl Tert-Butyl Ether
mv	Millivolts
MY	Main Yard
NA	Not Applicable
NAA	No Action Alternative
NAPL	Non Aqueous Phase Liquid
NCP	National Contingency Plan
NF	North Field
NF/MY	North Field/Main Yard
NFA	No Further Action
NFE	North Field Extension
NGVD	National Geodetic Vertical Datum
NJDEP	New Jersey Department of Environmental Protection
NPT	National Pipe Thread
NRDCSCC	Non-Residential Direct Contact Soil Cleanup Criteria
NRDCSCS	Non-Residential Direct Contact Soil Cleanup Standard
O&M	Operation and Maintenance
ORC	Oxygen Releasing Compound
ORP	Oxidation/Reduction Potential
OVM	Organic Vapor Monitor
PAH	Polycyclic Aromatic Hydrocarbon
PCE	Perchloroethylene
PCOC	Principal Contaminant of Concern

PDI	Pre-Design Investigation
PID	Photo Ionization Detector
POTW	Publicly Owned Treatment Works
ppb	Parts Per Billion
PPE	Personal Protective Equipment
ppm	Parts Per Million
PQL	Practical Quantitation Level
psig	Pounds per Square Inch Gauge
PVC	Poly-Vinyl Chloride
QA/QC	Quality Assurance/Quality Control
RAO	Remedial Action Objective
RCRA	Resource Conservation Recovery Act
RFI	RCRA Facility Investigation
SCC	Soil Cleanup Criteria
scfm	Standard Cubic Feet per Minute
SMS	Stabilization Measures Status
SOD	Soil Oxidant Demand
SP	Sparge Point
SRFI	Supplemental RFI
S/S	Solidification and Stabilization
SVOC	Semi-Volatile Organic Compound
SWMU	Soil Waste Management Unit
TAL	Target Analyte List
TCA	Trichloroethane
TCE	Trichloroethylene
TCL	Target Constituent List
TCLP	Toxicity Characteristic Leaching Procedure
TDS	Total Dissolved Solids
TDU	Thermal Desorption Unit
TEL	Tetra-Ethyl Lead
TIC	Tentatively Identified Compound
TOC	Total Organic Compound
TOL	Total Organic Lead
TOS	Top of Screen
TPH	Total Petroleum Hydrocarbons
TSP	Tri-Sodium Phosphate
TVOC	Total Volatile Organic Compounds
UCS	Unconfined Compressive Strength
ug/L	Micrograms per Liter (ppb)
USCS	Unified Soil Classification System

USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
UTS	Universal Treatment Standards
VC	Vinyl Chloride
VOC	Volatile Organic Compound
WQIP	Water Quality Indicator Parameters
XRF	X-Ray Fluorescence

EXECUTIVE SUMMARY

This Corrective Measures Studies Report (CMS Report) has been prepared for the Chevron U.S.A. Products Company (Chevron) Perth Amboy Refinery (Site) located at 1200 State Street, Perth Amboy, New Jersey. The CMS is being conducted pursuant to the Corrective Action Requirements contained in the facility's Hazardous and Solid Waste Amendments Permit (HSWA Permit) (EPA ID No. NJD081982902). The HSWA Permit for the facility was issued by Region 2 of the United States Environmental Protection Agency (USEPA) on June 1, 1994. This CMS addresses many, but not all of the Solid Waste Management Units (SWMUs) and Areas of Concern (AOCs) subject to the Permit. Specifically, this CMS addresses the SWMUs and AOCs located in the Main Yard/North Field (Main Yard), East Yard, and Central Yard of the Site.

In a letter dated March 30, 2005, Chevron informed USEPA that it would like to begin CMS activities under the HSWA permit while awaiting final comments on the RCRA Facility Investigation (RFI). In a letter dated April 13, 2005, USEPA approved Chevron's request to initiate the CMS process.

Chevron initiated the CMS for these areas in 2006. There are 45 SWMUs and 49 AOCs included in this CMS. These SWMUs and AOCs are identified in Table 1 and are shown on Figures 2 through 4. This CMS Report provides the results of the evaluation of corrective measure alternatives for these SWMUs and AOCs in these three Yards in accordance with applicable provisions of Appendix B of the HSWA Permit (Scope of Work for a Corrective Measures Study). The report also includes the recommended corrective measure alternatives for each of these SWMUs and AOCs. Many of the SWMUs and AOCs are relatively close to each other or even overlap each other resulting in contiguous areas of soil or groundwater contamination. Therefore, most of the recommended corrective measures are also grouped by environmental media. The overall objective of this CMS is to develop, evaluate and select the most appropriate remedial alternatives for the SWMUs and AOCs in the Main Yard, East Yard and Central Yard.

As expected at a refinery site, the primary contaminants encountered at the site are petroleum constituents and associated compounds. These include volatile organic contaminants such as benzene, polycyclic aromatic hydrocarbons such as benzo(a)pyrene, and metals such as lead. Impacts have been observed in both soil and groundwater. For the most part, the SWMUs are the remnants of historic waste managements units that are no longer used by the Refinery.

The specific objectives of the CMS are as follows:

1. Conduct a CMS PDI to fill in data gaps identified as a result of the USEPA and NJDEP review of the RFI Report, provide additional data for the evaluation of potential corrective measures (CMs) for the subject SWMUs and AOCs, and determine the extent of contaminated media requiring CMs.
2. Establish cleanup goals and media-specific cleanup criteria/standards.
3. Screen and select the appropriate demonstrated and available CM technologies for each of the contaminated media.
4. Evaluate the most appropriate CMs for each of the contaminated media and each of the SWMUs and AOCs.
5. Develop, evaluate and select the most appropriate remedial alternatives for the Site.

This CMS Final Report for the Site is organized into the following eight sections: 1) Introduction; 2) CMS Pre-Design Investigation; 3) Establishment of Cleanup Goals and Media-Specific Cleanup Criteria/Standards; 4) Preliminary Screening of Corrective Measures Technologies; 5) Evaluation of Selected Corrective Measures Technologies; 6) Development and Evaluation of Remedial Alternatives; 7) Conclusions and Recommendations; and 8) References.

Section 1 of this CMS Final Report discusses the facility description, HSWA permit status, scope of the CMS, CMS project objectives, environmental setting and overview of previous investigations. Chevron purchased the facility in 1946 from Barber Asphalt Company who had owned and operated the facility since 1911. The Chevron facility operated as a full scale petroleum refinery from 1946 to 1983. Its operation included the production of liquefied petroleum gas, gasoline, fuel oil, asphalt and sulfur. In 1983, Chevron reduced its operations to refining asphalt and continued operations as a petroleum terminal. The site is primarily located in the industrial zone of Perth Amboy and is bounded to the east by the Arthur Kill. A small portion of the site extends into Woodbridge Township. A United States Geological Survey (USGS) Site Vicinity Map is shown in Figure 1.

Current operations at the site include the refining of crude oil into asphalt and gasoline blending products, along with a petroleum products terminal. Raw materials (crude oil) are received by ship or barge on docks located along the Arthur Kill. The oil is off-loaded in the East Yard of the refinery where it is stored in a series of above ground tanks. Eventually,

this oil is transferred through a series of above ground piping into the Main Yard for processing through the refinery's crude unit. Finished asphalt is pumped into storage tanks in the Central and East Yards for eventual loading into marine barges and customer's trucks for off-site distribution.

Currently, the refinery is a large quantity generator of hazardous wastes and no longer operates any permitted RCRA regulated hazardous waste management units. As a hazardous waste generator, Chevron maintains a short term (less than 90 days) hazardous waste storage area. During the 1980s, the facility operated several regulated hazardous waste management units such as the Surge Pond and a land treatment unit. These units have been closed in accordance with approvals from the New Jersey Department of Environmental Protection (NJDEP) pursuant to New Jersey's delegated RCRA Subtitle C program. Closure of these units triggered the issuance of the HSWA Permit on June 1, 1994 by EPA Region 2. The HSWA Permit contains Corrective Action Requirements pursuant to Section 3004(u) of HSWA. Chevron's 1994 HSWA Permit expiration date was 2004. However, Chevron requested a renewal of the permit in a renewal application dated June 29, 2004 (submitted to the Regional Administrator of EPA Region 2).

The general corrective action process required under the Refinery's HSWA includes three steps: 1) the RCRA facility Assessment ("RFA") to identify potential sources of contamination and evaluate if releases have occurred; 2) the RCRA Facility Investigation ("RFI") to evaluate the nature and extent of confirmed releases; and 3) a Corrective Measures Study ("CMS") to evaluate, select, and implement appropriate remedies to address contamination associated with SWMUs and AOCs.

The environmental setting subsection of this CMS Final Report includes a discussion of the Site subsurface stratigraphy and hydrogeologic conditions. In the Main yard, the subsurface stratigraphic progression typically consists of fill overlying a discontinuous peat layer, gray clay (Clay Horizon A) and glacial till. The groundwater table across the Main Yard was detected in the fill layer perched on the native clay and till. The fill contains varying amounts of sands, silts and clay. In the East Yard the lithology is composed of fill overlying a discontinuous peat layer, gray clay (Clay Horizon A) and glacial till. The fill also contains varying amounts of sands, silts and clay. Groundwater across the East Yard was also detected in the fill layer. In the Central Yard the lithology is also composed of fill overlying gray clay (Clay Horizon A) and glacial till. Groundwater throughout the Central Yard was also detected in the fill layer. The fill also contains varying amounts of sands, silts and clay.

The shallow groundwater in the Refinery is mainly observed in the unconfined fill layer, perched on native clay, peat and till. In the Main Yard the groundwater flow direction is in a northeasterly to southeasterly direction and the hydraulic gradients ranged from 0.05 to 0.016 ft/ft. In the East Yard the groundwater flow direction is in a northeasterly direction, and groundwater contours suggest a "ridge" of groundwater trending northeast-southeast through the central portion of the East Yard. The hydraulic gradient ranged from 0.014 to 0.0125 ft/ft. In the Central Yard, the groundwater flow direction is in a north to northeasterly direction. The hydraulic gradients measured across the Central Yard vary significantly from the northern portion of the site to the southern portion. In the north, gradients range from 0.18 to 0.02 ft/ft, while in the south, the average gradient is 0.01 ft/ft, except in the immediate vicinity of the Garretson Avenue right-off-way. In this area the native surface dips to the east or southeast. The hydraulic gradient in this area between wells MW-169R and MW-191 was gauged at approximately 0.03 ft/ft in 2005 (Chevron, 2005).

Section 2 of the CMS Final Report discusses the CMS Pre-Design Investigation (PDI) Report. To date, approximately 3,000 soil and groundwater locations have been sampled at the Chevron Perth Amboy Refinery. Therefore, the extent of contamination is largely known, including the extent of non-aqueous phase liquid (NAPL), dissolved phase compounds in groundwater, and constituents of concern (COCs) in soils. However, additional sampling during the CMS PDI was required to: 1) obtain additional contaminant specific data for CMS purposes, 2) identify whether soils known to have benzene and lead concentrations in excess of their respective New Jersey Department of Environmental Protection (NJDEP) Non-Residential Direct Contact Soil Cleanup Criteria (NRDCSCC) also exceed their respective RCRA TCLP criteria, and 3) evaluate whether NAPL impacted soil is characteristically hazardous for benzene.

The CMS PDI scope of work included the following activities: 1) direct-push soil and groundwater sampling; 2) installation of monitoring wells; 3) monitoring well sampling; and 4) preparation of a CMS PDI Results Report. The CMS PDI Results Report for the Site (including the Main Yard, SWMU 43, East Yard, and Central Yard) is organized into the following seven sections: 1) Introduction; 2) Site Background; 3) Site Conditions; 4) Sampling and Analysis Plan; 5) Results; 6) Conclusions and Recommendations; and 7) References.

The overall objective of the CMS PDI was to collect additional soil and groundwater data, and present the results, in conjunction with previously collected soil data, to determine the extent of contaminated media that require corrective measures. In addition, the data

presented allowed the screening and evaluation of appropriate demonstrated and available remedial technologies for each of the contaminated media.

The specific objectives of the CMS PDI were as follows:

1. Delineate the horizontal and vertical extent of the soils, known to have benzene concentrations in excess of its NJDEP NRDCSCC, which are also characteristically hazardous for benzene, as determined by TCLP testing.

2. Delineate the horizontal and vertical extent of the soils, known to have lead concentrations in excess of its NJDEP Non-Residential Direct Contact Soil Cleanup Standard (NRDCSCS), which are also characteristically hazardous for lead, as determined by TCLP testing.

3. Determine if NAPL impacted soil is characteristically hazardous for benzene and, if so, collect and analyze the samples needed to delineate the horizontal and vertical extent of these soils.

4. Delineate the horizontal and vertical extent of soils that exceed the NJDEP NRDCSCC for benzene, lead, and benzo(a)pyrene, the principal COCs (PCOCs) at the Site, based on their being the Site-related chemicals with the most exceedences of their applicable regulatory criteria as identified from previous Site environmental investigations, as well as their toxicity. The PCOCs also serve as indicator compounds for their broader analytical parameter category, such as volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), and metals, because exceedences of other COCs are generally found in the presence of exceedences of the PCOCs within the same samples.

5. Delineate the horizontal extent of groundwater that exceeds the NJDEP Evaluation Criteria for benzene, lead, and benzo(a)pyrene.

6. Further evaluate the existing Light Non Aqueous Phase Liquid (LNAPL) data to quantify trends in LNAPL areas and volumes at the Site.

Soil and groundwater data modeling was conducted using RockWorks, a geological data management, analysis, and visualization software. The CMS PDI data analysis used RockWorks in the following manner:

1. to create two dimensional (2-D) models that show the PCOC concentrations in soil and groundwater, and
2. to query and plot borehole lithology/stratigraphy, organic vapor meter (OVM) concentration profiles, X-ray fluorescence (XRF) concentration profiles, and analytical data from select borings to create cross-sections of contaminated soil areas.

The CMS PDI modeling results are presented in Figures 5 through 7. These figures show the distribution of the PCOCs in soil and groundwater. In addition, Tables 6 through 9 summarize the contaminated media areas and volumes sitewide and for the Main, East, and Central Yards, respectively. The CMS PDI Results Report is being submitted in conjunction with the CMS Final Report. A summary of the overall results of the CMS PDI by contaminated media is discussed below.

CONTAMINATED HAZARDOUS SOIL RESULTS

The CMS PDI results showed that, in general, except for the arsenic contamination, the occurrence of characteristically hazardous soil contamination is related to its proximity to former tetraethyl lead (TEL) burial areas, historical waste management practices, and operational and storage areas. The refinery related hazardous soil contamination does not extend off-site.

The total volume of soil found to be characteristically hazardous for **lead**, as determined by TCLP lead testing, was delineated and estimated to be 3,000 cubic yards. The total volume of soil found to be characteristically hazardous for **benzene**, as determined by TCLP benzene testing, was delineated and estimated to be 800 cubic yards. The volume of SWMU 43 contaminated soil is estimated to be 33,200 cubic yards based on the area of SWMU 43 and the depth to native soil.

CONTAMINATED SOIL RESULTS

The CMS PDI results showed that, in general, except for the arsenic contamination, the occurrence of non- characteristically hazardous soil contamination is related to its proximity to former TEL burial areas, historical waste management practices, and operational and storage areas. The Refinery related non-hazardous soil contamination does not extend off-site.

The soil contaminated areas with benzene in concentrations from 13 to 100 mg/kg were delineated during the CMS PDI. The cross-sections along transects in the soil benzene contaminated areas illustrated that the depth of benzene contamination varied from 0.5 to 15.5 feet below ground surface (bgs). With the exception of the SWMU 8 area, the results showed that benzene contamination throughout the Refinery has been found primarily in the fill material. The total volume of soil benzene contamination between 13-100 mg/kg was estimated to be 35,600 cubic yards.

The soil contaminated areas with benzene in concentrations above 100 mg/kg at the Site were delineated during the CMS PDI. The cross-sections along transects in the soil benzene contaminated areas illustrated that the depth of contamination with benzene concentrations above 100 mg/kg varied from one to 14.5 feet bgs. With the exception of the SWMU 8 area, the results showed that benzene contamination throughout the Refinery has been found primarily in the fill material. The total volume of soil benzene contamination greater than 100 mg/kg was determined to be 3,200 cubic yards.

The soil lead contaminated areas at the Site were delineated during the CMS PDI. The cross-sections along transects in the soil lead contaminated areas illustrated that the depth of lead contamination in concentrations above its NJDEP NRDCSCS of 800 mg/kg varied from 0.5 to 32 feet bgs. The results showed that lead contamination throughout the Refinery has been found primarily in the fill material. However, cross-sections along transects in the soil lead contaminated areas of the East Yard and Central Yard showed lead contamination extending to the native material underneath the fill. The total volume of soil lead contamination greater than 800 mg/kg was estimated to be 17,700 cubic yards.

ARSENIC IMPACTED SOIL RESULTS

The Supplemental RCRA Facility Investigation (SRFI) delineated the extent of soil with arsenic contamination in concentrations exceeding its NJDEP NRDCSCC. This area was estimated to be 41,900 square yards. This contamination is located predominantly in the southeastern portion of the East Yard, adjacent to the ASARCO smelting facility, and is associated with deposition of stack emissions from past operations performed at the ASARCO facility. Additionally, SWMU 39 in the Main Yard had arsenic concentrations in surface soil (0 – 2 feet bgs) greater than 20 mg/kg.

Chevron did not generate arsenic waste as part of its refinery operations. Furthermore, the only RCRA listed hazardous wastes for the petroleum refinery industry that include arsenic as a regulated constituent are K171 and K172, which are spent hydrotreating catalysts

including guard beds used to desulfurize feeds to other catalyst reactors. These wastes were not generated at the Site.

BENZO(A)PYRENE >10 mg/kg IMPACTED SOIL RESULTS

The contoured areas of soil contaminated with benzo(a)pyrene in concentrations greater than 10 mg/kg were quantified and found to be consistently contaminated with non-aqueous phase liquid (NAPL) based on observances of NAPL in boring logs at these sampled locations. The total volume of soils contaminated with benzo(a)pyrene in concentrations greater than 10 mg/kg is estimated to be 6,600 cubic yards

LNAPL CONTAMINATION RESULTS

The LNAPL areas at the Site were estimated based on the average LNAPL thickness found in numerous Site monitoring and recovery wells during 2007 (Parsons. 2008b). The LNAPL areas estimated in 2007 are 3,300, 6,800 and 500 square yards for LNAPL thicknesses >0.01' and <0.1', >0.1' and <0.5', and >0.5' and <1', respectively.

CONTAMINATED GROUNDWATER RESULTS

Shallow Contaminated Groundwater Results

The groundwater contaminated areas at the Site were further evaluated during the CMS PDI. The groundwater results showed that, in general, the occurrence of groundwater contamination is related to the migration of soil contamination from former TEL burial areas, historical waste management practices, and operational and storage areas. With the exception of the groundwater contamination delineated in the SWMU 8 area in the East Yard and AOCs 22 and 36 in the Central Yard, groundwater contamination in the Refinery does not extend off-site.

The groundwater contamination was evaluated in the shallow water bearing zone within the unconfined fill layer, which is perched on native clay, peat and till. The delineated contaminated groundwater includes the following estimates based on modeling of groundwater sampling results: 1) a volume of 850,000 cubic yards of groundwater contaminated with benzene in concentrations from 1 to 100 ug/L (outside the source areas' soil contamination), and 122,000 cubic yards contaminated with benzene at concentrations greater than 100 ug/L (within the source areas' soil contamination), and 2) a volume of 68,000 cubic yards of groundwater contaminated with lead in concentrations from 5 to 50

ug/L (outside the source areas' soil contamination), and 19,000 cubic yards of groundwater contaminated with lead at concentrations greater than 50 ug/L (within the source areas' soil contamination). In general, the groundwater flows to the northeast in the Refinery. However, the delineated groundwater contamination plumes are not migrating into the water bodies bordering the northern and eastern boundaries of the Site where the groundwater discharges, but are stable within the boundaries of the refinery with minor off-site migration in the SWMU 8 and AOCs 22 and 36 areas.

Based on the aforementioned CMS PDI results, 91.9% of the contaminated groundwater is a result of benzene exceedences of its Evaluation Criteria of 1 ug/L.

Deep Contaminated Groundwater Results

During the SRFI, ten deep permanent monitoring wells were installed on-site. As a result, 22 deep monitoring wells and three deep piezometers exist on-site, improving Chevron's understanding of the vertical hydrogeology of the site. All the deep wells were paired with shallow wells to investigate the hydrogeologic relationship between the first shallow and first native water-bearing zones across several SRFI Areas of Investigation (AOIs). Following purging, groundwater samples were collected and analyzed for VOCs, semi-volatile organic compounds (SVOCs) and metals.

In the Main Yard, 5 deep wells were installed in the NF2, NF5 and NF6 areas of investigation (AOI). For AOI NF2 deep monitoring well MW-240, no VOCs were detected indicating evidence of hydraulic isolation between the first shallow water bearing zone and the first native water-bearing zone in this location.

For AOI NF5 deep monitoring wells, MW-237 did show evidence of hydraulic connectivity between water bearing zones from MW-136 (shallow) and MW-237, however no dissolved VOCs or SVOCs were detected in groundwater samples from either well in concentrations exceeding their NJDEP Groundwater Quality Standards (GWQSs). Monitoring well MW-238 did not detect any VOCs while shallow well MW-117 did, indicating hydraulic isolation between the first shallow water-bearing zone and first native water bearing zone in this location.

For AOI NF6 deep monitoring wells, only one VOC, bromodichloromethane (2J ug/L), was detected in groundwater at a concentration exceeding its NJDEP GWQS (1 ug/L) in well MW-239. However, bromodichloromethane is a common artifact of chlorinated potable water, which may have been introduced during well development activities. Additionally,

no SVOCs were detected in concentrations exceeding their NJDEP GWQSs in MW-239. The variation in VOC and SVOC detections between shallow well RW-42 and deep well MW-239 provides further evidence of hydraulic isolation between the first shallow water-bearing zone and first native water-bearing zone in this location. No VOCs or SVOCs were detected in concentrations exceeding their NJDEP GWQSs in deep well MW-244 providing further evidence of hydraulic isolation between the first shallow water-bearing zone and first native water-bearing zone in this location.

In the East Yard, 3 deep monitoring wells were installed in SRFI AOI1, AOI2 and AOI3. In AOI1, groundwater samples were analyzed for VOCs, SVOCs, and metals from the two deep monitoring wells MW-246 and MW-247. Despite evidence of hydraulic interconnectivity between water-bearing zones in both the MW-246 and MW-247 locations, samples from both wells contained no VOCs and SVOCs in concentrations exceeding their NJDEP GWQSs.

Deep monitoring well MW-255 located in AOI2 indicated hydraulic interconnectivity between water-bearing zones in its vicinity. However, the groundwater sample analyzed contained no dissolved VOCs and SVOCs at concentrations exceeding their NJDEP GWQSs.

In AOC 31 in the East Yard, one deep monitoring well (MW-250) was installed. Deep well MW-250 was paired with a previously installed shallow well (MW-0090) to investigate the hydrogeologic relationships between the first shallow and first native water-bearing zones across the AOC 31 area. Groundwater samples collected in MW-250 and MW-0090 detected VOC concentrations exceeding their NJDEP GWQSs, but not SVOCs. The results suggest additional investigation is warranted across Tank 772 to obtain full vertical and horizontal contaminant delineation. Chevron has recently installed an additional six shallow monitoring wells and four deep wells in this area to confirm vertical and horizontal delineation. Additionally, Chevron initiated a biosparge pilot study in the source zone of the shallow groundwater to remediate the VOCs, which are impacting the deep groundwater in this area. The biosparge pilot study will be performed for a period of approximately six months. The details of this biosparge pilot study for AOC 31 are presented in the "AOC 31 Pilot Study Workplan" (Chevron. 2008b).

In SWMU 8 in the East Yard, one deep monitoring well (MW-252) was installed. MW-252 was paired with previously installed shallow well MW-132 to investigate the hydrogeologic relationships between the first shallow and first native water-bearing zones across the SWMU 8 area. A groundwater sample collected from MW-252 contained no VOCs and

SVOCs in concentrations exceeding their Evaluation Criteria, providing further evidence of hydraulic isolation between the first shallow water-bearing zone and first native water-bearing zone in this vicinity.

Section 3, of the CMS Final Report discusses the establishment of the cleanup goals and media specific cleanup criteria/standards. The cleanup goals proposed for the soils in the Main Yard, East Yard, and Central Yard include:

1. Mitigate or reduce direct human exposure that may occur through direct contact to soil impacted with COCs at concentrations exceeding regulatory standards.
2. Prevent or minimize further migration of contaminants from source materials (soil) to the groundwater.

The cleanup goals proposed for groundwater in the Main Yard, East Yard, and Central Yard include:

1. Prevent exposure of humans to groundwater contaminants in concentrations above regulatory standards.
2. Reduce contaminant concentrations in the shallow and deep aquifers below regulatory standards.
3. Prevent or minimize migration of the contaminant plume for the PCOCs.

The cleanup goal for LNAPL will be its treatment or removal to the extent practicable and mitigation of LNAPL as a potential source of groundwater contamination.

The applicable cleanup criteria/standards for soil are as follows:

1. NJDEP NRDCSCC; and
2. NJDEP NRDCSCS;

The following two criteria are potentially applicable and will also be considered for soils as appropriate:

1. USEPA TCLP Characteristic Hazardous Waste Regulatory Levels for benzene and lead; and
2. USEPA Land Disposal Restrictions (LDRs) for potential RCRA listed hazardous wastes F037, F038, K051 and K052 in SWMU 43.

Additionally, the TEL delineation criteria of 2 mg/kg will be used as an action level and the cleanup goal for TEL.

The NJDEP NRDCSCC are applicable to non-hazardous soil at the Site. While the NJDEP adopted new Remediation Standards at N.J.A.C. 7:26D on June 2, 2008, Chevron will meet the requirements of the Phase in Period Guidance under N.J.A.C. 7:26E-1.3(d)1 to remediate the Site soil to the NJDEP NRDCSCC, with the exception of naphthalene whose NRDCSCS is more than an order of magnitude below its NRDCSCC and thus subject to the order of magnitude exclusion under the Brownfield Act (N.J.S.A. 58:10:B-12j and 13e) and implemented in the Technical Rules under N.J.A.C. 7:26E-6.1(b)2. A summary of the applicable cleanup criteria/standards for non-hazardous soil is given in Table 2 in Appendix B. The NJDEP GWQSs are applicable to the groundwater at the Site. A summary of the GWQSs is provided in Table 5 as Appendix B.

The USEPA TCLP Characteristic Hazardous Waste Regulatory Levels are shown in Table 3 in Appendix B. Of these, only the two levels for benzene and lead (0.5 mg/L and 5 mg/L, respectively) are applicable to the soil contamination at the Site.

The LDRs for RCRA listed hazardous wastes F037, F038, K051, and K052 are presented in Table 4 in Appendix B. These standards are only potentially applicable to the soil in SWMU 43 under the USEPA's contained-in rule.

Section 4 discusses the preliminary screening of corrective measures (CMs) technologies. General CMs are broad classes of actions that may satisfy the cleanup goals for the Site. General CM categories for the Site described in this Section are based on the nature and extent of the contamination at the Site, as described in Section 1 as well as USEPA's "Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA" (USEPA. 1988). These general CMs include the following: 1) no action alternative, 2) institutional controls, 3) monitored natural attenuation (MNA), 4) containment, 5) ex-situ groundwater treatment, 6) in-situ groundwater and soil treatment, and 7) contaminated soil removal, transport, ex-situ treatment and disposal. Each of these general CMs is discussed in more detail in this Section, as well as its applicability to the contamination in the soil and groundwater at the Site.

The USEPA encourages the use of presumptive remedies and historical information to streamline the screening and selection of CMs for sites subject to RCRA corrective action. Therefore, only those technologies/specific CMs that have been proven effective at other, similar sites with similar contamination or identified in USEPA guidance documents are

being considered in this CMS for the Site. The preliminary screening of these technologies/specific CMs identified in this Section involves the analysis of their effectiveness, implementability, and relative cost. These three preliminary screening analytical criteria are described below.

1. Effectiveness – This criterion focuses on the potential effectiveness of each technology/specific CM in remediating the contaminated soil and groundwater and in meeting the cleanup goals with regard to protection of human health and the environment. Specific information considered in this analysis includes the type(s) of contamination, contaminant concentration(s), volume(s), and areal extent of contaminated soil and groundwater, as well as the timeframe to achieve the applicable cleanup criteria/standards. Each technology/specific CM is classified as being effective, limited, or not effective for each contaminated media.

2. Implementability – This criterion considers the relative degree of technical implementability and the administrative feasibility of implementing the technology/specific CM including any substantive requirements of permits, availability of treatment, storage and disposal services/facilities, and the availability of necessary equipment and skilled workers to implement the technology/specific CM. The implementability of technologies/specific CMs is classified as easy, moderate, difficult, or not implementable for each contaminated media

3. Cost – This criterion is based on general unit costs of each technology/specific CM used at similar sites with similar contamination. Both capital costs and operating costs are considered in this analysis. The costs of technologies/specific CMs for each contaminated media are classified as none, low, moderate, high, or very high.

The results of the preliminary screening of corrective measures are presented Table 4.1. The table also identifies the CMs to be retained for further evaluation, which include all CMs with an overall preliminary screening score of 10 or higher. Table 4.2 summarizes the retained CMs and their applicability to the Site contaminated media for further evaluation in developing remedial alternatives for the Site. Based on this and the rest of the information presented in this Section and summarized in Table 4.2, the following CMs are selected for the following contaminated media for further evaluation in developing remedial alternatives for the Site:

1. No Further Action (NFA) for the clean soil and groundwater areas;

2. Deed notices for the following soil contaminated areas: a) non-hazardous soil with lead concentrations >800 mg/kg, b) non-hazardous soil with benzo(a)pyrene concentrations > 0.66 mg/kg and <10 mg/kg, and c) arsenic impacted soil with concentrations >20 mg/kg;

3. Classification Exception Areas (CEAs) for groundwater areas utilizing MNA as the CM;

4. Caps for the following areas: a) arsenic impacted soil in the Main and East Yards, and b) potentially RCRA-listed hazardous soil in SWMU 43;

5. Excavation, ex-situ stabilization, and disposal for the following areas: a) non-hazardous benzo(a)pyrene >10 mg/kg impacted soils; b) characteristically hazardous soil with TCLP lead concentrations >5 mg/L; c) TEL and total organic lead (TOL) impacted soil with concentrations >2 mg/kg and total lead concentrations <800 mg/kg; and d) other contaminated soils that may be excavated for construction and other purposes.

6. Low Temperature Thermal Desorption (LTTD) for excavated organic contaminated soil;

7. In-situ Chemical Oxidation (ISCO) for the following areas: a) hazardous and non-hazardous organic contaminated soil, and b) organic contaminated groundwater in contamination source areas with benzene concentrations >100 ug/L;

8. In-situ stabilization for non-hazardous soil with lead concentrations >800 mg/kg;

9. In-situ thermal treatment for the following areas: a) hazardous and non-hazardous organic contaminated soil; and b) organic contaminated groundwater in contamination source areas with benzene concentrations > 100 ug/L.

10. Ex-situ and in-situ bioremediation for the following areas: a) hazardous and non-hazardous organic contaminated soil; and b) organic contaminated groundwater in contamination source areas with benzene concentrations >100 ug/L.

11. Air sparging/soil vapor extraction for organic contaminated groundwater in contamination source areas with benzene concentrations >100 ug/L.

12. MNA for organic contaminated groundwater in non-source areas with benzene concentrations ranging from 1 ug/L to 100 ug/L; and

13. LNAPL Removal Measures (LRMs) for areas with LNAPL thicknesses >0.01 feet.

Section 5, presents the evaluation of CMs technologies selected in Section 4. The following USEPA National Contingency Plan (NCP) (USEPA. 1993) criteria are used to evaluate selected CM technologies in this Section: 1) overall protection of human health and the environment, 2) compliance with applicable standards, 3) long-term effectiveness and permanence, 4) reduction of toxicity, mobility, or volume through treatment, 5) short-term effectiveness, 6) implementability, and 7) cost.

Additionally, bench-scale treatability testing was conducted on the following selected CMs to further evaluate their applicability for remediating the contaminated media at the Site: 1) ISCO, 2) LTTD, and 3) stabilization. Also, historical groundwater geochemical analytical data (2002 to 2007) was also analyzed to evaluate monitored natural attenuation (MNA) as a potential CM. A description and evaluation of each of the selected CMs, as well as a summary of the bench-test results for ISCO, LTTD, and stabilization is provided in this Section.

The ISCO bench test consisted of jar and column tests. The ISCO jar tests involved testing the soil oxidant demand and contaminant removal efficiencies for three oxidants: 1) Fenton's Reagent (FR), 2) activated persulfate, and 3) Regen-Ox. The ISCO jar test results indicated that FR is the most effective in reducing the concentrations and mass of VOCs and SVOCs in the shortest timeframe at the Site. This was followed up with an ISCO soil column test using FR as the oxidant, which showed a 77% reduction in total VOCs and a 21% reduction in benzene concentrations. In order to further evaluate the effectiveness of ISCO in treating the organic contaminated soil and groundwater at the Site, a pilot test was performed in September 2008 in SWMU 43 in the vicinity of S2249, the area with the best ISCO bench test results. Following receipt of the ISCO pilot test post-treatment sampling results, an ISCO Pilot Test Report will be prepared for submission to the USEPA and NJDEP providing the results of the ISCO pilot test.

In order to further evaluate the applicability of LTTD to remediate the organic contamination in the Site soil, TD*X Associates performed a pilot test on the thermal desorption treatment of samples collected from the Site in November 2007. The goals of the LTTD test were as follows: 1) determine the level of organic reduction achievable from the samples using the TD*X high performance, indirect thermal desorption unit at varied

operating conditions, and 2) compare the treated soil residual contaminant levels with the RCRA LDR Universal Treatment Standards (UTS), applicable to the SWMU 43 soil.

Tables 5.6 and 5.7 show the overall mass balance achieved and the analytical results, respectively, for the three test runs. The overall mass balance results of the LTTD test show that 95% of the soil masses of each of the runs were recovered, with the bulk of the masses (50%) ending up in the vapor phase. The analytical results of the LTTD pilot test indicate that the contaminant concentrations in the treated soils are all well below their respective RCRA LDR UTSs, with the overwhelming majority of contaminants being undetected. Therefore, implementation of indirect heated thermal desorption treatment at the Site would successfully remove organic compounds to very low levels.

In order to further evaluate the applicability of stabilization to remediate the metals contamination (predominantly lead) in the Site soils, Entact conducted a stabilization bench test in May 2008 in their laboratory in Friendswood, Texas. The purpose of the bench test was to test several stabilization binders and binder to soil ratios to determine the optimum binder and ratio for reducing the leachability of lead contaminated soil at the Site.

Three binders were chosen for the bench test based on Entact's past experience with stabilizing similar lead-contaminated soils: 1) tri-sodium phosphate (TSP), 2) Enviroblend 80/20 from Premier Chemicals (a phosphate-based binder), and 3) Redoxite from Redox Solutions (an iron sulfide compound). Additionally, the following binder to soil ratios were used as part of the bench test: 1) 5%, 7.5%, and 10% by weight for Enviroblend 80/20, 2) 5% and 10% for TSP, and 3) 5% and 10% for Redoxite.

The results of this bench test showed that Enviroblend 80/20 performed the best in reducing the lead leachability in the stabilized soil to below 5 mg/L, its RCRA TCLP Characteristic Hazardous Level, in both soil samples tested. There was no correlation between TCLP results and binder to soil ratio for Enviroblend (80/20). Additionally, TSP successfully reduced the lead leachability in both soil samples in the 10% binder to soil ratio test. Finally, Redoxite increased the lead leachability in the stabilized soil in proportion to the binder to soil ratio. Given these results, either Enviroblend (80/20) at a 5% binder to soil ratio or TSP at a 10% binder to soil ratio should be used for stabilizing lead contaminated soils at the Site, depending on the cost of these binders used at the aforementioned binder to soil ratios. It also may be possible to use a lower binder to soil ratio for Enviroblend (80/20) if additional testing is conducted to determine the lowest ratio capable of reducing TCLP lead levels below 5 mg/L.

In order to evaluate the potential to implement MNA, geochemical data from the monitoring wells located in the Main Yard, East Yard and Central Yard of the Site were analyzed. A total of approximately 80 wells throughout these yards were sampled and analyzed for groundwater geochemical (MNA) parameters during 2007. These data were analyzed to evaluate the potential for MNA to effectively reduce low levels of organic contamination in the groundwater. The results of this analysis demonstrate that MNA is occurring in both the VOC impacted groundwater plume at the Site, as well as the chlorinated VOC (CVOC) plume in AOC 36.

Section 5 also provides a description and evaluation for an on-site Corrective Action Management Unit (CAMU). The preliminary conceptual design of the CAMU presented in Figures 20 and 21 show the following design parameters: 1) 16.5' height with a 18.5' height crown and 4% top slope, 2) 3H:1V side slope ratio, 3) 200 feet in width, 4) up to 1,000 feet in length, and 5) drainage berms to initially direct surface water runoff to the oily water sewer system, and subsequently direct the runoff to the North Field Basin following installation of the CAMU cap. Additionally, the following items will be included as part of the CAMU design, which are displayed in Figure 21: 1) a double liner, 2) a leachate collection system, and 3) an engineered cap with a top soil vegetation layer.

The relationship between the CAMU capacity and CAMU area and length is displayed as Figure 26. As shown in this figure, the maximum capacity of treated contaminated soil that would be able to fit within a CAMU with a maximum area of 200,000 square feet and with the design parameters given above would be 88,600 cubic yards. This is more than six times greater than the anticipated volume of 14,400 cubic yards to be disposed in the CAMU.

In order to compare the cost effectiveness of the CAMU with off-site transportation, treatment, and disposal, a cost comparison was prepared for a wide range of potential soil volumes to be disposed from 6,600 to 129,300 cubic yards. The current unit cost to transport, treat, and dispose of hazardous soil from the Site is $510/cubic yard. Figure 22 shows the cost savings from disposing lead contaminated hazardous and benzo(a)pyrene >10 mg/kg impacted soils in a CAMU versus off-site disposal (including transportation, treatment and disposal). As shown in this Figure the breakeven volume where disposal in a CAMU and off-site are the same is 8,600 cubic yards. Therefore, for volumes less than this, it is anticipated that off-site disposal costs will be less than the CAMU costs. However, as mentioned above, the anticipated volume of soil to be disposed is 14,400 cubic yards. At this volume, the cost savings from disposing treated soil in a CAMU versus off-site disposal is approximately $2 million.

In addition, Section 5 provides the latest status of the LNAPL areas at the Site and the LNAPL corrective measures. Also, a biosparge pilot study is discussed that was conducted in the EY1 LNAPL area in 2006 to evaluate the effectiveness of biosparging in removing benzene and other VOCs from LNAPL and residual contamination below the groundwater table. The effectiveness of the study was evaluated based on the reduction in dissolved-phase BTEX concentrations in groundwater and estimated total mass removal of BTEX from the EY1 LNAPL area. The biosparging technology, as demonstrated in this pilot test is applicable for volatile and readily biodegradable petroleum hydrocarbons. However, after the BTEX fractions are degraded, weathered free product in heavier fractions can still persist. As stated in the Letter Report, treatment using this technology is not expected to reduce contaminants to their applicable GWQSs due to limitations in the removal of the less mobile fractions of LNAPL.

AOC 29 remedial alternatives are also discussed in Section 5. Based on the subsurface investigation data, geotechnical data, remedial action objectives (RAOs), and an engineering analysis, various remedial alternatives were evaluated for implementation in AOC 29. The evaluation of alternatives was conducted in three stages that included the following:

1. Identification of alternatives and preliminary technical screening to assess the ability for each alternative to achieve the RAOs, its long-term effectiveness, and its implementability (19 total alternatives were identified);
2. Conductance of a preliminary cost analysis of those alternatives found to meet the first stage criteria (7 total alternatives); and
3. Performance of a detailed screening on those alternatives found to be both technically and economically feasible as a result of the first two stages of evaluation (6 total alternatives).

Based on the results of the evaluation of alternatives, constructing a revetment to control erosion along the Arthur Kill in combination with asphalt collection and long-term operation, maintenance, and monitoring is recommended as the most appropriate alternative.

Further, Section 5 discusses the arsenic contaminated soil corrective measure. Elevated arsenic concentrations in soil are present predominantly in an area located in the southeast corner of the East Yard of the Site. Given the site orientation, a prevailing wind from the south or south west would directly place the Site downwind of the emissions from the ASARCO smelting process. Therefore, during those periods of south-southwesterly winds, arsenic may have been deposited on the East Yard of the Site and subsequently buried when

this area was filled in. An analysis of the primary prevailing wind direction, using climatological data from Newark Liberty International Airport (approximately 19 miles due north from the Site) and the deposition pattern of arsenic contamination displayed on Figure 9, demonstrates that the adjacent ASARCO Facility is the source of the arsenic deposited on the Site. Further, Chevron did not generate arsenic waste as part of its refinery operations. As a result a containment CM using a cap would be appropriate to prevent any worker exposure to arsenic contamination exceeding its NJDEP NRDCSCC at the Site.

Finally, a discussion of waste minimization considerations relevant to some of the selected CMs is provided in Section 5.

Section 6 describes the development of the remedial alternatives for the Main Yard, East Yard and Central Yard using the CMs selected for the contaminated media. For the purpose of this development, the contaminated areas of the three Yards are divided into the following contaminated media categories:

1. SWMU 43 Contaminated Hazardous Soil,
2. Non-SWMU 43 contaminated Hazardous Soil,
3. Contaminated Soil,
4. Arsenic Impacted Soil,
5. Benzo(a)pyrene >10 mg/kg Impacted Soil,
6. Groundwater, and
7. LNAPL.

Five remedial alternatives were developed for the Site based on the most applicable CMs identified in Section 4.2 and evaluated in Section 5.0.

The five CM remedial alternatives were evaluated based on the evaluation criteria identified in the USEPA NCP (USEPA. 1993) with the exception of the inclusion of Schedule and omission of Compliance with Closure Criteria in the evaluation criteria. The evaluation criteria included: 1) Long-term Effectiveness and Permanence; 2) Short-term effectiveness; 3) Implementability; 4) Cost; 5) Regulatory Acceptance; and 6) Schedule.

The six evaluation criteria were weighted by Chevron according to their relative value. Then each remedial alternative was rated for each of the evaluation criteria. The ratings used for each of the criteria, except for cost, were positive, neutral, and negative. The cost criteria ratings ranged from 100% for the most cost effective remedial alternative to 25% for the least cost effective remedial alternative. The non-cost evaluation criteria were quantified

in the following manner: 1) a positive rating received 100% of the weighted value of the evaluation criteria, 2) a neutral rating received 75% of the weighted value of the evaluation criteria, and 3) a negative rating received 50% of the weighted value of the criteria. The rating values were then multiplied by the weighted values to obtain a score for each of the evaluation criteria for each of the CMS remedial alternatives. The scores for each of the evaluation criteria were then added to obtain a total score for each CMS remedial alternative. The results of the evaluation of remedial alternatives are shown in Table 6.1. These results indicate that CMS Alternative 1, with a total score of 83.13, scored the highest of all of the CMS remedial alternatives.

Based on the selection of CMS Remedial Alternative 1, Table 6.2 summarizes the selected CMs for each of the contaminated media, as well as the basis of selection and constructability for each of the active CMs. A summary of the CMs for each of the contaminated media for CMS Remedial Alternative 1 is given below.

CMS Remedial Alternative 1

- SWMU 43 Hazardous Soil – Hot spot in-situ treatment in the TCLP-benzene exceedence area, and in-situ stabilization with a non-RCRA cap and file a deed notice afterwards; ISCO is anticipated to be the in-situ treatment technology for the TCLP-benzene exceedence area; however, in-situ thermal treatment is also being retained;
- Non-SWMU 43 Hazardous Soil – In-situ treatment for organic contamination, and excavation, ex-situ stabilization and disposal in a tailored CAMU for lead contamination; ISCO is anticipated to be the in-situ treatment technology for the non-SWMU 43 hazardous soil; however, in-situ thermal treatment and ex-situ bioremediation are also being retained;
- Non-Hazardous Soil – In-situ treatment for organic contamination, and in-situ stabilization for lead contamination and file a deed notice afterwards; ISCO is anticipated to be the in-situ treatment technology for the non-hazardous soil organic contamination; however, in-situ thermal treatment and ex-situ bioremediation are also being retained;
- Arsenic Impacted Soil – Capping of arsenic soil contamination and file a deed notice afterwards;
- Benzo(a)pyrene >10 mg/kg Impacted Soil – Excavation, stabilization and disposal in a tailored CAMU; however, ISCO and in-situ thermal treatment are also being retained;

- AOC 29 – Revetment, asphalt collection, and operation, maintenance, and monitoring of groundwater and surface water;
- Groundwater – In-situ treatment for benzene >100 ug/L, and MNA for benzene ≤100 ug/L and establish a CEA; ISCO is anticipated to be the in-situ treatment technology for benzene >100 ug/L in groundwater; however, in-situ bioremediation, air sparging/soil vapor extraction, and in-situ thermal treatment are also being retained; and
- LNAPL – Mitigate to the extent practicable with LRMs or CMs, such as ISCO and in-situ thermal treatment for low levels of LNAPL.

Section 7 presents the conclusions and recommendations of the CMS. These conclusions and recommendations are based on the following: 1) the results of all soil investigations conducted to date at the Site including the CMS PDI summarized in Section 2.0, 2) the results of the latest sitewide LNAPL monitoring summarized in Section 2.0, 3) the results of the latest groundwater sampling events conducted in each Yard summarized in Section 2.0, 4) applicable media-specific cleanup standards summarized in Section 3.0, 5) the results of the preliminary screening of applicable CM technologies summarized in Section 4.0, 6) the results of the evaluation of selected CM technologies including bench test results summarized in Section 5.0, and 7) the results of the development and evaluation of remedial alternatives summarized in Section 6.0.

The conclusions and recommendations are provided below for each of the following contaminated media: 1) hazardous soil, 2) non-hazardous soil, 3) benzo(a)pyrene >10 mg/kg impacted soils, 4) East Yard arsenic impacted soil, 5) AOC 29, 6) LNAPL contamination, and 7) groundwater contamination. For each contaminated media, the following information is presented: 1) a summary of the volume to be remediated, 2) identification of the applicable criteria/standards and remedial goals to be achieved, and 3) the recommended CM(s) to be implemented. Further, the areas where each of the recommended CMs are to be implemented and the corresponding SWMUs and AOCs to be remediated are displayed on Figures 23 through 25 "Summary of Corrective Measures for Contaminated SWMUs and AOCs for the Main Yard, East Yard, and Central Yard", respectively. Also a summary of the CM status and recommendations for each of the Site SWMUs and AOCs, along with their associated exceedences, is shown in Table 1. Additionally, a summary of the contaminated media areas and volumes and associated impacted SWMUs and AOCs is given in Tables 6 through 9 for the Sitewide, and the Main, East, and Central Yards, respectively. Further, a summary of the CMS recommendations including the recommended CM(s) for each contaminated media and the associated SWMUs

and AOCs is given in Table 7.1. Finally, the remediation goals for each of the contaminated media is provided in Table 7.2.

Characteristic HAZARDOUS SOIL

The CMS PDI results identified the following hazardous soil at the Site: 1) 800 cubic yards of characteristically hazardous benzene, 2) 3,000 cubic yards of characteristically hazardous lead, and 3) 33,200 cubic yards of potentially listed hazardous soil in SWMU 43. A summary of the potentially applicable USEPA standards for RCRA TCLP characteristic hazardous soil is provided in Table 4. The applicable remedial goal for the potentially listed hazardous soil in SWMU 43 is the USEPA RCRA LDR Standards for petroleum refining waste codes F037, F038, K051 and K052. A summary of the applicable USEPA LDR standards for these RCRA listed hazardous waste codes is presented in Table 3. The recommended CMs to be implemented for these soils are as follows: 1) ISCO for characteristically hazardous benzene, 2) excavation, ex-situ stabilization, and disposal in the on-site CAMU for characteristically hazardous lead, and 3) ISCO hot-spot treatment for characteristically hazardous benzene and in-situ stabilization with installation of a non-RCRA cap and filing of a deed notice for SWMU 43. Additionally, the following CMs are being retained for consideration of their potential use, either as a stand-alone CM or as part of a treatment train, to ensure the remediation goals will be achieved: 1) in-situ thermal treatment for SWMU 43 hazardous soil, and 2) in-situ thermal treatment and ex-situ bioremediation for non-SWMU 43 hazardous soils.

NON-Characteristically HZARDOUS contaminated SOIL

The CMS PDI results identified the following non-hazardous contaminated soil at the Site: 1) 17,700 cubic yards of lead contamination in exceedence of its NJDEP NRDCSCS of 800 mg/kg, and 2) 38,700 cubic yards of benzene in exceedence of its NJDEP NRDCSCC of 13 mg/kg. The applicable regulatory standards/criteria for these soils are as follows: 1) NJDEP NRDCSCS for lead and naphthalene, and 2) NJDEP NRDCSCC for benzene and all other contaminants. A summary of the applicable NJDEP NRDCSCC and NRDCSCS is given in Table 2. The recommended CMs to be implemented for these soils are as follows: 1) ISCO for benzene and other organic contaminated soil, 2) in-situ stabilization with filing of a deed notice for lead contaminated soil, and 3) excavation, ex-situ stabilization, and disposal in the on-site CAMU for TEL/TOL concentrations >2 mg/kg with total lead concentrations <800 mg/kg. Additionally, in-situ thermal treatment and ex-situ bioremediation are being retained for consideration of their potential use, either as a stand-alone CM or as part of a treatment train, to ensure the remediation goals will be achieved.

BENZO(A)PYRENE >10 mg/kg IMPACTED SOILS

The CMS PDI results identified 6,600 cubic yards of benzo(a)pyrene concentrations greater than 10 mg/kg at the Site. The applicable regulatory criteria for this soil is the NJDEP NRDCSCC for benzo(a)pyrene of 0.66 mg/kg with a recommended action level of 10 mg/kg for benzo(a)pyrene. The recommended CMs to be implemented for soil with benzo(a)pyrene above the recommended action level of 10 mg/kg are excavation, ex-situ stabilization, and disposal in the on-site CAMU. The recommended CM to be implemented for soil with benzo(a)pyrene concentrations greater than 0.66 mg/kg and less than 10 mg/kg is to file a deed notice. Additionally, ISCO and in-situ thermal treatment are being retained for consideration of their potential use, either as a stand-alone CM or as part of a treatment train, to ensure the remediation goals will be achieved.

ARSENIC IMPACTED SOIL

The SRFI results identified 41,900 square yards of arsenic impacted soil in the East Yard with concentrations exceeding its NJDEP NRDCSCC of 20 mg/kg, which is the applicable regulatory criteria for this soil. Additionally, SWMU 39 in the Main Yard had arsenic concentrations in the surface soil (0 – 2 feet bgs) >20 mg/kg. The recommended CM to be implemented for these soils is containment consisting of a cap with filing a deed notice.

AOC 29

Based on the results of a separate evaluation of alternatives for AOC 29 as mentioned previously, the recommended CMs for AOC 29 includes constructing a revetment to control erosion along the Arthur Kill in combination with asphalt collection and long-term operation, maintenance, and monitoring of groundwater and surface water with filing of a deed notice. The complete results of this evaluation will be presented in a separate CMS Report for 5 Berth (AOC 29) expected to be submitted to the USEPA and NJDEP by December 31, 2008.

LNAPL CONTAMINATION

The results of LNAPL monitoring conducted in 2007 identified approximately 10,700 square yards of LNAPL at the Site at a thickness greater than 0.01 feet. The applicable regulatory criteria for LNAPL is to remove it to the extent practicable in accordance with 7:26 E-6.1 of the latest revised NJDEP Technical Requirements for Site Remediation dated

September 2, 2008. The recommended CMs to be implemented for LNAPL contamination are to continue the use of LRMs including the use of a vac truck, belt skimmers and absorbent socks, as necessary. Additionally, ISCO and in-situ thermal treatment are being retained for consideration of their potential use for low levels of LNAPL, either as a stand-alone CM or as part of a treatment train, to ensure the remediation goals will be achieved.

GROUNDWATER CONTAMINATION

The CMS PDI results identified the following groundwater contamination at the Site: 1) 850,000 cubic yards of saturated zone soils with groundwater benzene concentrations between 1 to 100 ug/L, 2) 122,000 cubic yards of saturated zone soils with groundwater benzene concentrations greater than 100 ug/L, and 3) 86,800 cubic yards of saturated zone soils with groundwater lead concentrations greater than 5 ug/L. The applicable regulatory standards for groundwater contamination are the NJDEP GWQSs. A summary of the applicable NJDEP GWQSs is shown in Table 5. The recommended CMs to be implemented for this groundwater contamination are as follows: 1) ISCO for groundwater contamination in the source areas with benzene concentrations greater than 100 ug/L, 2) MNA for groundwater contamination outside the source areas with benzene concentrations between 1 to 100 ug/L and CVOC exceedences <100 ug/L, 3) enhanced in-situ bioremediation (EIB) in AOC 36 area with CVOC exceedences >100 ug/L, and 4) in-situ stabilization in the source areas with lead concentrations greater than 50 ug/L. A CEA will be filed for each groundwater area with contamination in excess of its respective GWQS. Additionally, in-situ bioremediation, air sparging/soil vapor extraction, and in-situ thermal treatment are being retained for consideration of their potential use, either as a stand-alone CM or as part of a treatment train, to ensure the remediation goals will be achieved.

As discussed in each of the contaminated media conclusions and recommendations summaries above, Chevron is proposing to retain for consideration all of the retained technologies screened and evaluated in Sections 4.2 and 5.0, respectively, for potential use at the Site. This will provide the necessary flexibility to ensure that remediation goals are met in an efficient manner. This performance based approach is required in a complex operating refinery with multiple SWMUs and AOCs, some of which are located in process areas and other active portions of the facility. The specific technology(ies) for individual SWMUs and AOCs will be designed as part of the Corrective Measures Implementation, and will be based on the performance from site-specific bench and pilot studies, as appropriate. If necessary, additional pilot study evaluations may be completed during the design investigation process to further evaluate the performance of retained technologies, and to potentially revise the locations where each technology would be utilized and/or to

develop treatment trains for specific SWMUs and AOCs to ensure the remediation goals will be achieved.

1.0 INTRODUCTION

1.1 FACILITY DESCRIPTION

This Corrective Measures Studies Report (CMS Report) has been prepared for the Chevron U.S.A. Products Company (Chevron) Perth Amboy Refinery site located at 1200 State Street, Perth Amboy, New Jersey. The CMS is being conducted pursuant to the Corrective Action Requirements contained in the facility's Hazardous and Solid Waste Amendments of 1984 (HSWA) Permit (EPA ID No. NJD081982902). The HSWA Permit for the facility was issued by Region 2 of the United States Environmental Protection Agency (USEPA) on June 1, 1994. This CMS addresses many, but not all of the Solid Waste Management Units (SWMUs) and Areas of Concern (AOCs) subject to the Permit.

Chevron purchased the facility in 1946 from Barber Asphalt Company who had owned and operated the facility since 1911. The Chevron facility operated as a full scale petroleum refinery from 1946 to 1983. Its operation included the production of liquefied petroleum gas, gasoline, fuel oil, and asphalt. In 1983, Chevron reduced its operations to refining asphalt and continued operations as a petroleum terminal. The site is primarily located in the industrial zone of Perth Amboy and is bounded to the east by the Arthur Kill. A small portion of the site extends into Woodbridge Township. A United States Geological Survey (USGS) Site Vicinity Map is shown in Figure 1.

In 1994, at the time of the issuance of the initial HSWA permit, the Chevron permitted facility consisted of approximately 368 acres. The active facility was divided into a series of yards known as the East Yard, Central Yard, North Field/Main Yard (Main Yard), West Yard and Amboy Field. In addition to these five areas, the HSWA permitted facility also included an unused 29 acre piece of property owned by Chevron, known as the North Field Extension (NFE), which is located across Woodbridge Creek, east of the Main Yard. Over the past five years portions of the facility, the West Yard and Amboy Field, have been decommissioned and sold to others for the construction of commercial warehousing as part of the City of Perth Amboy's redevelopment efforts. Currently, Chevron continues to own approximately 268 acres, which include the remaining three yards and the NFE.

Current operations at the site include the refining of crude oil into asphalt and gasoline blending products, along with a petroleum products terminal. Raw materials (crude oil) are received by ship or barge on docks located along the Arthur Kill. The oil is off-loaded in the East Yard of the refinery where it is stored in a series of above ground tanks. The crude oil

is transferred through a series of piping into the Main Yard for processing through the refinery's crude unit. Finished asphalt is pumped into storage tanks in the Central and East Yards for eventual loading into marine barges and customer's trucks for off-site distribution.

A more detailed description of the facility can be found in the Description of Current Conditions (DOCC) (ESE. 1994), Module II of the 1994 HSWA Permit, and the RFI Documents.

1.2 HSWA CORRECTIVE ACTION PERMIT STATUS AND SCOPE OF THE CMS

1.2.1 HSWA Corrective Action Permit Status

Currently, the refinery is a large quantity generator of hazardous wastes and no longer operates any permitted RCRA regulated hazardous waste management units. As a hazardous waste generator, Chevron maintains a short term (less than 90 days) hazardous waste storage area. During the 1980s, the facility operated several regulated hazardous waste management units such as the Surge Pond and a land treatment unit. These units have been closed in accordance with approvals from the New Jersey Department of Environmental Protection (NJDEP) pursuant to New Jersey's delegated RCRA Subtitle C program. Closure of these units triggered the issuance of the HSWA Permit on June 1, 1994 by USEPA Region 2. The HSWA Permit contains Corrective Action Requirements pursuant to Section 3004(u) of HSWA. Chevron's 1994 HSWA Permit expiration date was 2004. However, Chevron requested a renewal of the permit in a renewal application dated June 29, 2004, which was submitted to the Regional Administrator of EPA Region 2.

The general corrective action process required under the Refinery's HSWA Permit includes the following steps: 1) the RCRA Facility Assessment ("RFA") to identify potential sources of contamination and evaluate if releases have occurred; 2) the RCRA Facility Investigation ("RFI") to evaluate the nature and extent of confirmed releases; and 3) a Corrective Measures Study ("CMS") to evaluate and select appropriate remedies to address contamination associated with SWMUs and AOCs.

The USEPA and the NJDEP jointly review the documents that Chevron submits pursuant to its HSWA Permit. The EPA is the lead agency.

USEPA Region 2 conducted the initial RFA at the site and included its findings in the facility's 1994 HSWA Permit. This initial RFA identified 51 SWMUs and 16 AOCs (1994 HSWA Permit, Module III, Pages 14 – 17). Chevron initiated RFI activities shortly after issuance of the HSWA Permit. As discussed below in Section 1.5, the RFI for the facility has been conducted in phases. As part of the RFI, hundreds of soil borings and monitoring wells have been installed to fully investigate the nature and extent of soil and groundwater contamination at the site. Additionally, surface water, sediment and other environmental media investigations have also been conducted as part of the RFI process. Chevron has submitted results of the RFI investigations for review by the USEPA and NJDEP. The USEPA and NJDEP are currently reviewing the February 2008 Supplemental RFI report.

In a letter dated March 30, 2005, Chevron informed USEPA that it would like to begin CMS activities under the HSWA permit while awaiting final comments on the RFI. In a letter dated April 13, 2005, USEPA approved Chevron's request to initiate the CMS process.

1.2.2 Scope of CMS

The Scope of this CMS includes the SWMUs and AOCs in the Main Yard, East Yard, and Central Yard portions of the facility. These three Yards comprise the remaining portion of Chevron's currently operating facility. As discussed below, the remaining SWMUs and AOCs outside of these three Yards are being addressed or will be addressed in subsequent submittals.

Chevron initiated the CMS for these areas in 2006. There are 45 SWMUs and 49 AOCs included in this CMS. These SWMUs and AOCs are identified in Table 1 and are shown on Figures 2 through 4. This CMS Report provides the results of the evaluation of corrective measure alternatives for these SWMUs and AOCs in these three Yards in accordance with applicable provisions of Appendix B of the HSWA Permit (Scope of Work for a Corrective Measures Study). The report also includes the recommended corrective measure alternatives for each of these SWMUs and AOCs. Many of the SWMUs and AOCs are relatively close to each other or even overlap each other resulting in contiguous areas of soil or groundwater contamination. Therefore, most of the recommended corrective measures are also grouped by environmental media.

It is important to note that these three Yards comprise the operating portions of the facility. Active process, waste management and storage areas may impact the timing or implementability of specific corrective measures. Additionally, operations at the active

petroleum facility may require maintenance or upgrades which could also impact the timing or implementation of corrective measures.

Chevron is completing the remediation of the SWMUs and AOCs for the West Yard and Amboy Field under a Memorandum of Agreement (MOA) between the NJDEP and Chevron. The MOA issued pursuant to New Jersey regulations N.J.A.C. 7:26C, allowed for the expedited remediation of these two parcels for sale and redevelopment. The remediation of these two yards is mostly complete. As part of the remediation, effort was made to take into account both New Jersey regulatory requirements and HSWA corrective action permit conditions. Following the completion of remedial efforts for the West Yard and Amboy Field, Chevron intends to obtain a no further action determination for the areas, as appropriate, pursuant to the administrative requirements under the HSWA Permit. Therefore, these areas are not being addressed under this CMS.

As previously discussed, the vacant 29 acre Chevron owned parcel located across Woodbridge Creek known as the NFE is not included within the scope of this CMS. Chevron has previously asserted that the SWMUs and AOCs identified under the HSWA Permit on the NFE are attributable to past operations of others. Chevron has brought suit against these parties and hopes to be nearing the negotiating of an agreement which will provide for the remediation of these SWMUs and AOCs. Chevron and the defendants in the NFE matter have completed and submitted remedial investigation reports for the NFE (see the following two reports: "North Field Extension, Results of Total Petroleum Hydrocarbon Soil and Chlorinated Groundwater Investigations, Chevron Perth Amboy Refinery, Perth Amboy, New Jersey" prepared by TRC Raviv Associates, Inc., dated February 2005; and "Remedial Investigation Report, North Field Extension Site, Woodbridge, New Jersey" prepared by Roux Associates Inc., dated March 2005).

1.3 CMS PROJECT OBJECTIVES

The overall objective of the CMS is to develop, evaluate and select the most appropriate remedial alternatives for the SWMUs and AOCs in the Main Yard, East Yard and Central Yard.

The specific objectives of the CMS are as follows:

1. Conduct a CMS PDI to fill in data gaps identified as a result of the USEPA and NJDEP review of the RFI Report, provide additional data for the evaluation of

potential corrective measures (CMs) for the subject SWMUs and AOCs, and determine the extent of contaminated media requiring CMs.

2. Establish cleanup goals and media-specific cleanup criteria/standards.
3. Screen and select the appropriate demonstrated and available CM technologies for each of the contaminated media.
4. Evaluate the most appropriate CMs for each of the contaminated media and each of the SWMUs and AOCs.
5. Develop, evaluate and select the most appropriate remedial alternatives for the Site.

This CMS Final Report for the Main Yard, East Yard and Central Yard (CMS Final Report) is organized into the following eight sections: 1) Introduction; 2) CMS Pre-Design Investigation Results Report; 3) Establishment of Cleanup Goals and Media-Specific Cleanup Criteria/Standards; 4) Preliminary Screening of Corrective Measures Technologies; 5) Evaluation of Selected Corrective Measures Technologies; 6) Development and Evaluation of Remedial Alternatives; 7) Conclusions and Recommendations; and 8) References.

1.4 ENVIRONMENTAL SETTING

Physiographic Setting

The Chevron Perth Amboy Facility is located in the Atlantic Coastal Plain Physiographic Province along Raritan Bay of Central New Jersey. The Coastal Plain is characterized as northeast-trending lowland. The Coastal Plain is relatively flat with topographic elevations that rise gently from near sea level at the coastline. The northern, central, and eastern portions of the Refinery are relatively flat. At the refinery, the elevation of the ground surface varies from 3 to 44 feet NGVD. The topography at the Refinery has been shaped by stream erosion, the last glaciation (approximately 20,000 years ago), and construction activities performed during site development such as cut and fill grading. There are berms around each petroleum storage tank for spill containment.

Prior to site development, the areas adjacent to Woodbridge Creek and the Arthur Kill were tidal marshlands with small, meandering tidal creeks. Small streams and shallow swales crossed the other portions of the site providing surface drainage. During development, the tidal marshlands were filled. Sheet piles have been installed along stretches of the site

adjacent to the Arthur Kill, Woodbridge Creek, and Spa Spring Creek to stabilize the fill zones and prevent them from sloughing off into the adjacent creeks.

Regional Geologic Setting

The Refinery is located near the western edge of the Coastal Plain physiographic province. The Coastal Plain deposits extend from the Fall Line at the edge of the Piedmont (approximately three miles northeast of the Refinery) out onto the Continental Shelf. The Coastal Plain deposits form a wedge that thickens eastward (seaward) from a feather edge at the Fall Line to almost 10,000 feet thick along the central New Jersey coastline (Woodward-Clyde. 1981). The Coastal Plain strata consist of unconsolidated to semi-consolidated sedimentary units of Tertiary and Cretaceous age, that overlie an assemblage of bedrock units including sandstone, shale, and diabase known as the Newark Supergroup of Triassic and Jurassic age.

The bedrock beneath the Coastal Plain deposits at the Refinery was deposited during the Triassic and Jurassic Period. Rock types in the Newark Basin include terrigenous sediments, diabase, and basalts. The Newark Basin typically dips to the northwest (Woodward-Clyde. 1981). The site is predominantly underlain by Jurassic basalt and diabase that is considered to be a part of the Palisade Sill, although some areas are underlain by mudstones and argillites of the Triassic-age Lockatong Formation. The Triassic sedimentary units unconformably overlie Precambrian and Paleozoic rocks of the Piedmont and Manhattan Prong (Woodward-Clyde. 1981). Most of the structural features in the region such as folds and faults in the Perth Amboy area have been associated with the formation of the Triassic Newark Basin and the Paleozoic Appalachian Highlands west and north of the site. The region is tectonically quiet at present, although occasional minor earthquakes (magnitude 3 or less) have been documented (Woodward-Clyde. 1981). This seismic activity appears to be primarily limited to the Triassic border fault system along the western edge of the Newark Basin (20 miles northwest of the site), and to the area near Cheesequake, New Jersey, Sandy Hook, and Raritan Bay (Woodward-Clyde. 1979). No seismically induced ground surface ruptures have ever been documented in the northeastern United States (Woodward-Clyde. 1981).

In the Perth Amboy area, the sedimentary units overlying bedrock include the partially-consolidated sands and clays of the Raritan Formation deposited during the Cretaceous Period; unconsolidated sands, gravels, silts and clays deposited as glacial till and outwash during the Pleistocene Epoch; silts, clays, and organic deposits (peat) deposited in a coastal

environment during the Holocene Epoch; and fill deposited during construction activities over the last 100 years (ESE. 1994 and Woodward-Clyde. 1981). Beneath the Refinery, the sediments are approximately 60 feet to 100 feet thick. A discontinuous veneer of Quaternary deposits unconformably overlies the Cretaceous sediments in the site region. The Quaternary deposits include glacial deposits laid down during the Wisconsin advance, which ended approximately 18,000 years ago (Harper and Goldstein. 2000) and more recent coastal deposits. The glacial deposits consist of terminal and ground moraine deposits (till), outwash, and lacustrine deposits. Post-glacial alluvial and paludal deposits up to a few tens of feet thick are also present in stream valleys and lowlands throughout the site region.

In the Raritan Bay area, the Cretaceous age deposits consisting of clays, sand, lignite, and gravels represent the Raritan Formation. The Raritan Formation represents pro-gradational alluvial plain, coastal, and near shore marine environments. These environments were formed by a series of major transgressions and regressions of the seas during the Late Cretaceous, specifically the Cenomanian Stage (approximately 93 to 100 million years ago). The Raritan Formation includes the Raritan Fire Clay, Farrington Sand Member, Woodbridge Clay Member, Sayreville Sand Member, and the South Amboy Fire Clay Member (oldest to youngest, respectively) (Messina and Stoffer. 1996).

A discontinuous layer of Quaternary Age deposits unconformably overlies the Cretaceous sediments. The Quaternary deposits include glacial deposits laid down during the Wisconsin glacial advance, which ended approximately 18,000 years ago (Harper and Goldstein. 2000), and more recent coastal deposits. The older glacial deposits consist of terminal and ground moraine deposits (till), outwash sand, gravel, and lacustrine deposits formed during the Pleistocene Epoch. These glacial deposits are referred to as the Wisconsin Glacial Till. The younger coastal deposits consist of silts, clays, and organic deposits (peat) deposited during the Holocene Epoch. These coastal deposits represent estuarine and fluvial sediments deposited behind barrier islands that developed during a period ranging from 12,000 to about 7,000 years ago (Messina and Stoffer. 1996). Over the last 100 years, these Quaternary sediments have been shaped by natural erosion and human activities performed during site development such as cut and fill grading.

1.4.1 Site Subsurface Stratigraphy

The general stratigraphy of the Refinery consists of six major units which overly the bedrock, including fill; organic clay and peat (Clay Horizon A); glacial till and outwash; and three members of the Raritan Formation – the Woodbridge Clay (Clay Horizon B), Farrington Sand (Sand Horizon B), and Raritan Fire Clay (Clay Horizon C). The

stratigraphic units beneath the Refinery were first identified and described by Woodward-Clyde (1981). A description of these units that is based primarily on Woodward-Clyde's work is provided below.

Over large parts of the site, fill covers the land surface. Some of the fill appears to be derived from onsite glacial deposits. In addition, the North Field/Main Yard has been used for petroleum-related activities since the late 1800's, and much of this area has been filled with petroleum impacted soils, catalyst beads and other fill materials. The fill was placed directly on top of marshland and other existing deposits, before the construction of surface impoundments. The fill was also used to build up dikes around the edges of the impoundments. The fill at the site consists largely of sand, with variable amounts of silt, clay, gravel and miscellaneous debris. The fill also includes ash, construction debris, and catalyst beads. The fill is generally less than ten feet thick, but can be up to 20 feet thick. Based on the location of the property in relation to several water bodies and the industrial development of the property over time, varying depths of fill can be found throughout the site. Fill materials are heterogeneous with varying permeabilities. However, the fill materials can be generally categorized as having low permeability, with the exception of discontinuous lenses of sands or catalyst beads placed over time.

Clay Horizon A is found underlying the fill unit, or at the ground surface in areas of the site that are not covered by fill, glacial till, or fluvial channel sands. Clay Horizon A is a dark gray to black organic clay with minor amounts of sand and gravel. Peat and meadow mat (partially decomposed marsh vegetation) are locally important components of Clay Horizon A. It is typically about 20 feet thick, but may be up to 35 feet thick. Clay Horizon A is interpreted to have been deposited in an estuarine (coastal) environment, along with fluvial stream channel sands. The sands are found as thin lenses and seams deposited within and above Clay Horizon A. Typically, these lenticular and ribbon sands may be up to 5 feet thick, but pinch out laterally.

The glacial till and outwash deposits are an areally extensive layer beneath Clay Horizon A in the northern and eastern parts of the Refinery. In the southern and western portions of the Refinery, the glacial till and outwash deposits outcrop at the surface. The till consists predominantly of clay and silt, with varying amounts of sand and gravel. The outwash deposits are primarily sand and gravel with some silt and clay. The glacial deposits have a characteristic reddish-brown color, variable texture (stratified/unstratified, well-sorted/poorly sorted), and are found as surficial soils and at depths of 25 to 50 feet bgs. Some of the clay units in the southern portion of the Site may be of glaciolacustrine origin. The glacial unit varies in thickness from 20 to over 40 feet. Erosion before and during

Pleistocene glaciation resulted in localized removal of Cretaceous units below the till, sometimes resulting in a juxtaposition of glacial till directly over bedrock. This erosional juxtaposition of till over bedrock has been observed in the eastern portion of the site adjacent to the Arthur Kill .

In the western portions of the site, the glacial unit is underlain by Clay Horizon B, Sand Horizon B, and Clay Horizon C. These three units are members of the Raritan Formation, which was deposited in a marginal marine environment. Clay Horizon B has been correlated with the Woodbridge Clay Member, Sand Horizon B with the Farrington Sand Member, and Clay Horizon C with the Raritan Fire Clay Member.

The Sayreville Sand Member, which is stratigraphically above Clay Horizon B, is a white, coarse-grained, cross-bedded sand. It has only been tentatively identified in a few soil borings at the site and appears to have a maximum thickness of five feet.

Clay Horizon B, or the Woodbridge Clay, is typically a gray to dark gray or pale red/orange micaceous clayey silt. It is locally interbedded with gray to light gray, micaceous, clayey fine sand. Clay Horizon B can contain small wood fragments and lignite. Although the Woodbridge Clay can be up to 90 feet thick, it is less than 50 feet thick beneath the Refinery.

Sand Horizon B, or the Farrington Sand, was deposited in the Raritan Bay Area on an undulating erosional surface above Clay Horizon C. The Farrington Sand is typically about 80 feet thick, and has a maximum thickness of 129 feet. At the Refinery, the Farrington Sand is 15 to 25 feet thick. Based on soil boring data, the Farrington Sand at the Refinery is a clean, white to brown, arkosic fine-to-coarse-grained sand, with common gravel and dark silty lenses. The Farrington Sand is very micaceous and cross-bedded. It is continuous beneath the site, except at the eastern section adjacent to the Arthur Kill, where it was apparently removed by erosion. The Farrington Sand crops out at the ground surface less than a mile to the northwest of the Refinery, where it is recharged by precipitation.

Clay Horizon C, or the Raritan Fire Clay, is a dark green to dark gray, hard, dense, plastic clay to silty clay with some sand. It can contain dark-colored rock fragments and gravel and have reddish to whitish streaks in the clay. The Raritan Fire Clay can be up to 86 feet thick with thickness increasing to the south and east. Beneath the site, the Raritan Fire Clay ranges in thickness from 12 feet to 20 feet.

Bedrock was encountered in several deep borings onsite at 65 to 85 feet bgs. There is a layer of saprolite that overlies competent bedrock, which formed from very well weathered and decomposed rock, which was either diabase or mudstone of the Lockatong Formation. The saprolite grades upward into the Raritan Fire Clay without a distinct contact. The saprolite appears to be laterally continuous across the site and is typically up to 5 feet thick.

1.4.1.1 Main Yard

In general, the Main Yard lithology is composed of the following stratigraphic progression: fill overlying a discontinuous peat layer, gray clay (Clay Horizon A) and glacial till. Groundwater through out the Main Yard was detected in the fill layer. The fill contains varying amounts of sands, silts and clay. Five, four and two cross-sections are presented in Figures 11, 13 and 14, respectively, which show the variable thickness of the fill material in the Main Yard. The cross-sections were developed at locations where soil concentrations of benzene, lead and benzo(a)pyrene were greater than 13 mg/kg, 800 mg/kg, and 10 mg/kg, respectively. The description of the general lithology of the Main Yard is based on these cross-sections, which were generated from the soil boring logs prepared as part of the CMS PDI. More detailed information on the Main Yard lithology is given in these soil boring logs that are provided in Appendix C1.

The fill layer is encountered throughout the entire Main Yard. The thickness of the fill layer varies throughout the Main Yard. In the northern portion of the Main Yard, the thickness of the fill varies from 4 to 10 feet (see cross-section A-A' in Figure 13). Beneath the fill layer is an underlying clay layer (Clay horizon A) from 1 to 4 feet in thickness. Sometimes the clay layer is absent and the fill is overlaying glacial till. The thickness of the glacial till is 4 to 10 feet.

In the central and western portion of the Main Yard, the stratigraphy consists of 3 to 15 feet of fill overlying native clay (Clay Horizon A). The thickness of the clay layer is 1-12 feet. Beneath the clay layer is the glacial till layer.

In the southeastern portion of the Main Yard, most of the soil borings did not penetrate past the fill layer (see cross-section D-D' in Figure 13). The thickness of the fill material is greater than 8 feet. When the soil borings penetrate past the fill material, either clay or till is encountered.

Previous investigations indicated the Main Yard is composed of fill ranging in thickness from 3 to 15 feet, overlying a glacial till and a discontinuous clay/peat layer (SAIC. 2008).

The clay is described as Clay Horizon A and can be as much as 30 feet thick in close proximity to Woodbridge Creek. The glacial till appears to be continuous in the Main Yard and can extend to about 40 feet in some areas.

1.4.1.2 East Yard

In general, the East Yard lithology is composed of the following stratigraphic progression: fill overlying a discontinuous peat layer, gray clay (Clay Horizon A) and glacial till. Groundwater through out the East Yard was detected in the fill layer. The fill contains varying amounts of sands, silts and clay. Six and two cross-sections are displayed in Figures 16 and 18, respectively, which show the variable thickness of the fill material in the East Yard. The cross-sections were developed at locations where soil concentrations of benzene and lead were greater than 13 mg/kg and 800 mg/kg, respectively. The description of the general lithology of the East Yard is based on these cross-sections, which were generated from the soil boring logs prepared as part of the CMS PDI. More detailed information on the East Yard lithology is given in these soil boring logs that are provided in Appendix C1.

The silty clay fill layer is encountered throughout the entire East Yard. The thickness of the fill layer varies throughout the East Yard. In the western portion of the East Yard, the thickness of the fill varies from 4 to 10 feet (see cross-section A-A' in Figure 16) and from 9 to 14 feet (see cross-section B-B' in Figure 16). In the northeastern portion of the East Yard, the thickness varies from 7 to 20 feet (see cross-section C-C' in Figure 16) and 6 to 14 feet (see cross-section D-D' in Figure 16). In the central portion of the East Yard, the thickness of the fill layer is 5 to 7 feet (see cross-section F-F' in Figure 16). Similarly, in the western portion of the East Yard, the thickness of the fill layer varies from 4 to 15 feet (see cross-section E-E' in Figure 16).

Beneath the fill material, native clay (Clay Horizon A) is generally observed. The thickness of the clay layer varies throughout the East Yard. In the northeastern portion of the East Yard, the clay layer appears to be continuous beneath the fill layer and varies in thickness between 1 to 11 feet (see cross-sections A-A' and B-B' in Figure 16). In the northwestern portion of the East Yard, the clay layer appears to be continuous beneath the fill layers except at a few locations where there appears to be lenses of clay within the fill material (see cross-section C-C' in Figure 16). The thickness of the clay layer in the northwestern portion varies between 1 to 14 feet (see cross-sections C-C' and D-D' in Figure 16). In the central and eastern portion of the East Yard, the clay layer appears to be below the fill layer and the thickness varies between <1 foot to 5 feet (see cross-sections E-E' and F-F' in Figure 16).

In addition to fill and clay layers, lenses of till were also observed in the northwestern portion of the East Yard. The till lenses are 1 to 4 feet in thickness and were observed intermittently in the soil borings. The till appears as reddish-brown silt with varying amounts of clay, sand and gravel.

Previous investigations indicated that discontinuous lenses are found at the base of the clay at depths ranging from 15 to 25 feet (SAIC. 2008). Also, beneath the till and Clay Horizon A is clay Horizon B, the Woodbridge Clay. Borings conducted by previous investigations have shown this clay to be from 20 to 30 feet thick in the East Yard.

1.4.1.3 Central Yard

In general, the Central Yard lithology is composed of the following stratigraphic progression: fill overlying gray clay (Clay Horizon A) and glacial till. Groundwater throughout the Central Yard was detected in the fill layer perched on the native clay and till. The fill contains varying amounts of sands, silts and clay. Cross-section A-A' in Figure 23 shows the soil borings advanced in the southern portion of the Central Yard. The cross-section was developed at locations where soil concentrations of lead were greater than 800 mg/kg. The description of the general lithology of the Central Yard is based on this cross-section, which was generated from the soil boring logs prepared as part of the CMS PDI. More detailed information on the Central Yard lithology is given in these boring logs that are provided in Appendix C1.

The thickness of the fill layer varies from 7 to 19 feet, and beneath this layer is native clay (Clay Horizon A), the thickness of which varies between 3 to 19 feet. Intermittent layers of till were observed within the clay layer. The fill material consist of several inches of asphalt and gravel over a mixture of native soils, sands, clays, and pea gravel with construction debris including bricks, ceramic chips, and other items. This layer is dry to approximately 5 feet and is reddish brown, reddish yellow, or strong brown in color. The color of the fill material near the water table changes to dark gray to reddish black. Layers containing large amounts of construction debris are highly conductive. The contact between the fill deposit and till represents the prior land surface. Traces of roots can be found at that elevation. In the northern portion of the study area, gray marine clay is evident between the fill material and the till. This clay is limited in extent.

Based on previous investigations, immediately beneath the fill in the northern two thirds of the Central Yard is dark gray clay (Clay Horizon A), which was observed to be up to 20 feet

in thickness (SAIC. 2008). Clay Horizon A is described as a light gray to black organic marine deposit with minor amounts of sand and gravel.

In the southern portion of the Central Yard, Clay Horizon A is absent. Beneath the fill, the Wisconsin Glacial Till deposits contain narrow, winding, sand-filled channels bounded by silt/clay facies. The fluvial channel sequence within the till consists of sediments displaying a classical "fining upwards" grain size distribution beginning with coarse sands/gravels in the base, grading to finer sands, then silts and clays towards the top of the layer. Previous investigations in this area have identified three sand channels (southwest, central, and northeast) each having a northwest-southeast orientation. The sand facies tend to develop in the structurally low areas. Sand is structurally and stratigraphically high, just a few feet from the surface, in the Shops Building area but occurs more deeply towards the south and southeast. The fluvial channel sequence cuts into the underlying marine/tidal flat deposit (Woodbridge Clay) discussed below, forming an irregular contact surface. The northeastern channel sequence is poorly developed. Down-cutting of the channel sequence is evident towards the west in the Central Yard. In contrast, the central channel sequence edges out to the east and southeast of the Central Yard under the State Street properties. A more detailed description of these three fluvial sand channels is presented in the AOC 36 Chlorinated Plume Investigation Report (SAIC. 2005).

Underlying the glacial till, a dark blue gray colored clay or clayey silt is evident representing a coastal marine sequence, which is typically found across the Central Yard. Existing data indicates this marine clay is as much as 40 ft thick in the Central Yard. This massive clay has been identified as the Woodbridge Clay Member of the Raritan Formation, which directly overlies the Farrington Sand Member in the area of investigation.

Marine sand deposits underlying the Woodbridge Clay were identified during previous investigations in the Central Yard as the Farrington Sand Member of the Raritan Formation.

1.4.2 Site Hydrogeologic Conditions

Regional Hydrogeology

The most productive aquifer within the north and western parts of the Coastal Plain is the wedge-shaped Potomac-Raritan-Magothy aquifer system, which is comprised of the Potomac, Raritan and Magothy Formations (Zapecza. 1984). In the Perth Amboy area, only the Raritan Formation is present (Barksdale and others. 1943; Owens and others. 1995). The

Raritan Formation consists of four members: the Sayreville Sand, the Woodbridge Clay, the Farrington Sand, and the Raritan Fire Clay (Barksdale. 1943; and Owens and others. 1995).

In the northeastern portion of the New Jersey Coastal Plain, the Raritan-Magothy aquifer system can be divided into two major aquifers, the Farrington Aquifer and the Old Bridge Aquifer. The Farrington and the Old Bridge aquifers function as separate hydrogeologic units in Middlesex County, and can both be traced downdip into Monmouth County (Barksdale and others. 1943; Owens and others. 1995). The South Amboy Fire Clay Member of the Magothy Formation is an extensive confining unit that separates the overlying Old Bridge Sand Member of the Magothy Formation from the underlying Sayreville Sand of the Raritan Formation. The Sayreville Sand is separated from the Farrington Sand by the Woodbridge Clay, which also functions as a regionally extensive confining unit. The Woodbridge Clay can also be traced downdip from its outcrop area in Raritan Bay to the shore area in Monmouth County (Barksdale and others. 1943; Perry and others. 1975). The lower confining unit in Middlesex County consists mainly of the Raritan Fire Clay and the underlying consolidated rocks (Barksdale and others. 1943).

At the Refinery and the surrounding vicinity in Perth Amboy, the only member of the Magothy Formation that may be present is the South Amboy Fire Clay. The Sayreville Sand, Woodbridge Clay confining unit, the Farrington Sand aquifer, and the basal confining unit (the Raritan Fire Clay) of the Raritan Formation have been identified as present. The Old Bridge Sand Aquifer has not been identified in outcrops north of the Raritan River or Raritan Bay. The South Amboy Fire Clay may be present under the Refinery, as thin (less than 10 feet) discontinuous stringers and lenses (Barksdale and others. 1943; Farlekas. 1979) in the southern part of the site. Based on boring logs from the Refinery, it appears that the Sayreville Sand Member is discontinuous and only locally present beneath the Refinery. The top of the Farrington Sand strikes northeast and dips to the southeast at 45 to 60 feet per mile. The Refinery is situated in the general area designated as the outcrop-recharge area for the Farrington Sand aquifer (Barksdale and others. 1943; Farlekas. 1979).

Regional Flow Directions

Groundwater flow within water table aquifers generally mimics surface water drainage. In the region near the Refinery, groundwater flows towards the Raritan River, Woodbridge Creek, and the Arthur Kill.

Prior to the onset of significant groundwater withdrawal for water supply, the groundwater in the Farrington Aquifer flowed from topographically high recharge areas in its northeast

trending outcrop belt in Middlesex County to the southeast towards the Raritan River and beyond in Monmouth County to the New Jersey Coast. Recharge occurs in the Farrington Aquifer by percolation of precipitation in the outcrop belt (Barksdale and others. 1943; Farlekas. 1979). Prior to significant withdrawal by pumping, discharge from the Farrington Aquifer in the Site area was upward into the overlying aquifers, the Arthur Kill, and the Raritan River (Farlekas. 1979). At present, discharge from the Farrington Aquifer is most likely to the Raritan River and the Arthur Kill. Significant withdrawal of groundwater from the Farrington Aquifer for water supply is no longer occurring in the vicinity of the Refinery.

The Farrington Sand was formerly a flowing artesian aquifer, but the potentiometric surface has been lowered substantially by pumping in areas south of the site, especially in the vicinity of South Amboy and Sayerville. The potentiometric surface for the Farrington Aquifer has its area of maximum drawdown in the vicinity of South Amboy. From 1959 to 1973, the center of the cone of depression was drawn down from approximately 20 feet below mean sea level to 70 feet below mean sea level. The historical pumping resulted in widespread saltwater encroachment, particularly in the area south of the Raritan River (Barksdale and others. 1943; Appel. 1962) and south of Woodbridge Creek, just north of the Refinery (Barksdale and others. 1943).

Regional Groundwater Quality

In New Jersey, Class II groundwater is considered suitable for the provision of potable water with conventional water supply treatment. Class III groundwaters are not suitable for potable water due to natural hydrogeologic characteristics (geologic units that are aquitards) or natural water quality (saline groundwater with greater than 3,000 mg/L chloride or 5,000 mg/L total dissolved solids).

Groundwater in the Perth Amboy area is classified by NJDEP as Class IIA, a potable water supply. However, groundwater quality in the uppermost water-bearing unit is degraded, because of the various industrial activities and stormwater runoff from streets in this urban area. Near the Refinery, the Farrington Aquifer outcrops along Woodbridge Creek. As noted previously, historical pumping of the Farrington Aquifer caused salt water intrusion as the saline waters of Woodbridge Creek were drawn into the recharge area of the Farrington Aquifer. As documented in NJAC 7:9, Subchapter 6, which covers Groundwater Quality Standards, the Farrington Aquifer along the banks of Woodbridge Creek at and near the Refinery is designated as Class IIIB groundwater, which is not suitable for conversion to potable uses.

The Farrington Sand Aquifer that occurs at depths greater than 60 feet bgs is a potentially usable aquifer. However, groundwater is not actually used as a source of water supply within at least two miles of the Refinery, because historical pumping from the Farrington Sand has resulted in salt water encroachment near the Refinery, The high concentrations of naturally-occurring dissolved solids in the Farrington Sand near the Refinery have rendered it unusable.

Site Hydrogeology

The upper water-bearing unit at the Refinery is an unconfined shallow water-bearing zone that is present within the fill layer. A middle water-bearing zone is present within the glacial outwash deposits. The lower water-bearing unit is the Farrington Sand (Sand Horizon B), which has been used in the past in the Perth Amboy area as a local public water supply source, or drinking water source unit, but is no longer used for these purposes.

In the northern and eastern areas of the Refinery, the upper water-bearing zone in the fill is separated from the water-bearing zones in the Glacial outwash and Farrington Sand (where present) by the Clay Horizon A (organic clay) unit. In the southern and western areas of the refinery, Clay Horizon A pinches out and the water-bearing zone in the fill is underlain by the glacial till, or glaciolacustrine clays. The Farrington Sand is further isolated from groundwater within the fill by the Woodbridge Clay.

The low permeability clays and silts that separate the permeable water-bearing zones are discontinuous. For example, in the eastern areas of the Refinery, Clay Horizon B has been removed by erosion, so that the glacial deposits directly overlie the Farrington Sand. At these locations it is likely that there is hydraulic communication between the two permeable units. At the easternmost areas of the Refinery, the Farrington Sand, and in some cases the Raritan Fire Clay have also been removed by erosion, so that the glacial till and outwash rests unconformably on top of bedrock.

In general, groundwater is encountered at depths ranging from two feet bgs, in the low lying areas of the Refinery, to an approximate maximum depth of 10 feet bgs in the areas of higher elevation in Amboy Field. Site data indicate that hydraulic communication between the permeable zones is limited where the intervening low permeability units are present. Historical water level elevations from nested or closely spaced wells screened in the shallow and deep zones vary as much as 4 feet. Ground water flow direction also varies between the zones. Based on limited historical data, the groundwater in the Farrington Sand beneath the

Refinery generally flows to the east or southeast, which is similar to the regional flow pattern.

Tidally influenced groundwater level fluctuations and salt water intrusion into the shallow water-bearing zone have been observed and documented in the areas near Woodbridge Creek. Data from wells in the North Field Basin area have shown a tidally related groundwater elevation fluctuation of up to 1.5 feet. In contrast, monitoring wells in the East Yard Basin area have shown little tidal influence. This limited tidal influence in the East Yard is attributed to the bulkheads that have been placed along the Arthur Kill. Salt water intrusion into the Farrington Sand has been documented in the area south of Woodbridge Creek at and near the Refinery (Barksdale and others. 1943).

Several long-term aquifer tests and slug tests have been performed at and in the vicinity of the Refinery as part of groundwater supply investigations and environmental investigations. These aquifer tests are summarized below.

- In 1956, a 7-day pump test conducted within the Farrington Sand in South Brunswick (Leggette and others. 1961) yielded a transmissivity of 100,230 gallons per day per foot and a storativity of 1.6×10^{-4}. A 72-hour pump test was conducted by Hardt and Jablonski (1959) within the Farrington Sand to assess the potential for salt water intrusion in the vicinity of the Refinery. This test, which used two Chevron (then California Oil Co.) wells as observation wells, yielded a transmissivity of 16,000 gallons per day per foot and a storativity of 2.3×10^{-4}. In 1975, Dames & Moore conducted limited permeability tests at the site. The results of these tests indicated that groundwater in the Farrington Sand was under artesian pressure. There were insufficient data to define direction of groundwater flow in the Farrington Sand. Dames and Moore believed that the piezometric surface most likely conformed to the regional flow pattern, sloping to the southeast at about 5 to 10 feet per mile (Barksdale and others. 1943). Groundwater withdrawal from Chevron water supply wells No. 1 and No. 2 apparently created shallow cones of depression in the western portion of the Refinery until these wells were shut down. The permeability of the Farrington Sand as assessed from the Chevron water supply wells, was on the order of 1×10^{-1} to 1×10^{-2} centimeters per second (cm/sec), with a natural rate of flow of about 1 to 2 feet per day.
- In 1976, Dames & Moore performed permeability tests on the Woodbridge Clay. The results of these tests indicated a very low permeability of 1×10^{-8} to 5×10^{-8} cm/sec in the vicinity of the production well No. 2. Seepage rates appeared to be extremely low. Based on the permeability data, Dames and Moore estimated that the amount of water that would seep through Clay Horizon B under a gradient of one in an area 60 feet by 60

feet (an area the approximate size of the test landfarm) would be approximately 4 gallons per day. They estimated that water would infiltrate the clay at a flow rate of about 0.005 inches per day, or about 1.8 inches per year.

- In 1982, Woodward & Clyde derived horizontal permeability values for the Woodbridge Clay of $6x10^{-5}$ to $3x10^{-6}$ from slug tests conducted in the Landfarm area.
- In 1982, Woodward-Clyde conducted slug testing in the North Field. Their results indicated that in the shallow water-bearing zone (fill layer) horizontal permeability ranges from $2x10^{-4}$cm/sec to $5x10^{-7}$cm/sec. Laboratory analysis of undisturbed soil samples from Clay Horizon A showed that the vertical permeability within the clay samples ranged from $1x10^{-7}$cm/sec to $8x10^{-8}$cm/sec. Water level measurements from wells surrounding the North Field Basin indicated ground water mounding. This resulted in radial flow outward from the Basin.
- Slug tests conducted in the North Field (Woodward-Clyde. 1982) yielded horizontal permeability values of $1x10^{-2}$cm/sec for the Farrington Sand) and $4x10^{-3}$ cm/sec for the glacial outwash.
- In 1990, Dan Raviv Associates, Inc. (DRAI) conducted slug tests in the shallow water-bearing zone (fill layer) in the East Yard. The results of these tests and those completed by Woodward-Clyde indicated vertical hydraulic conductivities ranging from $1.24x10^{-5}$cm/sec to $4.0x10^{-6}$cm/sec. Ground water in the shallow zone flowed to the northeast with an average gradient of 0.003 feet per foot. A four-foot seasonal variation in groundwater elevation in the shallow zone was also noted during these investigations. Water level measurements taken in nested wells SB-13a (glacial outwash, lower water bearing zone) and SB-13b (fill, upper water-bearing zone) demonstrated a four foot elevation difference, indicating the lower aquifer is confined or semi-confined and hydraulic communication is very limited (Woodward-Clyde. 1982).
- In 1993, Ebasco conducted a pump test in the North Field. The well used for groundwater extraction, NF-11, was partially screened in a sandy zone contained within Clay Horizon A. The results of the pump test were inconclusive, but generally supported the findings of the earlier slug tests conducted by Woodward-Clyde. The pump test data demonstrated a distinct drop in sustainable yield three hours into the test, which indicated that the storage of the sandy zone was significant yet limited. The geographic extent and location of the sand is unknown at this time, but is believed to be limited, because the sand is thought to be a ribbon sand that resulted from deposition in a tidal creek within a mud flat.

1.4.2.1 Shallow Water-Bearing Zone

The shallow groundwater in the Refinery is mainly observed in the unconfined fill layer, perched on native clay, peat and till. Groundwater gauging was performed by Science Application International Corporation (SAIC) on February 21, 2007. The results of the groundwater elevations were used to develop groundwater contours, which are shown on Figure 6.

1.4.2.1.1 Main Yard

As indicated by the groundwater elevation contours on Figure 6, generally the groundwater flow direction is in a northeasterly to southeasterly direction from a high at MW-0039 of 9.56 feet above mean sea level (MSL) to a low of -1.75 feet above MSL at NF-13 along the Woodbridge Creek.

Hydraulic gradients were determined by drawing equipotential elevation lines perpendicular to the flow line and dividing the drop in elevation between flow lines by the distance between these two lines. The hydraulic gradients measured across the Main Yard ranged from 0.05 to 0.016 ft/ft.

1.4.2.1.2 East Yard

As indicated by the groundwater elevation contours on Figure 6, generally the groundwater flow direction is in a northeasterly direction from a high at MW-129 (State Street parking lot) of 22.51 feet above MSL to a low of 3.46 feet above MSL in MW-254. The contours suggests a “ridge” of groundwater trending northeast-southeast through the central portion of the East Yard.

Hydraulic gradients were determined by drawing equipotential elevation lines perpendicular to the flow line and dividing the drop in elevation between flow lines by the distance between these two lines. In the central portion of the East Yard the gradient was estimated to be 0.21 while in the outer boundaries (southwest, northeast & northwest) of the East Yard the gradient ranged from 0.014 to 0.0125 ft/ft. To the north of this ridge, the groundwater flows to the northeasterly direction; while to the south of this ridge the groundwater flows to the southeasterly direction.

1.4.2.1.3 Central Yard

As indicated by the groundwater elevation contours on Figure 6, generally the groundwater flow direction is in a north to northeasterly direction north of MW-110 while it is southeasterly south of MW-230. Additionally, the groundwater flow direction is in a westerly direction west of both wells.

Hydraulic gradients were determined by drawing equipotential lines perpendicular to the flow line and dividing the drop in elevation between flow lines by the distance between these two lines. The hydraulic gradients measured across the Central Yard vary significantly from the northern portion of the site to the southern portion. In the north, gradients range from 0.18 to 0.02 ft/ft, while in the south, the average gradient is 0.01 ft/ft, except in the immediate vicinity of the Garretson Avenue right-off-way. In this area the native surface dips to the east or southeast. The hydraulic gradient in this area between wells MW-169R and MW-191 was gauged at approximately 0.03 ft/ft in 2005 (Chevron, 2005).

1.4.2.2 Deep Water-Bearing Zone

As per the SRFI Report (SAIC. 2008), through analysis of 22 deep monitoring wells and three deep piezometers on-site, Chevron is currently monitoring the vertical hydrogeology of the site beneath the fill layer (shallow water bearing zone). These deep monitoring wells and piezometers are primarily screened in the indigenous glacial till layer (first native water bearing zone) evident beneath the fill layer and Clay Horizon A. In this case, Clay Horizon A was utilized as a natural aquitard separating these two water bearing zones. In a few cases, Clay Horizon A is absent and the fill and glacial till layers are in direct contact with each other.

The direction of groundwater flow follows regional projections, east-northeast toward the Woodbridge Creek and the Arthur Kill. The horizontal gradients varied across the Main Yard, from 0.000475 to 0.00817. In the East Yard, the horizontal gradients varied from 0.00675 on the western side to 0.00947 on the eastern side.

The vertical gradients across the site range from 0.01063 in the Main Yard (RW-42/MW-239) to 0.6364 in the Central Yard AOC 36 Area (MW-101/MW-184). Seventeen of the 21 shallow/deep well pairs analyzed were calculated to indicate downward flow. The four remaining well pairs exhibiting upward flow were located in the Main Yard (SAIC. 2008).

Section 2.3.5.2 discusses the groundwater quality found in the deep monitoring wells. Despite indications of downward flow, only the deep wells at AOC 31 exhibit PCOC exceedences. As such, additional deep monitoring wells were installed in the vicinity of AOC 31 by Chevron in 2008. The results from groundwater sampling of these wells are currently being evaluated.

1.5 OVERVIEW OF RFI INVESTIGATIONS

Chevron has conducted the HSWA Permit RFI for the site in a phased approach. The purpose of the RFI was to determine the nature, extent, direction, and rate of migration of hazardous substances and constituents in soils, groundwater, surface water/sediment, and subsurface gas. Based on these multimedia analyses, the types and concentrations of contaminants present, the boundaries of the contamination (e.g., plumes) were determined. Data from the RFI was also used to develop and screen remedies as part of the CMS.

The results of the RFI investigations which included the Main Yard, East Yard and Central Yard include the following reports:

- Background Soils Investigation (1996),
- 1st RCRA Facility Investigation (RFI) Phase Soils Investigation (January 1997),
- 1st RFI Phase Groundwater Investigation (January 1997),
- 1st Phase RFI Groundwater Addendum Investigation (December 1997),
- Phase I Oily Water Sewer System (OWSS) Investigation (December 1997),
- Phase II OWSS Investigation (2002),
- Full RFI (November 2003), and
- Supplemental RFI (SRFI) (February 2008).

These investigations have provided a large database of analytical results. The database includes analyses from both source areas (e.g. SWMUs) and potentially affected media. Chevron performed and submitted the 1st Phase Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI) Reports for soil, groundwater and the Site oily water sewer system (OWSS) Area of Concern (AOC)-16 between January 1997 and December 1999. The objective of the 1st Phase RFI was to determine whether or not releases of hazardous wastes and their constituents had occurred from Solid Waste Management Units (SWMUs). The data for target analytes in soil and groundwater were compared to a set of action levels composed of RCRA Subpart S Action levels, proposed NJDEP Non-Residential Direct Contact and Impact to Groundwater Soil Cleanup Criteria (NRDCSCC and IGWSCC, respectively) for soil and NJDEP Groundwater Quality Criteria (GWQC) for

groundwater. If one or more target analytes in soil or groundwater at a given SWMU exceeded the action level concentrations(s), then Chevron recommended further investigation of the SWMU as part of the full RFI. If no analytes were detected at concentrations exceeding the action levels during the confirmatory sampling, then Chevron recommended no further action for the SWMU.

Between 2001 and 2003, Chevron conducted a Full RFI to identify releases that resulted from practices employed before the advent of modern waste management procedures and current regulations at the Site. Additional AOCs and SWMUs were identified as part of the RFI. Figures 2 through 4 show the locations of the AOCs and SWMUs for the Main, East and Central Yards, respectively, at the Site, as well as a summary of the principal contaminants of concern (PCOCs) distribution in soil and groundwater impacting them. In addition, Table 1 summarizes all of the exceedences identified to date for all COCs for each of the AOCs and SWMUs as well as their proposed corrective measures (CMs).

The AOCs consist of suspected petroleum discharge locations, areas with stained soils, aboveground storage tank basins, and fill areas. The SWMUs mostly consist of suspected tetraethyl lead (TEL) burial sites and former stormwater or wastewater ponds or basins. The COCs are petroleum products and associated volatile organic compounds (VOCs), lead and other metals, and some polynuclear aromatic hydrocarbons (PAHs). However, based on extensive soil and groundwater sampling and an evaluation of the relative toxicities of the contaminants present, the PCOCs present at the Site are benzene, lead, TEL, benzo(a)pyrene, and arsenic. The PCOCs also serve as indicator compounds for their broader analytical parameter category, such as volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), and metals, because exceedences of other COCs are generally found in the presence of exceedences of the PCOCs within the same samples.

A Full RFI Report was submitted to the USEPA and the NJDEP in November 2003 (SAIC. 2003). The 2003 Full RFI Report concluded that the distribution of the Site-related COCs in soils, the characterization of light non-aqueous phase liquids (LNAPL) and TEL areas, the delineation of petroleum hydrocarbon areas in groundwater, and the evaluation of the potential migration pathways to surface water and sediment were completed as follows:

1. Benzene, toluene, ethylbenzene and xylenes (BTEX), PAHs and some metal soil impacts were the primary contaminants detected and are mostly limited to the fill and/or are co-located with Site wastes (e.g., catalyst beads, fly ash and oily fill), and only sporadic exceedences of the NJDEP NRDCSCC have been detected in surface soil.

2. TEL burial/weathering locations have been confirmed and most of the lead associated with TEL has been retained in soils, which in general does not pose a threat to groundwater.

3. LNAPL areas are present at relatively shallow depths (less than 10 feet below ground surface (bgs)) within the fill material (fly ash and catalyst beads), and can be characterized as typically being composed of weathered crude oil, refining residuals, weathered diesel and weathered gasoline.

4. Groundwater contaminant plumes were identified and delineated. These consisted primarily of benzene and related petroleum type volatile organics. One area of chlorinated hydrocarbon groundwater contamination was identified in the southern portion of the Central Yard. While several areas of groundwater impacted by dissolved phase constituents have been identified within the Site, data from the sentinel well system indicates that, with the exception of the delineated chlorinated hydrocarbon plume in the Central Yard, migration off-site is not occurring.

5. Elevated levels of PAHs and metals have been detected in sediments and, to a much lesser extent, in surface waters. Elevated concentrations were found at background locations, as well as locations adjacent to the Site. Off-site background sources are likely contributing to elevated contaminant concentrations. Based on the evaluation of on-site soil and groundwater conditions, there is no indication of ongoing discharges of these substances from the site.

6. The data obtained from the RFI allowed Chevron to develop cleanup goals and begin the Corrective Measures Study (CMS) pursuant to the HSWA Permit.

Chevron received comments on the 2003 Full RFI Report from the USEPA and NJDEP on January 21, 2005. In response to these comments, a supplemental RFI (SRFI) investigation was conducted in 2006 and 2007. The results of this investigation are presented in the report entitled, "Supplemental RFI Report" (SAIC. 2008). The conclusions of the SRFI Report are as follows:

Soil – The SRFI has confirmed the COCs found in soil during previous investigations (e.g., RFI). In addition, the SRFI has delineated both horizontally and vertically all contaminated soil areas site-wide. Through data visualization modeling and a strategic decision-based sampling program, Chevron completed its soil investigations of all existing AOCs and

SWMUs in the Main and East Yards, with the exception of SWMUs 32 and 51. The Central Yard was not investigated during the SRFI. However, the southern portion of the Central Yard was investigated and reported in the AOC 36 – Chlorinated Plume Investigation Report (SAIC. 2005), which occurred between the RFI and SRFI.

COCs in soil are primarily found in the fill materials at varying depths near waste management areas or operational areas. The fill material is composed primarily of low permeability silts and clays with some discontinuous lenses of sand. Across most of these areas, the fill material is underlain by a naturally-occurring layer of low permeability clay (Clay Horizon A) or a glacial till composed of silts and clay with some sand lenses.

Benzene and several PAHs comprise the majority of facility-related exceedences noted through the years. An analysis of the numerous soil samples revealed benzene as the primary indicator analyte for VOCs in soils at the Refinery. A similar analysis indicates benzo(a)pyrene as the primary indicator for SVOCs in soils at the Refinery associated with the fill material. The occurrence of benzo(a)pyrene site-wide is primarily sporadic with the exception of the northwestern corner and central portion of the NF near NF3A, where it is more common. Various metals have also been noted in exceedence of the soil evaluation criteria; however, with the exception of lead found at TEL sites and to a lesser degree antimony, the presence of metals does not appear to correlate well to areas impacted by historic operations. During the SRFI, frequent occurrences of arsenic were found in the soils in the southeastern portion of the East Yard. Investigations conducted by ASARCO revealed similar results on their property in that area adjacent to the Chevron East Yard property. Since ASARCO once operated a smelter on their property with large stacks, the arsenic is most likely from past operations on the ASARCO site.

Of the COCs, PAHs and metals have a relatively low mobility potential in the unsaturated zone due to their low solubilities and high adsorption to soil (most of the PAHs detected have relatively high K_{ow} coefficients). Therefore, these constituents are only a potential concern for direct contact.

As part of the SRFI, several TEL burial areas were confirmed and delineated at the site. In general, the TEL areas provided the highest concentrations of target analytes at the site. However, these areas were found to be of limited spatial distribution. During the SRFI, no TEL was detected, only lead. An XRF survey of SWMU 20 indicated that the lead contamination is generally shallow, at an average depth of approximately 4.5 ft. bgs within the fill material, and bound by the native material underneath.

In summary, contaminated soil areas at the site were delineated during the SRFI. Contamination exists primarily in the fill zone and is composed primarily of petroleum constituents. Refinery-related soil contamination is limited in its aerial extent and does not extend off-site.

LNAPL – LNAPL has been found in the subsurface at 19 locations in the Main, East, and Central Yards. Based on GC fingerprinting, the LNAPL is highly weathered, resulting in a relatively viscous material with limited remaining soluble constituents. It was not uncommon to obtain a soil sample adjacent to an LNAPL zone for laboratory analysis based on color, PID readings or other field screening techniques and have no exceedences noted. This result was not unexpected, given the long history of refining operations at the site and the implementation of improved spill control measures and operating procedures over the past several decades. LNAPL is therefore historical in nature and not the result of ongoing operations at the Site.

Subsurface investigations conducted to evaluate these areas were successful in delineating the nature and extent of the LNAPL. All of the 19 LNAPL areas are limited to within the Site boundary. The highly weathered LNAPL has limited mobility in the subsurface. When present, dissolved phase organic contamination (typically benzene) emanating from the LNAPL areas appears to attenuate quickly.

Groundwater – Benzene, arsenic, and lead were the most frequently detected COCs when SRFI Evaluation Criteria exceedences were found in shallow groundwater monitoring wells. Chevron has completed the horizontal and vertical delineation of contaminants in groundwater sitewide with the exception of AOC 31. For the most part, groundwater contamination is limited to the shallow water-bearing zone encountered within the fill layer. Deep wells screened in the first water-bearing zone beneath the fill and Clay Horizon A confirmed this with the exception of the AOC 31 (Tank Basin 772 Pump Pad) area in the northeast portion of the East Yard and AOC 36 (Chlorinated Solvent Plume) in the southern portion of the Central Yard.

The first water-bearing zone encountered exists within the fill material placed on the site for construction purposes. The depth to water is relatively shallow, typically within 10 feet of the ground surface. In general, the shallow groundwater flows to the northeast, discharging to adjacent saline and tidal flowed surface water bodies (the Arthur Kill and the Woodbridge Creek). Measured hydraulic gradients are relatively flat, with an average of approximately 0.01 ft/ft. Hydraulic conductivities within the fill are anticipated to be in the range of $1x10^{-4}$ cm/sec. This translates into relatively slow groundwater seepage velocity rates.

In 2005, Chevron delineated the chlorinated VOC (CVOC) plume known as AOC 36 in the southern portion of the Central Yard. In this case, the CVOC plume is migrating to the southeast through the fill material, but also through paleo-sand channels in the glacial till at depth. The CVOC plume was delineated horizontally and vertically off-site on neighboring properties. Clay Horizon A was found to be absent in this portion of the site. However, the Woodbridge Clay was very prevalent beneath the till, which confines the contamination in this area.

With the twenty two deep monitoring wells and three deep piezometers that exist on-site, Chevron has a better understanding of the vertical hydrogeology of the site. The direction of groundwater flow follows regional projections, east-northeast toward the Woodbridge Creek and the Arthur Kill. The horizontal gradients varied across the Main Yard, from 0.000475 to 0.00817. In the East Yard, the horizontal gradients varied from 0.00675 on the western side to 0.00947 on the eastern side.

The vertical gradients across the site ranged from 0.01063 in the Main Yard (RW-42/MW-239) to 0.6364 in the Central Yard AOC 36 Area (MW-101/MW-184). Seventeen of the 21 shallow/deep well pairs analyzed were calculated to have downward flow. The four remaining well pairs exhibiting upward flow were located in the Main Yard.

In all but one case (AOC 31), when VOCs, SVOCs, and metals were evident in concentrations exceeding the SRFI Evaluation Criteria in the shallow monitoring wells, the corresponding deep wells did not contain VOC or SVOC exceedences. The analytical data, coupled with lithologic information from each boring, indicate no evidence of contaminant migration between the first shallow water-bearing zone and first native water-bearing zone across these areas other than AOC 31, despite the number of well pairs calculated to have downward flow.

In summary, vertical delineation of groundwater has been achieved in each of the areas discussed above based upon an analysis of the deep well/shallow well pair data. Additional deep monitoring wells were recently installed in the vicinity of AOC 31 by Chevron in 2008. The results from groundwater sampling of these wells are currently being evaluated to ensure that full vertical and horizontal delineation of dissolved phase contaminants at AOC 31 is obtained.

Based on Chevron's review of environmental investigations conducted on the neighboring properties owned by ASARCO and Amerada Hess Corporation, Chevron will continue to

monitor these off-site activities to support Chevron's groundwater monitoring program in the East Yard (e.g., SWMU 8 and perimeter well MW-6).

2.0 CMS PRE-DESIGN INVESTIGATION (PDI) RESULTS REPORT

2.1 INTRODUCTION

To date, approximately 3,000 soil and groundwater locations have been sampled at the Chevron Perth Amboy Refinery. Therefore, the extent of contamination is known, including the extent of dissolved phase compounds in groundwater, LNAPL, and COCs in soils. This data was evaluated as part of Chevron's internal CMS planning process. Chevron determined that additional sampling was required to: 1) obtain additional contaminant specific data for CMS purposes; 2) identify whether soils known to have benzene and lead concentrations in excess of their respective NJDEP NRDCSCC also exceed their respective RCRA TCLP criteria; and 3) evaluate whether NAPL impacted soil is characteristically hazardous for benzene. These additional investigation tasks were conducted under a process not specifically required in the HSWA Permit, which Chevron termed a "CMS Pre-Design Investigation" (PDI). The results of the PDI along with the extensive RFI database, were used as part of the CMS analysis. The following Section provides a summary of the findings of the PDI. A CMS PDI Report is provided along with this CMS Final Report as a separate document.

A CMS PDI Work Plan was prepared for each of the three yards subject to this CMS at the Site. The total numbers of sample locations investigated were 74 in the Main Yard, 60 in the East Yard and 13 in the Central Yard. Details on the sampling plan and procedures, and data management are included in the Main Yard, East Yard and Central Yard PDI Work Plans dated October 2006, December 2006, and August 2007, respectively (URS. 2006a) (URS. 2006b) (URS. 2007a).

An additional task of this PDI was to collect data in support of a potential Delisting Petition planned for the SWMU 43 area. As part of this investigation, 50 soil borings were advanced for the collection of soil samples. These samples were analyzed to determine the concentration of constituents regulated under the Land Disposal Restrictions (LDR) for listed hazardous wastes F037, F038, K051 and K052 known to have been disposed in the SWMU 43 area, as well as for Toxicity Characteristic Leaching Procedure (TCLP) characteristics for benzene and lead contaminants. Details on the delisting petition including the rationale for sampling are presented in the report entitled "Petition to Delist SWMU 43" dated April 2, 2007 (URS. 2007b). Chevron does not intend to submit the SWMU 43

delisting petition at this time. Two additional soil borings were advanced in the SWMU 43 area during the Central Yard PDI.

The results of the CMS PDI were evaluated to obtain the contaminated media areas and volumes for the PCOCs including the following: 1) the benzene NJDEP NRDCSCC of 13 mg/kg, 2) the lead NJDEP NRDCSCS of 800 mg/kg, 3) the benzo(a)pyrene site-specific soil cleanup recommended action level of 10 mg/kg, 4) the TCLP benzene RCRA Characteristic Hazardous Waste Regulatory Level of 0.5 mg/L, 5) the TCLP lead RCRA Characteristic Hazardous Waste Regulatory Level of 5 mg/L, 6) the benzene NJDEP GWQS of 1 ug/L, and 7) the lead NJDEP GWQS of 5 mg/L in the Chevron Perth Amboy Refinery. A summary of the CMS PDI results is given in Section 2.3 below. The complete CMS PDI results are presented in the CMS PDI Results Report, which is being submitted in conjunction with this CMS Final Report.

Following the completion of the CMS PDI, additional soil samples were collected in the areas of the Site with the highest benzene and lead concentrations for the purpose of performing the following bench- and pilot-scale treatability tests and evaluating the following applicable CMs: 1) in-situ chemical oxidation (ISCO); 2) low temperature thermal desorption (LTTD); and 3) stabilization. The results of the ISCO bench test are summarized in Section 5.1.2 and presented in Appendix C3. The results of the LTTD pilot test are summarized in Section 5.2.2 and presented in Appendix C2. The results of the stabilization bench test are summarized in Section 5.3.2 and presented in Appendix C1.

An ISCO pilot test was conducted in September/October 2008. The purpose of the pilot test is to develop design parameters necessary for the full-scale design, as well as verify the unit costs associated with ISCO treatment at the Site. The pilot test was conducted within the only area in SWMU 43 with a benzene concentration exceedence of both its NJDEP NRDCSCC, as well as its USEPA TCLP Characteristic Hazardous Waste Regulatory Level. The test was conducted for a duration of approximately two weeks. More details about this test are presented in Section 5.1.5, as well as in a Request for Authorization of Discharge to Groundwater by Permit by Rule submission to the NJDEP dated July 29, 2008 (Chevron. 2008a).

2.2 CMS PDI SCOPE OF WORK AND PROJECT OBJECTIVES

The PDI scope of work included the following activities: 1) direct-push soil and groundwater sampling; 2) installation of monitoring wells; 3) monitoring well sampling; and

4) preparation of a CMS PDI Results Report. The CMS PDI Results Report for the Site (including the Main Yard, SWMU 43, East Yard, and Central Yard) is organized into the following seven sections: 1) Introduction; 2) Site Background; 3) Site Conditions; 4) Sampling and Analysis Plan; 5) Results; 6) Conclusions and Recommendations; and 7) References.

The overall objective of the CMS PDI was to collect additional soil and groundwater data, and present the results, in conjunction with previously collected data, to determine the extent of contaminated media that require corrective measures. In addition, the data presented will allow the screening and evaluation of appropriate demonstrated and available remedial technologies for each of the contaminated media. Previously, both the RFI and SRFI delineated the extent of soil and groundwater contamination in all on-site SWMUs and AOCs.

The specific objectives of the CMS PDI were as follows:

1. Delineate the horizontal and vertical extent of the soils, known to have benzene concentrations in excess of its NJDEP NRDCSCC that are also characteristically hazardous for benzene, as determined by TCLP testing.

2 Delineate the horizontal and vertical extent of the soils, known to have lead concentrations in excess of its NJDEP NRDCSCS, which are also characteristically hazardous for lead, as determined by TCLP testing.

3. Determine if NAPL impacted soil is characteristically hazardous for benzene and, if so, collect and analyze the samples needed to delineate the horizontal and vertical extent of these soils.

4. Delineate the horizontal and vertical extent of soils that exceed the NJDEP NRDCSCC for benzene, lead, and benzo(a)pyrene the PCOCs at the Site, based on their being the Site-related chemicals with the most exceedences of their applicable regulatory criteria as identified from previous Site environmental investigations, as well as their toxicity. The PCOCs also serve as indicator compounds for their broader analytical parameter category, such as volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), and metals, because exceedences of other COCs are generally found in the presence of exceedences of the PCOCs within the same samples.

5. Delineate the horizontal extent of groundwater that exceeds the NJDEP GWQSs for benzene and lead.

6. Further evaluate the existing LNAPL data to quantify trends in LNAPL areas and volumes at the Site.

Consistent with the RFI, soil and groundwater data modeling was conducted using RockWorks, a geological data management, analysis, and visualization software. The CMS PDI data analysis used RockWorks in the following manner:

1. to create two dimensional (2-D) models that show the PCOC concentrations in soil and groundwater, and
2. to query and plot borehole lithology/stratigraphy, organic vapor meter (OVM) concentration profiles, X-ray fluorescence (XRF) concentration profiles, and analytical data from select borings to create cross-sections of contaminated soil areas.

2.3 CMS PDI RESULTS

The CMS PDI modeling results are presented in Figures 5 through 7. These figures show the distribution of the PCOCs in soil and groundwater. In addition, Tables 6 through 9 summarize the contaminated media areas and volumes sitewide and for the Main, East, and Central Yards, respectively. The CMS PDI Results Report is being submitted in conjunction with the CMS Final Report. A summary of the overall results of the CMS PDI by the contaminated media is discussed below.

2.3.1 Hazardous Soil Results

The CMS PDI results showed that, in general, except for the arsenic contamination, the occurrence of hazardous soil contamination is related to its proximity to former TEL burial areas, historical waste management practices, and operational and storage areas. The refinery related hazardous soil contamination does not extend off-site.

The total volume of soil found to be characteristically hazardous for lead, as determined by TCLP lead testing, was delineated and estimated to be 3,000 cubic yards. The total volume of soil found to be characteristically hazardous for benzene, as determined by TCLP benzene testing, was delineated and estimated to be 800 cubic yards.

The volume of SWMU 43 contaminated soil is estimated to be 33,200 cubic yards based on the area of SWMU 43 and the depth to native soil. SWMU 43 is a former below grade surface impoundment, approximately 280 feet long and 254 feet wide, which was in service from approximately 1955 to 1975. The unit was designed to manage oily stormwater, process water and solids associated with process waters. Dredged material from the Surge Pond (SWMU 2), No. 4 Separator (SWMU 35), and the Old Pond (SWMU 40) also may have been placed in SWMU 43 between late 1956 and early 1957. SWMU 43 also was reportedly used as a spent catalyst disposal area in the mid 1950s. During the course of its usage, SWMU 43 received RCRA-listed hazardous wastes F037, F038, K051, and K052. The impoundment was taken out of service and filled in 1977 (ESE. 1994).

Subsurface conditions underlying SWMU 43 are similar to those in other parts of the refinery. During the RFI, Chevron installed monitoring wells and soil borings to delineate the LNAPL within and adjacent to SWMU 43. In addition, during the CMS PDI investigation an additional 52 borings were advanced to collect data in support of a delisting petition proposed for the SWMU 43 area.

2.3.2 Non-Hazardous Soil Results

The CMS PDI results showed that, in general, except for the arsenic contamination, the occurrence of non-hazardous soil contamination is related to its proximity to former TEL burial areas, historical waste management practices, and operational and storage areas. The Refinery related non-hazardous soil contamination does not extend off-site.

The soil contaminated areas with benzene in concentrations from 13 to 100 mg/kg were further delineated during the CMS PDI. The cross-sections along transects in the soil benzene contaminated areas illustrated that the depth of benzene contamination varied from 0.5 to 15.5 feet bgs. With the exception of the SWMU 8 area, the results showed that benzene contamination throughout the Refinery has been found primarily in the fill material. The total volume of soil benzene contamination between 13-100 mg/kg was estimated to be 35,600 cubic yards.

The soil contaminated areas with benzene in concentrations above 100 mg/kg at the Site were further delineated during the CMS PDI. The cross-sections along transects in the soil benzene contaminated areas illustrated that the depth of contamination with benzene concentrations above 100 mg/kg varied from one to 14.5 feet bgs. With the exception of the SWMU 8 area, the results showed that benzene contamination throughout the Refinery has

been found primarily in the fill material. The total volume of soil benzene contamination greater than 100 mg/kg was determined to be 3,200 cubic yards.

The soil lead contaminated areas at the Site were further delineated during the CMS PDI. The cross-sections along transects in the soil lead contaminated areas illustrated that the depth of lead contamination in concentrations above its NJDEP NRDCSCS of 800 mg/kg varied from 0.5 to 32 feet bgs. The results showed that lead contamination throughout the Refinery has been found primarily in the fill material. However, cross-sections along transects in the soil lead contaminated areas of the East Yard and Central Yard showed lead contamination extending to the native material underneath the fill. The total volume of soil lead contamination greater than 800 mg/kg was estimated to be 17,700 cubic yards.

The SRFI estimated area of soil with arsenic contamination in concentrations exceeding its NJDEP NRDCSCC is 41,900 square yards. This contamination is located predominantly in the southeastern portion of the East Yard, adjacent to the ASARCO smelting facility, and is associated with deposition of stack emissions from past operations performed at the ASARCO facility (see Figure 9).

Chevron did not generate arsenic waste as part of its refinery operations. Furthermore, the only RCRA listed hazardous wastes for the petroleum refinery industry that include arsenic as a regulated constituent are K171 and K172, which are spent hydrotreating catalysts including guard beds used to desulfurize feeds to other catalyst reactors. These wastes were not generated at the Site.

2.3.3 Benzo(a)pyrene >10 mg/kg Impacted Soil Results

The contoured areas of soil contaminated with benzo(a)pyrene in concentrations greater than 10 mg/kg were found to be contaminated with NAPL based on observances of NAPL in boring logs at these sampled locations. The total volume of benzo(a)pyrene >10 mg/kg impacted soils is estimated to be 6,600 cubic yards based on these contoured areas.

2.3.4 LNAPL Contamination Results

LNAPL contamination on the Site has been delineated. Delineated LNAPL areas were monitored from 2005 through 2007. Figures 10 through 12 show the extent of LNAPL contamination in the years 2005 through 2007, respectively. Additionally, Table 2.1 shows the areas of LNAPL contamination for various thickness ranges for the years 2005 through 2007. Reductions in the areas of LNAPL delineated between 2005 and 2007 was calculated

for various thickness ranges to evaluate the effectiveness of the ongoing interim remedial measures (IRMs) being conducted at the Site. A summary of sitewide LNAPL thickness area reductions between 2005 and 2007 is presented in Table 2.1 below.

Table 2.1
Sitewide Summary of LNAPL Thickness Area Reductions Between 2005 and 2007

LNAPL Thickness Range (feet)	2005	2006		2007		Total Percentage Area Reduction between 2005 and 2007
	Area (SY)	Area (SY)	Percentage Area Reduction from 2005	Area (SY)	Percentage Area Reduction from 2006	
>0.01, <0.1	15,423	2,475	84%	3,285	NA	79%
>0.1, <0.5	9,356	7,514	20%	6,816	9%	27%
>0.5, <1	1,605	397	75%	516	NA	68%
>1, <2	277	0	100%	0	NA	100%
>2, <4	91	0	100%	0	NA	100%

Notes:
1. SY = Square Yards
2. NA = Not Applicable

2.3.5 Contaminated Groundwater Results

2.3.5.1 Shallow Contaminated Groundwater Results

The groundwater contaminated areas at the Site were further evaluated during the CMS PDI. The groundwater results showed that, in general, the occurrence of groundwater contamination is related to the migration of soil contamination from former TEL burial areas, historical waste management practices, and operational and storage areas. With the exception of the groundwater contamination delineated in the SWMU 8 area in the East Yard and AOCs 22 and 36 in the Central Yard, groundwater contamination in the Refinery does not extend off-site.

The groundwater contamination was evaluated in the shallow water bearing zone within the unconfined fill layer, which is perched on native clay, peat and till. The delineated contaminated groundwater includes the following estimates based on modeling of groundwater sampling results: 1) a volume of 850,000 cubic yards of groundwater contaminated with benzene in concentrations from 1 to 100 ug/L, and 122,000 cubic yards contaminated with benzene at concentrations greater than 100 ug/L, and 2) a volume of 68,000 cubic yards of groundwater contaminated with lead in concentrations from 5 to 50 ug/L, and 19,000 cubic yards of groundwater contaminated with lead at concentrations

greater than 50 ug/L. In general, the groundwater flows to the northeast in the Refinery. However, the delineated groundwater contamination plumes are not migrating into the water bodies bordering the northern and eastern boundaries of the Site where the groundwater discharges, but are stable within the boundaries of the refinery with minor off-site migration evident in the SWMU 8 and AOCs 22 and 36 areas.

Based on the aforementioned CMS PDI results, 91.9% of the contaminated groundwater is a result of benzene exceedences of its GWQS of 1 ug/L.

The RFI and SRFI identified some exceedences of the NJDEP GWQS for benzene in several temporary well points advanced in AOC 16 and AOC 37 in the East Yard. The CMS PDI only used the results from the latest available groundwater sampling data from permanent monitoring wells for preparing groundwater contours of the PCOCs of the Site because data obtained from temporary well points are not reflective of actual dissolved phase groundwater concentrations. Samples obtained from impacted temporary well points typically have high concentrations of fines, which cause the analytical results to be biased higher than the actual dissolved-phase concentrations. Temporary well points are generally used to determine if groundwater contamination is present and, if so, to identify where additional permanent monitoring wells need to be installed, as was done during the CMS PDI. In the aforementioned East Yard areas, permanent monitoring wells have not yet been installed in the areas where exceedences were found in the temporary well points. Therefore, additional permanent monitoring wells will be installed in AOC 16 and AOC 37 in the East Yard in the vicinity where benzene exceedences were found in the temporary well points to verify whether benzene exceedences are present in the dissolved phase groundwater in these areas.

2.3.5.2 Deep Contaminated Groundwater Results

During the SRFI, ten deep permanent monitoring wells were installed on-site. As a result, 22 deep monitoring wells and three deep piezometers exist on-site, improving Chevron's understanding of the vertical hydrogeology of the site. All the deep wells were paired with shallow wells to investigate the hydrogeologic relationship between the first shallow and first native water-bearing zones across several SRFI Areas of Investigation (AOIs). Following gauging, groundwater samples were collected and analyzed for VOCs, semi-volatile organic compounds (SVOCs) and metals.

In the Main Yard, 5 deep wells were installed in the NF2, NF5 and NF6 areas of investigation (AOI). For AOI NF2 deep monitoring well MW-240, no VOCs were detected

indicating evidence of hydraulic isolation between the first shallow water bearing zone and the first native water-bearing zone in this location.

For AOI NF5 deep monitoring wells, MW-237 did show evidence of hydraulic connectivity between water bearing zones from MW-136 (shallow) and MW-237, however no dissolved VOCs or SVOCs were detected in groundwater samples from either well in concentrations exceeding their NJDEP GWQSs. Monitoring well MW-238 did not detect any VOCs while shallow well MW-117 did, indicating hydraulic isolation between the first shallow water-bearing zone and first native water bearing zone in this location.

For AOI NF6 deep monitoring wells, only one VOC, bromodichloromethane (2J ug/L), was detected in groundwater at a concentration exceeding its NJDEP GWQS (1 ug/L) in well MW-239. However, bromodichloromethane is a common artifact of chlorinated potable water, which may have been introduced during well development activities. Additionally, no SVOCs were detected in concentrations exceeding their NJDEP GWQSs in MW-239. The variation in VOC and SVOC detections between shallow well RW-42 and deep well MW-239 provides further evidence of hydraulic isolation between the first shallow water-bearing zone and first native water-bearing zone in this location. No VOCs or SVOCs were detected in concentrations exceeding their NJDEP GWQSs in deep well MW-244 providing further evidence of hydraulic isolation between the first shallow water-bearing zone and first native water-bearing zone in this location.

In the East Yard, 3 deep monitoring wells were installed in SRFI AOI1, AOI2 and AOI3. In AOI1, groundwater samples were analyzed for VOCs, SVOCs, and metals from the two deep monitoring wells MW-246 and MW-247. Despite evidence of hydraulic interconnectivity between water-bearing zones in both the MW-246 and MW-247 locations, samples from both deep wells contained no VOCs and SVOCs in concentrations exceeding their NJDEP GWQSs.

Deep monitoring well MW-255 located in AOI2 indicated hydraulic interconnectivity between water-bearing zones in its vicinity. However, the groundwater sample analyzed contained no dissolved VOCs and SVOCs at concentrations exceeding their NJDEP GWQSs.

In AOC 31 in the East Yard, one deep monitoring well (MW-250) was installed. Deep well MW-250 was paired with a previously installed shallow well (MW-0090) to investigate the hydrogeologic relationships between the first shallow and first native water-bearing zones across the AOC 31 area. Groundwater samples collected in MW-250 and MW-0090

detected VOC concentrations exceeding their NJDEP GWQSs, but not SVOCs. The results suggest additional investigation was warranted across Tank 772 to obtain full vertical and horizontal contaminant delineation. Chevron has recently installed an additional six shallow monitoring wells and four deep wells in this area to confirm vertical and horizontal delineation. Additionally, Chevron initiated a biosparge pilot study in the source zone of the shallow groundwater to remediate the VOCs, which are impacting the deep groundwater in this area. The biosparge pilot study will be performed for a period of approximately six months. The details of this biosparge pilot study for AOC 31 are presented in the "AOC 31 Pilot Study Workplan" (Chevron. 2008b).

In SWMU 8 in the East Yard, one deep monitoring well (MW-252) was installed. MW-252 was paired with previously installed shallow well MW-132 to investigate the hydrogeologic relationships between the first shallow and first native water-bearing zones across the SWMU 8 area. A groundwater sample collected from MW-252 contained no VOCs and SVOCs in concentrations exceeding their NJDEP GWQSs, providing further evidence of hydraulic isolation between the first shallow water-bearing zone, and first native water-bearing zone in this vicinity.

3.0 ESTABLISHMENT OF CLEANUP GOALS AND MEDIA SPECIFIC CLEANUP CRITERIA/STANDARDS

3.1 CLEANUP GOALS

Cleanup goals are established to allow the identification and screening of remedial alternatives that: 1) will achieve protection of human health and the environment consistent with the reasonably anticipated land use; and 2) comply with applicable HSWA Permit requirements. The Main Yard, East Yard, and Central Yard are part of the active portion of the Refinery. These active Yards are not accessible to the public and are subject to continuous stringent site access controls including fencing, security gates and security patrols. The environmental media addressed in this CMS for the three Yards are soil and groundwater.

The following cleanup goals are proposed for the soils in the Main Yard, East Yard, and Central Yard at the Site:

1 Mitigate or reduce direct human exposure that may occur through direct contact to soil impacted with COCs at concentrations exceeding regulatory standards.

2 Prevent or minimize further migration of contaminants from source materials (soil) to the groundwater.

The following cleanup goals are proposed for groundwater in the Main Yard, East Yard, and Central Yard at the Site:

1. Prevent exposure of humans to groundwater contaminants in concentrations above regulatory standards.
2. Remediate contaminant concentrations in the shallow and deep aquifers below regulatory standards.
3. Prevent or minimize migration of the contaminant plume for the PCOCs.

The cleanup goal for LNAPL will be its treatment or removal to the extent practicable and mitigation of LNAPL as a potential source of groundwater contamination.

3.2 MEDIA SPECIFIC CLEANUP CRITERIA/STANDARDS

Media specific cleanup criteria/standards are applicable regulatory contaminant levels for each specific media.

The applicable cleanup criteria/standards for soil are as follows and are described below:

1. NJDEP NRDCSCC (1999);
2. NJDEP NRDCSCS (June 2, 2008);

The following two criteria are potentially applicable and will also be considered for soils as appropriate:

1. USEPA TCLP Characteristic Hazardous Waste Regulatory Levels for benzene and lead; and
2. USEPA LDRs for potential RCRA listed hazardous wastes F037, F038, K051 and K052 in SWMU 43.

Additionally, the TEL delineation criteria of 2 mg/kg will be used as an action level and cleanup goal for TEL.

The NJDEP NRDCSCC are applicable to non-hazardous soil at the Site. While the NJDEP adopted new Remediation Standards at N.J.A.C. 7:26D on June 2, 2008, Chevron will meet the requirements of the Phase in Period Guidance under N.J.A.C. 7:26E-1.3(d)1 to remediate the Site soil to the NJDEP NRDCSCC, with the exception of naphthalene whose NRDCSCS is more than an order of magnitude below its NRDCSCC and thus subject to the order of magnitude exclusion under the Brownfield Act (N.J.S.A. 58:10:B-12j and 13e) and implemented in the Technical Rules under N.J.A.C. 7:26E-6.1(b)2.

The NJDEP NRDCSCS includes the following 13 COCs whose NRDCSCS is an order of magnitude below its NRDCSCC: 1) bis(2-chloroisopropyl)ether, 2) bromodichloromethane, 3) bromomethane, 4) chloroform, 5) chloromethane, 6) dibromochloromethane, 7) 1,4-dichlorobenzene, 8) 1,1-dichloroethane, 9) hexachlorocyclopentadiene, 10) 4-methylphenol, 11) naphthalene, 12) 1,1,2,2-tetrachloroethane, and 13) 1,1,2-trichloroethane. Of these 13, only naphthalene concentrations were found in the Site soil in exceedence of its respective NRDCSCS of 17 mg/kg, and will need to be remediated to this standard. Additionally, in accordance with the Order of Magnitude Guidance, Chevron intends to remediate lead contamination in soil to its NRDCSCS of 800 mg/kg because its NRDCSCS is higher than

its NRDCSCC of 600 mg/kg. A summary of the applicable cleanup criteria/standards for non-hazardous soil is given in Table 2 in Appendix B.

Based on the correlation between the observance of NAPL and benzo(a)pyrene concentrations greater than 10 mg/kg as discussed in Section 2.3.3 of this Report, Chevron proposes to remove the delineated volumes of benzo(a)pyrene concentrations in soil greater than 10 mg/kg. This site-specific soil proposed action level addresses both NAPL found in soil as well as benzo(a)pyrene contaminated soil. This is not a proposed soil remediation criterion, rather it is being proposed as an action level above which soils would be removed from the subsurface. The NJDEP NRDCSCC will still apply to benzo(a)pyrene impacted soils. This criteria for benzo(a)pyrene is supported by its lack of mobility in the Site soil as indicated by only three benzo(a)pyrene exceedences being found in the Site groundwater (see Figures 5 through 7, "Main Yard, East Yard, and Central Yard Summary of Principal Contaminants of Concern in Soil and Groundwater", respectively, in Appendix A). Additionally, benzo(a)pyrene exceedences in soil are only present in subsurface soil more than two feet bgs. Therefore, at least two feet of clean soil is already present over areas with benzo(a)pyrene exceedences. Further, a deed restriction will be obtained for those areas with benzo(a)pyrene concentrations greater than its NJDEP NRDCSCC of 0.66 mg/kg. At a meeting at the Site on July 13th, 2006, with NJDEP and USEPA, Chevron discussed this potential remedial approach for benzo(a)pyrene and received preliminary support from the agencies.

The USEPA TCLP Characteristic Hazardous Waste Regulatory Levels are shown in Table 3 in Appendix B. Of these, only the two levels for benzene and lead (0.5 mg/L and 5 mg/L, respectively) are applicable to the soil contamination at the Site.

The LDRs for RCRA listed hazardous wastes F037, F038, K051, and K052 are presented in Table 4 in Appendix B. These standards are only potentially applicable to the soil in SWMU 43 under the USEPA's contained-in rule.

The NJDEP GWQSs are applicable to the groundwater at the Site. A summary of the GWQSs is provided in Table 5 as Appendix B.

4.0 PRELIMINARY SCREENING OF CORRECTIVE MEASURES TECHNOLOGIES

All applicable, and demonstrated and available CMs were identified and screened using USEPA's RCRA Corrective Action screening criteria of effectiveness, implementability, and cost. The purpose of this process is to retain only those CMs proven effective at other, similar sites with similar contamination, or identified in USEPA guidance documents, for further evaluation and selection as CMs for each of the subject SWMUs and AOCs. The identification and screening of these CMS is detailed in Sections 4.1 and 4.2 below.

4.1 GENERAL CORRECTIVE MEASURES

General CMs are broad classes of actions that may satisfy the cleanup goals for the Site. General CM categories for the Site described in this Section are based on the nature and extent of the contamination at the Site, as described in Section 1 as well as USEPA's "Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA" (USEPA. 1988). These general CMs include the following: 1) no action alternative, 2) institutional controls, 3) monitored natural attenuation (MNA), 4) containment, 5) ex-situ groundwater treatment, 6) in-situ groundwater and soil treatment, and 7) contaminated soil removal, transport, ex-situ treatment and disposal. Each of these general CMs is discussed in more detail below, as well as its applicability to the contamination in the soil and groundwater at the Site.

4.1.1 No Action Alternative

No action indicates that no remedial action will be conducted for a particular area at the Site. The area is allowed to remain in its current state. Additionally, neither access restrictions nor deed restrictions are placed on the area. The USEPA National Contingency Plan (NCP) requires that "no action" be included among the general response actions evaluated in every feasibility study (FS), as detailed in 40 CFR 300 430(e)(6). The no action CM provides a baseline for comparison to the other CMs. This CM is applicable to those areas of the Site where the cleanup goals have been met, and no exceedences of applicable criteria/standards have been found or continue to be present.

4.1.2 Institutional Controls

Institutional controls are non-engineering measures, such as administrative and/or legal controls, that help minimize the potential for human exposure to contamination and/or protect the integrity of a CM by limiting the land use in the area to which it was applied. There are four general categories of institutional controls: 1) governmental controls, 2) proprietary controls, 3) enforcement and permit tools with institutional control components, and 4) informational controls. Examples of institutional controls that may be applicable to areas of the Site not entirely remediated to their applicable cleanup criteria/standards include the following: 1) land use controls (deed restrictions), 2) groundwater use restrictions, 3) community awareness, and 4) health and safety policies and procedures to limit exposure to contaminants during construction activities.

4.1.3 Monitored Natural Attenuation (MNA)

MNA refers to the reliance on natural attenuation processes to achieve site-specific cleanup criteria/standards within a timeframe that is reasonable compared with that offered by other more active CMs. The processes, under favorable conditions, act without human intervention to reduce the mass, toxicity, mobility, volume, and/or concentration of contaminants in soil and/or groundwater. These in-situ processes include the following: 1) biodegradation; 2) dispersion; 3) dilution; 4) sorption; 5) volatilization; and 6) chemical or biological stabilization, transformation, or destruction of contaminants. Unlike No Further Action, MNA requires monitoring and documenting progress of natural attenuation processes in relation to achieving the desired cleanup criteria/standards. MNA is applicable to areas of the Site with groundwater exceedences of organic and inorganic contaminants outside the source areas of contamination.

4.1.4 Containment

Containment CMs control or reduce migration of the contaminated materials into the surrounding environment. They could also be used to isolate contaminated soil and groundwater to reduce the possibility of exposure by direct contact. These CMs may involve the use of physical barriers to block a contaminant migration pathway. Containment CMs for contaminated groundwater typically include caps, hydraulic gradient controls, vertical barriers, and horizontal barriers. Slow contaminant removal (as a consequence of the gradient control system) or natural attenuation may gradually achieve the cleanup criteria/standards within the contained area. Containment is applicable to areas of the Site not remediated to the cleanup criteria/standards for one or more constituents, and where the

possibility of migration of contamination exists. Institutional controls will also usually be required to be implemented when containment is used as the CM.

4.1.5 Ex-Situ Groundwater Treatment

Ex-situ groundwater treatment is used to reduce groundwater contaminant levels more rapidly than containment or MNA CMs, in addition to preventing plume migration off-site. An extraction system is used to remove contaminated groundwater from the affected aquifer. This step is followed by treatment, if required, and discharge or reinjection of treated water to surface water, a Publicly Owned Treatment Works (POTW) or back into the aquifer. Extraction can be achieved by using pumping wells, french drains, or extraction trenches. Pumping may be continuous or pulsed to remove contaminants after they have been given time to desorb from the aquifer material and equilibrate in the groundwater. Aboveground treatment may involve physical and chemical processes such as air stripping, carbon adsorption, and biological treatment, depending on the physical and chemical properties of the contaminants.

4.1.6 In-situ Groundwater and/or Soil Treatment

In-situ treatment consists of CMs that treat contaminants in-place. In-situ treatment of contaminated soil or groundwater generally includes methods to separate and remove contaminants, or to degrade contaminants in-place. In-situ treatment methods to separate and remove contaminants include soil flushing, in-situ thermal treatment, air sparging, and soil vapor extraction. In-situ treatment methods to degrade contaminants in-place include ISCO and in-situ biological treatment. Soil flushing involves the introduction of mixtures of water, chemical surfactants, or co-solvents into the subsurface to strip or dissolve contaminants, and then remove them through groundwater extraction. In-situ thermal treatment mobilizes contaminants in the subsurface through heating, and then removing the contaminants by vapor or water extraction. Air sparging involves injecting air into the aquifer to strip or flush volatile contaminants through air bubbles rising through the groundwater and being captured by a vapor extraction system installed above the water table. Stripped or volatized contaminants usually are removed through soil vapor extraction (SVE) wells, treated, if necessary, with carbon adsorption or thermal oxidizer technologies, depending on the concentration of volatile contaminants in the extracted air, and discharged to the atmosphere.

CMs utilizing in-situ degradation generally involve adding reagents to the subsurface (via wells, injection points, or treatment walls) that facilitate chemical or biological destruction.

The types of in-situ degradation used at contaminated sites include various types of ISCO, in-situ biological treatment and permeable treatment walls or gates. ISCO involves injecting chemicals such as hydrogen peroxide, sodium persulfate, potassium permanganate, or ozone, and associated catalysts and pH adjustment compounds into the subsurface to breakdown the organic contaminants into degradation products such as water and carbon dioxide. In-situ groundwater bioremediation involves pumping nutrients and/or an oxygen source (such as air) into the aquifer to enhance biodegradation of contaminants in the groundwater. Passive treatment walls (permeable reactive barriers) act like contaminant treatment zones. Contaminated groundwater comes into contact with the wall, which is permeable, and a chemical reaction takes place. The walls are placed in the subsurface across the natural flow path of the contaminant plume. They can be combined with impermeable flow barriers in a "funnel and gate" arrangement, in which flow is directed through the treatment walls or gates. In-situ groundwater and soil treatment is applicable to areas of the Site with exceedences of their hazardous and non-hazardous cleanup criteria/standards for organic contaminants and non-hazardous cleanup criteria/standards for metals contaminants.

4.1.7 Soil/Waste, Transport, Ex-situ Treatment and Disposal

This action involves complete or partial removal of source material followed by transportation, ex-situ treatment and disposal. Source materials would be excavated using conventional earth-moving equipment such as front-end loaders and hydraulic excavators. Shoring, sheet piling, or other specialized techniques may be necessary to excavate near buildings or other structures. Excavation below the depth to groundwater or to depths below the reach of conventional excavators (approximately 15 feet) may require specialized equipment. Shoring may be necessary to excavate below the water table or in loose, unconsolidated material to stabilize the excavation walls and minimize groundwater intrusion. Containment and treatment of water encountered during excavation may be necessary. Dust suppression during excavation may also be necessary. Removed source material would be transported to on-site or off-site treatment facilities and/or disposal sites in trucks. Factors affecting the costs and feasibility of truck hauling include the haul distances, the cost of off-site treatment and disposal in comparison to on-site costs, and the acceptability by the surrounding community through which trucks would haul the contaminated media.

Ex-situ treatment consists of actions that treat contaminants after removal from the subsurface. Ex-situ treatment of contaminated soil includes CMs to stabilize contaminants, separate and remove contaminants, or to degrade contaminants. Ex-situ treatment CMs to

stabilize contaminants include solidification or stabilization. Solidification refers to a process that encapsulates the polluted soil or sludge and cements in into a solid block. Stabilization refers to a process that chemically binds the contaminants so they become less mobile. Methods to separate and remove contaminants include soil washing, thermal treatment, and mechanical aeration. Soil washing involves introduction of water, chemical surfactants, or co-solvents into the soil to strip or dissolve contaminants from the contaminated soil and then remove them. Thermal treatment volatilizes contaminants in the soil through heating, followed by treatment (such as carbon adsorption or incineration) to remove the contaminants from the vapor phase prior to discharge to the air. Mechanical aeration involves injecting air or oxygen into the soil while mechanically mixing it to strip volatile contaminants. Stripped or volatized contaminants are either discharged directly to the atmosphere or further treated to remove them from the vapor phase in a similar manner as with thermal treatment. Treatment of vapors following stripping or volatilization would be dependent on vapor phase concentrations.

Methods of ex-situ degradation generally include thermal, chemical, and biological methods. Thermal destruction (incineration) is similar to thermal treatment, but at temperatures high enough to break down chemicals into their elemental constituents. Ex-situ chemical degradation includes chemical oxidation. This technology involves pumping chemicals such as hydrogen peroxide, sodium persulfate, potassium permanganate, or ozone and associated catalysts and pH adjustment compounds into the soil to break down the organic contaminants into degradation products like water and carbon dioxide. Ex-situ bioremediation involves adding nutrients and/or an oxygen source such as air into the soil to enhance the biodegradation of organic contaminants. Ex-situ biological treatment CMs include land treatment units, biopiles, and composting.

On-site disposal options could be applied to treated or untreated contaminated materials. The design configuration of an on-site disposal facility would depend on the toxicity, the type of material, and the quantity of the material requiring disposal. The disposal facility could range in complexity from an earthen cap to a RCRA Corrective Action Management Unit (CAMU). Additionally, treated soil may be reused or used for a beneficial reuse on-site depending on the concentrations of COCs remaining in the treated soil.

Off-site disposal involves excavating, transporting, and placing contaminated material in an engineered, licensed containment facility located outside the Site. Non-hazardous waste could possibly be disposed of in an off-site permitted solid waste landfill in compliance with applicable laws. Materials that are deemed to be hazardous waste would require disposal in a RCRA-permitted Subtitle C disposal facility.

Soil removal, transport, ex-situ treatment and disposal is applicable to areas of the Site with exceedences of their hazardous cleanup standards, as well as areas with residual product.

4.1.8 LNAPL Removal

LNAPL removal CMs are used to remove a separate phase LNAPL layer from the top of the soil/groundwater interface. These CMs include multiphase extraction (MPE), vac trucks, belt skimmers, and absorbent socks. Vac trucks, belt skimmers, and absorbent socks are designed to remove low levels of LNAPL (generally less than one foot in thickness) on an interim or intermittent basis. A vac truck is a mobile MPE system that is rented on a daily or weekly basis. Belt skimmers are installed in recovery wells and operated continuously or intermittently, and set by a timer. Absorbent socks are made of hydrophobic material, and are placed in recovery wells and replaced periodically after becoming saturated with LNAPL. Belt skimmers are installed in recovery wells where LNAPL readily accumulates at thicknesses approximately 0.5 feet and greater. Vac trucks are utilized at recovery wells where LNAPL accumulates at less than 0.5 feet and absorbent socks are used when only trace amounts of LNAPL are present.

MPE involves the simultaneous extraction of soil vapor, LNAPL and groundwater from a recovery well to remediate all phases of contaminated media. MPE is typically applied in recovery wells with significant amounts of LNAPL (greater than one foot in thickness). Recovery wells used with MPE systems typically have at least two feet of well screen extending above the top of the LNAPL layer. The extracted air/liquid mixture is separated in an air/liquid separator with the vapor phase generally being treated either with vapor-phase carbon adsorption units or catalytic oxidizers, depending on the concentrations of organic contaminants in the vapor stream, prior to discharge to the atmosphere. The liquid-phase is subsequently separated in an oil/water separator with the oil phase being recycled and the water phase generally being treated with bag filters and liquid-phase carbon adsorption units prior to discharge to either the groundwater, surface water, or to a POTW. While there are no MPE systems being operated at the Site, vac trucks are being utilized on a weekly basis in SWMUs 42, and 43 and AOCs 8 and 25 at the Site.

Belt skimmers involve an electrical motor revolving a 1 to 2-inch wide belt into a layer of LNAPL inside a recovery well. The belt becomes coated with the LNAPL product, which is then scraped off at the well head and drained into a drum or tank. This CM is useful for removing LNAPL with a high enough viscosity to adhere to the belt. Belt skimmer systems are currently being used in SWMU 43 and AOC 19 at the Site.

Absorbent socks are passive product recovery devices that utilize absorbent, hydrophobic material to recover LNAPL from recovery wells. Each absorbent sock is placed in a stainless steel canister. A cord is then attached to the support loop of the canister and then lowered into the LNAPL layer. Periodically, the canister is raised from the well, and the sock is removed from the canister and disposed of in accordance with applicable regulations. Absorbent socks are currently being utilized in SWMU 41 and AOC 8.

4.2 CORRECTIVE MEASURES PRELIMINARY SCREENING

This section describes the preliminary screening of potential technologies/specific CMs for the remediation of contaminated soil and groundwater at the Site, for each general CM identified in Section 4.1. The USEPA encourages the use of presumptive remedies and historical information to streamline the screening and selection of CMs for sites subject to RCRA corrective action. Technologies/specific CMs that have been proven effective at other, similar sites with similar contamination or identified in USEPA guidance documents are being considered in this CMS for the Site. The preliminary screening of these technologies/specific CMs identified in this Section involves the analysis of their effectiveness, implementability, and relative cost. These three preliminary screening analytical criteria are described below.

1. Effectiveness – This criterion focuses on the potential effectiveness of each technology/specific CM in remediating the contaminated soil and groundwater and in meeting the cleanup goals with regard to protection of human health and the environment. Specific information considered in this analysis includes the type(s) of contamination, contaminant concentration(s), volume(s), and areal extent of contaminated soil and groundwater, as well as the timeframe to achieve the applicable cleanup criteria/standards. Each technology/specific CM is classified as being effective, limited, or not effective for each contaminated media.

2. Implementability – This criterion considers the relative degree of technical implementability and the administrative feasibility of implementing the technology/specific CM including any substantive requirements of permits, availability of treatment, storage and disposal services/facilities, and the availability of necessary equipment and skilled workers to implement the technology/specific CM. The implementability of technologies/specific CMs is classified as easy, moderate, difficult, or not implementable for each contaminated media.

3. Cost – This criterion is based on general unit costs of each technology/specific CM used at similar sites with similar contamination. Both capital costs and operating costs are considered in this analysis. The costs of technologies/specific CMs for each contaminated media are classified as none, low, moderate, high, or very high.

4.2.1 No Action Alternative

The no action alternative CM provides a baseline for comparing other CMs. This CM entails no actions to contain or remediate contaminants at a site, and provides no legal or administrative controls to protect human health or the environment. The preliminary screening for this CM is given below.

1. Effectiveness – The NFA CM is not effective in remediating the contaminated soil and groundwater at the Site.

2. Implementability – The NFA CM is easy to implement because it does not require any actions to be taken.

3. Cost – There are no construction or operation and maintenance (O&M) costs associated with the NFA CM because no actions are taken and no site monitoring is conducted.

The NFA CM is only appropriate for those areas of the Site with no exceedences of applicable criteria/standards.

4.2.2 Institutional Controls

Institutional controls may be appropriate to protect human health and the environment in areas where soil and groundwater contaminant concentrations will exceed applicable criteria/standards following the application of a CM.

The following institutional controls will be considered for the Site: 1) land use controls, 2) groundwater restrictions, 3) community awareness, and 4) site administrative procedures. A summary of each of these controls is given below.

4.2.2.1 Land Use Controls

Zoning could be implemented to control the present and future land uses on or around a source area not remediated to applicable cleanup criteria/standards. The objective of zoning would be to prevent public or private use of a source area that could pose an unacceptable potential for human exposure to the contaminants present in the area.

Deed Notices could be used to prevent the transfer of property without the property recipient being notified of limitations on the use of the property, or of requirements related to preserving and protecting the effectiveness of CMs that may have been taken. Both elements are intended to limit the potential for human exposure to residual source contamination.

4.2.2.2 Groundwater Restrictions

The New Jersey GWQSs (N.J.A.C. 7:9-6) provide the basis for the protection of the ambient groundwater quality of the State through the establishment of constituent standards for groundwater pollutants. The Standards impact all site remediation cases where groundwater contamination exceeds the standards applicable to the groundwater classification area in which the site is located. Classification Exception Areas (CEAs) are established in order to provide notice that the constituent standards for a given aquifer classification are not or will not be met in a localized area due to natural water quality or anthropogenic influences, and that designated aquifer uses are suspended in the affected area for the term of the CEA. The intent of such action is to ensure that the uses of the aquifer are restricted until the GWQSs are achieved, thereby limiting the potential for human exposure.

4.2.2.3 Community Awareness

Community awareness could include a range of informational and educational programs designed to enhance community understanding and awareness of the potential hazards posed by the source areas and contaminated groundwater, the purpose and effectiveness of CMs taken, and the Site's responsibilities in the maintenance of the CMs. Individuals or groups that may be responsible for implementing such informational and educational programs include the USEPA, the NJDEP, local health officials, or the principal responsible party(ies) for a site.

4.2.2.4 Site Administrative Procedures

Administrative procedures, such as site-specific health and safety policies and procedures, could be used as a mechanism to manage potential risks at the Site such as from exposure of an industrial or construction worker to site contaminants if excavation into potentially contaminated soil and/or groundwater is required. Administrative health and safety policies and procedures are currently in place on the Site to limit contaminant exposure to workers.

The preliminary screening for all of the aforementioned institutional controls is given below.

1. Effectiveness – The effectiveness of institutional controls depend on how the control is written and how it is enforced. Existing institutional controls such as health and safety policies and procedures, and deed restrictions have been found to be effective in protecting human health and the environment at the Site. It is anticipated that additional institutional controls such as additional deed restrictions and a CEA would be effective at the Site.

2. Implementability – Considering the soil and groundwater contamination is limited to the Site, it is anticipated that the implementability of institutional controls will be moderate.

3. Cost – While the initial cost of an institutional control should be low, the long-term costs involved with institutional controls may be difficult to quantify, such as the impacts on the value of the property. Given the fact that institutional controls are already in-place at the Site, it is anticipated that the costs to implement institutional controls will be low.

Although institutional controls do nothing to remediate the contamination at the Site, they are effective in managing human exposure to contaminants. Institutional controls will be applicable to those areas of the Site not remediated to their applicable criteria/standard.

4.2.3 Monitored Natural Attenuation

MNA refers to the reliance on natural processes to achieve groundwater cleanup within a reasonable timeframe. These include chemical, physical, and biological processes such as biodegradation, dispersion, dilution, adsorption, volatilization, and chemical and biological stabilization to reduce the mass, volume, mobility, toxicity, and/or concentration of groundwater contaminants. Naturally occurring biological stabilization or destruction of contaminants (also known as intrinsic bioremediation) can be a dominant process in the fate and transport of contaminants. It occurs when naturally occurring microorganisms consume

or otherwise degrade contaminants either aerobically or anaerobically, and ultimately transforms the contaminants into harmless byproducts such as carbon dioxide and water. To enhance natural attenuation, supplements such as nutrients, ph adjustments, or electron donors/acceptors may be added to the groundwater. This process is known as enhanced natural attenuation.

The efficiency of natural attenuation can be defined in terms of contaminant attenuation relative to rates of contaminant transport. If the rates of contaminant attenuation are fast relative to rates of contaminant transport, the efficiency of natural attenuation is relatively high. Conversely, if rates of attenuation are slow relative to rates of transport, the efficiency of natural attenuation is relatively low.

The two most practical lines of evidence for assessing the efficiency of natural attenuation are as follows:

1. Historical groundwater chemistry data showing plume stabilization and/or loss of contaminant mass over time; and
2. Groundwater chemistry data showing that geochemical conditions are suitable for biodegradation, and that active biodegradation has occurred as indicated by the consumption of electron acceptors and/or the production of final products. These chemical and geochemical analytical data can include evidence of:
    - depletion of electron acceptors and donors;
    - increasing metabolic byproduct concentrations;
    - decreasing parent compound concentrations; and
    - increasing daughter compound concentrations (Weidemeier, et al. 1996).

A preliminary evaluation of MNA at the Site, (see Section 4.4) indicates that natural attenuation processes are operating at the Site. In addition, only one exceedence of NJDEP GWQSs for the PCOCs was observed in the sentinel wells at the Site during the CMS PDI. This well, MW-149, is located behind the sheet pile bulkhead in the East Yard. This suggests that the groundwater plume is not migrating and has the potential to attenuate after adequate source reduction is accomplished. Also, the groundwater at the Site is not being used as potable water. Therefore, there is no specific time constraint for the groundwater to achieve compliance in an expedited manner that may otherwise warrant enhanced CMs. The preliminary screening for this CM is given below.

1. Effectiveness – The effectiveness of MNA at the Site depends on site conditions such as source strength and persistence, pH, temperature, microbial activity, and oxidation-reduction potential. However, biodegradation of fuel hydrocarbons readily occurs in groundwater. In fact, natural attenuation is occurring at the Site, as indicated by the geochemical parameter distributions shown in Figures 14 through 19 in Appendix A and evaluated in Section 4.4, as well as a compound specific isotope analysis that was conducted for the chlorinated groundwater plume in the Central Yard (AOC 36), which is also evaluated in Section 4.4. This evaluation indicates that MNA will be effective for organic contaminants within a reasonable timeframe for the contaminated plume area outside of the source areas of contamination.

2. Implementability – Implementation of MNA as a CM entails a comprehensive groundwater monitoring program to provide periodic data to evaluate biodegradation rates, and to monitor the extent of the plume. A monitoring well network already exists at the Site, which is being periodically monitored for MNA parameters. Therefore, MNA is easy to implement at the Site.

3. Cost – The costs to implement and maintain a MNA program to monitor natural attenuation are low to moderate, depending upon the number of wells sampled, the frequency of sampling, and the duration of sampling.

MNA alone will not achieve the NJDEP GWQSs for organic contaminants within a reasonable timeframe for groundwater in the source areas of contamination. However, MNA may be used as a follow-up to other more aggressive source area CMs and in areas of the Site with groundwater exceedences outside the source areas of contamination.

4.2.4 Containment

Containment CMs include the use of physical barriers to block a contaminant migration pathway, such as a soil-to-groundwater pathway, or groundwater migration, as well as hydraulic gradient controls. Each of these CMs is discussed in more detail below.

4.2.4.1 Soil Physical Barriers

Soil physical barriers such as caps could be used to reduce precipitation infiltration through contaminated soil and prevent potential migration to groundwater in source areas. A cap over contaminated soil areas could be constructed of clay, asphalt, concrete, or by using synthetic liners such as polyvinyl chloride (PVC) or polyethylene. The areas above

contaminated soil and groundwater at the Site currently include some paved parking lots, roadways, building foundations and refinery structures. The preliminary screening for this CM is given below.

1. Effectiveness – Caps at the Site could reduce migration of contaminants from soil to groundwater due to infiltration of precipitation. However, sources of contamination would remain and could continue to affect groundwater. Capping could also have the effect of reducing oxygen availability in the capped area by reducing the infiltration of oxygenated precipitation and by cutting off contact of oxygen in the air with the vadose zone and shallow groundwater. As a result, capping could reduce the degree of aerobic degradation of organic contaminants occurring in the area. However, in areas with metal contaminants, such as arsenic, a cap would significantly reduce the potential for worker exposure. Therefore, caps are ranked as having limited effectiveness to being effective.

2. Implementability – Capping is considered a standard construction practice and is easily implemented. Equipment and construction materials associated with capping are readily available, and design methods and requirements are well understood.

3. Cost – The cost to construct a cap for Site source areas would be moderate and the maintenance cost would be low.

Containment with soil physical barriers such as caps would not reduce contaminant concentrations to meet cleanup criteria/standards. However, they may be effective in reducing worker exposure to metal contaminants, especially arsenic.

4.2.4.2 Groundwater Physical Barrier

Physical containment methods to isolate groundwater at the Site could include sheet piling and cutoff or curtains walls. These types of physical barriers could be used in conjunction with in-situ treatment walls or gates commonly referred to as permeable reactive barriers. The preliminary screening for this CM is given below.

1. Effectiveness – For a groundwater barrier to be effective at the Site, it would need to fully isolate the contaminated portion of the aquifer, both laterally and vertically. This would require keying the barrier on top of the clay layer underlying the fill and glacial till. Also, the vertical barrier may need to encircle the source area to preclude any groundwater flow around the barrier. Effective containment of groundwater at the source areas by physical barriers would allow cleanup of downgradient groundwater

using other remedial actions. However, groundwater containment by itself would not remediate source areas nor reduce groundwater contamination to meet NJDEP GWQSs, and is therefore rated as not effective.

2. Implementability – Groundwater containment using vertical barriers may be difficult to implement due to the ongoing operations and presence of refinery structures throughout the Site. Therefore, groundwater containment is rated difficult to implement at the Site.

3. Cost – Groundwater barriers at the Site would have a very high cost to construct given the areal extent of the groundwater plume at the Site. Maintenance costs of groundwater barriers are considered low.

Groundwater containment with physical barriers alone would not reduce groundwater contaminant concentrations to meet NJDEP GWQSs. Therefore, groundwater containment with physical barriers will not be a retained CM for further evaluation and consideration in developing remedial alternatives for the Site.

4.2.4.3 Hydraulic Barrier

Groundwater containment could also be achieved through the use of hydraulic barriers. Hydraulic containment may include the use of pumping wells, french drains, or extraction trenches to create hydraulic sinks that would collect contaminated groundwater, preventing it from migrating. Hydraulic containment would require groundwater treatment prior to discharge or reinjection. The preliminary screening for this CM is given below.

1. Effectiveness – Hydraulic containment could be expected to be effective at preventing migration of contaminant plumes, but does not provide remediation of contaminated groundwater. Some reduction in source area contaminant mass could be achieved by this CM because hydraulic containment requires the removal of contaminated groundwater. However, containment by itself would not remediate source areas nor effectively reduce groundwater contamination to meet NJDEP GWQSs within a reasonable period of time. Further, the groundwater contaminant plume is stable at the Site, eliminating the necessity for a migration prevention CM. Therefore this CM is rated as not effective.

2. Implementability – Equipment and construction materials associated with hydraulic containment are readily available, and design methods and requirements are well understood. Groundwater containment has been successfully implemented at other,

similar sites. In addition, numerous groundwater monitoring wells have been installed at the Site, and information is available on the Site hydrogeology. Therefore, hydraulic containment is rated as easy to implement.

3. Cost – Groundwater containment at the Site would have a moderate cost to construct and a moderate to high cost to operate and maintain.

Groundwater containment with hydraulic barriers alone would not reduce groundwater contaminant concentrations to meet NJDEP GWQSs. Further, the groundwater plume is not migrating, eliminating the necessity for a migration prevention CM. Therefore, groundwater containment with hydraulic barriers will not be a retained CM for further evaluation and consideration in developing remedial alternatives for the Site.

4.2.5 Ex-Situ Groundwater Treatment

Ex-situ groundwater treatment, also described as pump and treat, consists of an extraction system, a treatment system and a discharge system.

Two-types of extraction system technologies are considered applicable to the Site source areas: 1) extraction wells, and 2) collection trenches. Small diameter (2 to 6-inch) wells are the most common method of extracting contaminated groundwater and could be used at the Site. Extraction wells are typically installed vertically into the aquifer with a well screen and pump placed below the water table. Design of extraction wells, including spacing, would be based on aquifer characteristics such as hydraulic gradient and hydraulic conductivity. Computer modeling may be used to predict required well spacing and pumping rates, but pilot testing (pump test) would be recommended to better determine the system design parameters. Extraction wells could be designed to remove from specific depths within the aquifer or from across the entire thickness of groundwater contamination.

Collection trenches or horizontal wells could be used in the source area, where depths to the base of the shallow aquifer are generally less than 20 feet. The collection trench would typically be constructed as a gravel filled trench below the groundwater table with perforated pipe connected to a collection sump containing a pump. Collection trenches may also serve as a hydraulic barrier and can be more effective than vertical extraction wells at preventing off-site migration of contamination. However, the installation of collection trenches would be difficult to construct around the Site because of ongoing operations and the presence of refinery structures. The preliminary screening of this CM is given below.

1. Effectiveness – Extraction wells are considered effective for intercepting and extracting groundwater. Collection trenches are also considered effective for shallow aquifers. Although extractions wells and collection trenches can create a hydraulic barrier and can remove contaminant mass, this CM by itself would not remediate source areas nor effectively reduce groundwater contamination to meet NJDEP GWQSs within a reasonable period of time. Therefore, this CM is rated as not effective.

2. Implementability – Extraction wells are easy to construct and a widely available technology. Collection trenches are considered difficult to implement at the Site given the ongoing operations and presence of refinery structures. Therefore, extraction wells and collection trenches are rated easy and difficult to implement, respectively.

3. Cost – Extraction wells and collection trenches are considered low to moderate in cost, which would depend on the number of wells or trenches that would need to be installed. However, the O&M of a pump and treat system would be considered moderate to high in cost, depending on the duration of treatment.

Pump and treat using extraction wells and collection trenches would not remediate source areas nor effectively reduce groundwater contamination to meet NJDEP GWQSs within a reasonable period of time. Therefore, this CM will not be retained for further evaluation and consideration in developing remedial alternatives for the Site. As a result, no further discussion of treatment and discharge systems associated with pump and treat systems is warranted.

4.2.6 In-Situ Groundwater and Soil Treatment

In-situ treatment refers to those CMs that treat groundwater and/or soil contaminants in-place. In-situ treatment of contaminated groundwater and soil generally includes methods to separate and remove contaminants or to degrade contaminants in-place. Since minimal or no removal or handling of contaminated groundwater or soil is required for these CMs, associated capital costs are minimized. As a result, in-situ CMs tend to be more economical than ex-situ CMs.

In-situ treatment CMs to separate and remove VOC contaminants include air sparging and vapor extraction. In-situ treatment CMs that degrade contaminants involve adding reagents to the subsurface via wells, injection points or treatment walls that facilitate chemical or biological destruction. The types of in-situ degradation CMs most frequently used at

petroleum hydrocarbon contaminated sites include in-situ thermal, in-situ chemical, and in-situ biological treatment. Each of these CMs is discussed in more detail below.

4.2.6.1 Air Sparging and Soil Vapor Extraction (SVE)

Air Sparging and SVE are two independent technologies that can be used alone or in combination. Air sparging is a process in which air is injected into the saturated zone below or within the areas of contamination. As the injected air rises through the saturated zone, it tends to volatilize and remove adsorbed VOCs in soil as well as strip dissolved VOCs from groundwater. Air sparging also oxygenates the groundwater, thereby enhancing the potential for biodegradation at sites with contaminants that degrade aerobically, such as the VOCs. When air is first introduced below the water table, mounding of contaminated groundwater and changes to groundwater flow paths may occur. However, these disruptions typically abate once steady-state conditions are attained. Air sparging is most effective at sites with homogeneous, high-permeability soil and unconfined aquifers. Air sparging can be designed to treat a specific zone or area of contamination, or it may be used as a treatment barrier with horizontal or vertical injection wells perpendicular to the flow of groundwater.

Air sparging can be enhanced in a number of ways. In biosparging, a heated mixture of air, water, nutrients, and bacteria is injected into a well. As the mixture moves across the contamination zone, bacteria with the aid of the nutrients, as well as oxygen from the air stream, degrade many of the VOC contaminants. Ozone sparging is used to inject an ozone-air mixture into a sparge point. In addition to extracting dissolved VOCs out of contaminated groundwater, the ozone reacts rapidly with the VOCs to oxidize them into end products consisting of carbon dioxide and water.

SVE is an in-situ remediation CM that applies a vacuum to vapor extraction wells (horizontal and/or vertical) and induces air flow through the contaminated vadose zone soil. Contaminants sorbed onto soil particles, in free phase or in soil moisture, will desorb from these phases to the vapor phase and be drawn to the extraction wells. The extracted soil vapors may then be treated, if necessary, and discharged. SVE does not remove contaminants in saturated soil or groundwater. SVE's effectiveness can be enhanced by heating the subsurface soil using in-situ thermal CMs. Heating effectively raises the vapor pressure of the contaminants, increasing the removal rate. Heating is done by injecting hot air or steam into the soil, or by placing electrodes in the ground for six phase heating.

Air sparging systems typically are coupled with SVE systems to remove contaminants stripped from the groundwater, and to prevent contaminated soil vapor from migrating to previously uncontaminated areas. The use of SVE during air sparging may be required to minimize the release of untreated VOC vapors from the treatment area. In addition, the treatment area could be sealed with a vapor barrier to ensure that no fugitive emissions escape from the surface of the treatment area, and to reduce the potential short-circuiting of atmospheric air to the SVE wells. The preliminary screening of these CMs are given below.

1. Effectiveness – Air sparging is an effective and commonly used technology for remediation of saturated zone VOCs. Additionally, SVE is often used successfully for the treatment of vadose zone VOC-contaminated soil, or in conjunction with air sparging as mentioned above. The ability of air sparging and SVE CMs to meet cleanup criteria/standards in a reasonable timeframe is dependent upon the nature and extent of the contaminated media. The presence of NAPL-impacted soil or LNAPL-impacted groundwater may significantly extend remediation timeframes. Additionally, air sparging can cause groundwater mounding that could potentially result in plume migration. Overall, the effectiveness of air sparging and SVE at the Site is considered limited to effective.

2. Implementability – Air sparging and SVE are CMs that have extensive full-scale applications. Air sparging and SVE systems require ex-situ equipment installation, power input, and routine O&M. Air sparging and SVE are considered to be easy to moderate to implement at the Site, depending upon aquifer depths, and the presence of existing structures and other physical constraints that could inhibit component installation. The off-gas extracted as the result of air sparging and SVE may require additional ex-situ treatment to adsorb or destroy organic contaminants prior to discharge to the atmosphere. Additionally, depending on the amount of contaminants discharged to the atmosphere, an air permit may be required for these CMs.

3. Cost – The cost of implementing air sparging, including installation of air lines, sparge points and equipment shelters, is considered moderate. However, when combined with SVE, the cost of this alternative may increase depending upon the complexity of the air sparging and SVE network, as well as the vapor treatment system required. The cost of O&M for air sparging and SVE is considered moderate.

Although, the presence of NAPL-impacted soil and LNAPL could significantly increase the timeframe for remediation, air sparging and SVE may be effective for reducing VOC-

contaminated groundwater at the Site. Therefore, air sparging and SVE will be retained as potential CMs.

4.2.6.2 In-Situ Thermal Treatment

In-situ thermal treatment CMs include steam injection, six-phase heating, and radio frequency heating of the subsurface. Thermal treatment is typically used in saturated zone areas where high concentrations of VOCs and/or NAPL-contaminated soil are present. The increased temperatures of thermal treatment CMs help to volatilize VOCs. Vaporized contaminants rise to the unsaturated zone where they are removed by vacuum extraction and then treated ex-situ in the same manner as SVE. The preliminary screening of this CM is given below.

1. Effectiveness – Thermal treatment CMs are effective in remediating VOC-contaminated soil and groundwater, and could be effective in treating NAPL-impacted soil at the Site.

2. Implementability – The components of this CM are readily available. However, the location of contaminated soil and groundwater near operating facilities and structures would make this technology moderate to implement.

3. Cost – Thermal treatment CMs are expensive technologies and are generally considered cost effective only at sites with very high contaminant concentrations, or LNAPL. The cost of implementing, operating and maintaining thermal treatment CMs at the Site is considered to be moderate to high.

The cost of thermal treatment CMs compared to other CMs are high, except possibly when significant contaminant mass is present in the treatment zone. However, in-situ thermal techniques have a high level of effectiveness and are less affected by variations in subsurface geology/hydrogeology. Therefore, in-situ thermal treatment CMs will be retained for further evaluation and consideration in developing remedial alternatives for the Site.

4.2.6.3 In-Situ Chemical Oxidation (ISCO)

ISCO is a commonly used technology for remediating the following contaminants in both soil and groundwater: 1) VOCs, 2) CVOCs, 3) SVOCs, 4) total petroleum hydrocarbons (TPH), 5) polychlorinated biphenyls, 6) organic pesticides and herbicides, and 7) munitions constituents (RDX, TNT, HMX, etc.). ISCO involves the injection of a chemical oxidant

such as ozone, hydrogen peroxide, potassium or sodium permanganate, or sodium persulfate into the soil and/or groundwater through injection wells or points to treat both organic contaminated soil and groundwater. ISCO chemical reactions produce carbon dioxide, water and minerals, such as inorganic chloride, depending on the type of contamination, and the type of oxidant and associated chemicals used. Catalysts and acids are sometimes used to enhance the rate of the ISCO reaction, as well as increase the oxidation reduction potential (ORP). The two main advantages of ISCO over other applicable, and demonstrated and available technologies is that little to no waste material is generated during the ISCO process and the duration of remediation commonly occurs over a much shorter time frame. These advantages result in significant cost savings, especially in operation and maintenance costs, which are minimal to non-existent for ISCO (ITRC. 2005). The preliminary screening of this CM is given below.

1. Effectiveness – ISCO is effective at treating organic soil and groundwater contamination. Low permeable stratigraphy could make it difficult to deliver the oxidant to the contaminant. This can be overcome by fracturing these soils to create preferential pathways. Applied oxidants could also be consumed by natural organic matter and other interferences in the subsurface. The presence of subsurface interferences can be evaluated through bench and pilot-scale ISCO treatment tests.

2. Implementability – ISCO is considered to be easy to moderate to implement at the Site, depending on the permeability of the soil. Additionally, skid-mounted or trailer-mounted components of this CM are readily available. Permeability limitations can be overcome with fracturing pretreatment to create preferential soil pathways.

3. Cost – The cost for ISCO is directly affected by how many injection wells and how much oxidant is required to degrade soil and groundwater contaminants. This will be a function of the radius of influence and quantity of subsurface interferences, respectively. As mentioned above, the radius of influence around each injection point can be enhanced with fracturing pretreatment. Additionally, beyond the injection of ISCO reagents, there are no O&M costs associated with this CM. Therefore, the cost of ISCO at the Site is considered to be low to moderate, with O&M costs non-existent.

ISCO will be retained as a CM for both soil and groundwater contamination.

4.2.6.4 Enhanced Aerobic Bioremediation (EAB)

Bioremediation of petroleum VOCs in groundwater may be accomplished in a highly aerobic environment. EAB can be promoted by the addition of oxygen into a contaminated area to provide electron acceptors. Oxygen enhancement can be accomplished by several methods including the following: 1) air sparging, 2) hydrogen peroxide, and 3) slow oxygen releasing crystalline compounds. Air sparging was discussed above in Section 3.2.6.1. The use of hydrogen peroxide for oxygen enhancement is limited for in-situ groundwater treatment because concentrations greater than 200 ppm in groundwater inhibit the growth of microorganisms. Therefore, lower concentrations must be maintained. At these lower concentrations, the achievable biological degradation rate and, hence, the effectiveness of the treatment are limited. Therefore, this discussion will focus on the use of oxygen releasing compounds (ORCs) for oxygen enhancement. The preliminary screening of this CM is given below.

1. Effectiveness – EAB by the addition of ORCs is an effective CM for sites with shallow depths to groundwater (less than 60 feet bgs), such as at the Site. Also, ORCs do not generate vapor emissions that would need to be collected and treated such as with air sparging. EAB should be effective for degradation of petroleum VOCs, such as BTEX compounds, in groundwater. The effectiveness of EAB could be limited by low permeable stratigraphy in the aquifer, which will impede the movement of ORCs through the targeted contamination in the saturated zone. This can be overcome by fracturing these soils to create preferential pathways. Slow groundwater velocities will also limit the distribution of ORCs and require a large number of injection points. EAB reactions are much slower than ISCO reactions and would require a much greater duration to reduce contaminant concentrations to their respective cleanup criteria/standards. This time would vary based upon contaminant concentrations and hydrogeological conditions. Pilot testing would help determine reaction rates and areas of influence around monitoring wells where ORCs were placed. This information could be used to quantify the amount of ORCs needed, the number of wells and/or well points necessary, and the estimated duration of remediation required. EAB is considered limited to effective for the Site VOC contamination in groundwater, depending on the results of pilot testing for this CM.

2. Implementability – Implementation of EAB by the addition of ORCs is considered to be easy to moderate for the VOC contaminated groundwater, depending on the permeability of the soil. In addition, EAB produces no residual waste and requires little capital

equipment and power input. Permeability limitations can be overcome with fracturing pretreatment to create preferential soil pathways.

3. Cost – The cost of implementing EAB is low to moderate depending on the depth of contamination, contaminant concentrations, amount of ORCs needed, the number of wells and/or well points necessary, and the duration of remediation required. The cost of O&M is also considered low to moderate for EAB for the same reasons given above.

EAB may be appropriate for VOC contaminated groundwater, and will be retained as a CM pending the outcome of a pilot test to evaluate its potential as a full-scale groundwater CM.

4.2.6.5 In-Situ Solidification and Stabilization (S/S)

S/S is a commonly used technology for treating soil contaminated with metals, as well as polynuclear aromatic hydrocarbons and radionuclides. S/S uses various binders to chemically react with or physically encapsulate contaminants to significantly reduce their leachability. Leachability testing is typically performed with S/S to measure the immobilization of contaminants. Auger/caisson, backhoe, and injector head systems are delivery and mixing systems typically used with in-situ S/S. Implementation of this technology is highly dependent on the physical properties and interferences present in the soil.

Factors that may limit the effectiveness and, hence, applicability of in-situ S/S include the following: 1) the depth of contaminants may limit some types of application processes, 2) the future usage of the site may disturb the stabilized materials and affect the long-term immobilization of contaminants, 3) some in-situ S/S processes result in a significant increase in volume as a result of addition of S/S binders to immobilize contaminants, and 4) certain wastes, such as NAPL, may interfere with S/S reactions, which may require alternative S/S binders and/or higher concentrations of S/S binders. The preliminary screening of this CM is given below.

1. Effectiveness – In-situ S/S is effective in immobilizing most metal contaminants in soils, including lead.

2. Implementability – The implementability of in-situ S/S at the Site is moderate. Underground utilities and refinery structures may interfere with the ability to utilize the augers, backhoes, and injector heads necessary to implement in-situ S/S. The areas of

the site where in-situ S/S is applicable will have to be evaluated individually to determine its implementability.

3. Cost – The costs associated with in-situ S/S are considered to be moderate with the O&M cost non-existent.

In-situ S/S will be retained as a CM for metals contaminated soil.

4.2.7 Contaminated Soil Removal, Transport, Ex-situ Treatment, and Disposal

These CMs involve complete or partial removal of contaminated soil source material followed by transportation, on-or off-site treatment, and disposal at an on- or off-site facility. Each of these CMs is discussed in further detail below.

4.2.7.1 Soil Removal and Transportation

Contaminated soil source materials can be excavated from the vadose zone or the upper portions of the saturated zone using conventional earth-moving equipment such as hydraulic excavators, backhoes, and front-end loaders. Containment and treatment of water encountered during excavation activities at or beneath the groundwater table may be necessary.

Removed contaminated soil could be transported to a treatment or disposal facility on- or off-site in trucks. Factors affecting the costs and feasibility of truck hauling on- or off-site include the haul distances, volume of materials, and the price of fuel. The preliminary screening of this CM is given below.

1. Effectiveness – Soil removal by mechanical excavation is considered an effective means of removing source material in the vadose zone at the Site. Excavation in the saturated zone can be accomplished but may be less effective due to handling difficulties of saturated soil such as sloughing, as well as the potential need to collect and treat contaminated groundwater. The use of trucks is considered an effective means to transport excavated materials.

2. Implementability – Excavation and transportation of contaminated soil is a common practice that has been implemented successfully at many sites with similar contamination. Excavation is expected to be easy to difficult to implement in the Site source contaminated soil areas, depending on the depth of soil contamination and the

presence of refinery structures. Some refinery structures, including buildings and foundations, are located in close proximity to contaminated soil areas. As a result, excavation near these structures would be difficult to accomplish. Excavated soil would also need to be backfilled with clean NJDEP-approved backfill material following its excavation.

3. Cost – The cost of excavation to approximately 15 feet bgs is expected to be low because it is within the reach of most excavation equipment. The cost of excavation is moderate to high for greater depths and below the groundwater table because heavy-duty equipment may be needed and contaminated groundwater may need to be collected and treated. The cost of on-site transportation is expected to be low. However, off-site transportation costs could be high depending on the haul distances, volume of materials, and the price of fuel. In addition, depending on the volume of material that will need to be excavated and transported off-site, the use of sheet piling and dewatering may be required to reduce the total volume to be disposed off-site, which would increase the cost for off-site disposal.

Soil removal by excavation and transportation will be retained as a CM in conjunction with ex-situ soil treatment and disposal CMs discussed below.

4.2.7.2 Ex-Situ Soil Physical/Chemical Treatment/Biological Treatment

Ex-situ soil physical and chemical treatment CMs remediate contaminated soil by separating and removing, destroying, or immobilizing the contamination. These CMs involve technologies that use separation processes (such as soil washing, and LTTD), immobilization processes (such as ex-situ S/S), and destruction processes (such as incineration). Most of these technologies involve batch treatment of contaminated soil with no long-term O&M. Ex-situ biological treatment CMs remediate contaminated soil through either aerobic or anaerobic biological degradation processes aboveground in land farms, biopiles or compost piles. Each of these CMs is discussed in more detail below.

4.2.7.2.1 Soil Washing

Soil washing consists of an aqueous process in which soil is washed with water to remove contaminants adsorbed onto soil particles. The wash water can be supplemented with a basic leaching agent, surfactant, pH adjustment agent, or chelating agent to help remove organics and heavy metals from soil. Soil washing is applicable to larger grain soils such as sand and gravel because contaminants can be more easily dislodged from these soils. Contaminants

tend to bind to finer grain soils such as clay and silt, and are not readily dislodged using soil washing processes. The soil washing wastewater containing dislodged contaminants is then separated from the washed soil and further treated to remove contaminants prior to discharge. Treated soil can then be backfilled into the area from which it was excavated. The preliminary screening of this CM is given below.

1. Effectiveness – Soil washing is expected to have limited effectiveness at the Site because the geology of the contaminated areas is heterogeneous fill material with intermixed course and fine grain lenses.

2. Implementability – Soil washing is expected to be difficult to implement at the Site because of the large amount of soil that would need to be excavated and the potential interferences from underground utilities and refinery structures.

3. Cost – The cost of soil washing is expected to be high as a result of excavation costs, soil treatment costs, soil washing wastewater treatment costs, and disposal costs for the contaminants residuals removed from the soil washing wastewater.

As a result of its limited effectiveness, difficult implementability and high cost, soil washing will not be retained as a CM for the Site.

4.2.7.2.2 Low Temperature Thermal Desorption (LTTD)

LTTD is a physical separation process in which contaminants are heated to between 200°F to 600°F to volatilize organic contaminants. Vapors are then removed from the system using a carrier gas or through pressure venting, treated if necessary using carbon adsorption or secondary combustion unit processes and discharged to the atmosphere. VOCs and some SVOCs contaminated soil would be expected to be effectively treated using LTTD. Excavated soil would be processed through the thermal desorption unit with a sufficient residence time to ensure the applicable cleanup criteria/standards would be achieved. Treated soil could then be backfilled into its excavation areas. LTTD can be applied both on- or off-site. The preliminary screening for this CM is given below.

1. Effectiveness – Thermal desorption is an effective process in removing VOCs and some SVOCs in soil, and is a presumptive treatment technology for soil (USEPA. 1993).

2. Implementability – Mobile LTTD units are commonly available. Space is available for staging the unit at the Site, especially on the concrete pad in SWMU 43. Air emission

permit requirements may be difficult to attain unless an indirect LTTD unit is used. Overall, the implementability of LTTD at the Site is considered moderate.

3. Cost – The costs associated with LTTD are considered to be moderate to high due to the cost of fuel to operate the system. Treatment costs are directly related to the amount of contamination in the soil, the volume of soil to be treated, and the price of fuel.

LTTD will be retained as a CM in conjunction with excavation, transportation, and disposal CMs discussed in this Section.

4.2.7.2.3 Incineration

Incineration is similar to thermal desorption but involves the use of a combustion chamber or kiln operating at temperatures between 1,600 to 2,200°F to destroy organic contaminants in soil. Excavated soil would be processed through the incinerator and treated with a sufficient residence time to ensure the applicable cleanup criteria/standards would be achieved. Off-gases and combustion products may require additional treatment prior to discharge to the atmosphere. Incineration can be applied both on- or off-site. If treated on-site, soil could then be backfilled into its excavation areas. The preliminary screening for this CM is given below.

1. Effectiveness – Incineration is an effective process for destroying organic contaminants in soil.

2. Implementability – There are no known, permitted incineration facilities in close proximity to the Site. However, mobile incineration units are commercially available. On-site incineration may be difficult to implement due to air emission permit requirements. Overall, the implementability of incineration at the Site is considered to be difficult.

3. Cost – The costs associated with incineration are considered very high due to the cost of fuel both to operate the system (both on- and off-site) and transport the contaminated soil (off-site only).

As a result of its difficult implementability and very high costs, incineration will not be retained as a CM for the Site.

4.2.7.2.4 Ex-Situ S/S

Ex-situ S/S is similar to in-situ S/S except it is applied to excavated soil in pug-mill type mixing equipment, similar to cement mixers and backhoes. As a result of this equipment, ex-situ S/S provides better mixing of S/S binders and contaminated soil than in-situ S/S. This results in a higher throughput of ex-situ stabilized materials, which can be either placed back in its excavated areas or disposed in a RCRA landfill or CAMU, depending on the nature of the contamination stabilized. The preliminary screening of this CM is given below.

1. Effectiveness – Ex-situ S/S is effective in immobilizing most metal contaminants in soils, including lead. Additionally, ex-situ S/S is effective in increasing the unconfined compressive strength of contaminated materials to be disposed in land disposal units.

2. Implementability – The implementability of ex-situ S/S at the Site is easy. Pug mill equipment is readily available. Also, a staging area for the pug mill is available on the concrete pad of SWMU 43.

3. Cost – The costs associated with S/S are considered to be moderate to high with the O&M costs non-existent if stabilized materials are placed in a land disposal unit. Ex-situ S/S is more expensive than in-situ S/S because of the additional excavation and backfill costs associated with this CM. However, because it provides better mixing and immobilization results, it is typically applied to contaminated materials requiring a higher degree of certainty to the long-term integrity of the stabilized materials, such as characteristically hazardous waste/contaminated soil and benzo(a)pyrene >10 mg/kg impacted soils.

Therefore, ex-situ S/S will be retained as a CM for metals and benzo(a)pyrene >10 mg/kg impacted soils in conjunction with excavation, transportation, and disposal CMs discussed in this section.

4.2.7.2.5 Off-Site Disposal

Off-site disposal involves placing excavated contaminated material in an engineered and permitted land disposal facility located outside the Site. Non-hazardous and organic contaminated hazardous soils can be more cost effectively treated in-situ at the Site. Therefore, primarily metals contaminated hazardous and benzo(a)pyrene >10 mg/kg impacted soils are anticipated to be excavated and land disposed from the Site. Other soils

may need to be excavated and disposed off-site (e.g., for construction purposes). Non-hazardous benzo(a)pyrene >10 mg/kg impacted soils could be disposed of in a RCRA-permitted Subtitle D solid waste landfill. Hazardous soil would require disposal in a RCRA-permitted Subtitle C hazardous waste landfill. The preliminary screening of this CM is given below.

1. Effectiveness – Off-site disposal is considered effective in completely removing the contaminated soil from the Site and containing it in an engineered and permitted land disposal facility.

2. Implementability – Disposal at an off-site landfill is easily implementable. However, issues regarding community acceptance may arise as a result of transporting hazardous soils through adjoining residential neighborhoods.

3. Cost – Transportation and disposal costs associated with RCRA permitted Subtitle D solid waste landfills are expected to be high; while transportation and disposal costs associated with RCRA-permitted Subtitle C hazardous waste landfills are considered to be very high. The costs are directly related to the volume of waste disposed and the price of fuel.

Off-site disposal will be retained as a CM for contaminated soils and debris including metals contaminated hazardous and benzo(a)pyrene >10 mg/kg impacted soils at the Site.

4.2.7.2.6 On-Site Disposal

On-site disposal involves placing excavated contaminated material in an engineered CAMU located on the Site. The CAMU would at a minimum consist of a liner, leachate collection system, and a cap, and would be designed to eliminate exposure to and migration of remediation waste such as metals contaminated hazardous and benzo(a)pyrene >10 mg/kg impacted soils disposed on-site. The preliminary screening of this CM is given below.

1. Effectiveness – On-site disposal is an effective means of completely removing the contaminated soil from the Site and containing it in an engineered and permitted CAMU.

2. Implementability – Disposal in an on-site CAMU is easily implementable. Sufficient open space for a CAMU is available on-site. Materials and construction methods associated with building a CAMU are readily available. Also, design methods and

requirements are well understood. A modification to the Site HSWA permit would be required, which may take approximately one year to obtain approval from USEPA.

3. Cost – Disposal costs associated with placing excavated soil into an on-site CAMU are considered low. Costs associated with the design and construction of an on-site CAMU are considered to be moderate to high, depending on the volume of soil disposed in the CAMU. The greater the volume, the lower the unit cost of disposal into the CAMU. Above a certain threshold, the unit cost of on-site disposal in a CAMU will be less than the unit cost of disposing contaminated soil off-site. This comparison is further discussed in section 4.5.2.7.

On-site disposal will be retained as a CM for remediation waste such as metals contaminated hazardous and benzo(a)pyrene >10 mg/kg impacted soils at the Site.

4.2.7.2.7 Ex-Situ Bioremediation

Ex-situ bioremediation is carried out aboveground by physically extracting the impacted soil and placing it in land farms, biopiles or compost piles for biological degradation. The primary advantage to these ex-situ approaches to bioremediation is the degree of control that can be exerted over the biological processes being used to degrade the contaminants. This CM requires putting excavated soil into aboveground enclosures or spreading it over treatment beds that may include leachate and aeration systems. The careful control of moisture, heat, nutrients, oxygen and pH can enhance biodegradation processes. Prepared treatment beds may be tilled, as in the case of land farming, to enhance aerobic biodegradation of the contaminants. The enhanced microbial activity results in degradation of adsorbed petroleum product constituents through microbial respiration. If contaminated soils are shallow (i.e., < 3 feet below ground surface), it may be possible to effectively stimulate microbial activity without excavating the soils. If petroleum contaminated soil is deeper than 5 feet, the soils can be excavated and reapplied on the ground surface.

Ex-situ bioremediation has been proven effective in reducing concentrations of many petroleum products and wastes typically found at refinery sites. Lighter (more volatile) petroleum products (e.g., gasoline) maybe removed through volatilization during aeration processes (e.g. tilling or plowing for landfarming) and, to a lesser extent, degraded by microbial respiration, and may need controls for VOC emissions. The mid-range hydrocarbon products (e.g., diesel fuel, kerosene) contain lower percentages of lighter (more volatile) constituents than does gasoline. Biodegradation of these petroleum products is

more significant than volatilization. Heavier (non-volatile) petroleum products do not significantly evaporate during ex-situ bioremediation aeration; the dominant mechanism that breaks down these petroleum products is biodegradation.

Chevron has on-site experience with Landfarming. An experimental Landfarm was operated at the facility by Chevron during the 1980s for the treatment of various petroleum wastes.
Generally, the primary disadvantage of ex-situ bioremediation is the expense and disruption associated with removal, treatment, and disposal or replacement of the impacted soil.
Many factors affect the selection of potential ex-situ bioremediation technologies including the following:

- Contaminant type and characteristics (physical properties, toxicity, volume, location, and exposure risk);
- Site characteristics (soil types, permeability, surface and ground water properties, climate, site infrastructures, topography, and location);
- Costs (capital, operating, and maintenance);
- Regulatory and public acceptance; and,
- Remediation schedule.

The preliminary screening of this CM is given below:

1. Effectiveness – Ex-situ bioremediation is an effective means of degrading/destroying the COCs to meet the remediation goals. The treated soils can be potentially reused on-site, disposed in an on-site CAMU or disposed off-site, depending on the residual COC concentrations. Generally there is a high degree of regulatory and public acceptance for this CM.

2. Implementability – Ex-situ bioremediation is considered to be moderately implementable at the Site. Sufficient open space is available on-site. Materials and construction methods associated with constructing ex-situ bioremediation cell(s) are readily available. However, atmospheric emissions may require treatment, which may also require an air permit, thereby delaying the implementation of this CM.

3. Cost – The capital costs and O&M costs associated with ex-situ bioremediation are low. The greater the volume, the lower the unit cost for implementing ex-situ bioremediation.

Ex-situ bioremediation will be retained as a CM for organic contaminated soils at the Site.

4.2.8 LNAPL Removal

These CMs involve the removal of LNAPL from a recovery well and include LNAPL Removal Measures (LRMs) and MPE systems. Each of these CMs is discussed in further detail below.

4.2.8.1 LNAPL Recovery Measures (LRMs)

LRMs are designed to remove low levels of LNAPL (generally less than one foot) on an interim or intermittent basis. LRMs include vac trucks, belt skimmers and absorbent socks. The preliminary screening of this CM is given below.

1. Effectiveness – LRMs are effective in removing low levels of LNAPL. LNAPL removal at the Site has been effective through the use of the above described LRMs. Table 2.1 shows the reductions of LNAPL areas of varying thicknesses between 2005 and 2007 as a result of the utilization of these LRMs.

2. Implementability – LRMs are easy to implement. There is an existing network of recovery wells on-site where LRMs are being utilized.

3. Cost – The cost to implement LRMs is a function of the amount of LNAPL at the Site and the rate of product mitigation from the subsurface lithology to the recovery wells. The capital cost to implement LRMs at the Site is considered low to moderate, depending on the number of recovery wells, skimmer belts and absorbent socks needed; while the O&M costs would be considered low to moderate, depending on the duration of treatment needed to achieve the extent practicable LNAPL removal.

LRMs will be retained as a CM for LNAPL impacted areas.

4.2.8.2 Multi-Phase Extraction (MPE)

MPE involves simultaneous extraction of soil vapor, LNAPL, and groundwater to remediate all phases of contaminated media. MPE is typically applied in recovery wells with significant amounts of LNAPL (greater than one foot in thickness). Recovery wells used with MPE systems typically have at least two feet of well screen extending above the top of the LNAPL layer to ensure a sufficient extraction of soil vapor from the well. The preliminary screening of this CM is given below.

1. Effectiveness – MPE is effective in removing moderate to high levels of LNAPL, but limited in effectiveness to not effective in removing low levels of LNAPL, which are currently present at the Site.

2. Implementability – MPE is moderate to difficult to implement depending on the number and location of recovery wells requiring LNAPL removal, the extent of subsurface piping required to connect these recovery wells to the MPE systems, the number of MPE systems required, the LNAPL thicknesses on the groundwater, the permeability of the subsurface lithology, and the presence of surface and subsurface structures and utilities.

3. Cost – The capital cost to implement MPE at the Site is considered moderate to high depending on the number of recovery wells requiring LNAPL removal, the extent of subsurface piping required to connect these recovery wells to the MPE systems, the number of MPE systems and the size of the MPE systems required. The O&M cost to implement MPE at the Site is considered moderate to high depending on the duration of treatment needed to achieve the extent practicable LNAPL removed.

As a result of the low levels of LNAPL present at the Site, MPE is not expected to be effective and will not be retained as a CM.

4.2.9 Summary of Preliminary Screening of Corrective Measures

Table 4.1 summarizes the results of the preliminary screening of CMs by contaminated media for the remediation of the Site. The table also identifies the CMs to be retained for further evaluation, which include all CMs with an overall preliminary screening score of 10 or higher. Table 4.2 summarizes the retained CMs and their applicability to the Site contaminated media for further evaluation in developing remedial alternatives for the Site.

As presented in Table 4.2, for some organic contaminated media there are several retained CMs that are applicable. However, ISCO in-situ thermal treatment and LTTD (applied ex-situ) CMs are capable of treating both VOCs and SVOCs in soil simultaneously as opposed to SVE, which primarily is capable of treating VOCs (although SVE can enhance biodegradation of SVOCs). Table 1 shows that there are 20 SWMUs and AOCs with exceedences of both VOCs and SVOCs in soil. Additionally, ISCO and in-situ thermal treatment technologies are more cost effective when applied in source areas with elevated contaminant concentrations, and are designed to remediate contamination within a short period of time. While effective with VOCs, SVE requires significantly more time to remediate contamination and is a longer term approach to source reduction. Further, ISCO

and in-situ thermal treatment are also capable of treating both VOCs and SVOCs in groundwater simultaneously as opposed to air sparging and SVE, which are primarily capable of treating VOCs. Table 1 also shows that there are 9 SWMUs and AOCs with exceedences of both VOCs and SVOCs in groundwater. It will be far more cost effective to utilize CMs that are capable of treating all of the contaminants for a particular contaminated media as opposed to using multiple technologies to treat VOCs and SVOCs within the same contaminated media. Finally, ISCO and in-situ thermal treatment can be utilized to treat both contaminated soil and groundwater simultaneously, which will be more cost effective than using separate technologies for these media within the same SWMUs and AOCs. Table 1 indicates that there are 21 SWMUs and AOCs with exceedences of organic contaminants in both the soil and groundwater.

While ISCO, in-situ thermal treatment, aerobic bioremediation, air sparging, and MNA are applicable for contaminated groundwater, ISCO, in-situ thermal treatment, aerobic bioremediation and air sparging will be more cost effectively utilized in the contamination source areas, those areas with organic contaminant exceedences in soil. As shown in Figures 5 through 7, these soil source areas generally coincide with groundwater benzene concentrations greater than 100 ug/L. Therefore, MNA will only be applied as a CM to groundwater with benzene exceedences from 1 ug/L to 100 ug/L.

While LTTD and ex-situ stabilization are both applicable for benzo(a)pyrene >10 mg/kg impacted soil, ex-situ stabilization is far more cost effective than LTTD, which is reflected in its higher overall preliminary screening score. Therefore, ex-situ stabilization will be retained as a CM for benzo(a)pyrene >10 mg/kg impacted soil, with the exception of AOC 29, which will have a separate CMS to address this AOC.

Based on this and the rest of the information presented in this Section and summarized in Table 4.2, the following CMs are retained for the following contaminated media for further evaluation in developing remedial alternatives for the Site:

1. NFA for the clean soil and groundwater areas;

2. Deed notices for the following soil contaminated areas: a) non-hazardous soil with lead concentrations >800 mg/kg, b) benzo(a)pyrene impacted soil with concentrations >0.66 mg/kg and <10 mg/kg, and c) arsenic impacted soil with concentrations >20 mg/kg;

3. CEAs for groundwater areas utilizing MNA as the CM;

4. Caps for the following areas: a) arsenic impacted soil in the Main and East Yards, and b) potentially RCRA-listed hazardous soil in SWMU 43;

5. Excavation, ex-situ stabilization, and disposal for the following areas: a) non-hazardous benzo(a)pyrene >10 mg/kg impacted soil; b) characteristically hazardous soil with TCLP lead concentrations >5 mg/L; c) TEL and TOL impacted soil with concentrations >2 mg/kg and total lead concentrations <800 mg/kg, and d) other contaminated soils that may be excavated for construction and other purposes;

6. LTTD for excavated organic contaminated soil;

7. ISCO for the following areas: a) hazardous and non-hazardous organic contaminated soil, and b) organic contaminated groundwater in contamination source areas with benzene concentrations >100 ug/L;

8. In-situ stabilization for non-hazardous soil with lead concentrations >800 mg/kg;
9. In-situ thermal treatment for the following areas: a) hazardous and non-hazardous organic contaminated soil; and b) organic contaminated groundwater in contamination source areas with benzene concentrations > 100 ug/L;

11. Ex-situ and in-situ bioremediation for the following areas: a) hazardous and non-hazardous organic contaminated soil; and b) organic contaminated groundwater in contamination source areas with benzene concentrations >100 ug/L;

11. Air sparging/soil vapor extraction for organic contaminated groundwater in contamination source areas with benzene concentrations >100 ug/L;

12. MNA for organic contaminated groundwater in non-source areas with benzene concentrations ranging from 1 ug/L to 100 ug/L; and

13. LRMs for areas with LNAPL thicknesses >0.01 feet.

Following the completion of active remedial activities at the Site, a map will be prepared delineating the areas to be deed noticed, based on the latest post-treatment soil sampling results, as described in CM No. 2 above.

Table 4.1
Summary of Preliminary Screening of Corrective Measures by Contaminated Media

Contaminated Media	General CM	Specific CM	Effectiveness	Implementability	Cost	Overall Preliminary Screening Score	CM Disposition
Hazardous and Non-Hazardous Soils	No Further Action	No Further Action	0	5	5	10	Retain
	Institutional Controls	Zoning / Deed Notices/ Community Awareness / Site Administrative Procedures	5	3	4	12	Retain
	Containment	Caps	3-5	5	3	11-13	Retain
	Removal	Excavation and Transportation	5	1-5	2-3	8-13	Retain
	Disposal	Off-Site Land Disposal	5	5	1-2	11-12	Retain
		On-Site Land Disposal (CAMU)	5	5	2-3	12-13	Retain
	Ex-Situ Treatment	Soil Washing	3	1	2	6	Reject
		LTTD	5	3	2-3	10-11	Retain
		S/S	5	5	2-3	12-13	Retain
		Incineration	5	1	1	7	Reject
		Ex-situ Bioremediation	5	3	4	12	Retain
	In-Situ Treatment	Soil Vapor Extraction	3-5	3-5	3	9-13	Retain
		ISCO	5	3-5	3-4	11-14	Retain
		Thermal Treatment	5	3	2-3	10-11	Retain
		S/S	5	3	3	11	Retain

Table 4.1
Summary of Preliminary Screening of Corrective Measures by Contaminated Media

Contaminated Media	General CM	Specific CM	Effectiveness	Implementability	Cost	Overall Preliminary Screening Score	CM Disposition
Groundwater	No Further Action	No Further Action	0	5	5	10	Retain
	Institutional Controls	CEAs	5	3	4	12	Retain
	MNA	MNA	0-5	5	3-4	8-14	Retain
	Containment	Physical Barriers (Sheet pile, cut-off or curtain walls)	0	1	1	2	Reject
		Hydraulic Barriers (Extraction Wells etc.)	0	5	3	8	Reject
	Ex-Situ Treatment	Pump and Treat	0	1-5	3	4-8	Reject
	In-Situ Treatment	ISCO	5	3-5	3-4	11-14	Retain
		Aerobic Bioremediation	3-5	3-5	3-4	9-14	Retain
		Air Sparging	3-5	3-5	3	9-13	Retain
		Thermal Treatment	5	3	2-3	10-11	Retain

Table 4.1
Summary of Preliminary Screening of Corrective Measures by Contaminated Media

Contaminated Media	General CM	Specific CM	Effectiveness	Implementability	Cost	Overall Preliminary Screening Score	CM Disposition
LNAPL	Ex-Situ Treatment	Multi-Phase Extraction	0-3	1-3	2-3	3-9	Reject
	In-Situ Treatment	LNAPL Removal Measures	5	5	3-4	13-14	Retain

Notes:
1. The scores for effectiveness criteria ratings are as follows: 1) effective = 5, 2) limited = 3, and 3) not effective = 0.
2. The scores for implementability criteria ratings are given as follows: 1) easy = 5, 2) moderate = 3, 3) difficult = 1, and 4) not implementable = 0.
3. The scores for cost criteria ratings are given as follows: 1) none = 5, 2) low = 4, 3) moderate = 3, 4) high = 2, and 5) very high = 1.
4. All specific CMs with an overall preliminary screening score of 10 or higher are retained for further evaluation in developing remedial alternatives for the Site.

Table 4.2
Summary of Retained Corrective Measures and their Applicability to the Site Contaminated Media

Retained Specific Corrective Measures	Contaminated Media											Overall Preliminary Screening Score
	Hazardous Soils			Non - Hazardous Soils			Benzo(a)pyrene >10 mg/kg Impacted Soil	Arsenic Impacted Soil	Groundwater (VOCs)	LNAPL	Clean Soil and Groundwater[1]	
	VOCs	SVOCs	Metals	VOCs	SVOCs	Metals						
No Further Action											X	10
Institutional Controls (Deed Notices and CEAs)					X	X		X	X			12
Containment (Caps)	X	X	X					X				11-13
Removal (Excavation and Transportation)			X				X					8-13
Off-Site Land Disposal			X				X					11-12
On-Site Land Disposal (CAMU)			X				X					12-13
LTTD	X	X		X	X		X					10-11
Ex-Situ S/S			X				X					12-13
Ex-Situ Bioremediation	X	X		X	X		X					12
In-Situ Thermal Treatment	X	X		X	X		X		X			10-11
Soil Vapor Extraction	X			X								9-13
ISCO	X	X		X	X		X		X			11-14
In-Situ S/S						X						11
MNA									X			8-14
Aerobic Bioremediation									X			9-14
Air Sparging									X			9-13
LRMs										X		13-14

Notes:
1. Clean soil and groundwater refers to soil and groundwater with no exceedences of applicable regulatory criteria/standards.

5.0 EVALUATION OF SELECTED CORRECTIVE MEASURES TECHNOLOGIES

This Section evaluates the CMs technologies selected in Section 4.2.9 for the contaminated soil and groundwater at the three Yards. The following USEPA NCP (USEPA. 1993) criteria are used to evaluate the selected CM technologies in this Section: 1) overall protection of human health and the environment, 2) compliance with applicable standards, 3) long-term effectiveness and permanence, 4) reduction of toxicity, mobility, or volume through treatment, 5) short-term effectiveness, 6) implementability, and 7) cost. Additionally, bench-scale treatability testing was conducted on the following selected CMs to further evaluate their applicability for remediating the contaminated media at the Site: 1) ISCO, 2) LTTD, and 3) stabilization. A description and evaluation of each of the selected CMs, as well as a summary of the bench-test results for ISCO, LTTD, and stabilization is given below.

5.1 IN-SITU CHEMICAL OXIDATION

5.1.1 Description

ISCO involves the injection of a chemical oxidant, such as ozone, hydrogen peroxide, potassium or sodium permanganate, or sodium persulfate into the subsurface soil and/or groundwater through injection wells or points to treat both organic contaminated soil and groundwater. ISCO chemical reactions produce carbon dioxide, water and minerals depending on the type of oxidant and associated chemicals used, as well as the type of contaminants being degraded. Catalysts and acids are sometimes used to enhance the rate of the ISCO reaction, as well as increase the ORP.

5.1.2 ISCO Bench Test Scope of Work

In order to further evaluate the applicability of ISCO to remediate the organic contamination in the soil and groundwater at the Site, URS conducted an ISCO bench-test.

Two soil samples (Soils I and II) were collected from the site for this bench test in March 2008. Soil 1 was collected in the vicinity of soil boring location S2249 in SWMU 43 between the concrete pad and the surge pond, the location with the highest benzene concentration in SWMU 43. Soil 2 was collected in the vicinity of soil boring location

S1016 in SWMU 18 in the Main Yard between tanks 300, 301, 326, and 327, the location with the highest benzene concentration at the refinery. These soils were collected in appropriate sampling containers, and shipped under ice in a cooler to Spectrum Analytical, Inc., located in Agawam, MA to conduct the ISCO bench test. The primary goal of the ISCO bench test was to evaluate the following ISCO reagents to determine the most effective reagent for degrading the organic contamination in the Site soil and groundwater: 1) Fenton's Reagent (FR), 2) catalyzed sodium persulfate, and 3) RegenOx™. The following tasks were conducted as part of this ISCO bench test.

Task 1: Preparation and Characterization of the two Site Soils.

To eliminate heterogeneity associated with soil sampling and soil contamination and to produce two uniform and homogenized soil samples for the test, each of the collected soils were composited. The two composite soils were then characterized in duplicate for the following parameters: 1) VOCs, 2) SVOCs, 3) TCLP-benzene, 4) TCLP-Pb, 5) total Pb, 6) TEL, 7) pH, and 8) total organic carbon (TOC). Grain size analysis was also conducted on the two soils.

Task 2: Jar Test Oxidation of the Site Soil with the FR Oxidation Process and Soil Oxidant Demand.

This test was conducted for the following reasons: 1) to investigate the influence of hydrogen peroxide concentration used in the FR process on organic contaminant degradation, 2) determine the treatment efficiency and necessary field dosage of the FR oxidant, 3) quantify the peroxide soil oxidant demand of the Site soil tested. The oxidant concentrations at reaction times of 2 hours, 4 hours and 1 day was measured. All tests were conducted in duplicate.

Task 3: Jar Test Oxidation of the Site Soil with the Catalyzed Persulfate Oxidation Process and Soil Oxidant Demand.

This test was conducted for the following reasons: 1) to investigate the influence of catalyzed persulfate concentrations on organic contaminant degradation, 2) determine the treatment efficiency and necessary field dosage for the catalyzed persulfate oxidant, and 3) quantify the persulfate soil oxidant demand of the Site soil tested. This test was conducted with Fe(III) ethylenediaminetetraacetic acid (EDTA) as the catalyst. The oxidant concentrations at reaction times of 1, 4 and 10 days was measured. All tests were conducted in duplicate.

Task 4: Jar Test Oxidation of Site Soil with the RegenOx™ Oxidation Process and Soil Oxidant Demand.

This test was conducted for the following reasons: 1) to investigate the influence of RegenOx™ concentrations on organic contaminant degradation, 2) determine the treatment efficiency and necessary field dosage for the RegenOx™ oxidant, and 3) quantify the RegenOx™ soil oxidant demand of the Site soil tested. The oxidant concentrations at reaction times of 1, 4 and 10 days was measured. All tests are conducted in duplicate.

Task 5: Soil Column Oxidation Test

Two soil column oxidation tests were conducted using intact soil cores from the two soil samples collected to simulate the behavior of the oxidants in the Site subsurface. FR was selected as the oxidant for column testing because the jar test results for the FR oxidant were the best of the 3 oxidants tested under Tasks 2 through 4. The FR reagents were pumped into the column in an upflow mode, while the reagent volume injected was recorded. The dosage and concentration of the FR reagents for the column test were determined from the jar test results.

After the soil column test was completed, soil from each column was collected for sampling. The soil samples were homogenized to obtain a representative sample, and analyzed for VOCs, SVOCS, TCLP-benzene, TCLP-Pb, total Pb, and TEL. In addition, measurements of COCs, water quality parameters and residual oxidant were collected at days 7, 14, and 21 in the soil column effluent. The volume of gas generated was also measured, and the VOCs in the gas phase were analyzed.

The results of the ISCO jar and soil column bench tests are presented below.

5.1.3 ISCO Jar Test Results

Tables 5.1 and 5.2 shown below summarize the results of the ISCO jar test results for the two soil samples tested.

Table 5.1
ISCO Jar Test Results – Soil 1
Chevron Soil ID – S2249RG2

Constituent	Concentration in Soil (mg/kg)						
		Oxidant Tested and Post-Treatment Sample Results					
	Pre-Treatment Sample Result	Fenton's Reagent with 15% Hydrogen Peroxide	Fenton's Reagent with 25% Hydrogen Peroxide	20 g/L Activated Persulfate	40 g/L Activated Persulfate	18 g/L Regen-OX	54 g/L Regen-OX
Benzene	231.5	4.8	5.75	100.55	39.45	123.95	55.30
Total VOCs	831.9	104.2	103.53	487.95	278.80	521.71	369.47
Benzo(a)pyrene	4.0	1.9	2.25	5.30	5.66	17.60	18.55
Total SVOCs	903.5	74.9	83.46	112.58	123.50	88.54	105.50

Constituent	Oxidant Tested and Removal Efficiency (% Concentration Reduction)					
	Fenton's Reagent with 15% Hydrogen Peroxide	Fenton's Reagent with 25% Hydrogen Peroxide	20 g/L Activated Persulfate	40 g/L Activated Persulfate	18 g/L Regen-OX	54 g/L Regen-OX
Benzene	98	98	57	83	46	76
Total VOCs	87	88	41	66	37	56
Benzo(a)pyrene	53	44	NA	NA	NA	NA
Total SVOCs	92	91	88	86	90	88

The jar test results for Soil 1 show that the FR oxidant represented by the 15% and 25% hydrogen peroxide columns performed the best in reducing the levels of benzene and total VOCs. The removal efficiency for benzene was 98% with both 15 and 25% hydrogen peroxide catalyzed with iron (FR). The removal efficiency for benzene ranged from 57 to 83% with activated persulfate, and ranged from 46 to 76% with Regen-Ox. The removal efficiency for total VOCs ranged from 87 to 88% with FR, 41 to 66% with activated persulfate, and 37 to 56% with Regen-Ox.

The jar test results for Soil 1 also show that FR performed the best in reducing the levels of SVOCs including benzo(a)pyrene. The removal efficiency for benzo(a)pyrene was 53% and 44% with 15 and 25% FR, respectively. The removal efficiency for benzo(a)pyrene for activated persulfate and Regen-Ox could not be calculated as the pre-treatment soil concentration was less then the post-treatment concentrations for these oxidants. The removal efficiency for SVOCs was 92 and 91% with 15 and 25% FR, respectively. The

removal efficiency for SVOCs ranged from 86 to 88% with activated persulfate, and ranged from 88 to 90% with Regen-Ox.

The estimated soil oxidant demand (SOD) was 781 g/kg with 15% FR and 1,303 g/kg with 25% FR. The estimated SOD was 85.3 g/kg and 162.5 g/kg with 20 and 40 g/L activated persulfate, respectively. The estimated SOD was 92.5 g/kg and 281 g/kg with 18 and 54 g/L Regen-Ox, respectively. While FR had the highest SOD, it also had the highest removal efficiency.

Table 5.2
ISCO Jar Test Results – Soil 2
Chevron Soil ID – S1016RC1

Target Constituent	Concentration in Soil (mg/kg)						
	Pre-Treatment Sample Result	Oxidant Tested and Post-Treatment Sample Results					
		Fenton's Reagent with 15% Hydrogen Peroxide	Fenton's Reagent with 25% Hydrogen Peroxide	20 g/L Activated Persulfate	40 g/L Activated Persulfate	18 g/L Regen-OX	54 g/L Regen-OX
Benzene	3.78	0.26	0.28	1.45	1.24	0.67	0.90
Total VOCs	143.40	33.55	39.25	140.75	74.54	100.18	117.46
Benzo(a)pyrene	1.20 U	0.20	0.13	13.45	13.45	0.46	0.41
Total SVOCs	41.00	16.07	8.61	22.27	22.28	23.79	24.13

Target Constituent	Oxidant Tested and Removal Efficiency (% Concentration Reduction)					
	Fenton's Reagent with 15% Hydrogen Peroxide	Fenton's Reagent with 25% Hydrogen Peroxide	20 g/L Activated Persulfate	40 g/L Activated Persulfate	18 g/L Regen-OX	54 g/L Regen-OX
Benzene	93	93	62	67	82	76
Total VOCs	77	73	2	48	30	18
Benzo(a)pyrene	NA	NA	NA	NA	NA	NA
Total SVOCs	61	79	46	46	42	41

The jar test results for Soil 2 show that FR performed the best in reducing the levels of benzene and total VOCs. The removal efficiency for benzene was 93% with both 15 and 25% FR. The removal efficiency for benzene ranged from 62 to 67% with activated persulfate, and ranged from 76 to 82% with Regen-Ox. The removal efficiency for total

VOCs ranged from 77 to 73% with FR, 2 to 48% with activated persulfate, and 18 to 30% with Regen-Ox.

The jar test results for Soil 2 also show that FR performed the best in reducing the levels of SVOCs. The removal efficiency for SVOCs was 61 and 79% with 15 and 25% FR, respectively. The removal efficiency for SVOCs was 46% with activated persulfate, and ranged from 41 to 42% with Regen-Ox. Benzo(a)pyrene was not detected above the method detection limit of 1,200 ug/kg in the pre-treatment soil sample. Consequently, the removal efficiency of benzo(a)pyrene could not be calculated. However, post-treatment results show that both FR and Regen-Ox were able to reduce the benzo(a)pyrene concentrations below 500 ug/kg.

The estimated SOD was 778 g/kg with 15% FR and 1,298 g/kg with 25% CFR. The estimated SOD was 85.3 g/kg and 162.5 g/kg with 20 and 40 g/L activated persulfate, respectively. The estimated SOD was 92.5 g/kg and 281 g/kg with 18 and 54 g/L Regen-Ox, respectively. While FR had the highest SOD, it also had the highest removal efficiency.

In summary, the ISCO jar tests with both soil samples show that ISCO using FR is the most effective in reducing the concentrations and mass of VOCs and SVOCs in the shortest timeframe at the Site. The oxidant demand for FR is high due to its high reactivity with other interfering oxidizable materials in the soil fill material.

5.1.4 ISCO Soil Column Test Results

The ISCO jar tests confirmed that FR was the best oxidant in terms of its removal efficiency. Consequently, it was selected as the oxidant to use in the soil column test. Table 4.3 below summarizes the soil column test aqueous effluent results.

Total VOCs in the column effluent at Day 7, Day 14 and Day 21 were measured at 178.4, 294.4 and 192.5 ug/L, respectively. The total VOCs is the sum of VOCs detected minus acetone and 2-butanone. These compounds are degradation products of natural organic matter such as peat. Benzene was detected at a concentration of 33 ppb on Day 7, 43 ppb on Day 14, and 26 ppb on Day 21. Total SVOCs were detected at 400.4, 1,366 and 553 ug/L on Day 7, Day 14 and Day 21, respectively.

The residual peroxide concentration in the effluent increased from 0.658 g/L on Day 7 to 1.31 g/L on Day 21, indicating that the demand for oxidant was diminishing over time as the contaminants were being oxidized.

Table 5.3
ISCO Soil Column Test Aqueous Results – Soil 2

Constituent	Concentration in Aqueous Column Effluent (ug/L)		
	Day 7	Day 14	Day 21
VOCs (ug/L)			
Acetone	6,000	8,600	9,300
Benzene	33 J	43	26 J
2-Butanone	340	470	570
Ethylbenzene	<3.3	22	16 J
Methylene chloride	12 J	<4.4	12
Toluene	<7.1	13	<7.1
1,2,4-Trimethylbenzene	26 J	40	30 J
1,3,5-Trimethylbenzene	10 J	15	10 J
m,p-Xylene	65	120	83
o-Xylene	22 J	37	27 J
SVOCs (ug/L)			
Acenaphthene	<6.6	74 J	33 J
Anthracene	<7.5	100 J	41 J
Benzo(a)anthracene	<7.4	32 J	<25
Benzo(a)pyrene	<7.8	30 J	<26
Benzo(b)fluoranthene	<12	29 J	<40
Benzo(k)fluoranthene	<8.8	17 J	<29
Bis(2-ethylhexyl)phthalate	<20	<36	51 J
Chrysene	<8.8	94 J	47 J
Dibenzofuran	<5.8	<10	28 J
2,4-Dimethylphenol	290	130 J	<80
Fluoranthene	<8.0	130 J	59 J
Fluorene	<6.7	71 J	36 J
1-Methylnaphthalene	<6.3	120 J	54 J
2-Methylnaphthalene	<6.6	50 J	<22
4-Methylphenol	<8.8	19 J	<29
Phenanthrene	<8.0	370	150 J
Pyrene	<7.1	100 J	54 J
Wet Chemistry Parameters			
Dissolved oxygen, mg/L	6.77	8.20	12.7
pH	3.99	3.03	2.40
ORP, mV	483.8	585.9	632.4
Conductivity, mS/cm	2.84	4.48	6.11
Peroxide, g/L	0.658	1.01	1.31

Notes:
1. ORP = oxidation reduction potential
2. J = indicates that the detected concentration is below the practical quantitation limit (PQL) of the analytical method

Following the completion of the ISCO soil column test on Day 22, a soil sample was collected for analysis and comparison with the pre-treatment soil sampling results. The post ISCO soil column test soil sampling results for VOCs are presented in Table 5.4 below.

Table 5.4
ISCO Soil Column Test Soil Results – Soil 2

Constituent	Concentration in Soil (mg/kg)		
	Pre-Treatment Samples		Day 22 Post-Treatment Sample from Column
VOCs	S1016RC1	S1016RC1 (duplicate)	
Acetone	<14.90	<14.80	11.00
Benzene	4.77	2.78	3.00
n-Butylbenzene	5.84	0.91	0.68
sec-Butylbenzene	2.33	0.20	0.094
Ethylbenzene	3.46	1.65	2.50
Isopropylbenzene	6.01	1.11	0.67
4-Isopropyltoluene	3.14	0.20	0.066
Naphthalene	8.01	7.74	1.20
n-Propylbenzene	12.80	2.30	0.87
Toluene	1.58	<0.27	1.50
1,2,4-Trimethylbenzene	72.10	29.60	6.50
1,3,5-Trimethylbenzene	35.80	9.39	2.00
m,p-Xylene	46.80	22.10	11.00
o-Xylene	2.92	2.69	2.60
Total VOCs	205.56	80.67	32.68
Average VOCs	143.12		32.68
Average Benzene	3.78		3.00
%Reduction VOCs			77
% Reduction Benzene			21

The results of the ISCO soil column test indicate that there was a 77% reduction in total VOCs and a 21% reduction in benzene concentrations. The reduction in benzene is low compared to that observed in the jar test (93%) with FR for Soil 2.

The complete results of the ISCO bench test are summarized in the final report entitled "Treatability Report" dated June 26, 2008, and included in Appendix C3. Table 22 of this Treatability Report shows the concentrations of VOCs collected in the soil gas sample from the column test. Using the total volume of gas generated during the 22 day ISCO soil column test, approximately 413 ug of VOCs were lost in the gas generated from the ISCO reaction. This is a negligible amount of VOCs in the gas phase (0.0013%) as compared to

the initial mass of VOCs in the soil column (31,342 ug) based on the soil mass in the column (219 g) and the initial VOC concentration in the soil (143,116 ug/kg).

The SVOC data for the ISCO soil column test were inconclusive in determining the mass removal of SVOCs due to method detection limit problems, with the exception of 1-methylnaphthalene and 2-methylnaphthalene. The concentrations of 1-methylnaphthalene and 2-methylnaphthalene in the soil column were decreased by 57 % and 79 % respectively when compared to the pre-treatment concentrations found in the soil.

5.1.5 ISCO Pilot Test

In order to further evaluate the effectiveness of ISCO in treating the organic contaminated soil and groundwater at the Site, a pilot test was performed in September/October 2008 in SWMU 43 in the vicinity of S2249, the area with the best ISCO bench test results.

The objectives of the pilot test are as follows: 1) to confirm the effectiveness of ISCO in treating the organic contaminated soil and groundwater at the Site, and 2) to obtain engineering data to finalize the design of the full scale ISCO remediation including the injection flow rates of the reagents, the injection pressures, and the radius of influence around the injection point. The duration of the pilot test was approximately two weeks. Based on the results of the bench tests, FR was the selected oxidant for the pilot test. The pilot test will also provide information to refine the ISCO cost estimate, as well as determine the duration of treatment.

The scope of work for the ISCO pilot test consisted of the following activities: 1) installation of an injection point and piezometer, 2) mobilization, 3) injection of ISCO chemicals, 4) post-pilot test sampling, and 5) preparation of an ISCO Pilot Test Report.
Following receipt of the ISCO pilot test post-treatment results, an ISCO Pilot Test Report will be prepared for submission to the USEPA and NJDEP providing the results of the ISCO pilot test. The report will contain the pre-pilot test data, a summary of the pilot test activities, the post-pilot test data, an evaluation of the pilot test regarding its effectiveness in degrading the VOC and SVOC contaminated soil and groundwater in the vicinity of the test, and its radius of influence.

5.1.6 Evaluation of ISCO Technology

5.1.6.1 Overall Protection of Human Health and the Environment

ISCO significantly reduces the levels of contamination in soil and groundwater, thereby reducing the potential for direct exposure and groundwater impacts and, as a result, provides for protection of human health and the environment.

5.1.6.2 Compliance with Applicable Standards

ISCO will meet the applicable criteria/standards for the Site soil and groundwater through direct destruction /oxidation of soil and groundwater contaminants.

5.1.6.3 Long-Term Effectiveness and Permanence

ISCO destroys organic contamination in both soil and groundwater. Therefore, it is very effective in the long term and its effects on contamination are permanent.

5.1.6.4 Reduction of Toxicity, Mobility, or Volume through Treatment

ISCO reduces the toxicity, mobility and volume of contamination in both soil and groundwater by converting it into carbon dioxide, water and minerals.

5.1.6.5 Short-Term Effectiveness

The implementation of ISCO results in minimal impacts to human health and the environment. The ISCO tasks will be performed on-site. During the injection of ISCO reagents, there is minimal risk for exposure to the Site workers from volatilized contaminants. This risk will be mitigated through the use of the appropriate personal protective equipment (PPE) and air quality monitoring.

As mentioned above, ISCO destroys organic contamination in both soil and groundwater, and ISCO reactions occur very rapidly. Rebound effects in groundwater can occur if an insufficient amount of ISCO reagents is injected into the subsurface to destroy the bulk of the contamination, which is typically adsorbed to the saturated zone soil. Therefore, when designed properly to address the saturated zone soil contamination, ISCO is very effective in the short term.

5.1.6.6 Implementability

ISCO is a proven technology and can easily be implemented at the site. A permit for implementing ISCO is issued following a Request for Authorization of Discharge to Groundwater by Permit by Rule under N.J.A.C. 7:14A-7.5. This permit is typically granted within one to two months following submission of its request provided it includes the information necessary for the NJDEP to evaluate the proposed discharge to groundwater. Finally, the equipment as well as the chemicals required to implement ISCO are readily available.

5.1.6.7 Cost

The unit cost of ISCO for the applicable areas to be treated at the Site is approximately $40/cubic yard based on average unit costs for full-scale ISCO treatment of petroleum contaminated soils given at the 21st Annual International Conference on Soils, Sediments and Water ISCO Workshop on October 17, 2005 in Amherst, MA.

5.2 LOW TEMPERATURE THERMAL DESORPTION

5.2.1 Description

LTTD is an ex-situ remedial technology that uses heat to physically separate petroleum hydrocarbons from excavated soils. Thermal desorbers are designed to heat soils to temperatures sufficient to cause constituents to volatilize from the soil. Although they are not designed to destroy organic contaminants, thermal desorbers can cause some of the contaminants to completely or partially decompose depending upon the specific organics present and the temperature of the desorber system. The vaporized hydrocarbons are generally treated in a secondary treatment unit (e.g., an afterburner, catalytic oxidation chamber, condenser, or carbon adsorption unit) prior to discharge to the atmosphere. Afterburners and oxidation chambers destroy the organic contaminants, while condensers and carbon units transfer the contaminants to the liquid and solid phases, respectively. Some pre- and post-processing of soil is necessary when using LTTD. Excavated soils are first screened to remove large (greater than 2 inches in diameter) objects. These objects may be sized (e.g., crushed or shredded) and then recycled back to the feed material. After leaving the desorber, soils are cooled, re-moistened to control dust, and stabilized (if necessary) to increase their unconfined compressive strength and prepare them for

disposal/reuse. Organic contamination is generally completely removed from soil following LTTD treatment. Therefore, treated soil may be recycled on-site.

5.2.2 LTTD Pilot Test Results

In order to further evaluate the applicability of LTTD to remediate the organic contamination in the Site soil, TD*X Associates performed a pilot test on the thermal desorption treatment of samples collected from the Site in November 2007. A TD*X high performance thermal desorption unit (TDU) was used to treat composite soil samples collected by Entact in the vicinity of soil boring location S1016 in the SWMU 18 area between tanks 300, 301, 326, and 327, and in the vicinity of soil boring S2249 in SWMU 43 between the concrete pad and the surge pond. The pilot test was conducted at TD*X's Robstown, NC facility. The goals of the LTTD test were as follows: 1) determine the level of organic reduction achievable from the samples using the TD*X high performance thermal desorption unit at varied operating conditions, and 2) compare the treated soil residual contaminant levels with the RCRA LDR Universal Treatment Standards (UTS), applicable to the SWMU 43 soil.

The high performance TDU is a waste separation technology that was developed to separate organic contaminants from soil. Prior LTTD treatment performed by TD*X on organic contaminated soils have shown that very low residual organic concentrations can be achieved in the treated soils. The test equipment and protocol used by TD*X are highly representative of full-scale equipment. The pilot high performance TDU that was used for this test has a working capacity of up to 4 liters, and a maximum achievable solids temperature of 1,300 °F. For this test, three different treatment temperatures were used on the contaminated soils to give a range of residual levels in the treated soils.

The feed consisted of four one gallon soil samples that were received from Entact. The four containers were labeled S1016 1 of 2, S1016 2 of 2, S2249 1of 2 and S2249 2 of 2. The four samples were combined into a five gallon container and thoroughly mixed. Three composite samples were then tested in this LTTD pilot test. The procedure for each test was to feed the soil with the LTTD unit operating at a normal furnace temperature of about 600 °F, and then allow the soil to heat to the "treatment" temperature, with the furnace set about 100-150 °F higher than this desired endpoint temperature. This is very close to the actual practice in a full-scale LTTD unit, where the soils are normally allowed to heat until they achieve the treatment temperature prior to being discharged from the unit as treated soils. Table 5.5 describes the summary of operating conditions for the three samples tested in this LTTD pilot test.

Table 5.5
Summary of Operating Conditions for the LTTD Pilot Test

Sample ID	Run Date / Feed Mass (lb)	Furnace Temp Drying (°F) / Drying Time (min)	Furnace Temp Heating (°F) / Heating Time (min)	Final Soil Temp (°F) / Total Heating Time (min)	Condensate (lb)
Run#1	12/20/07	818	788	700	
Perth – 071220A	12.65	50	57	107	3.5
Run#2	12/20/07	882	995	850	
Perth – 071220A	11.05	45	49	94	2.73
Run#2	12/20/07	844	1,105	1,000	
Perth – 071220A	11.82	40	60	100	2.75

Furnace Temp Drying – Initial dryer furnace temperature used to remove water from the sample during feeding. After feeding is terminated and the bulk of the water is removed, the temperature is increased to the Furnace Temp Heating temperature.
Drying Time – Time from when heat is initially applied to the material until the bulk of the water has been removed from the material.
Furnace Temp Heating – Final dryer furnace temperature condition used to heat the soil after the water has been removed from it.
Heating Time – Time required to adjust the soil to the target temperature after the water has been removed.
Final Soil Temp – Final soil temperature is the soil temperature just before turning off the furnace at the end of the LTTD pilot test run.
Total Heating Time – The total time that the material is in the furnace.

Tables 5.6 and 5.7 show the overall mass balance achieved and the analytical results, respectively, for the three test runs. The overall mass balance results of the LTTD test show that 95% of the soil masses of each of the runs were recovered, with the bulk of the masses (50%) ending up in the vapor phase. The analytical results of the LTTD pilot test indicate that the contaminant concentrations in the treated soils are all well below their respective RCRA LDR UTSs, with the overwhelming majority of contaminants being undetected. Therefore, implementation of indirect heated thermal desorption treatment at the Site would successfully remove organic compounds to very low levels.

The complete results of the LTTD pilot test are presented in the final report entitled "Pilot Demonstration Results for Thermal Desorption Treatment of Contaminated Soil from

Chevron's Facility in Perth Amboy, NJ" dated January 15, 2008, which is included as Appendix C2.

Table 5.6
Overall Mass Balance for the LTTD Pilot Test

Test Run (Batch Number)	Mass In (lb)	Mass Out (lb)	% Recovery
Run 1	12.65	5.91	
Run 2	11.05	5.88	
Run 3	11.82	5.98	
Condensed water (Runs 1-3)		8.98	
Solids Carryover (Runs 1-3)		7.02	
TOTAL (Runs 1-3)	**35.52**	**33.77**	**95.1**

Table 5.7
Summary of Analytical Results for the LTTD Pilot Test

Final Soil Temperature			<700 °F		<850 °F		<1000 °F	
Sample	PREP	FEED 1	PRODUCT 1	FEED 2	PRODUCT 2	FEED 3	PRODUCT 3	
TDX Sample ID	309-03-13	309-3-29	309-4-4	309-4-6	309-4-12	309-4-17	309-4-23	
USET LIMS No.	80215	80536	80531	80535	80528	80532	80526	RCRA LDR UTS
Constituent								
VOCs (mg/kg)								
Benzene	8.89	3.58	0.97	1.55	U (0.50)	1.02	U (0.50)	10
Ethylbenzene	47.37	7.70	U (0.50)	5.17	U (0.50)	2.84	U (0.50)	10
Methylene Chloride	U (0.50)	1.49	0.54	1.08	0.57	1.26	0.69	30
Toluene	10.98	2.91	1.96	1.92	U (0.50)	1.09	U (0.50)	10
Xylenes (total)	153.79	31.65	U (0.50)	29.35	U (0.50)	16.50	U (0.50)	30
SVOCs (mg/kg)								
Acenaphthene	U (0.25)	U (0.25)	U (0.25)	U (0.25)	U (0.25)	0.28	U (0.25)	3.4
Anthracene	U (0.25)	0.58	U (0.25)	U (0.25)	U (0.25)	U (0.25)	U (0.25)	3.4
Benzo(a)anthracene	U (0.25)	0.44	U (0.25)	U (0.25)	U (0.25)	U (0.25)	U (0.25)	3.4
Chrysene	U (0.25)	1.04	U (0.25)	0.29	U (0.25)	0.25	U (0.25)	3.4
Fluoranthene	24.85	1.34	U (0.25)	U (0.25)	U (0.25)	U (0.25)	U (0.25)	3.4
Fluorene	9.94	U (0.25)	U (0.25)	U (0.25)	U (0.25)	U (0.25)	U (0.25)	3.4
Naphthalene	63.12	4.62	0.51	1.52	0.60	1.28	0.30	5.6
Phenanthrene	31.81	2.04	U (0.25)	U (0.25)	U (0.25)	0.70	U (0.25)	5.6
Pyrene	U (0.25)	U (0.25)	U (0.25)	U (0.25)	U (0.25)	0.35	U (0.25)	8.2
Hexachlorobenzene	7.55	U (0.25)	U (0.25)	U (0.25)	U (0.25)	U (0.25)	U (0.25)	NA
bis(2-Ethylhexyl)phthalate	U (0.25)	0.58	1.67	U (0.25)	0.70	U (0.25)	U (0.25)	28
di-n-butyl phthalate	U (0.25)	U (0.25)	U (0.25)	U (0.25)	0.54	U (0.25)	U (0.25)	NA
2,4-dinitrotoluene	U (0.25)	U (0.25)	U (0.25)	U (0.25)	2.05	U (0.25)	2.52	140
di-n-octyl phthalate	U (0.25)	U (0.25)	U (0.25)	U (0.25)	0.53	U (0.25)	U (0.25)	NA
phenol	9.84	U (0.25)	0.74	U (0.25)	U (0.25)	U (0.25)	U (0.25)	6.2
Total solids, % wet wt.	77.0	67.5	99.8	67.3	99.9	66.6	99.9	
pH	7.52	4.54	4.69	7.23	6.36	4.75	8.74	
Test America LIMS No.	560-7946-1	560-8086-5	560-8086-6	560-8086-1	560-8086-2	560-8086-3	560-8086-4	
TDX Sample Id No	309-03-14	309-3-30	309-4-4	309-4-6	309-4-12	309-4-17	309-4-23	
TPH, mg/kg wet wt.	15,000	19,000	J 200	19,000	J 50	23,000	U (35)	
Ash content, % wet wt.	57	57	90	60	86	56	91	
Bulk density, loose g/cc	-	1.19	1.13	1.50	1.09	1.50	1.14	
Bulk density, packed g/cc	-	1.63	1.13	1.87	1.09	1.75	1.14	

Notes:
- = test not requested
NA = test not applicable
U (a) = Undetected below the analytical method's practical quantitation limit (PQL), "a" is the respective PQL

5.2.3 Evaluation of LTTD Technology

5.2.3.1 Overall Protection of Human Health and Environment

LTTD significantly reduces the levels of contamination in soil, thereby reducing the potential for direct exposure and providing for the protection of human health and the environment.

5.2.3.2 Compliance with Applicable Standards

LTTD will meet the RCRA LDR UTSs for the Site soil, as well as other applicable soil criteria/standards, through thermal desorption of the contaminated soil.

5.2.3.3 Long-term Effectiveness and Permanence

LTTD desorbs and volatilizes organic contamination in soil. Therefore, it is very effective in the long-term and its effects are permanent.

5.2.3.4 Reduction of Toxicity, Mobility or Volume through Treatment

LTTD reduces the toxicity, mobility and volume of contamination in soil by desorbing and volatilizing it. Volatilized contaminants are typically destroyed or removed from the vapor phase using afterburners, catalytic oxidation chambers, condensers, or carbon adsorption units. The treated soils can then be recycled on-site following any necessary determination that the soils meet all applicable criteria/standards.

5.2.3.5 Short-Term Effectiveness

The implementation of LTTD will result in minimal impacts to human health and the environment. The LTTD tasks would be performed on-site. There will be minimal risk for exposure to site workers from volatilized contaminants that would be mitigated through the use of the appropriate PPE and air quality monitoring. As mentioned above, LTTD desorbs and volatilizes organic contamination in soil within a short period of time (less than two hours for each of the test runs). Therefore, LTTD is very effective in the short term.

5.2.3.6 Implementability

LTTD is a proven technology, which can be implemented on-site, or excavated soil can be transported to a fixed LTTD facility off-site. Indirect-fired LTTD units are not considered incinerators by USEPA and NJDEP. Therefore, it is much easier to obtain an air permit for an indirect-fired LTTD unit, as opposed to a direct-fired unit. Finally, portable LTTD units are readily available, as well as permitted in the state of New Jersey.

5.2.3.7 Cost

The unit cost for LTTD treatment on-site is $100/ton or $150/cubic yard based on a unit cost estimate given by TD*X. Off-site LTTD treatment costs would generally be higher than on-site costs because of the additional transportation costs to haul contaminated soil to a fixed LTTD facility.

5.3 STABILIZATION

5.3.1 Description

Stabilization is a commonly used technology for treating soil contaminated with metals. Stabilization uses various binders to chemically react with or physically encapsulate metal contamination to significantly reduce its leachability. Stabilization can be performed either in-situ or ex-situ.

In-Situ Stabilization is typically applied in the following cases: 1) when metals contaminated soil can be left in place after treatment, and 2) when metals contaminated soil is too saturated or does not have a sufficient unconfined compressive strength (UCS) to handle efficiently with equipment necessary to excavate it to conduct ex-situ stabilization.

Ex-Situ Stabilization is typically applied in the following cases: 1) when metals contaminated soils cannot be left in place after treatment either because of the high metal concentrations or redevelopment plans, and 2) when metals contaminated soil has a sufficient UCS to be handled efficiently with excavation equipment.

5.3.2 Stabilization Bench Test Results

In order to further evaluate the applicability of stabilization to remediate the metals contamination (predominantly lead) in the Site soils, Entact conducted a stabilization bench test in May 2008 in their laboratory in Friendswood, Texas. The purpose of the bench test was to test several stabilization binders and binder to soil ratios to determine the optimum binder and ratio for reducing the leachability of lead contaminated soil at the Site.

Two soil samples from Site locations with the highest lead concentrations were collected for the bench-scale test. The soil samples were collected from the following locations: 1) soil boring location S2387 in SWMU 8 in the East Yard, the location with the highest lead concentration at the refinery (176,000 mg/kg), and 2) soil boring location S2197 in the Main Yard, the location with the highest lead contamination in the Main Yard (20,500 mg/kg). These samples were collected in appropriate sampling containers and shipped under ice in a cooler to Entact's Laboratory in Friendswood, TX.

The collected samples were homogenized separately to obtain uniform conditions prior to being sampled and analyzed for TCLP lead levels. The soil samples S2197RB2 and S2387RF4 exhibited pre-stabilization TCLP lead levels of 11.7 mg/l and 1,240 mg/l, respectively.

Three binders were chosen for the bench test based on Entact's past experience with stabilizing similar lead-contaminated soils: 1) tri-sodium phosphate (TSP), 2) Enviroblend 80/20 from Premier Chemicals (a phosphate-based binder), and 3) Redoxite from Redox Solutions (an iron sulfide compound). Additionally, the following binder to soil ratios were used as part of the bench test: 1) 5%, 7.5%, and 10% by weight for Enviroblend 80/20, 2) 5% and 10% for TSP, and 3) 5% and 10% for Redoxite.

A summary of the binders and binder to soil ratios used in this bench test are shown in Table 5.8 below.

Table 5.8
Summary of Stabilization Bench Test
Binders and Binder to Soil Ratios

Binder	Binder to Soil Ratios (% by weight)
Enviroblend 80/20	5% - 7.5% - 10%
Tri-Sodium Phosphate	5% - 10%
Redoxite	5% - 10%

The binders were completely mixed with each of the two soil samples at each of the binder to soil ratios shown in Table 5.8 using mixing bowls and a Kitchen Aid blender. A total of seven binder/soil mixes were prepared for each soil sample. Following homogenization, these mixtures were allowed to sit to allow the stabilization reactions to go to completion. After approximately three days, post-treatment soil samples were collected from each mixture, placed in appropriate sampling containers, and shipped to Lancaster Laboratories for analysis of TCLP lead. The stabilization bench test results are shown in Table 5.9 below.

Table 5.9
Summary of Stabilization Bench Test TCLP Lead Results

Soil Sample ID	Pre-Treatment Sample Results	Binders and Binder to Soil Ratios for Post-Treatment Sample Results (mg/L)						
		Enviroblend (80/20)			TSP		Redoxite	
		5%	7.5%	10%	5%	10%	5%	10%
S2197RB2	11.7	ND	ND		ND	0.0141	49.5	257
S2387RF4	1,240	0.740		1.07	271	0.155	2,730	67,200

The results of this bench test showed that Enviroblend 80/20 performed the best in reducing the lead leachability in the stabilized soil to below 5 mg/L, its RCRA TCLP Characteristic Hazardous Level, in both soil samples. There was no correlation between TCLP results and binder to soil ratio for Enviroblend (80/20). Additionally, TSP successfully reduced the lead leachability in both soil samples in the 10% binder to soil ratio test. Finally, Redoxite increased the lead leachability in the stabilized soil in proportion to the binder to soil ratio. Given these results, either Enviroblend (80/20) at a 5% binder to soil ratio or TSP at a 10% binder to soil ratio should be used for stabilizing lead contaminated soils at the Site, depending on the cost of these binders used at the aforementioned binder to soil ratios. It also may be possible to use a lower binder to soil ratio for Enviroblend (80/20) if additional

testing is conducted to determine the lowest ratio capable of reducing TCLP lead levels below 5 mg/L.

The complete results of the stabilization bench test are summarized in the final report entitled "Bench Scale Treatability Study" dated May 19, 2008, and included as Appendix C1.

5.3.3 Evaluation of Stabilization Technology

5.3.3.1 Overall Protection of Human Health and Environment

Stabilization with the appropriate binder significantly reduces the leachable levels of metals, especially lead, in soil, thereby reducing the potential for direct exposure and groundwater impacts, and providing protection of human health and the environment.

5.3.3.2 Compliance with Applicable Standards

Stabilization will meet the applicable TCLP-lead regulatory level for the Site soil by reducing its leachability.

5.3.3.3 Long-Term Effectiveness and Permanence

Stabilization immobilizes metals contamination in soil, and is especially effective with lead, a dense, low mobile metal. Additionally, hazardous metals contaminated soils will be treated using ex-situ stabilization and disposed in a CAMU with a double liner, a cap, and a leachate collection system, thereby insuring the permanence of this technology. In-situ stabilization of non-hazardous lead contaminated soils has been shown to be effective in the long-term at other sites with similar levels of contamination.

5.3.3.4 Reduction of Toxicity, Mobility, or Volume through Treatment

Stabilization reduces the mobility and, hence, the toxicity of metals contaminated soils, especially lead.

5.3.3.5 Short-Term Effectiveness

The implementation of stabilization will result in minimal impacts to human health and the environment. The stabilization tasks will be conducted on-site. During both ex-situ and in-

situ applications, there is minimal risk for exposure of site workers to lead contaminated soil. This risk will be mitigated through the use of the appropriate PPE and air quality monitoring during tasks with the potential for exposure to nuisance dust containing lead such as during excavation and in-situ soil mixing activities. As mentioned in Section 4.3.2, stabilization reactions with the binders used in the bench test occur rapidly (within three days). Therefore, stabilization is anticipated to be very effective in the short-term.

5.3.3.6 Implementability

Stabilization is a proven technology and can be implemented at the Site. Ex-situ stabilization involves the use of a pug mill or other methods to mix the metals contaminated soils and stabilization binders; while in-situ stabilization involves the use of a back hoe or other earth moving equipment to conduct this mixing activity. Stabilization equipment is readily available. For the most part, the soils that are to be treated for lead at the site are miscellaneous granular fill and sandy deposits. These surface soils are underlain by silty and clayey soils forming a barrier to downward migration of contaminants. Granular soils with little fines are generally easy to work with using excavation equipment and mechanical mixers to achieve uniform distribution in the soil of the stabilization binders.

5.3.3.7 Cost

The unit cost of in-situ and ex-situ stabilization are approximately $35 ton and $50 ton, respectively. Ex-situ stabilization costs are higher than in-situ stabilization because of the additional transportation and backfill costs required with this technology. These unit costs are based on Entact's recent experience in performing stabilization at similar sites.

5.4 MONITORED NATURAL ATTENUATION

5.4.1 Description

Natural attenuation is defined by the USEPA as the biodegradation, diffusion, dilution, sorption, volatilization, and/or chemical and biochemical stabilization of contaminants to effectively reduce contaminant toxicity, mobility, or volume to levels that are protective of human health and the environment (USEPA. 1999).

MNA is being further evaluated as a potential CM for non-source groundwater areas or, in other words, groundwater outside the source areas which coincide with benzene concentrations ranging from 1 ug/L to 100 ug/L.

5.4.2 Evaluation of MNA Groundwater Sampling Results

In order to evaluate the potential to implement MNA, geochemical data from the monitoring wells located in the Main Yard, East Yard and Central Yard of the Site were analyzed. A total of approximately 80 wells throughout these yards were sampled and analyzed for groundwater geochemical (MNA) parameters between 2002 and 2007. These data were analyzed to evaluate the potential for MNA to effectively reduce low levels of organic contamination in the groundwater.

MNA parameters such as total alkalinity, pH, ORP, sulfates, sulfides, dissolved iron, total iron, DO, and nitrates provide information on the biodegradation potential of the contaminated media. When biological processes occur, there is a depletion of DO followed by a switch to the next most favorable electron acceptors in the order of nitrates, iron, sulfates and carbon dioxide (methanogenesis). In addition, there will be a decrease in the ORP indicating the biological processes are driving the media from aerobic to anaerobic conditions. Also, there is an increase in the alkalinity of the system due to the mineralization of VOCs to carbon dioxide. Therefore, comparing the MNA parameters between the groundwater samples results obtained in the contaminated media versus the clean media (background) can provide qualitative information on the biodegradation potential of the contaminated media.

Table 5.10 provides the latest MNA parameter analytical results for the 80 monitoring wells sampled and analyzed for these parameters in the second half of 2007. These results were contoured using Rockworks software and are shown on the following figures: 1) Figure 14 – "Second Half 2007 Groundwater Alkalinity and pH Distribution," 2) Figure 15 – "Second Half 2007 Groundwater ORP Distribution," 3) Figure 16 – "Second Half 2007 Groundwater Sulfate and Sulfide Distribution," 4) Figure 17 – "Second Half 2007 Groundwater Iron Distribution," 5) Figure 18 – "Second Half 2007 Groundwater Dissolved Oxygen Distribution," and 6) Figure 19 – "Second Half 2007 Groundwater Nitrate Distribution." In addition, these figures show the contoured areas for each of the MNA parameters, as well as the trend graphs from 2002 for each of the wells sampled at least twice between 2002 and 2007.

Table 5.10 and Figure 14 show that the pH ranged from 3.72 in well MW-224 to 9.16 in well MW-265, but was generally between 5 and 9 for almost all sample locations, including for the historical data, which is consistent with the range of pHs that can support biological reactions. An increase in pH is generally observed with biological reactions as a result of the production of bicarbonate alkalinity. Total alkalinity was found at relatively high concentrations, ranging from 20.5 in well MW-127 to 2,450 mg/L in well MW 252. As mentioned previously, an increase in alkalinity is related to the transformation of VOCs to carbon dioxide with the consumption of electron acceptors such as DO, nitrates, iron, sulfates and carbon dioxide. Furthermore, trend graphs for the fourteen monitoring wells presented in Figure 14 show that, in general, there was a gradual increase in alkalinity indicating the biotransformation of contaminants of concern to carbon dioxide.

Table 5.10 and Figure 15 indicate that ORP values ranged from -432 in well MW-252 to 160 in well MW-224, with 76% of the values being negative indicating reductive conditions typical of anaerobic biological reactions. Trend graphs for selective wells shown in Figure 15 further illustrate the general decrease in ORP values in most of the monitoring wells over the sampled period (2002 through 2007) further suggesting that reductive, anaerobic conditions were occurring at the Site.

Table 5.10 and Figure 16 show sulfate concentrations ranged from 5.6 mg/L in well MW-156 to 2,940 mg/L in well MW-253; while sulfide concentrations ranged from 0.6 mg/L in well MW-136 to 199 mg/L in well MW-252. Although, sulfate concentrations are approximately an order of magnitude higher than the sulfide concentrations in the Site groundwater, sulfide has the potential to undergo geochemical reactions with metals such as ferrous iron produced during iron reduction or with other dissolved metals in the groundwater to from precipitates. However, several monitoring well locations showed complete depletion of sulfate and production of sulfide including the following: 1) wells MW-237, MW-241, MW-259 and MW-273 in the Main Yard, and 2) wells MW-0090, MW-245, MW-246, MW-256, and MW-270 in the East Yard. This suggests that anaerobic sulfate reduction may be a dominant electron accepting process for the MNA reactions occurring in the Site groundwater.

Table 5.10 and Figure 17 indicate dissolved iron concentrations ranged from 54.2 ug/L in well MW-170 to 416,000 ug/L in well MW-253; while total iron concentrations ranged from 96 ug/L in well MW-186 to 333,000 ug/L in well MW-253. The ratio of dissolved iron to total iron was very high on average for wells where both parameters were analyzed (>90%), demonstrating that dissolved iron was produced because of biological reactions in the

consumption of VOCs, with the concurrent reduction of ferric iron (Fe(III)) to the soluble ferrous iron (Fe(II)). Fe(III) is the most abundant electron acceptor in subsurface soils.

Table 5.10 and Figure 18 show that the DO concentration ranged from 0 mg/L in wells MW 0045 and MW-245 to 6.23 mg/L in well MW-126. 73% of the wells sampled had DO concentrations ≤1 mg/L, indicating the depletion of DO as a result of aerobic biological reactions. In addition, the trend graphs showing the historic data (2002 through 2007) for 41 monitoring wells showed a general decrease in DO concentrations over the sampling period, further suggesting that aerobic biological reactions were responsible for the DO depletion and that biotransformation of COCs was occurring.

Table 5.10 and Figure 19 indicate that the nitrate concentrations ranged from not detected to 6,600 ug/L in well MW-225. Nitrates were not detected in 84% of the sampled wells, demonstrating that they were also consumed by biological reactions. Nitrate is very quickly consumed by biological reactions because the energy yield is very close to that of dissolved oxygen on a molar basis of contaminant destroyed. Trend graphs showing the historic nitrate concentrations (2002 through 2007) show a general decrease in nitrate concentrations in monitoring wells that detected nitrate indicating biological reactions are causing the depletion.

Chevron has already evaluated and implemented MNA as a remedial approach for AOC 36, a chlorinated plume in the southern portion of the Central Yard that emanated from the southwestern portion of the Shops building. MNA parameters analyzed during this evaluation, and documented in Chevron's "Central Yard AOC 36 Triad-Based Approach Chlorinated Plume Investigation Report" dated August 25, 2005 (SAIC. 2005), indicated that daughter products of chlorinated solvents trichloroethane (TCA) and perchloroethylene (PCE), including dichloroethane (DCA), chloroethane (CA), trichloroethylene (TCE), dichloroethylene (DCE), and vinyl chloride (VC), were detected in the area groundwater indicating that anaerobic biological reactions were occurring. Corroborating evidence was identified in the form of low DO concentrations (<1 mg/L), nitrate depletion, and production of dissolved iron and methane, indicating biological degradation through multiple pathways..

Chevron continues to conduct MNA monitoring of the CVOC concentrations in the groundwater in AOC 36. In response to an NJDEP comment on AOC 36 during a July 28, 2011 teleconference, Chevron prepared and sent to the NJDEP, an "AOC 36 Chlorinated Hydrocarbon Exceedences" figure showing chlorinated hydrocarbon groundwater concentrations for AOC 36 monitoring wells from 2006 through 2010. Additionally,

Chevron sent the NJDEP an "AOC 36 CVOC COC Analysis - Central Yard DCE and VC Groundwater Concentration Distributions" figure showing groundwater contours for DCE and VC from their respective NJDEP GWQSs in AOC 36, as well as trend graphs for monitoring wells that were routinely sampled between

Table 5.10
Second Half 2007 MNA Groundwater Sampling Results

Location ID	MW-0034	MW-0044	MW-0045	MW-0051	MW-0090	MW-102	MW-116	MW-126	MW-127	MW-129	MW-133	MW-136	MW-144	MW-149	MW-152	MW-153	MW-156	MW-167	MW-169R	MW-275
Total Alkalinity (mg/L)	552	67.8	71.8	207	557	276	368	101	20.5	259	331	313	527	777	450	23.2	404	241	263	174.1
pH	6.99	6.17	5.38	6.21	6.28	5.66	7.39	6.48	6.44	7.1	7.34	6.49	5.87	6.99	5.99	5.16	6.17	6.18	6.01	9.03
Dissolved Iron (ug/L)	ND	ND	28,000	63,100	49,200	27,400	4,150	777	372	238	10,700	3,950	25,700	53,100	1,870	125	2,040	262	262	NAN
Total Iron (ug/L)	ND	1,180	26,200	62,900	48,800	27,300	4,990	799	693	18,700	16,900	10,200	23,700	54,800	8,460	3,470	3,640	2,240	908	537
Dissolved Oxygen (mg/L)	NAN	2.76	0	2.16	NAN	1.11	5.63	6.23	NAN	0.2	4.3	1.09	NAN	0.26	NAN	3.03	NAN	1.4	0.82	NAN
Nitrates (ug/L)	ND	55	ND	ND	ND	ND	500	960	1,800	ND	ND	ND	ND	ND	ND	240	ND	ND	470	520
Oxidation Reduction Potential (mV)	-374	18	27	-102	-134	-71	-109	83	-303	33	-69	-109	-125	-47	-69	59	-63	40	36	-90
Sulfates (ug/L)	1,070,000	98,500	88,700	17,200	ND	ND	43,600	2,070,000	64,700	ND	13,800	6,800	1,470,000	ND	ND	109,000	5,600	98,100	25,600	79,200
Sulfides (ug/L)	17,700	NAN	NAN	ND	1,900	NAN	ND	ND	ND	NAN	ND	600	850	ND	ND	ND	ND	NAN	NAN	740

Location ID	MW-170	MW-178	MW-186	MW-190	MW-192	MW-208	MW-209	MW-210	MW-211	MW-216	MW-217	MW-219	MW-221	MW-222	MW-224	MW-225	MW-226	MW-233	MW-234	MW-276
Total Alkalinity (mg/L)	21.8	154	128	157	245	348	108	1,100	712	NAN	334	125	235	149	NAN	85.5	228	209	282	1,670
pH	4.86	7.59	6.39	5.85	6.36	6.35	6	6.86	6.82	4.23	6.18	5.9	6.59	6.42	3.72	6.03	6.56	6.65	7.21	6.79
Dissolved Iron (ug/L)	54.2	NAN	ND	197	40,300	6,640	50,600	1,810	20,600	5,390	17,200	2,980	ND	383	28,600	ND	ND	5,740	398	NAN
Total Iron (ug/L)	1,280	415	96	362	41,600	20,200	52,500	8,260	27,100	4,800	20,800	4,550	284	610	29,500	103	617	22,000	ND	1,380
Dissolved Oxygen (mg/L)	0.49	2.36	4.24	2.02	0.12	NAN	NAN	1.13	2.71	0.66	0.41	NAN	NAN	NAN	0.53	0.43	0.4	0.33	NAN	0.8
Nitrates (ug/L)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	200	ND	ND	6,600	ND	ND	ND	ND
Oxidation Reduction Potential (mV)	70	-1	53	90	-117	-156	-117	-83	-41	144	-83	-15	46	32	160	32	-10	-116	-183	-168
Sulfates (ug/L)	39,800	52,800	25,000	183,000	ND	ND	45,000	ND	10,700	70,200	170,000	37,600	101,000	65,800	142,000	138,000	37,900	ND	13,100	9,300
Sulfides (ug/L)	NAN	ND	NAN	ND	ND	ND	ND	ND	ND	ND	NAN	NAN	NAN	NAN	NAN	NAN	NAN	ND	ND	2,800

Location ID	MW-235	MW-236	MW-237	MW-238	MW-239	MW-240	MW-241	MW-242	MW-243	MW-244	MW-245	MW-246	MW-247	MW-248	MW-249	MW-250	MW-251	MW-252	MW-253	MW-277
Total Alkalinity (mg/L)	464	280	2,330	228	607	301	379	163	192	201	214	166	152	89.1	155	511	459	2,450	195	1,200
pH	6.41	6.52	6.83	6.5	7.26	6.67	6.68	6.8	6.42	6.59	6.41	5.55	5.43	6.54	6.71	6.03	6.69	6.88	5.07	6.97
Dissolved Iron (ug/L)	605	24,900	NAN	ND	ND	642	29,000	1,670	654	4,670	63,200	69,900	39,200	ND	119	4,890	17,300	NAN	416,000	NAN
Total Iron (ug/L)	5,290	31,400	5,520	587	ND	642	29,900	15,300	2,850	9,620	62,500	66,900	39,600	162	466	4,990	17,800	108	333,000	1,450
Dissolved Oxygen (mg/L)	3.9	0.45	0.98	2.21	4.08	2.66	0.83	0.33	NAN	0.17	0	0.67	0.09	1.46	NAN	2.1	0.37	NAN	NAN	NAN
Nitrates (ug/L)	580	ND	ND	150	1,300	ND	ND	ND	ND	220	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Oxidation Reduction Potential (mV)	35	-170	-176	-112	90	-7	-140	-70	-110	-20	-189	-78	-61	143	15	-28	-150	-432	-13	-61
Sulfates (ug/L)	78,100	ND	ND	157,000	157,000	175,000	ND	95,200	6,700	72,900	ND	ND	7,900	19,100	23,300	10,600	99,600	84,500	2,940,000	421,000
Sulfides (ug/L)	ND	ND	2,800	ND	ND	ND	1,500	ND	1,900	ND	2,000	640	1,500	920	620	ND	ND	199,000	3,000	ND

Location ID	MW-254	MW-255	MW-256	MW-257	MW-258	MW-259	MW-261	MW-262	MW-263	MW-264	MW-265	MW-266	MW-267	MW-268	MW-269	MW-270	MW-271	MW-272	MW-273	MW-9
Total Alkalinity (mg/L)	232	1,450	476	277	585	287	269	166	1,210	1,390	1,817	571	603	664	194	432	460	427	1,040	95.8
pH	6.2	6.92	6.98	6.97	6.75	6.95	5.99	6.74	7.43	6.84	9.16	7.09	7.51	6.5	6.76	6.29	6.35	6.23	6.2	6.19
Dissolved Iron (ug/L)	47,200	12,100	29,600	62,500	8,860	5,200	12,300	8,700	19,200	3,070	128	7,270	2,690	21,900	9,160	70,700	24,800	43,800	17,900	21,600
Total Iron (ug/L)	53,200	14,200	30,000	65,300	8,020	5,140	16,100	8,640	20,900	3,650	675	9,770	13,300	28,400	9,130	72,700	23,400	46,000	20,900	22,900
Dissolved Oxygen (mg/L)	NAN	NAN	0.95	NAN	NAN	0.63	0.48	0.73	0.35	1.05	NAN	0.01	0.71	1.16	0.51	0.68	0.42	NAN	0.13	0.26
Nitrates (ug/L)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Oxidation Reduction Potential (mV)	-122	-151	-125	-294	-176	-160	-215	-145	-105	-152	-415	-187	-138	-181	-117	-132	-130	-120	-210	-58
Sulfates (ug/L)	ND	361,000	ND	ND	ND	ND	ND	ND	ND	ND	10,800	ND	5,900	ND	90,000	ND	57,100	ND	ND	456,000
Sulfides (ug/L)	ND	1,200	2,600	ND	ND	1,100	ND	ND	ND	ND	77,900	ND	ND	ND	ND	1,000	ND	ND	3,600	ND

Notes:
1. ND = Not Detected
2. NAN = Not analyzed

2006 and 2010. DCE is the CVOC with the highest concentration in AOC 36, which was found in well MW-217 (810 ug/L as of August 3, 2010). VC is a biodegradation product of DCE, and is the most toxic of all of the CVOCs being the only one that is a Class A human carcinogen. These figures were sent to the NJDEP in Chevron's Response to NJDEP Follow-up CMS Comments Regarding AOC 36 Letter dated September 7, 2011 (Chevron. 2011b).

These figures demonstrate a primary line of evidence of MNA in the AOC 36 groundwater. DCE is a biodegradation product of PCE and TCE. Levels of DCE in MW-217 have decreased 33% between 2006 and 2010. Additionally, DCE levels in well MW-230 have decreased 80% between 2006 and 2010. Currently, the overall CVOC plume is approximately half its size in 2005. Further, the off-site migration of the CVOC plume has receded. The AOC 36 CVOC COC Analysis figure shows the hot spot of the CVOC plume centers around wells MW-216 and MW-217.

Additionally, Chevron conducted a compound specific isotope analysis (CSIA) for the groundwater plume in AOC 36 (Chevron. 2008a). Isotope ratios can change as a result of biological and chemical reactions. CSIA is a method to measure isotope ratios for COCs to evaluate the occurrence of biodegradation. CSIA can demonstrate biodegradation of a variety of compounds, and may provide conclusive evidence that could not be obtained relying only on analyses of contaminant concentrations and MNA parameters. The results of the CSIA analyses for AOC 36 demonstrated the following MNA degradation pathways are occurring in this area: 1) reductive dechlorination of PCE and TCE to ethene; 2) reductive dechlorination of 1,1,1-TCA to CA, and further degradation of CA; and 3) abiotic transformation of 1,1,1-TCA to 1,1-DCE followed by reductive dechlorination of 1,1-DCE to ethene.

Finally, a detailed geological analysis conducted during Chevron's 2005 investigation of AOC 36 and documented in Chevron's "Central Yard AOC 36 Triad-Based Approach Chlorinated Plume Investigation Report" (SAIC. 2005) demonstrates that the CVOC plume is geologically constrained within AOC 36 as summarized below (SAIC. 2005). Chevron permanent groundwater monitoring wells MW-169R, MW-216 and MW-217 are strategically screened in the more highly conductive subsurface layers of the southern portion of the Central Yard between the fill layer and Woodbridge Clay Member of the Raritan Formation. During Chevron's 2005 Investigation of AOC 36, CVOCs were found to be constrained to a paleo-fluvial depositional sequence consisting of three sand channels (southwest, central, and northeast) within the glacial sediments in the southern portion of the

Central Yard. These sandy channel sequences fill the structurally low areas of AOC 36 wrapping around the central elevated area. MW-216 and MW-217 are screened in the northeast sand channel and MW-169R is screened in the central sand channel. Each channel consists of higher proportions of coarser sedimentary material separated by regions of clay and clayey silts and all are oriented generally northwest-southeast.

The southwest channel contains high amounts of coarse grained materials but is of limited aerial extent. It does not extend deeply into AOC 36 and does not appear to be a significant conduit for CVOC migration in groundwater. Conversely, the central and northeastern channels are of primary importance relative to CVOC migration. Two CVOC plumes were identified following the central and northeastern sand channels towards the southeast, generally following the ground water flow direction. CVOCs were found in the shallow groundwater near the source area and then sank deeper in the aquifer towards the southeast where they are bound vertically by the Woodbridge Clay, a massive clay unit that can be as much as 40 feet thick in the Central Yard.

The central channel is well defined in the Central Yard and consists of coarse, presumably more permeable sandy materials. However, further towards the southeast the central channel bifurcates, curves slightly towards the south, and transitions to lower conductivity silts and silty clays where it edges out under the State Street properties into the Woodbridge Clay. The northeast channel is less pronounced than the other channels in the model area with less coarse grained materials.

In an NJDEP Follow-up Comment Regarding AOC 36 from their Review of "Chevron's Response to USEPA/NJDEP Comments on their Review of CMS Related Submittals dated August 2010", and Included in a Comments Letter to Chevron dated December 6, 2010 (NJDEP. 2010),, the NJDEP stated that for AOC 36, MNA is acceptable for the off-site portion of the chlorinated plume, but either a barrier wall or active in-situ ground water remediation is required for the on-site portion of the chlorinated plume.

Chevron concurred with the NJDEP in a Response to Comments Letter to the NJDEP dated March 8, 2011 (Chevron. 2011a), that MNA is acceptable for the off-site portion of the chlorinated plume in AOC 36. As stated above, Chevron continues to conduct MNA monitoring at AOC 36. The concentration of DCE at well MW-217 was 1,200 ug/L on July 13, 2006; since then the concentration of DCE has steadily decreased to 810 ug/L as of August 3, 2010, or approximately 33% in four years. This provides additional confirmation of the results of Chevron's previous studies on MNA at AOC 36. In response to NJDEP's Comment for AOC 36, Chevron proposes to actively remediate the DCE contamination in

the vicinity of MW-217 to reduce the concentrations to below 100 ug/L followed by MNA to its GWQS of 1 ug/L through EIB.

The EIB will entail the injection of necessary amendments to the saturated zone to augment and sustain the reductive dechlorination of CVOC in AOC 36 groundwater. EIB encompasses two primary processes, namely biostimulation and bioaugmentation. Biostimulation entails the injection of an organic substrate (e.g., lactate, emulsified vegetable oil, etc.) to serve as an electron donor to provide the energy for microbial activities and the necessary hydrogen to replace the chlorine atom. Biostimulation may also involve the addition of a pH buffer to maintain the pH levels within optimal ranges (i.e., 6 to 9 s.u.) for biological activities. Bioaugmentation is typically implemented when the reductive dechlorination is incomplete or stalled, and involves the introduction of a microbial culture to augment the indigenous microbial community and support the complete reductive dechlorination of chlorinated ethenes to ethane and/or ethane. Bioaugmentation will only be conducted if necessary.

To implement the recommended EIB program, Chevron will prepare and submit a permit-by-rule application to NJDEP to authorize the amendment injection program. The permit-by-rule application will also include a detailed ground water monitoring program to track the progress and performance of EIB post-injection. The ground water monitoring program will include a baseline groundwater sampling event to characterize the groundwater prior to injection. This event will include groundwater sampling for VOCs, biodegradation parameters (e.g., total and dissolved iron, nitrate, manganese, sulfate, methane, alkalinity, TOC, etc.), and field indicator parameters ORP, DO, pH, conductivity, chloride, etc.). In addition, ground water samples will be collected for microbial/biological characterization to assess the indigenous microbial community.

Subsequent to their Comments Letter to Chevron dated December 6, 2010 and Chevron's Response to NJDEP Comments Letter dated March 8, 2011, and based on a review of 2006 groundwater data, the NJDEP requested that Chevron remediate around additional monitoring wells in AOC 36 with significant chlorinated solvent groundwater exceedences, such as MW-230, in a follow-up comment regarding AOC 36 during a Chevron/NJDEP teleconference on July 28, 2011. In an additional follow-up comment regarding AOC 36 from a Chevron/NJDEP teleconference on August 15, 2011, and Subsequent NJDEP Email to Chevron Dated August 15, 2011, the NJDEP requested that Chevron also remediate the groundwater area around monitoring well MW-169R because of the latest 2010 level of TCE in this well of 650 ug/L. However, if Chevron finds when they are ready to implement

EIB in AOC 36 that the contaminant levels are significantly reduced, then Chevron can propose to delete MW-169R from the area to be remediated.

In their Response to the NJDEP Follow-up CMS Comments Regarding AOC 36 dated September 7, 2011 (Chevron. 2011b), Chevron again proposes to utilize EIB through biostimulation of the AOC 36 hot spot by injecting a substrate (such as lactate, emulsified vegetable oil, etc.) through wells MW-216 and MW-217 to serve as an electron donor to provide the energy for stimulating microbial activities and the necessary hydrogen to replace the chlorine atoms on the CVOCs. The biostimulation may also include the addition of a pH buffer to maintain the pH levels within optimal ranges (i.e., 6 to 9 s.u.) for biological activities, as mentioned above.

A further analysis of the TCE concentrations in well MW-169R, which had a concentration of TCE of 650 ug/L in August 2010, demonstrates that these concentrations are decreasing at a rate of approximately 10.2% per year. This is calculated using the following formula:

$$Ci(1-X)^n = Cf$$

Where:
Ci = the initial concentration of TCE = 1,000 ug/L in 2006,
X = the annual % reduction/100,
n = the number of years between the concentrations Ci and Cf = 4, and
Cf = the final concentration of TCE = 650 ug/L in 2010

Solving for X yields the following:

$$\text{Log } Ci + n\text{Log } (1-X) = \text{Log } Cf$$
$$\text{Log } (1-X) = (\text{Log } Cf - \text{Log } Ci)/n$$
$$1-X = 10^{((\text{Log } Cf - \text{Log } Ci)/n)}$$
$$X = 1 - 10^{((\text{Log } Cf - \text{Log } Ci)/n)}$$

Substituting the values for each of the parameters results in X = 0.102, or a 10.2% annual reduction in TCE concentrations in well MW-169R.
Chevron also proposes to conduct EIB through biostimulation in well MW-169R to reduce the aforementioned TCE levels after conducting additional rounds of MNA monitoring in 2011 and 2012. If the results of the additional MNA monitoring show that TCE concentrations in MW-169R are continuing to be reduced at a rate of 10.2% or greater per year, then Chevron will continue to conduct MNA monitoring at this well instead of EIB.

First, Chevron will conduct an EIB bench test to identify the most effective biostimulation reagent for the AOC 36 saturated zone soils and groundwater. Chevron will then prepare and submit a permit-by-rule application to NJDEP to authorize the reagent injection program. The permit-by-rule application will also include a detailed groundwater monitoring program to track the progress and performance of the EIB process, including sampling for CVOCs, biodegradation geochemical parameters, and a microbial/biological characterization to assess the indigenous microbial community, thereby demonstrating primary, secondary, and tertiary lines of evidence of bioremediation.

5.5 IN-SITU THERMAL TREATMENT

5.5.1 Description

In-situ thermal treatment is a method to enhance the recovery of target contaminants in the subsurface. The approach uses electrical resistance, thermal conduction, or steam injection to increase subsurface temperatures which in turn increases the volatilization rate of volatile compounds. Standard extraction techniques are used (e.g., soil vapor extraction and/or multi-phase extraction) to remove contaminants from the subsurface during the process. The extracted vapor and fluid are then treated above grade using standard techniques before discharge. In some cases, the extraction of the contaminants are enhanced by both the increased volatilization rate due to temperature increases, and also the drying of the soils, which will increase pore permeability allowing greater fluid flow through the system. Lastly, the slow temperature decreases after the remedy is complete leaves a zone that is conducive to natural biodegradation, which leads to a polishing of the residual contaminants.

Three in-situ thermal technologies are discussed below and include the following: 1) electrical resistance heating, 2) thermal conduction, and 3) steam injection.

Electrical resistance heating (ERH) uses electrical current and the soils resistance to increase subsurface temperatures. Maximum temperatures are generally in the range of 90 to 95ºC. Electrodes (either augur drilled or pile driven) are installed across the site. A power control unit delivers electricity to each of the electrodes. The subsurface soil acts as a resistor as the current is passed between the electrodes delivering the energy required to raise the temperature. This approach is potentially applicable at the Site.

Thermal conduction uses radiant heat from high surface temperature wells to increase subsurface temperatures. Temperatures greater than 100ºC can be achieved in the soil volume between wells. Heater wells are installed at the site and heated to 800 to 900 ºC. Thermal conduction from these heater wells heats the larger soil volume. At these high temperatures, the extraction of contaminants are enhanced in a similar fashion to ERH, but additionally from in-situ degradation of contaminants through oxidation and pyrolysis. Soil vapor extraction wells integrated with the heater wells sweep the volatilized contaminants through these high temperature zones reducing the mass of contaminants, which are removed above grade for treatment. This approach is potentially applicable at the Site.

With steam injection, steam is injected below and within the contaminated zone to heat up the subsurface. To apply this process, steam injection wells are installed throughout the target treatment zone. Between these wells, extraction wells are installed to remove the contaminants from the subsurface in both the vapor and liquid phase. The extraction wells need to remove enough liquid from the system to off-set what is being injected to ensure there is no migration beyond the target area. The steam injection rate and, thus, the time required to achieve the desired temperature is dependent on the injection pressure. The injection pressure is limited by the depth of injection. The shallower the injection (less overburden pressure), the slower the injection rate, and the efficiency of the process decreases. In addition, heterogeneity in the surface can have a significant effect on the efficiency of the process. Low permeable zones may cause channeling or fingering, which may reduce the temperatures that are achieved in these areas. Because of the relatively shallow conditions at the Site and high level of heterogeneity, the use of steam is not considered viable.

5.5.2 Evaluation of In-Situ Thermal Treatment Technology

5.5.2.1 Overall Protection of Human Health and the Environment

In-situ thermal treatment can significantly reduce the levels of contamination in soil and groundwater, thereby reducing the potential for direct exposure and groundwater impacts and, as a result, provides for protection of human health and the environment.

5.5.2.2 Compliance with Applicable Standards

In-situ thermal treatment can meet the applicable criteria/standards for the Site soil and groundwater through recovery and treatment of contaminants.

5.5.2.3 Long-Term Effectiveness and Permanence

In-situ thermal treatment enhances contaminant recovery in both soil and groundwater. Therefore, it can be effective in the long term and its effects on contamination are permanent.

5.5.2.4 Reduction of Toxicity, Mobility, or Volume through Treatment

In-situ thermal treatment reduces the toxicity, mobility and volume of contamination in both soil and groundwater by facilitating recovery of the contaminants from the subsurface.

5.5.2.5 Short-Term Effectiveness

The implementation of in-situ thermal treatment results in some potential impacts to human health and the environment. Routine and non-routine construction hazards will be present during implementation. Routine construction hazards include the potential for slip, trips, and falls, vehicular traffic, and the presence of construction equipment. Non-routine construction hazards include the potential for Site workers to be exposed to volatilized contaminants, electrical hazards (if ERH is used), and the potential for Site workers to be exposed to hot surfaces. All of these risks will be mitigated through the use of the appropriate personal protective equipment (PPE), air quality monitoring, and activity hazards analysis and training.

5.5.2.6 Implementability

In-situ thermal treatment is a proven technology and can be implemented at the site. The equipment and knowledgebase associated with this technology are readily available. A significant amount of infrastructure is needed to apply this technology which will pose design challenges given the existing conditions of the Site.

5.5.2.7 Cost

The unit cost of in-situ thermal treatment for the applicable areas to be treated at the Site is approximately $80/cubic yard based on a site-specific cost estimate for ERH provided by one of the vendors.

5.6 ON-SITE CORRECTIVE ACTION MANAGEMENT UNIT (CAMU)

5.6.1 Description

A CAMU is defined as an area within a facility that is used for managing remediation wastes generated from implementing corrective action or cleanup at a facility (40 CFR 264.552) and is designated by the USEPA Regional Administrator or an authorized State. A CAMU must be located within the contiguous property under the control of the owner or operator where the wastes to be managed in the CAMU originated. A CAMU can manage only CAMU-eligible wastes, which include all solid and hazardous wastes, and all media (including groundwater, surface water, soils, and sediments) and debris that are managed as part of remedial activities. By definition, placing remediation wastes into or within a CAMU does not constitute land disposal. As such, the RCRA LDRs do not apply to such placement activities.

The CAMU that is being proposed for the Site will be an on-site disposal unit to be located next to SWMU 43 and over the area of the demolished tanks 312, 313, and 318 in the northwest corner of the Main Yard. Figures 20 and Figures 21 show the schematic plan view and elevation view, respectively, of the proposed CAMU for the Site. It is anticipated that the CAMU will be constructed with an area of approximately 200,000 square feet. The proposed CAMU will be built in cells capable of accommodating 15,000 cubic yards each, which is the initial volume of remediation waste such as lead contaminated hazardous and benzo(a)pyrene >10 mg/kg impacted soils needing to be disposed following ex-situ stabilization. At this capacity and with the preliminary conceptual design parameters given below, an area of approximately 38,000 square feet will be required for each CAMU cell. The CAMU will then be expanded with additional cells added on.

The CAMU regulations under 40 CFR Part 264.552(e)(3), provide design requirements for new units which include a composite liner and a leachate collection system that is designed and constructed to maintain less than a 30-cm depth of leachate over the liner. A composite liner means a system consisting of two components; the upper component must consist of a minimum 30-mil flexible membrane liner (FML), and the lower component must consist of at least a two-foot layer of compacted soil with a hydraulic conductivity of no more than 1 x 10^{-7} cm/sec. FML components consisting of high density polyethylene (HDPE) must be at least 60 mil thick. The FML component must be installed in direct and uniform contact with the compacted soil component. The USEPA may approve alternate liner requirements as long as it can be shown that the alternative provides an adequate degree of protection. For disposal CAMUs, the remediation waste must meet the applicable treatment requirements

contained in 40 CFR Part 264.552(e)(4) unless adjusted by the USEPA. The regulations also require that on final closure the disposal CAMU must have a final cover designed and constructed to meet the following performance criteria: 1) provide long-term minimization of migration of liquids through the closed unit; 2) function with minimum maintenance; 3) promote drainage and minimize erosion or abrasion of the cover; 4) accommodate settling and subsidence so that the cover's integrity is maintained; and 5) have a permeability less than or equal to the permeability of any bottom liner system or natural subsoil present. Chevron may consider the use of dredged sediment as a cap for beneficial reuse, as long as it meets the above listed performance criteria. Finally a disposal CAMU must incorporate post-closure monitoring and maintenance to ensure the integrity of the final cover.

The preliminary conceptual design of the CAMU presented in Figures 20 and 21 show the following design parameters: 1) 16.5' height with a 18.5' height crown and 4% top slope, 2) 3H:1V side slope ratio, 3) 200 feet in width, 4) up to 1,000 feet in length, and 5) drainage berms to initially direct surface water runoff to the oily water sewer system, and subsequently direct the runoff to the North Field Basin following installation of the CAMU cap.

Additionally, the following items will be included as part of the CAMU design, which are displayed in Figure 21: 1) a double liner, 2) a leachate collection system, and 3) an engineered cap with a top soil vegetation layer.

The relationship between the CAMU capacity and CAMU area and length is displayed as Figure 26. As shown in this figure, the maximum capacity of treated contaminated soil that would be able to fit within a CAMU with a maximum area of 200,000 square feet and with the design parameters given above would be 88,600 cubic yards. This is more than six times greater than the anticipated volume of 14,400 cubic yards to be disposed in the CAMU.

5.6.2 CAMU Evaluation

5.6.2.1 Overall Protection of Human Health and Environment

Lead contaminated hazardous and benzo(a)pyrene >10 mg/kg impacted soils will be excavated and treated using ex-situ stabilization prior to being disposed in the CAMU. The CAMU will have a double-liner bottom layer, a leachate collection system, and an engineered cap. The leachate collected will be treated in the on-site wastewater treatment system. Therefore, the CAMU will prevent the possibility of exposure to the remediation

waste such as lead contaminated hazardous and benzo(a)pyrene >10 mg/kg impacted soils and, hence, will provide overall protection of human health and the environment.

5.6.2.2 Compliance with Applicable Standards

Even though it is not required, the CAMU will meet the MTRs under 40 CFR 264.552(a)(5), as mentioned previously. Additionally, the treated soils placed into the CAMU will meet the treatment standard requirements under 40 CFR 264.552.

5.6.2.3 Long-term Effectiveness and Permanence

The CAMU will be designed to meet the requirements of the CAMU rule as mentioned above, thereby assuring its long-term effectiveness and permanence in containing and immobilizing the remediation waste such as stabilized lead contaminated hazardous and benzo(a)pyrene >10 mg/kg impacted soils disposed inside.

5.6.2.4 Reduction of Toxicity, Mobility or Volume through Treatment

As mentioned above, the contaminated soils placed into the CAMU will be first treated by ex-situ stabilization. The combination of stabilization treatment and containment in the MTR-designed CAMU will significantly reduce the mobility of remediation waste such as lead contaminated hazardous and benzo(a)pyrene >10 mg/kg impacted soils and, hence, their toxicity.

5.6.2.5 Short-term Effectiveness

The construction of a CAMU will result in minimal impacts to human health and the environment. The CAMU construction will occur on-site. During construction activities, there is minimal risk for exposure of site workers to remediation waste such as lead contaminated hazardous and benzo(a)pyrene >10 mg/kg impacted soils because these soils will be stabilized ex-situ prior to being placed in the CAMU. This risk will be mitigated through the use of the appropriate PPE and air quality monitoring during tasks with the potential for worker exposure including the transfer of stabilized soils into the CAMU.

Further, only contaminants that leach out of the CAMU will be collected in the leachate collection system and treated in the on-site wastewater treatment system, as mentioned above. Therefore, the CAMU is anticipated to be effective in the short-term.

5.6.2.6 Implementability

The area where the CAMU is planned to be constructed is expected to remain under Chevron's management. The area is level and the former tanks have already been removed. Minor site preparation will be necessary to remove the oily water sewer system and fire suppression system utilities from the CAMU area. The CAMU access is easy via existing facility roads. The CAMU will be constructed entirely above grade due to the shallow groundwater elevations in the area.

The procedures and performance criteria to design the CAMU are well understood and commonly used in landfill design. The equipment, methods, and materials to build the CAMU are readily available and commonly used in landfill construction.

Additionally, long-term management of the CAMU and leachate treatment system will be conducted. The existing on-site wastewater treatment system will be utilized for leachate treatment. It is anticipated that 22,500 gallons (gals)/day will be collected and treated during the first 1.5 years of CAMU construction, and 225 gals/day thereafter following the installation of the engineered cap. Finally, monitoring of wells installed immediately downgradient from the CAMU and CAMU cap inspection will be performed at a minimum on an annual basis.

5.6.2.7 Cost

The unit cost of the CAMU is calculated by dividing the total estimated cost of construction, operation and maintenance by the total estimated volume of soil to be disposed inside. A detailed summary of the CAMU costs, as well as volume of soil to be disposed inside the CAMU is included in Table 10. The unit cost of the CAMU will vary depending on the volume of soil to be disposed. Because a number of the construction costs are relatively fixed and not a function of the volume, the greater the volume to be disposed, the lower the CAMU unit cost. For the anticipated volume of soil to be disposed and shown in Table 10 (14,414 cubic yards), the CAMU unit cost is $418/cubic yard.

In order to compare the cost effectiveness of the CAMU with off-site transportation, treatment, and disposal, a cost comparison was prepared for a wide range of potential soil volumes to be disposed from 6,600 to 129,300 cubic yards. The current unit cost to transport, treat, and dispose of hazardous soil from the Site is $510/cubic yard. Figure 22 shows the cost savings from disposing lead contaminated hazardous and benzo(a)pyrene >10 mg/kg impacted soils in a CAMU versus off-site disposal (including transportation,

treatment and disposal). As shown in this Figure the breakeven volume where disposal in a CAMU and off-site are the same is 8,600 cubic yards. Therefore, for volumes less than this, it is anticipated that off-site disposal costs will be less than the CAMU costs. However, as mentioned above, the anticipated volume of soil to be disposed is 14,400 cubic yards. At this volume, the cost savings from disposing treated soil in a CAMU versus off-site disposal is approximately $2 million.

5.7 LNAPL CORRECTIVE MEASURES

This section provides the latest status for the LNAPL areas designated at the Site. There are nineteen (19) LNAPL areas that have been identified at the Site, which are shown in Figures 10 through 12.

A detailed discussion of the characterization, delineation and findings in each LNAPL area is provided in the report entitled "Full RFI Report" (SAIC. 2003). The latest summary of LNAPL monitoring and recovery activities is provided in the report entitled "2007 Stabilization Measures Status (SMS) Report" dated June 2008 (Parsons. 2008). The 2007 SMS provides an overview of each LNAPL area including site location and general subsurface assessment, as well as monitoring activities and corrective measures conducted during 2007. A discussion of SWMU 8 and SWMU 11B LNAPL areas will be included in the 2008 Stabilization Measures Report to be submitted in the second quarter of 2009.

As described in the above reports, LNAPL at the site is found at relatively shallow depths (less than 10 feet bgs) and is currently present at apparent thicknesses of less than one foot. Apparent thickness is the thickness of LNAPL measured in a monitoring well and is generally higher than the true thickness in the subsurface. LNAPL is typically found within the more permeable lenses and layers of flyash and catalyst beads. These more permeable layers and lenses were placed during various periods of filling at the Site and, based on borings log observations, are not continuous. Many of the lenses are located in the saturated zone. Analytical fingerprinting performed at 16 of the 19 LNAPL areas shows that the LNAPL is typically composed of various mixtures of weathered crude, refining residuals, weathered diesel, and weathered gasoline.

5.7.1 LNAPL Monitoring and Interim Remedial Measures

LNAPL monitoring and Interim Remedial Measures (IRMs) are currently being conducted in the LNAPL impacted areas. Table 1-1 of the 2007 SMS Report summarizes the status of the LNAPL areas including the following:

1. LNAPL area,
2. Areal extent of LNAPL,
3. Maximum reported LNAPL thickness,
4. Current reported LNAPL thickness,
5. Depth to LNAPL,
6. Vertical Location of LNAPL,
7. LNAPL type,
8. Current monitoring activities,
9. Current IRM activities, and
10. Status of IRM.

As presented in the table, the LNAPL areas have weekly or bi-weekly monitoring with the exception of SWMU 41, which has quarterly monitoring, and AOC 28 where monitoring is not conducted.

The IRMs currently being conducted at the Site include the following:

1. Active LNAPL extraction with a mobile vacuum truck is conducted weekly at twelve (12) of the LNAPL areas (SWMU 8, SWMU 11b, SWMU 43, AOC 8-NF6, AOC 19, NF2, NF3, NF5, AOC 25, SWMU 42, EY4a, and EY4b).
2. Belt skimmer systems are used at AOC 19 and SWMU 43. These systems are operated intermittently using timers. The LNAPL product is collected in a drum and periodically removed from the Site.
3. Passive LNAPL recovery with absorbent socks is utilized in monitoring wells that show limited LNAPL product (typically less than 2 inches). Absorbent socks are currently used in the LNAPL areas, AOC 8-NF6 and NF2.
4. Annual surficial asphalt removal is conducted at AOC 29.
5. A Biosparge Pilot test has been conducted in EY1.

There are no IRM activities being conducted in the following LNAPL areas: 1) SWMU 40, 2) SWMU 41, 3) NF4, 4) EY3, and 4) AOC 28.

Based on sitewide LNAPL monitoring activities between 2005 and 2007, LNAPL thickness distribution maps were generated and are presented as Figures 10 through 12, respectively. Table 2.1 shows the estimated areas of LNAPL for various thickness ranges for the years 2005 through 2007. Additionally, the % reduction of the LNAPL area for various thickness ranges was calculated to evaluate the efficiency of the ongoing IRMs. As shown in Table 1.1, the total percentage area reduction in LNAPL between 2005 and 2007 was 80, 27, 74 and 100% for thickness ranges of >0.01' - 0.1', >0.1' - 0.5', >0.5' - 1', and >1' - 2', respectively.

These LNAPL area reductions clearly demonstrate that the IRM activities currently being conducted at the Site appear to be effectively recovering LNAPL.

5.8 BIOSPARGE PILOT STUDY

Biosparging is an in-situ technology in which air is injected into contaminated groundwater to enhance the aerobic biodegradation of contaminants below the water table. This technology focuses on removal of the more volatile and biodegradable portion of the contamination, which primarily includes the more mobile contaminants.

A biosparge pilot study was conducted in the EY1 LNAPL area in 2006 to evaluate the effectiveness of biosparging in removing benzene and other VOCs from LNAPL and residual contamination below the groundwater table. The effectiveness of the study was evaluated based on the reduction in dissolved-phase BTEX concentrations in groundwater and estimated total mass removal of BTEX from the EY1 LNAPL area.

The EY1 LNAPL Area is located in the northwest portion of the East Yard in an area that primarily includes aboveground storage tanks 767, 771, and 777 used for the storage of crude oil and Tank 750 used for the storage of gasoline and which currently stores naphtha. The localized groundwater flow direction is generally to the northeast. The LNAPL in this area is a highly weathered gasoline manufactured prior to 1986 with a specific gravity of 0.7972 and a viscosity of 1.1 centistokes at 20 °C. It is only detected intermittently in this area at a maximum thickness of 0.02 feet. Groundwater sampling results indicate the presence of dissolved VOCs within the EY1 LNAPL area, but not downgradient of this area.

The biosparge system installed at EY1 consisted of 15 sparge points (SPs), three additional groundwater monitoring wells, five vapor monitoring points, and a trailer-mounted biosparge blower system with associated manifold piping. The operation of the biosparge

system was cycled through three zones, with each zone receiving approximately two hours of sparge time every six hours. Biosparge injection flow rates and pressures into each SP ranged from < 2 to 5 standard cubic feet per minute (scfm) and 4 to 8 pounds per square inch (psi), respectively. The biosparge system was operated for approximately 6 months between April 12 and October 23, 2006.

Baseline, 3-month, 4-month, and 6-month sampling events were conducted to monitor the BTEX concentrations in groundwater and to assess whether or not contamination was being displaced from the area. Following the system shut down, 2-, 4-, and 6-month rebound sampling events were conducted to monitor the BTEX concentrations in groundwater as steady state conditions returned.

During the baseline sampling event benzene concentrations ranged from non-detect to 7,300 ug/L. Following 6 months of biosparging, the analytical results showed benzene concentrations ranging from non-detect to 3,100 ug/L. Significant concentration reductions were observed in four of the five wells sampled. Free-phase LNAPL was not observed in any monitoring well during the pilot study.

At the completion of the pilot study sample results from two downgradient perimeter wells and one cross-gradient perimeter well revealed no detections of BTEX, indicating that displacement of dissolved-phase groundwater contamination from the area did not occur during the pilot study.

In general, the 2-month rebound sampling event showed both slight increases and decreases in BTEX concentrations. However, BTEX concentrations observed during the 4-month rebound event showed significant increases, particularly at well RW-61. Benzene concentrations at well RW-61 increased from 140 ug/L during the 2-month rebound event to 4,400 ug/L during the 4-month rebound event. The reasons for this increase in BTEX concentrations during the 4-month rebound sampling event may include migration of dissolved phase contamination into this area from the area immediately upgradient, or desorption of contaminants from saturated zone soils.

The total mass removal of BTEX constituents from groundwater during the 6-month pilot study was estimated to be approximately 4 kilograms. The complete results of this biosparge pilot study are given in the “Letter Report for the Biosparge Pilot Study Conducted at LNAPL Area EY1” dated June 28, 2007 (Chevron. 2007).

The biosparging technology, as demonstrated in this pilot test is applicable for volatile and readily biodegradable petroleum hydrocarbons. Even after the BTEX fractions are degraded, weathered free product in heavier fractions can still persist. As stated in the Letter Report, treatment using this technology is not expected to reduce contaminants to their applicable GWQSs due to limitations in the removal of the less mobile fractions of LNAPL.

Biosparging is a bioremediation technology and not a LNAPL removal/treatment technology. Although the weathering of LNAPL can be enhanced by biosparging, the process is very slow and less effective relative to other LNAPL removal technologies such as MPE. MPE involves physical removal, volatilization (by vacuum) and biodegradation to reduce levels of LNAPL.

In conclusion, biosparging can be effective for reducing VOCs in groundwater, but is not effective for treating LNAPL in free-phase form. It can be effective as a secondary treatment after the LNAPL mass has been reduced.

5.9 AOC 29 CORRECTIVE MEASURE

AOC 29, also known as the 5 Berth area, is rectangular in shape, approximately 400 feet long and 200 feet wide, and is located between the Arthur Kill and Wharf Avenue. The 5 Berth was constructed as a docking area for incoming barges and ships, and included several pipeways that were used to transport petroleum products from ships to the Site storage tanks. The area was constructed prior to 1946 and remained in operation until the late 1970s. Materials transported through the pipeways included No. 6 oil, No. 6 oil blend, petroleum distillate, No. 2 oil, crude oil, light cracked fuel, and lubricant.

During routine excavation activities at AOC 29, a black hardened asphalt-like material was encountered. The material migrates upwards during the summer months and emerges at ground surface. The deteriorating bulkhead on the east and north sides and the presence of the Arthur Kill waterway makes AOC 29 a priority with respect to remedial action.

Based on the regulatory requirements and a consideration of what is reasonable to achieve given the area conditions, three remedial action objectives (RAOs) were identified by Parsons as part of an evaluation of alternatives for AOC 29:

1. Minimize the encroachment of the Arthur Kill to the 5 Berth area;
2. Minimize human contact with the “asphalt” material and LNAPL; and

3. Ensure that the Arthur Kill is not adversely impacted by LNAPL or contaminated groundwater located within the 5 Berth area.

In order to support the evaluation of alternatives, Parsons reviewed existing data and performed a subsurface investigation. The subsurface investigation included test pits, soil borings and temporary well points. The information obtained from the investigation was used in conjunction with the historical data to determine the extent of impacted material, the groundwater quality, subsurface profiles and subsurface conditions.

Based on the subsurface investigation data, geotechnical data, RAOs, and an engineering analysis, various remedial alternatives were evaluated for implementation in AOC 29. The evaluation of alternatives was conducted in three stages that included the following:

1. Identification of alternatives and preliminary technical screening to assess the ability for each alternative to achieve the RAOs, its long-term effectiveness, and its implementability (19 total alternatives were identified);
2. Conductance of a preliminary cost analysis of those alternatives found to meet the first stage criteria (7 total alternatives); and
3. Performance of a detailed screening on those alternatives found to be both technically and economically feasible as a result of the first two stages of evaluation (6 total alternatives).

Based on the results of the evaluation of alternatives, constructing a revetment to control erosion along the Arthur Kill in combination with asphalt collection and long-term operation, maintenance, and monitoring is recommended as the most appropriate alternative. The complete results of this evaluation will be presented in the CMS Report for 5 Berth expected to be submitted to the USEPA and NJDEP by December 31, 2008.

5.10 ARSENIC CONTAMINATED SOIL CORRECTIVE MEASURE

Elevated arsenic concentrations in the shallow soil are present predominantly in an area located in the southeast corner of the East Yard of the Site. Figure 9 shows the distribution of arsenic contaminated soil in the East Yard. Additionally, SWMU 39 in the Main Yard had arsenic concentrations in surface soil (0 – 2 feet bgs) >20 mg/kg. Primary, non-ferrous, metal smelting and refining operations were conducted on the adjacent ASARCO facility, located immediately to the south of the East Yard, between 1894 and 1976. These activities may have been the source of arsenic contamination found at the Site since a “favorable”

wind direction may have dispersed airborne arsenic downwind and onto the Site as a result of emissions from the smelting process.

Given the site orientation, a prevailing wind from the south or south west would directly place the Site downwind of the emissions from the ASARCO smelting process. Therefore, during those periods of south-southwesterly winds, arsenic may have been deposited on the East Yard of the Site and subsequently buried when this area was filled in.

In order to determine the frequency of favorable wind direction, URS reviewed climatological data from Newark Liberty International Airport (approximately 19 miles due north from the Site). URS downloaded wind direction data from the National Oceanographic Atmospheric Administration (NOAA) website (ftp://ftp.wcc.nrcs.usda.gov/downloads/climate/windrose/) for Newark Airport. The wind direction data, compiled in a wind rose format, represents data collected over 30 years (1961-1990), by the United States Department of Agriculture, Natural Resources Conservation Center, including the last 15 years of operation of the ASARCO smelting facility. This data is considered a representative source of information regarding typical wind strength and wind direction for the Site.

A review of this data shows seasonal trends in wind direction and strength. In general, the prevailing wind comes from the southwest in the summer months and southwest to northwest in the winter months, with some variation observed. Table 5.11 presents the monthly primary prevailing wind direction for the Site.

Table 5.11
Summary of Monthly Primary Prevailing Wind Direction for the Site

Month	Primary Prevailing Wind Direction
January	Southwest to northwest
February	Southwest to northwest
March	Northwest
April	Southwest to northwest
May	Southwest
June	Southwest
July	Southwest
August	Southwest
September	Southwest

October	Southwest
November	Southwest
December	Southwest to northwest

As discussed earlier, Chevron did not generate arsenic waste as part of its refinery operations. Given the results of the primary prevailing wind direction in the vicinity of the Site shown in Table 5.11 and the deposition pattern of arsenic contamination displayed on Figure 9, it is evident that the adjacent ASARCO facility is the source of the arsenic deposited primarily in the southeastern corner of the East Yard, as well as in SWMU 39 in the Main Yard. As a result, a containment CM using a cap would be appropriate to prevent any worker exposure to arsenic contamination exceeding its NJDEP NRDCSCC at the Site.

5.11 WASTE MINIMIZATION CONSIDERATIONS

The selected active CMs evaluated in this Section include the following in-situ technologies: 1) ISCO and 2) in-situ stabilization. Both of these technologies do not generate any waste that would require transportation, treatment, or disposal. For ISCO, only a 1-2 week supply of reagents will be stored on-site to minimize storage capacity requirements. No ISCO reagents will remain following ISCO injection activities, and all ISCO reagents will be reacted, and converted to harmless products such as carbon dioxide, water, and minerals. Similarly for in-situ stabilization, only a 1-2 week supply of stabilization binders will be stored on-site to minimize storage capacity requirements. No binders will remain following the in-situ stabilization activities. All stabilization binders will be left in the ground, bound to the soil matrix.

Additionally, the selected active CMs evaluated in this Section include the following ex-situ technologies: 1) ex-situ stabilization, and 2) LTTD. The stabilized contaminated media treated using ex-situ stabilization will be disposed in an on-site CAMU. Therefore, no waste is anticipated to be transported over local roads and long distances on highways for off-site disposal, thereby eliminating the risk associated with hazardous waste transportation. These CMs (ex-situ stabilization and CAMU) will also minimize the carbon footprint associated with the Site remedial activities. The treated LTTD soil may or may not need to be disposed in the on-site CAMU. If the treated organic contaminated media is below the applicable criteria/standards, it may be recycled as clean fill at the Site. If it does not meet the applicable criteria/standards, in the worst-case it will be disposed in the on-site CAMU, with the same waste minimization benefits described above for ex-situ stabilization.

Organic contaminants volatilized in the LTTD process can be either destroyed in an after-burner or catalytic oxidation chamber, condensed and recycled using a condenser, or collected in a vapor phase carbon adsorption unit and destroyed when the carbon is regenerated.

While LNAPL collected in absorbent, hydrophobic socks is disposed of off-site, LNAPL collected from vac truck and skimmer belt LRMs are recycled.

The construction of a revetment around AOC 29 will generate minimal waste requiring disposal.

The construction of caps over the arsenic impacted soil and SWMU 43 will not generate any wastes.

6.0 DEVELOPMENT AND EVALUATION OF REMEDIAL ALTERNATIVES

6.1 DEVELOPMENT OF REMEDIAL ALTERNATIVES

This section describes the development of the remedial alternatives for the Main Yard, East Yard and Central Yard using the CMs selected for the contaminated media. For the purpose of this development, the contaminated areas of the three Yards are divided into the following contaminated media categories:

1. SWMU 43 Hazardous Contaminated Soil,
2. Non-SWMU 43 Hazardous Contaminated Soil,
3. Contaminated Soil,
4. Arsenic Impacted Soil,
5. Benzo(a)pyrene >10 mg/kg Impacted Soil,
6 Groundwater, and
7. LNAPL.

The preliminary screening in Section 4.2 and evaluation in Section 5.0 identified the most applicable CMs for each of these contaminated media, except for SWMU 43 hazardous soil. SWMU 43 represents the only known area of the Site where hazardous wastes were disposed, as described in Section 2.3.1. Additionally, SWMU 43 contains by far the largest volume of contaminated soil at the Site (33,166 cubic yards or 27% of the total) and the overwhelming majority of the hazardous soil at the Site (90% of the total). Therefore, the CMs selected for SWMU 43 will have the greatest impact on the overall cost effectiveness of the remedial alternative chosen for the Site.

In developing remedial alternatives for the Site for SWMU 43, a number of applicable CMs are identified below ranging from the most cost effective in-situ treatment CMs to the least cost effective ex-situ treatment and disposal CMs. The CMs selected for the remaining contaminated media are the most applicable CMs identified in Section 4.2 and evaluated in Section 5.0, and are the same for each of the remedial alternatives. The following five remedial alternatives have been developed for the Site and are described below. However, Chevron is proposing to retain for consideration all of the retained technologies previously screened and evaluated in Sections 4.2 and 5.0, respectively, for potential use at the Site. This will provide the necessary flexibility to ensure that remediation goals are met in an efficient manner. This performance based approach is required in a complex operating

refinery with multiple SWMUs and AOCs, some of which are located in process areas and other active portions of the facility. The specific technology(ies) for individual SWMUs and AOCs will be designed as part of the Corrective Measures Implementation, and will be based on the performance from site-specific bench and pilot studies, as appropriate. If necessary, additional pilot study evaluations may be completed during the design investigation process to further evaluate the performance of retained technologies, and to potentially revise the locations where each technology would be utilized and/or to develop treatment trains for specific SWMUs and AOCs to ensure the remediation goals will be achieved.

1. CMS Remedial Alternative 1

- SWMU 43 Hazardous Soil – Hot spot in-situ treatment in the TCLP-benzene exceedence area, and in-situ stabilization with a non-RCRA cap and file a deed notice afterwards; ISCO is anticipated to be the in-situ treatment technology for the TCLP-benzene exceedence area; however, in-situ thermal treatment is also being retained;
- Non-SWMU 43 Hazardous Soil – In-situ treatment for organic contamination, and excavation, ex-situ stabilization and disposal in a tailored CAMU for lead contamination; ISCO is anticipated to be the in-situ treatment technology for the non-SWMU 43 hazardous soil organic contamination; however, in-situ thermal treatment and ex-situ bioremediation are also being retained;
- Non-Hazardous Soil – In-situ treatment for organic contamination, and in-situ stabilization for lead contamination and file a deed notice afterwards; ISCO is anticipated to be the in-situ treatment technology for the non-hazardous soil organic contamination; however, in-situ thermal treatment and ex-situ bioremediation are also being retained;
- Arsenic Impacted Soil – Capping of arsenic soil contamination and file a deed notice afterwards;
- Benzo(a)pyrene >10 mg/kg Impacted Soil – Excavation, stabilization and disposal in a tailored CAMU; however, ISCO and in-situ thermal treatment are also being retained;
- AOC 29 – Revetment, asphalt collection, and operation, maintenance, and monitoring of groundwater and surface water;
- Groundwater – In-situ treatment for benzene >100 ug/L, and MNA for benzene ≤100 ug/L and establish a CEA; ISCO is anticipated to be the in-situ treatment technology for benzene >100 ug/L in groundwater; however, in-situ bioremediation, air

sparging/soil vapor extraction, and in-situ thermal treatment are also being retained; and

- LNAPL – Mitigate to the extent practicable with LRMs or CMs, such as ISCO and in-situ thermal treatment for low levels of LNAPL.

2. CMS Remedial Alternative 2

- SWMU 43 Hazardous Soil – In-situ treatment for organic contamination and in-situ stabilization and file a deed notice afterwards; ISCO is anticipated to be the in-situ treatment technology for the organic contamination; however, in-situ thermal treatment is also being retained;
- Non-SWMU 43 Hazardous Soil – In-situ treatment for organic contamination, and excavation, ex-situ stabilization and disposal in a tailored CAMU for lead contamination; ISCO is anticipated to be the in-situ treatment technology for the non-SWMU 43 hazardous soil organic contamination; however, in-situ thermal treatment and ex-situ bioremediation are also being retained;
- Non-Hazardous Soil – In-situ treatment for organic contamination, and in-situ stabilization for lead contamination and file a deed notice afterwards; ISCO is anticipated to be the in-situ treatment technology for the non-hazardous soil organic contamination; however, in-situ thermal treatment and ex-situ bioremediation are also being retained;
- Arsenic Impacted Soil – Capping of arsenic soil contamination and file a deed notice afterwards;
- Benzo(a)pyrene >10 mg/kg Impacted Soil – Excavation, stabilization and disposal in a tailored CAMU; however, ISCO and in-situ thermal treatment are also being retained;
- AOC 29 – Revetment, asphalt collection, and operation, maintenance, and monitoring of groundwater and surface water;
- Groundwater – In-situ treatment for benzene >100 ug/L, and MNA for benzene ≤100 ug/L and establish a CEA; ISCO is anticipated to be the in-situ treatment technology for benzene >100 ug/L in groundwater; however, in-situ bioremediation, air sparging/soil vapor extraction, and in-situ thermal treatment are also being retained; and
- LNAPL – Mitigate to the extent practicable with LRMs or CMs, such as ISCO and in-situ thermal treatment for low levels of LNAPL.

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3. CMS Remedial Alternative 3

- SWMU 43 Hazardous Soil – Excavation, LTTD, ex-situ stabilization and disposal in SWMU 43;
- Non-SWMU 43 Hazardous Soil – In-situ treatment for organic contamination, and excavation, ex-situ stabilization and disposal in a tailored CAMU for lead contamination; ISCO is anticipated to be the in-situ treatment technology for the non-SWMU 43 hazardous soil organic contamination; however, in-situ thermal treatment and ex-situ bioremediation are also being retained;
- Non-Hazardous Soil – In-situ treatment for organic contamination, and in-situ stabilization for lead contamination and file a deed notice afterwards; ISCO is anticipated to be the in-situ treatment technology for the non-hazardous soil organic contamination; however, in-situ thermal treatment and ex-situ bioremediation are also being retained;
- Arsenic Impacted Soil – Capping of arsenic soil contamination and file a deed notice afterwards;
- Benzo(a)pyrene >10 mg/kg Impacted Soil – Excavation, stabilization and disposal in a tailored CAMU; however, ISCO and in-situ thermal treatment are also being retained;
- AOC 29 – Revetment, asphalt collection, and operation, maintenance, and monitoring of groundwater and surface water;
- Groundwater – In-situ treatment for benzene >100 ug/L, and MNA for benzene ≤100 ug/L and establish a CEA; ISCO is anticipated to be the in-situ treatment technology for benzene >100 ug/L in groundwater; however, in-situ bioremediation, air sparging/soil vapor extraction, and in-situ thermal treatment are also being retained; and
- LNAPL – Mitigate to the extent practicable with LRMs or CMs, such as ISCO and in-situ thermal treatment for low levels of LNAPL.

4. CMS Remedial Alternative 4

- SWMU 43 Hazardous Soil – Excavation, LTTD, ex-situ stabilization and disposal in a tailored CAMU;
- Non-SWMU 43 Hazardous Soil – In-situ treatment for organic contamination, and excavation, ex-situ stabilization and disposal in a tailored CAMU for lead contamination; ISCO is anticipated to be the in-situ treatment technology for the

non-SWMU 43 hazardous soil organic contamination; however, in-situ thermal treatment and ex-situ bioremediation are also being retained;

- Non-Hazardous Soil – In-situ treatment for organic contamination, and in-situ stabilization for lead contamination and file a deed notice afterwards; ISCO is anticipated to be the in-situ treatment technology for the non-hazardous soil organic contamination; however, in-situ thermal treatment and ex-situ bioremediation are also being retained;
- Arsenic Impacted Soil – Capping of arsenic soil contamination and file a deed notice afterwards;
- Benzo(a)pyrene >10 mg/kg Impacted Soil – Excavation, stabilization and disposal in a tailored CAMU; however, ISCO and in-situ thermal treatment are also being retained;
- AOC 29 – Revetment, asphalt collection, and operation, maintenance, and monitoring of groundwater and surface water;
- Groundwater – In-situ treatment for benzene >100 ug/L, and MNA for benzene ≤100 ug/L and establish a CEA; ISCO is anticipated to be the in-situ treatment technology for benzene >100 ug/L in groundwater; however, in-situ bioremediation, air sparging/soil vapor extraction, and in-situ thermal treatment are also being retained; and
- LNAPL – Mitigate to the extent practicable with LRMs or CMs, such as ISCO and in-situ thermal treatment for low levels of LNAPL.

5. CMS Remedial Alternative 5

- SWMU 43 Hazardous Soil – Excavation, LTTD, ex-situ stabilization and disposal in a CAMU;
- Non-SWMU 43 Hazardous Soil – In-situ treatment for organic contamination, and excavation, ex-situ stabilization and disposal in a tailored CAMU for lead contamination; ISCO is anticipated to be the in-situ treatment technology for the non-SWMU 43 hazardous soil organic contamination; however, in-situ thermal treatment and ex-situ bioremediation are also being retained;
- Non-Hazardous Soil – In-situ treatment for organic contamination, and in-situ stabilization for lead contamination and file a deed notice afterwards; ISCO is anticipated to be the in-situ treatment technology for the non-hazardous soil organic contamination; however, in-situ thermal treatment and ex-situ bioremediation are also being retained;

- Arsenic Impacted Soil – Capping of arsenic soil contamination and file a deed notice afterwards;
- Benzo(a)pyrene >10 mg/kg Impacted Soil – Excavation, stabilization and disposal in a tailored CAMU; however, ISCO and in-situ thermal treatment are also being retained;
- AOC 29 – Revetment, asphalt collection, and operation, maintenance, and monitoring of groundwater and surface water;
- Groundwater – In-situ treatment for benzene >100 ug/L, and MNA for benzene ≤100 ug/L and establish a CEA; ISCO is anticipated to be the in-situ treatment technology for benzene >100 ug/L in groundwater; however, in-situ bioremediation, air sparging/soil vapor extraction, and in-situ thermal treatment are also being retained; and
- LNAPL – Mitigate to the extent practicable with LRMs or CMs, such as ISCO and in-situ thermal treatment for low levels of LNAPL.

The tailored CAMU refers to a CAMU that is built sequentially with separate cells that are tailored to the volume of material anticipated to be disposed. A detailed discussion of this CM is provided in Section 5.6.

AOC 29 is the 5 Berth area in the East Yard next to the Arthur Kill. A feasibility study for this area was prepared in 2005 (Parsons. 2005). A summary of the results from this feasibility study is provided in Section 5.9.

6.2 EVALUATION OF REMEDIAL ALTERNATIVES

This Section evaluates the remedial alternatives developed in Section 6.1 based on the evaluation criteria identified in the USEPA NCP (USEPA. 1993) with the exception of the inclusion of Schedule and omission of Compliance with Closure Criteria in the evaluation criteria. However, it is assumed that all applicable criteria/standards will be achieved by each of the remedial alternatives evaluated. The six remedial alternative evaluation criteria are described below.

6.2.1 Long-term Effectiveness and Permanence

This criterion addresses how well a remedial alternative maintains protection of human health and the environment after the applicable closure criteria have been initially met, and the degree of certainty that the remedial alternative will continue to meet the closure criteria

in the long-term. This criteria also includes the magnitude of residual risk, and the adequacy and long-term reliability of institutional and engineering controls.

6.2.2 Short-term effectiveness

This criterion addresses the protection of human health and the environment during implementation of the remedial alternative and immediately afterwards, and the short-term reliability of the alternative to meet the applicable closure criteria/standards. This criterion also includes the reduction in toxicity, mobility, and volume of contaminated media through treatment by the remedial alternative.

6.2.3 Implementability

This criterion addresses the technical and administrative feasibility of each remedial alternative including the availability of treatment, storage and disposal services/facilities, the availability of necessary equipment and skilled workers to implement the alternative, and the ability to obtain necessary approvals and permits.

6.2.4 Cost

This criterion addresses both the capital and O&M costs associated with the remedial alternatives.

6.2.5 Regulatory Acceptance

This criterion addresses the acceptability of the remedial alternatives to federal, state and local agencies as well as to the local residents and community. This criterion includes evaluation of the following parameters: 1) off-site management of hazardous media, 2) off-site exposure to hazardous media, 3) NJDEP potential to apply residential soil cleanup criteria, and 4) level of NJDEP involvement.

6.2.6 Schedule

This criterion addresses the potential of the remedial alternatives in meeting the desired project schedule for completion of the remediation of the Site. This criteria also includes the duration of remediation to achieve the applicable closure criteria/standards, and the potential of the remedial alternative to interfere with ongoing facility operations and future redevelopment plans for the Site.

6.2.7 Summary of Evaluation of Remedial Alternatives

The six evaluation criteria were weighted by Chevron according to their relative value. Then each remedial alternative was rated for each of the evaluation criteria. The ratings used for each of the criteria, except for cost, were positive, neutral, and negative. The cost criteria ratings ranged from 100% for the most cost effective remedial alternative to 25% for the least cost effective remedial alternative. The non-cost evaluation criteria were quantified in the following manner: 1) a positive rating received 100% of the weighted value of the evaluation criteria, 2) a neutral rating received 75% of the weighted value of the evaluation criteria, and 3) a negative rating received 50% of the weighted value of the criteria. The rating values were then multiplied by the weighted values to obtain a score for each of the evaluation criteria for each of the CMS remedial alternatives. The scores for each of the evaluation criteria were then added to obtain a total score for each CMS remedial alternative. The results of the evaluation of remedial alternatives are shown in Table 6.1. These results indicate that CMS Alternative 1, with a total score of 83.13, scored the highest of all of the CMS remedial alternatives.

Based on the selection of CMS Remedial Alternative 1, Table 6.2 summarizes the selected CMs for each of the contaminated media, as well as the basis of selection and constructability for each of the active CMs.

Table 6.1
Evaluation of CMS Remedial Alternatives

Risk Evaluation Criteria	Weighted Value (%)	CMS Remedial Alternative 1		CMS Remedial Alternative 2		CMS Remedial Alternative 3	
		Rating	Score	Rating	Score	Rating	Score
1. Long-term Effectiveness and Permanence (includes overall protection of human health and the environment)	15	75%	11.25	75%	11.25	100%	15
2. Short-term Effectiveness (includes reduction in toxicity, mobility and volume through treatment)	15	100%	15	100%	15	100%	15
3. Implementability	12.5	75%	9.375	75%	9.375	100%	12.5
4. Cost	27.5	100%	27.5	75%	20.625	50%	13.75
5. Regulatory Acceptance	20	50%	10	75%	15	50%	10
6. Schedule	10	100%	10	100%	10	50%	5
TOTAL	**100**		**83.13**		**81.25**		**71.25**

Notes:
1. N = Neutral Rating
2. Non-cost scores are quantified in the following manner: 1) a positive rating receives 100% of the weighted value of the evaluation criteria, 2) a neutral rating receives 75% of the weighted value of the evaluation criteria, and 3) a negative rating receives 50% of the weighted value of the evaluation criteria.
3. Cost scores are quantified in the following manner: 1) the least cost alternative receives 100% of the weighted value of the evaluation criteria; 2) the second least expensive cost alternative receives 75% of the weighed value of the evaluation criteria; 3) the median cost alternative receives 50% of the weighted value of the evaluation criteria; and 4) the second most and most expensive cost alternatives receive 25% of the weighted value of the evaluation criteria because their overall remedial cost estimates are very close (within 2.9%).
4. The ratings for the evaluation criteria were agreed upon at the SWMU 43 Strategic Analysis meeting held on October 23, 2007.

Table 6.1
Evaluation of CMS Remedial Alternatives

Risk Evaluation Criteria	Weighted Value (%)	CMS Remedial Alternative 4		CMS Remedial Alternative 5	
		Rating	Score	Rating	Score
1. Long-term Effectiveness & Permanence (includes overall protection of human health)	15	100%	15	100%	15
2. Short-term Effectiveness (includes reduction in toxicity, mobility and volume through treatment)	15	100%	15	100%	15
3. Implementability	12.5	100%	12.5	100%	12.5
4. Cost	27.5	25%	6.875	25%	6.875
5. Regulatory Acceptance	20	75%	15	75%	15
6. Schedule (pertaining to SWMU 43)	10	50%	5	50%	5
TOTAL	**100**		**69.38**		**69.38**

Notes:
1. N = Neutral Rating
2. Non-cost scores are quantified in the following manner: 1) a positive rating receives 100% of the weighted value of the evaluation criteria, 2) a neutral rating receives 75% of the weighted value of the evaluation criteria, and 3) a negative rating receives 50% of the weighted value of the evaluation criteria.
3. Cost scores are quantified in the following manner: 1) the least cost alternative receives 100% of the weighted value of the evaluation criteria; 2) the second least expensive cost alternative receives 75% of the weighed value of the evaluation criteria; 3) the median cost alternative receives 50% of the weighted value of the evaluation criteria; and 4) the second most and most expensive cost alternatives receive 25% of the weighted value of the evaluation criteria because their overall remedial cost estimates are very close (within 2.9%).
4. The ratings for the evaluation criteria were agreed upon at a DRB Presentation Preparation meeting held in October, 2008.

Table 6.2
Corrective Measures Selection and Constructability

Contaminated Media	Selected CMs	Basis for Selection for Active CMs	Constructability for Active CMs
SWMU 43 Hazardous Soil	ISCO and In-Situ Stabilization with a Non-RCRA Cap and Deed Notice	**A. ISCO** 1. High Long-term Effectiveness and Permanence 2. High Reduction in Toxicity and Volume 3. High Implementability 4. Low to Moderate Cost 5. No Long Term O&M 6. High Regulatory Acceptance 7. Successful Bench Test Results **B. Stabilization** 1. High Long-term Effectiveness and Permanence for Lead 2. High Reduction in Mobility 3. High Implementability 4. Moderate Cost 5. No Long Term O&M 6. High Regulatory Acceptance 7. Successful Bench Test Results	**A. ISCO** 1. 1-2 week supply of ISCO reagents will be stored on-site to minimize storage capacity requirements. 2. Underground utilities and appurtenances will be cleared prior to implementation. **B. Stabilization** 1. Concrete pad will be removed prior to implementation in SWMU 43. 2. 1-2 week supply of stabilization binders will be stored on-site to minimize storage capacity requirements. 3. Underground utilities and appurtenances will be cleared prior to implementation.
Non-SWMU 43 Hazardous Soil	ISCO and Excavation, Ex-situ Stabilization, and Disposal in CAMU		
Non-Hazardous Soil	ISCO and Stabilization with a Deed Notice		
Benzo(a)pyrene >10 mg/kg Impacted Soil	Excavation, Ex-situ Stabilization, and Disposal in CAMU		
Groundwater	ISCO and MNA with Establishment of a CEA		
LNAPL	Vac Truck, Belt Skimmer, and Absorbent Sock Removal of LNAPL to Extent Practicable	1. High Long-term Effectiveness and Permanence 2. High Reduction in Toxicity and Volume 3. High Implementability 4. Low Cost 5. High Regulatory Acceptance	1. These LRMs are ongoing. 2. LRMs are either mobile or temporary, with no permanent construction.

Table 6.2
Corrective Measures Selection and Constructability

Contaminated Media	Selected CMs	Basis for Selection for Active CMs	Constructability for Active CMs
AOC 29	Containment including Revetment and Asphalt Collection with a Deed Notice	1. Medium Long-term Effectiveness and Permanence 2. Medium Reduction in Volume and Mobility 3. High Implementability 4. Medium Cost 5. Medium Regulatory Acceptance 6. Low O&M Cost	1. Asphalt collection is ongoing. 2. Revetment installation will help stabilize the bulkhead in this area, which is in need of repair. 3. High constructability
Arsenic Impacted Soil	Containment Consisting of a Cap with a Deed Notice	1. Medium Long-term Effectiveness and Permanence 2. Medium Reduction in Mobility 3. High Implementability 4. Low Cost 5. Medium Regulatory Acceptance 6. Low O&M Cost	1. Cap will consist of either asphalt pavement or soil cover. 2. High constructability

Notes:
1. The following CMs are being retained for consideration of their potential use at the Site for the following contaminated media, either as a stand-alone CM or as part of a treatment train to ensure the remediation goals will be achieved: a) in-situ thermal treatment for SWMU 43 hazardous soil, b) in-situ thermal treatment and ex-situ bioremediation for non-SWMU 43 hazardous and non-hazardous soils, c) ISCO and in-situ thermal treatment for benzo(a)pyrene >10 mg/kg impacted soil, d) in-situ bioremediation, air sparging/soil vapor extraction, and in-situ thermal treatment for contaminated groundwater, and e) ISCO and in-situ thermal treatment for low levels of LNAPL.

7.0 CONCLUSIONS AND RECOMMENDATIONS

This Section presents the conclusions and recommendations of the CMS. These conclusions and recommendations are based on the following: 1) the results of all soil investigations conducted to date at the Site including the various RFIs and the CMS PDI, summarized in Section 2.0, 2) the results of the sitewide LNAPL monitoring summarized in Section 2.0, 3) the results of the latest groundwater sampling events conducted in each Yard summarized in Section 2.0, 4) applicable media-specific cleanup standards summarized in Section 3.0, 5) the results of the preliminary screening of applicable CM technologies summarized in Section 4.0, 6) the results of the evaluation of selected CM technologies including bench test results summarized in Section 5.0, and 7) the results of the development and evaluation of remedial alternatives summarized in Section 6.0.

Conclusions and recommendations are provided below for each of the following contaminated media: 1) hazardous soil, 2) non-hazardous soil, 3) benzo(a)pyrene >10 mg/kg Impacted Soil, 4) East Yard arsenic impacted soil, 5) AOC 29, 6) LNAPL contamination, and 7) groundwater contamination. For each contaminated media, the following information is presented: 1) a summary of the volume to be remediated, 2) identification of the applicable criteria/standards and remedial goals to be achieved, and 3) the recommended CM(s) to be implemented. Further, the areas where each of the recommended CMs are to be implemented and the corresponding SWMUs and AOCs to be remediated are displayed on Figures 23 through 25 "Summary of Corrective Measures for Contaminated SWMUs and AOCs for the Main Yard, East Yard, and Central Yard", respectively. Also a summary of the CM status and recommendations for each of the Site SWMUs and AOCs, along with their associated exceedences, is shown in Table 1. Additionally, a summary of the contaminated media areas and volumes and associated impacted SWMUs and AOCs is given in Tables 6 through 9 for the Sitewide, and the Main, East and Central Yards, respectively. Further, a summary of the CMS recommendations including the recommended CM(s) for each contaminated media and the associated SWMUs and AOCs is given in Section 7.8. Finally, the remediation goals for each of the contaminated media are provided in Section 7.9.

7.1 HAZARDOUS SOIL

The CMS PDI results identified the following hazardous soil at the Site: 1) 800 cubic yards of characteristically hazardous benzene, 2) 3,000 cubic yards of characteristically hazardous

lead, and 3) 33,200 cubic yards of potentially listed hazardous soil in SWMU 43. A summary of the potentially applicable USEPA standards for RCRA TCLP characteristic hazardous soil is provided in Table 4. The applicable remedial goal for the potentially listed hazardous soil in SWMU 43 is the USEPA RCRA LDR Standards for petroleum refining waste codes F037, F038, K051 and K052. A summary of the applicable USEPA LDR standards for these RCRA listed hazardous waste codes is presented in Table 3. However, unless the management of these wastes results in "placement," the USEPA LDRs are not regulatory requirements for in-situ containment, which is the ultimate disposition of SWMU 43 soils. The recommended CMs to be implemented for these soils are as follows: 1) ISCO for characteristically hazardous benzene, 2) excavation, ex-situ stabilization, and disposal in the on-site CAMU for characteristically hazardous lead, and 3) ISCO hot-spot treatment for characteristically hazardous benzene and in-situ stabilization with installation of a non-RCRA cap and filing of a deed notice for SWMU 43. Additionally, the following CMs are being retained for consideration of their potential use, either as a stand-alone CM or as part of a treatment train, to ensure the remediation goals will be achieved: 1) in-situ thermal treatment for SWMU 43 hazardous soil, and 2) in-situ thermal treatment and ex-situ bioremediation for non-SWMU 43 hazardous soils.

7.2 NON-HAZARDOUS SOIL

The CMS PDI results identified the following non-hazardous soil at the Site: 1) 17,700 cubic yards of lead contamination in exceedence of its NJDEP NRDCSCS of 800 mg/kg, and 2) 38,700 cubic yards of benzene in exceedence of its NJDEP NRDCSCC of 13 mg/kg. The applicable regulatory standards/criteria for these soils are as follows: 1) NJDEP NRDCSCS for lead and naphthalene, and 2) NJDEP NRDCSCC for benzene and all other contaminants. A summary of the applicable NJDEP NRDCSCC and NRDCSCS is given in Table 2. The recommended CMs to be implemented for these soils are as follows: 1) ISCO for benzene and other organic contaminated soil, 2) in-situ stabilization with filing of a deed notice for lead contaminated soil, and 3) excavation, ex-situ stabilization, and disposal in the on-site CAMU for TEL/TOL concentrations >2 mg/kg with total lead concentrations <800 mg/kg. Additionally, in-situ thermal treatment and ex-situ bioremediation are being retained for consideration of their potential use, either as a stand-alone CM or as part of a treatment train, to ensure the remediation goals will be achieved.

7.3 BENZO(A)PYRENE >10 mg/kg IMPACTED SOILS

The CMS PDI results identified 6,600 cubic yards of benzo(a)pyrene concentrations greater than 10 mg/kg at the Site. The applicable regulatory criteria for this soil is the NJDEP NRDCSCC for benzo(a)pyrene of 0.66 mg/kg with a recommended action level of 10 mg/kg for benzo(a)pyrene. The recommended CMs to be implemented for soil with benzo(a)pyrene above the recommended action level of 10 mg/kg are excavation, ex-situ stabilization, and disposal in the on-site CAMU. The recommended CM to be implemented for soil with benzo(a)pyrene concentrations greater than 0.66 mg/kg and less than 10 mg/kg is to file a deed notice. Additionally, ISCO and in-situ thermal treatment are being retained for consideration of their potential use, either as a stand-alone CM or as part of a treatment train, to ensure the remediation goals will be achieved.

7.4 ARSENIC IMPACTED SOIL

The SRFI results identified 41,900 square yards of arsenic impacted soil in the East Yard with concentrations exceeding its NJDEP NRDCSCC of 20 mg/kg, which is the applicable regulatory criteria for this soil. Additionally, SWMU 39 in the Main Yard had arsenic concentrations in surface soil >20 mg/kg. The recommended CM to be implemented for these soils is containment consisting of a cap with filing a deed notice.

7.5 AOC 29

Based on the results of a separate evaluation of alternatives for AOC 29 as mentioned previously, the recommended CMs for AOC 29 includes constructing a revetment to control erosion along the Arthur Kill in combination with asphalt collection and long-term operation, maintenance, and monitoring of groundwater and surface water with filing of a deed notice. The complete results of this evaluation will be presented in a separate CMS Report for 5 Berth (AOC 29) expected to be submitted to the USEPA and NJDEP by December 31, 2008.

7.6 LNAPL CONTAMINATION

The results of LNAPL monitoring conducted in 2007 identified approximately 10,700 square yards of LNAPL at the Site at a thickness greater than 0.01 feet. The applicable

regulatory criteria for LNAPL is to remove it to the extent practicable in accordance with 7:26 E-6.1 of the latest revised NJDEP Technical Requirements for Site Remediation dated September 2, 2008. The recommended CMs to be implemented for LNAPL contamination are to continue the use of LRMs including the use of a vac truck, belt skimmers and absorbent socks, as necessary. Additionally, ISCO and in-situ thermal treatment are being retained for consideration of their potential use for low levels of LNAPL, either as a stand-alone CM or as part of a treatment train, to ensure the remediation goals will be achieved.

7.7 GROUNDWATER CONTAMINATION

The CMS PDI results identified the following groundwater contamination at the Site: 1) 850,000 cubic yards of saturated zone soils with groundwater benzene concentrations between 1 to 100 ug/L, 2) 122,000 cubic yards of saturated zone soils with groundwater benzene concentrations greater than 100 ug/L, and 3) 86,800 cubic yards of saturated zone soils with groundwater lead concentrations greater than 5 ug/L. The applicable regulatory standards for groundwater contamination are the NJDEP GWQSs. A summary of the applicable NJDEP GWQSs is shown in Table 5. The recommended CMs to be implemented for this groundwater contamination are as follows: 1) ISCO for groundwater contamination in the source areas with benzene concentrations greater than 100 ug/L, 2) MNA for groundwater contamination outside the source areas with benzene concentrations between 1 to 100 ug/L and CVOC exceedences <100 ug/L, 3) EIB for groundwater contamination in AOC 36 area with CVOC exceedences >100 ug/L, and 4) in-situ stabilization in the source areas with lead concentrations greater than 50 ug/L. A CEA will be filed for each groundwater area with contamination in excess of its respective GWQS. Additionally, air sparging/soil vapor extraction, and in-situ thermal treatment are being retained for consideration of their potential use, either as a stand-alone CM or as part of a treatment train, to ensure the remediation goals will be achieved.

7.8 SUMMARY OF CMS RECOMMENDATIONS

A summary of the aforementioned CMS recommendations including the recommended CM(s) for each contaminated media, including clean soil and groundwater, and the associated SWMUs and AOCs, is presented in Table 7.1 below. As shown in Table 7.1, there are multiple CMs for hazardous and non-hazardous soils, as well as contaminated groundwater. In general, the sequence of CMs implementation for contaminated media and SWMUs/AOCs with multiple CMs will be excavation, ISCO and/or other retained CMs, followed by in-situ stabilization. In SWMUs and/or AOCs where LNAPL is present, LNAPL will be mitigated to the extent practicable prior to implementing ISCO and/or other retained CMs.

Table 7.1 can also be used as a cross-reference table to conduct an evaluation of remedial alternatives analysis for each SWMU and AOC by first identifying the contaminated media associated with each SWMU and AOC, and then referring to the evaluation of remedial alternatives in Section 6 of this Report for each of the contaminated media identified. Finally, Table 1 in Appendix B provides a summary of corrective measures selected for each SWMU and AOC, as well as associated soil and groundwater exceedences that were part of the bases used to select the CMs.

Table 7.1
Summary of Recommended Corrective Measures for Each Contaminated Media and Associated SWMUs and AOCs

Contaminated Media	CM(s)	SWMUs/AOCs
SWMU 43 Hazardous Soil	1. ISCO for characteristically hazardous benzene, 2. In-situ stabilization, 3. Installation of a non-RCRA cap, and 4. Filing a deed notice.	SWMUs: 5, 21, and 43
Non-SWMU 43 Hazardous Soil	1. ISCO for characteristically hazardous benzene, and	SWMUs: 8, 18, and 40 AOC: 16-MY
	2. Excavation, ex-situ stabilization, and disposal in the on-site CAMU for characteristically hazardous lead.	SWMUs: 8, 10, 17, 20, and 34 AOCs: 16-EY, 22, 23, and 46

Table 7.1
Summary of Recommended Corrective Measures for Each Contaminated Media and Associated SWMUs and AOCs

Contaminated Media	CM(s)	SWMUs/AOCs
Contaminated but Non-Characteristically Hazardous Soil	1. ISCO for benzene and other organic contaminated soil, and	SWMUs: 6, 8, 16, 17, 18, 19, 24, 35, 39, 40, 41, and 42 AOCs: 5, 8, 14, 15, 16-MY, 16-EY, 22, 26, 31, 37, 38, 39, 41, and 46
	2. In-situ stabilization with filing a deed notice for lead contaminated soil.	SWMUs: 6, 7, 10, 11a, 12, 18, 20, 27, 29, 31, 34, 39, 41, and 42 AOCs: 5, 14, 16-MY, 16-EY, 22, 23, 31, 33, 37, 41, and 46
	3. Excavation, ex-situ stabilization, and disposal in the on-site CAMU for TEL/TOL concentrations > 2 mg/kg with lead concentrations < 800 mg/kg.	SWMUs: 16, 19, 22, 24, and 26
	4. Containment consisting of a cap with filing a deed notice for arsenic concentrations in surface soil > 20 mg/kg.	SWMU: 39
Benzo(a)pyrene >10 mg/kg Impacted Soil	Excavation, ex-situ stabilization, and disposal in the on-site CAMU.	SWMUs: 19, 27, 34, and 38 AOCs: 16-MY, 16-EY, and 16-CY
East Yard Arsenic Impacted Soil	Containment consisting of a cap with filing a deed notice.	SWMUs: 36 AOCs: 14, 16, 31, 35, 38, 45, and 46
AOC 29	Revetment, asphalt collection and operation, maintenance, and monitoring of groundwater and surface water, with filing a deed notice.	AOC: 29
LNAPL	LRMs including the use of a vac truck, belt skimmers and absorbent socks.	SWMUs: 5, 6, 8, and 43 AOCs: 25 and 44

Table 7.1
Summary of Recommended Corrective Measures for Each Contaminated Media and Associated SWMUs and AOCs

Contaminated Media	CM(s)	SWMUs/AOCs
Groundwater	1. ISCO for groundwater contamination in the source areas with benzene concentrations >100 ug/L,	SWMUs: 8, 10, 16, 17, 18, 20, 35, and 42 AOCs: 8, 9A, 15, 16-MY, 16-EY, 16-CY, 22, 23, 31, 41, and 44
	2. MNA for groundwater contamination outside the source areas with benzene concentrations between 1 to 100 ug/L, and CVOC exceedences<100 ug/L in AOC 36,	SWMUs: 5, 6, 10, 19, 21, 22, 24, 34, 35, 40, 41, and 42 AOCs: 8, 9A, 9B, 14, 15, 16-MY, 16-EY, 16-CY, 22, 23, 25, 33, 36, 44, and 48
	3. EIB for groundwater contamination in AOC 36 area with CVOC exceedences >100 ug/L.	AOC: 36
	4. In-situ stabilization in the source areas with lead concentrations greater than 50 ug/L, and	SWMU: 34 AOC: 16-EY
	5. Filing a CEA for each groundwater area with contamination in excess of its respective GWQS.	SWMUs: 5, 6, 10, 19, 21, 22, 24, 31, 34, 35, 40, 41, and 42 AOCs: 8, 9A, 9B, 14, 15, 16-MY, 16-EY, 16-CY, 22, 23, 25, 33, 36, 44, and 48
Clean Soil	No Further Action	SWMUs: 11b, 13, and 14 AOCs: 7, 9A, 18, 21, 25, 30, 32, 34, 36, and, 42
Clean Groundwater	No Further Action	SWMUs: 7, 9, 12, 13,, 26, 27, 28, 30, 36, 39, 52, and 53 AOCs: 5, 6A, 6B, 6C, 7, 10, 13, 17, 18, 19, 21, 26, 27, 32, 34, 38, 39, 40, 42, 43, 45, 46, 47, and 49

Notes:
1. Clean soil and groundwater refers to soil and groundwater with no or low level exceedences of applicable regulatory criteria/standards.
2. Filing a CEA is only listed for those SWMUs and AOCs where MNA is the recommended CM.
3. NFAs have been requested but not yet received for AOCs 1, 2, and 3, and SWMUs 25 and 32.
4. NFI has been requested but not yet received for SWMU 51.
5. The following CMs are being retained for consideration of their potential use at the Site for the following contaminated media, either as a stand-alone CM or as part of a treatment train, to ensure the remediation goals will be achieved: a) in-situ thermal treatment for SWMU 43 hazardous soil, b) in-situ thermal treatment and ex-situ bioremediation for non-SWMU 43 hazardous and non-hazardous soils, c) ISCO and in-situ thermal treatment for benzo(a)pyrene >10 mg/kg impacted soil, d) in-situ bioremediation, air

sparging/soil vapor extraction, and in-situ thermal treatment for contaminated groundwater, and e) ISCO and in-situ thermal treatment for low levels of LNAPL.

7.9 REMEDIATION GOALS

The remediation goals identify endpoints needed to be achieved by the CM(s) for a particular contaminated media or SWMU/AOC in order to request a NFA determination from the NJDEP. The remediation goals for each of the contaminated media at the Site are summarized in Table 7.2 below.

Table 7.2
Remediation Goals for Each Contaminated Media

Contaminated Media	Remediation Goal
SWMU 43 Hazardous Soil	Following ISCO and in-situ stabilization, request the following: 1. A "no longer contains" or "contained-out" determination by the NJDEP if the COCs are below their respective NJDEP NRDCSCC, with the exception of naphthalene and lead whose closure criteria are their respective NJDEP NRDCSCC;. 2. Prepare a delisting petition if the COCs are below their respective RCRA LDRs, as well as the DRAS carcinogenicity risk factor and hazard quotient model guidance values; or 3. If concentrations of COCs are above their criteria/standards given in the above two options, then file a deed notice pursuant to N.J.A.C. 7:26E-8.2.
Non-SWMU 43 Hazardous Soil	Following ISCO treatment of organic COCs to below their respective NJDEP NRDCSCC, and excavation, ex-situ stabilization to RCRA LDR standards, and disposal in a CAMU for metal COCs, request an NFA determination by the NJDEP.
Contaminated but not characteristically hazardous Soil	Following ISCO treatment of organic COCs to below their respective NJDEP NRDCSCC, with the exception of naphthalene whose closure criteria is its NJDEP NRDCSCS, in-situ stabilization of metal COCs with filing a deed notice, and excavation, ex-situ stabilization and disposal in the on-site CAMU for TEL/TOL concentrations >2 mg/kg with total lead concentrations <800 mg/kg, request an NFA determination by the NJDEP.
Benzo(a)pyrene >10 mg/kg Impacted Soil	Following the removal of benzo(a)pyrene concentrations in soil >10 mg/kg, ex-situ stabilization, and disposal in a CAMU, and filing a deed notice for benzo(a)pyrene concentrations >0.66 mg/kg and <10 mg/kg, request an NFA determination by the NJDEP.
Arsenic Impacted Soil	Within 45 calendar days after receipt of the NJDEP's written approval of final deed notice submitted as part of the Remedial Action Report (RAR) following the installation of a cap over the East Yard arsenic contaminated soil and SWMU 39 in the Main Yard, provide a paper copy of the recorded deed notice and an electronic copy in read only format, including all exhibits, to the persons and entities given under N.J.A.C. 7:26E-8.2(g).
AOC 29	Within 45 calendar days after receipt of NJDEP's written approval of final deed notice submitted as part of the RAR following the installation of a revetment around AOC 29, provide a paper copy of the recorded deed notice and an electronic copy in read only format, including all exhibits, to the persons and entities given under N.J.A.C. 7:26E-8.2(g).
LNAPL	Following the removal of LNAPL to the extent practicable, request cessation of active LRMs or CMs.
Groundwater	Following ISCO treatment of benzene concentrations in groundwater to <100 ug/L, EIB treatment of CVOCs in groundwater to levels <100 ug/L at AOC 36, and establishment of a CEA, conduct MNA of the groundwater semi-annually until two consecutive rounds of groundwater sample results are below the applicable NJDEP GWQSs for the COCs. At that point, request the NJDEP remove the CEA and grant an NFA.

Notes:
1. The following CMs are being retained for consideration of their potential use at the Site for the following contaminated media, either as a stand-alone CM or as part of a treatment train, to ensure the remediation goals will be achieved: a) in-situ thermal treatment for SWMU 43 hazardous soil, b) in-situ thermal treatment and ex-situ bioremediation for non-SWMU 43 hazardous and non-hazardous soils, c) ISCO and in-situ thermal treatment for benzo(a)pyrene >10 mg/kg impacted soil, d) in-situ bioremediation, air sparging/soil vapor extraction, and in-situ thermal treatment for contaminated groundwater, and e) ISCO and in-situ thermal treatment for low levels of LNAPL.

7.10 CORRECTIVE MEASURE IMPLEMENTATION (CMI) SCHEDULE

A preliminary CMI schedule is provided as Figure 27. This preliminary schedule assumes review and approval of the CMS Final Report by the USEPA and NJDEP will be received by June 30th 2009. This schedule may be revised based on comments received from the USEPA and/or NJDEP.

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APPENDIX A
FIGURES

APPENDIX B
TABLES

APPENDIX C
BENCH SCALE TREATABILITY STUDIES

C1 – Stabilization Bench Scale Treatability Study
C2 – Low Temperature Thermal Desorption Pilot Test
C3 – In-Situ Chemical Oxidation (ISCO) Bench Test Treatability Report

Appendix C1: Stabilization Bench Scale Treatability Study

Appendix C2: Low Temperature Thermal Desorption Pilot Test

Appendix C3: In-Situ Chemical Oxidation (ISCO) Bench Test Treatability Report

APPENDIX D
DATA VALIDATION