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Hamilton Sundstrand Former Denver Facility

Corrective Measures Work Plan

Prepared for the Colorado Department of Public Health and Environment

January 2008

ARCADIS

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Hamilton Sundstrand

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1.0 Introduction

This Corrective Measures Work Plan (CMWP) evaluates and selects appropriate corrective measures for the remediation of environmental contamination at the Hamilton Sundstrand Former Denver Facility located at 2480 West 70th Avenue in Denver, Colorado (the site). ARCADIS U.S., Inc. (ARCADIS) is responsible for the design, implementation, and operation of the remediation systems at the site under a Guaranteed Remediation Program Agreement between ARCADIS, Hamilton Sundstrand Corporation, Carma Colorado, Inc. (Carma), and BPI Westminster (BPI). Carma and BPI will perform the demolition of existing structures with the intent to redevelop the property. Regulatory oversight for Resource Conservation and Recovery Act (RCRA) corrective action activities for the Hamilton Sundstrand facility was previously conducted by the U.S. Environmental Protection Agency (USEPA) under a Corrective Action Order on Consent dated August 16, 2000 (USEPA Docket No. RCRA-8-2000-11). However, with approval of the site's Integrated Corrective Action Plan (ICAP) Application (ARCADIS 2006b), regulatory oversight for corrective action activities has now shifted to the Colorado Department of Public Health and Environment (CDPHE) (CDPHE 2007b). The USEPA Consent Order was terminated as of April 5, 2007.

In addition to evaluating and selecting corrective measures, this CMWP also broadly summarizes site information and the results of activities identified in the ICAP Application including the implementation of interim corrective measures and pilot-scale tests of remedial technologies. The ICAP Application originally identified preparation of a Corrective Action Plan Report to describe activities conducted as part of the ICAP Application and to propose final corrective measures for CDPHE review. The Corrective Action Plan Report was to be followed by preparation of a Corrective Measures Implementation Plan describing implementation of the selected remedies. However, this CMWP combines the Corrective Action Plan Report and Corrective Measures Implementation Plan into a single document. Following a public comment review period and final acceptance of this CMWP by CDPHE, the next phase of the corrective action process for the Hamilton Sundstrand facility will be implementing the selected corrective measures presented herein.

The remaining sections of this introduction present the overall purpose and objectives of the CMWP, a description of the general approach to preparing the CMWP, and a document overview.

1.1 Purpose and Objectives

As previously described, the overall purpose of this CMWP is to broadly summarize site information and the results of activities identified in the ICAP Application, and to evaluate and select appropriate corrective measures for the site. The specific CMWP objectives are to:

- Summarize site background information, including site history, local geology and hydrogeology, and site conceptual model of contaminant transport and distribution.
- Identify contaminants of potential concern (COPCs) and health risk-based remedial goals.
- Develop corrective measures objectives (CMOs) that reflect the health risk-based remedial goals and address remediation requirements identified in the Guaranteed Remediation Program Agreement.
- Report on the results of activities conducted under the ICAP Application including:
    - Maintaining the current mitigation systems installed at the site
    - Implementing interim corrective actions that can be incorporated directly into the final remedy
    - Conducting pilot-scale testing to evaluate the efficacy of promising technologies as potential remedial alternatives and for incorporation into the final remedy
- Identify and evaluate technologies that have the potential for treating the site COPCs and achieving the CMOs.
- Compare and select corrective measures alternatives.
- Develop a preliminary implementation plan for the recommended corrective measures.

1.2 General Approach and Document Overview

The areas addressed in this plan include the Facility Parcel, where all manufacturing operations occurred, and off-site areas to the east including the Perl Mack residential neighborhood (Perl Mack Neighborhood) and the Vacant Parcel open area. Collectively, these areas will be referred to as the site in this document. All contaminant releases occurred on the Facility Parcel and groundwater contaminant plumes originating from the Facility Parcel have migrated beneath the Perl Mack Neighborhood and Vacant Parcel. For purposes of this CMWP, the Facility Parcel is further divided into the Main Contaminant Source Area (Main Source Area) associated with the primary manufacturing operations on the northern half of the Facility Parcel and the Remote Facility to the south that primarily consisted of testing facilities.

Previously, as part of the RCRA corrective action process, 13 solid waste management units (SWMUs) and six areas of concern (AOCs) were identified at the site (Harding ESE 2001). The SWMUs and AOCs were identified as the probable contaminant source areas where contaminants were originally released to the environment. No SWMUs or AOCs were identified beyond the Facility Parcel boundary except AOC 3 (groundwater), which extends off site beneath the Perl Mack Neighborhood and Vacant Parcel. This CMWP focuses on the evaluation of corrective measures for remediation of the larger contaminant source areas, including the Main Source Area and the Remote Facility, rather than the remediation of individual SWMUs or AOCs. Most of the individual SWMUs and AOCs identified are contained within the Main Source Area and Remote Facility. AOC 2, an area of polychlorinated biphenyl (PCB) contamination in soil at the south end of the Facility Parcel, is addressed separately primarily due to its isolated location. This CMWP also evaluates corrective measures for remediating the groundwater contaminant plumes (AOC 3) that have migrated beneath the Perl Mack Neighborhood and Vacant Parcel.

The following list summarizes the contents of the remaining major sections of this CMWP:

- Section 2.0, Site Characteristics, includes a basic description of the Hamilton Sundstrand Former Denver Facility and its history; the site geology, hydrogeology, and surface water characteristics; and a summary of the individual SWMUs and AOCs. Section 2.0 also includes a summary of the site risk evaluation including the identification of COPCs and development of the health risk-based remedial goals, and an overview of the distribution of contaminants. Finally, Section 2.0 describes the site's current mitigation systems including the Groundwater Barrier System (GBS), Seepage Water Remediation System, and indoor air mitigation systems in the Perl Mack Neighborhood.
- Section 3.0, Corrective Measures Objectives, summarizes the qualitative site CMOs as well as quantitative remedial goals for the Facility Parcel, Perl Mack Neighborhood, and Vacant Parcel.
- Section 4.0, Corrective Measures Technology Identification and Screening, describes the approach to evaluating and screening remedial technologies; evaluates and screens the technologies identified for remediation of the Facility Parcel, Perl Mack Neighborhood, and Vacant Parcel; and concludes with a subset of technologies retained for further evaluation and comparison in Section 6.0.

- Section 5.0, Interim Corrective Measures and Pilot-Scale Studies, describes the interim corrective measures and pilot-scale studies implemented under the ICAP Application. The interim corrective measures implemented include the following:
    - Construction and operation of Phase I in-situ enhanced reductive dechlorination (ERD) injection systems in the Perl Mack Neighborhood and Vacant Parcel
    - Completion and operation of the perimeter vapor barrier system (VBS) along the eastern boundary of the Facility Parcel
    - Expansion of the VBS to begin source remediation along the eastern boundary of the Facility Parcel

The pilot-scale studies implemented include the following:

- Short-term air sparge (AS) and soil vapor extraction (SVE) pilot tests in the Facility Parcel including the Main Source Area and Remote Facility
- Long-term AS/SVE pilot test in the Facility Parcel Main Source Area
- Long-term SVE pilot test in the Remote Facility

- Section 6.0, Corrective Measures Alternatives Evaluation and Comparison, describes the evaluation approach and presents a comprehensive evaluation and comparison of the corrective measures alternatives retained from the screening evaluations presented in Section 4.0. The evaluation and comparison also incorporates the results of the interim corrective measures and pilot-scale studies discussed in Section 5.0.
- Section 7.0, Selected Corrective Measures, summarizes those corrective measures recommended as final remedies for remediation of the Facility Parcel, Perl Mack Neighborhood, and Vacant Parcel.
- Section 8.0, Corrective Measures Implementation and Performance Monitoring Plan, presents conceptual designs and a schedule for implementation of the recommended corrective measures, as well as a conceptual plan for a monitoring program to evaluate the performance of the corrective measures and remediation progress.

2.0 Site Characteristics

The following sections discuss background information specific to the site, including the site history; characteristics of the site geology, hydrogeology, and surface water; descriptions of all SWMUs and AOCs; a summary of the site risk evaluation; description of the distribution of contaminants; and summary of all contaminant mitigation systems currently operating.

2.1 Site Description

The following sections describe the site location and history (with regard to manufacturing facilities and processes) and the history of RCRA corrective actions.

2.1.1 Location

The Hamilton Sundstrand Former Denver Facility is located at 2480 West 70th Avenue in Denver, Colorado. Three separate areas make up the entire site as defined in this CWMP: the 43-acre original plant area (referred to as the Facility Parcel), 138 acres of acquired land (referred to as the Vacant Parcel), and a residential neighborhood located north of the Vacant Parcel (referred to as the Perl Mack Neighborhood). As previously described, the Facility Parcel is further divided for purposes of this CMWP into the Main Source Area on the northern portion of the area and the Remote Facility to the south. The site is located in the eastern half of Section 5, Township 3 South, Range 68 West in Adams County, Colorado. **Figure 2.1** depicts the layout and boundaries of the site features.

2.1.2 Site History

The Hamilton Sundstrand Former Denver Facility was constructed in 1955 and originally consisted of the main manufacturing plant (Main Plant Building) in the north-central portion of the property. The Main Plant Building housed equipment and machinery used to support manufacturing processes. The Tape Manufacturing Building was constructed in 1966 as a west wing to the Main Plant Building and also housed equipment and machinery. Based on a 1954 aerial photograph of the site and a 1950 United States Geological Survey (USGS) 7.5-minute quadrangle map (EDR 2000), the Facility Parcel and Vacant Parcel to the east were undeveloped and used for agricultural purposes prior to 1955 (Harding ESE 2001).

Hamilton Sundstrand manufactured components for aerospace assemblies. The facility supported limited assembly of the components except in cell manufacturing areas where a component was started and completed within the cell. The parts were manufactured primarily from steel bar and sheet stock. Other raw materials included iron, copper, aluminum, titanium, and metal alloys. Ancillary raw materials included coolants; cleaning/degreasing solutions; electroplating solutions for copper, cadmium, nickel, bronze, and chromium plating, anodizing, and pacifying chemicals; welding/brazing supplies; paints; laboratory chemicals; and various other materials (Harding ESE 2001).

The Remote Facility was constructed in 1956 and is located in the southern portion of the Facility Parcel area. It was used for the testing of power generators used on space vehicles and for material handling and combustion testing of Otto Fuel for a U.S. Navy-sponsored torpedo testing program (Harding ESE 2001). Operations in the Remote Facility concluded in 1966. In recent years, the Remote Facility was mostly vacant and unused except for storing virgin products used in manufacturing operations.

Hamilton Sundstrand acquired 80 acres of agriculture and pasture land between the Facility Parcel and Pecos Street and 40 acres east of Pecos Street in 1991. In 1994, Hamilton Sundstrand purchased 18 acres of property immediately adjacent to the 40 acres previously purchased that was used for sand, clay, and gravel mining. The property was reclaimed by the previous owner under a Colorado Mine Reclamation Board Permit issued in 1992 (ARCADIS 2007c). Combined, these areas (138 acres) are now the Vacant Parcel.

Hamilton Sundstrand announced a phased closure of the Denver facility in October 2002. Decommissioning began in August 2003, and all production activities ceased by April 2004. Decommissioning was completed by May 2004. Approximately 777 tons of materials were generated that were either properly disposed of, recycled, or reused during the 9-month decommissioning project (ARCADIS 2004).

2.1.3 RCRA Corrective Action History

In 1980, Hamilton Sundstrand submitted a RCRA Part A permit application for the treatment of hazardous plating wastes generated as part of manufacturing operations. In 1982, Hamilton Sundstrand eliminated the need to treat plating waste on site by enhancing pretreatment processes so the remaining waste stream could be directly discharged to the Denver Metro Publicly Owned Treatment Works. As a result, Hamilton Sundstrand submitted a closure plan to the USEPA on June 2, 1983 for the clean closure of this treatment, storage, and disposal (TSD) facility. USEPA approved the clean closure of the plating waste treatment facility, and Hamilton Sundstrand was released from related financial assurance obligations.

In 1987, Hamilton Sundstrand voluntarily began to assess and remove underground storage tanks (USTs) prior to the issuance of federal UST regulations. In 1989, CDPHE issued a notice of violation regarding groundwater surfacing in the eastern portion of the site known as the Seeps Area. In May of 1995, Hamilton Sundstrand and CDPHE entered into a Compliance Order on Consent (No. 95-05-03-01) to resolve the state's concerns regarding the Seeps Area. The Seepage Water Remediation

System began continuous 24-hour-per-day operation on November 15, 1995. Section 2.7.2 further describes the Seepage Water Remediation System.

In April 1992, the GBS was constructed to capture and treat groundwater containing volatile organic compounds (VOCs) and light non-aqueous phase liquid (LNAPL). The system was installed along the eastern boundary of the Facility Parcel to prevent off-site contaminant migration. Section 2.7.1 further describes the GBS.

In 1999, regulatory oversight for RCRA Corrective Action activities was transferred from CDPHE to USEPA Region 8. On August 16, 2000, the Hamilton Sundstrand Corporation and USEPA Region 8 entered into a Corrective Action Order on Consent (USEPA Docket Number RCRA-8-2000-11) governed under RCRA Section 3008(h). The purpose of the consent order was to provide a framework to perform RCRA corrective action activities to address on-site and off-site contamination. On September 17, 2002, USEPA determined that "Human Health Exposures" at Hamilton Sundstrand were under control. On September 15, 2003, USEPA determined that the "Migration of Contaminated Groundwater" was under control (ARCADIS 2007c).

During a meeting on May 8, 2006, Hamilton Sundstrand, USEPA Region 8, CDPHE, and ARCADIS commenced discussions regarding returning the Hamilton Sundstrand Former Denver Facility to CDPHE oversight and completing final environmental remediation activities pursuant to Colorado Hazardous Waste Regulations (6 CCR 1007-3, paragraph 100.26). In January 2007, CDPHE approved the site’s ICAP Application and determined that the ICAP Application met the requirements for a Corrective Measures Study Work Plan (CDPHE 2007b). On February 13, 2007, CDPHE approved a request for No Further Action (NFA) for the Vacant Parcel contingent upon the property developer being contractually obligated to include passive vapor mitigation systems in any building constructed on the property (CDPHE 2007a). On April 5, 2007, USEPA officially terminated the previous Corrective Action Order on Consent (USEPA Docket Number RCRA-8-2000-11) (USEPA 2007).

2.2 Geology and Hydrogeology

The site and its surroundings overlie a paleochannel and paleoterrace that are now covered by unconsolidated alluvial and windblown (eolian) deposits. The paleochannel and paleoterrace are oriented parallel to the Clear Creek paleochannel, approximately 1 mile wide, which underlies the present Clear Creek (Lindvall 1979).

Bedrock at the site consists of green-blue claystone or olive-gray sandstone units of the Denver Formation. The bedrock surface slopes east-southeastward beneath the site and is located at a depth of 40 to 50 feet below ground surface (bgs), although this varies locally. Boring logs of two on-site groundwater production wells reveal that the uppermost bedrock unit, referred to as the Denver Formation, is approximately 125 feet thick. The Denver Formation is low-permeability bedrock, but the upper few feet are weathered and may afford some hydraulic conductivity.

In most areas of the site, the bedrock is overlain by 10 to 15 feet of sandy gravel mixed with cobbles in some areas. Overlying this gravel unit is a sand unit interbedded with discontinuous clay lenses of varying thickness. In some on-site and off-site areas, this sand unit is overlain by a clay layer that is generally 10 to 15 feet thick. This clay unit is present in the Facility Parcel but may be absent off site in parts of both the Perl Mack Neighborhood area and the Vacant Parcel. **Figure 2-2** is a geologic cross-section extending from west to east across the site showing the distribution of the primary geologic units.

The saturated zone in most of this area is composed of sandy or gravelly soil with only localized zones of finer material. One zone of finer material is located just east of the northern boundary of the Facility Parcel. A zone of less permeable clayey soil is also present in the Vacant Parcel east of Pecos Street. On the Facility Parcel, groundwater is first encountered 30 to 40 feet below the surface. This water-bearing unit is an unconfined aquifer averaging approximately 10 feet in thickness and is located just above bedrock. The thickness of the saturated zone ranges from 5 feet to 15 feet, and there is at least one location where the thickness is greater than 20 feet. Most of the differences among the saturated thicknesses can be accounted for by the difference in bedrock elevation. Saturated thickness tends to be greater than 10 feet beneath the Facility Parcel and somewhat less east of the Facility Parcel property line. The top 2 to 5 feet of the bedrock are weathered and therefore permeable in places. Below the top 2 to 5 feet, the bedrock is competent and relatively impermeable as compared to the overlying alluvium. Groundwater levels typically fluctuate by approximately 3 feet over the course of a normal year. Groundwater elevations are lowest during February, March, and April; they are highest in July, August, and September. Deeper water-bearing units were not considered in this report because these units are separated from the upper unit by low-permeability bedrock. Previous investigations have identified no contamination within or beneath the claystone bedrock underlying the site (Harding ESE 2001).

Groundwater generally flows from west to east. A weak southerly component to flow becomes more pronounced closer to Clear Creek. The hydraulic gradient is approximately 0.005 (feet per foot) south of West 68th Avenue, and 0.006 to the north. The natural gradient varies from 0.003 to 0.007, with local gradients much higher near the GBS extraction wells. As stated above, the lower 10 feet of the unit is mostly composed of gravel or sand. The hydraulic conductivity has been measured in at least three studies (Harding ESE 2001), but all known measurements have taken place in the northern part of the Facility Parcel. Long-duration pump tests were conducted when the first six extraction wells were installed for the GBS. These six values were relatively high, ranging from 62.4 feet per day (ft/day) or 2.2×10^{-2} centimeters per second (cm/sec) to 765 ft/day (2.7×10^{-1} cm/sec). The six conductivity values were in two clusters. The conductivity of the wells in the northern part of the Facility Parcel represented an average of 652.0 ft/day (2.30×10^{-1} cm/sec). To the south, the hydraulic conductivity averaged 69.9 ft/day (2.47×10^{-2} cm/sec). Thus, the data suggest that there is an order of magnitude difference in conductivity between these two areas. The geometric average of the six hydraulic conductivity measurements is 6.89×10^{-2} cm/sec, or 195 ft/day. This value is close to the 300 ft/day determined in the calibration of the groundwater flow model prepared for the site (ARCADIS 2007b).

Calibration of the groundwater flow model (ARCADIS 2007b) also predicted a zone of low hydraulic conductivity near the far eastern end of the Vacant Parcel in an area sometimes referred to as the Reversion Parcel. The hydraulic conductivity in this area is estimated at 0.05 ft/day. The borehole log for well GW-49 in this area indicates that the saturated zone is silty sand and silty clay, and that the saturated zone is less than 2 feet thick. Therefore, this zone of low hydraulic conductivity identified during model calibration is confirmed by the borehole log.

The natural gradient within the Facility Parcel is 0.005 to 0.006. Assuming the effective porosity is 0.25 (25 percent), Darcy's Law can be applied to compute the groundwater velocity. The computed velocity is on the order of 4 ft/day, which is consistent with the values computed by the groundwater model. This velocity is equivalent to 1,500 feet per year (ft/year). The natural gradient is higher off site; the velocity under natural conditions off site is 7 to 9 ft/day. Very low levels of natural organic carbon in the gravel matrix suggest that contaminant retardation from sorption is insignificant when computing the relative speed of any dissolved-phase contaminants in the groundwater with respect to that of the groundwater.

A tracer test conducted in the Perl Mack Neighborhood in 2007 revealed a heterogeneous flow regime governed by conduits of high conductivity. A recent advance in the conceptualization of solute transport in groundwater is the dual-domain model (Molz, et al., 2006; Payne, et al., 2007). The porous media are represented by two systems in close proximity, one mobile and the other immobile, exchanging mass by molecular diffusion. Following this dual-domain model, mobile porosity was estimated to be approximately 7 percent. Based on that estimate, the dual domain retardation factor for contaminant transport was computed to be 5. Consequently, the movement of VOCs dissolved in groundwater is estimated to average about 1 ft/day.

The flux of water across the site can be estimated using values for saturated thickness, hydraulic gradient, and hydraulic conductivity from the center of ranges determined from field observations and computer modeling. Assuming a saturated thickness of 12 feet on the western boundary of the Facility Parcel adjacent to the Main Source Area, an average gradient of 0.005, and a hydraulic conductivity of 300 ft/day, the flux of water across the 1,440 feet upgradient boundary is approximately 25,900 cubic feet per day (cfd), which is equivalent to 194,000 gallons per day (gpd) across the Main Source Area.

The water-bearing unit is recharged by percolation from precipitation and irrigation, and by leakage from reservoirs northwest of the former facility. Precipitation and irrigation upgradient of the site are the main sources of recharge by percolation. Parts of the site were irrigated in the past, but have not been watered since the facility ceased operations in 2004. Now the Facility Parcel and the Vacant Parcel receive only precipitation, minus runoff and evapotranspiration. The recharge has been estimated to be higher in residential areas due to the use of water to irrigate lawns, approximately 2 inches per year. The groundwater model calibration corroborated these estimates (ARCADIS 2007b). Leakage from canals connecting the large reservoirs northwest of the facility also recharges the underlying groundwater and provides much of the water in the aquifer. The water discharges to Clear Creek to the south and Kalcevic Gulch to the east. Water also seeps from the slopes in the southeastern part of the Vacant Parcel east of Pecos Street.

In summary, groundwater flows from west to east in the coarse sediment in the lower 10 feet of the unconsolidated material, and is able to move at an average of 4 to 9 ft/day under natural flow conditions. However, with the calculated contaminant retardation factor of 5, the contaminant migration velocity is about 1 ft/day. The groundwater formation is unconfined with a saturated zone that is approximately 10 feet thick. The lithology in most of the saturated zone is coarse sand and gravel.

2.3 Surface Water

The only surface water body that is adjacent to the Facility Parcel is the Little Dry Creek. The Vacant Parcel is adjacent to, bounded, or crossed by four other surface water bodies: Clear Creek, Lower Clear Creek Canal, South Pond, and the Kalcevic Gulch. Each of these water bodies is discussed in this section and shown in **Figure 2-1.**

Little Dry Creek drains a suburban area of Denver, is approximately 7.5 miles long, and runs from Arvada southeast to Clear Creek. In spite of its name, Little Dry Creek conveys water year round. The creek bed forms the diagonal southern boundary of the Facility Parcel. Several storm drains flow from the Facility Parcel into Little Dry Creek through the storm retention basin via a culvert. The basin prevents sediment from the Facility Parcel from reaching the creek.

Clear Creek is a direct tributary to the South Platte River. The creek flows within 100 feet of the southern boundary of the eastern portion of the Vacant Parcel. The segment of the creek south of the Facility Parcel and the Vacant Parcel flows to the northeast.

The Lower Clear Creek Canal is a manmade watercourse that forms much of the eastern boundary of the Vacant Parcel. The canal was constructed for irrigation purposes. Clear Creek bifurcates less than 100 feet from the southeast corner of the Vacant Parcel; the canal is the northern fork. The Lower Clear Creek Canal flows to the northeast approximately parallel to Clear Creek. The surface on the northern bank slopes steeply toward the Lower Clear Creek Canal. Groundwater is able to seep from the subsurface at this slope. The Seeps Water Remediation System (Section 2.7.2) was installed to prevent impacted groundwater seeping from the slope from reaching the canal or Clear Creek.

The Kalcevic Gulch is a natural channel flowing in a southeasterly direction through the neighborhood east of Pecos Street. The gulch is approximately 0.5 mile long. Its source is just south of Scott Carpenter Middle School. It flows under West 68th Avenue through a culvert. The gulch also passes under the Lower Clear Creek Canal via a second culvert and empties into Clear Creek. The culvert is located at the eastern tip of the Vacant Parcel.

The South Pond is a water body that is 180 feet long and 90 feet wide at its widest point. The pond is oriented in an east-west direction. South Pond is at the extreme south of the eastern part of the Vacant Parcel, 400 feet east of Pecos Street, and less than 200 feet northwest of Clear Creek.

2.4 Identification and Evaluation of SWMUs and AOCs

As previously discussed, the site's 13 SWMUs and six AOCs were identified as the probable areas where contaminants were originally released to the environment. No SWMUs or AOCs were identified beyond the Facility Parcel boundary except AOC 3 (groundwater), which extends off site beneath the Perl Mack Neighborhood and Vacant Parcel. In general, this CMWP focuses on the evaluation of corrective measures for remediation of the larger, combined contaminant source areas, including the Main Source Area and the Remote Facility, rather than the remediation of individual SWMUs or AOCs. Most of the individual SWMUs and AOCs identified are contained within the Main Source Area and Remote Facility. The subsections below summarize each SWMU and AOC in relation to its location within either the Main Source Area or Remote Facility. Only AOC 2, an area of PCB contamination in soil at the south end of the Facility Parcel, and AOC 3, site-wide groundwater, are described separately. **Figure 2.3** shows the locations of each SWMU and AOC. Detailed descriptions of each SWMU and AOC, including historical environmental investigations, are presented in the site RCRA Facility Investigation (RFI) report (ARCADIS 2007c).

2.4.1 Main Source Area

The Main Source Area primarily encompasses the northern portion of the Facility Parcel, including the Main Plant Building and Tape Manufacturing Building. The Main Source Area includes the following SWMUs and AOCs: SWMU 1, SWMU 2, SWMU 3, SWMU 4, SWMU 5, SWMU 10, SWMU 11, SWMU 12, SWMU 13, AOC 1, AOC 5, and AOC 6. Each SWMU and AOC is briefly described below.

2.4.1.1 SWMU 1 – Tank 6

Tank 6 was a 10,000-gallon steel UST located immediately south of the Tape Manufacturing Building. The tank was installed between 1972 and 1973 and was operational until service was discontinued in 1985. Tank 6 was used for storage of water and waste oil associated with the lathing, cutting, milling, and grinding operations. The tank was closed and removed in 1992. Relatively low concentrations (less than 1 milligram per kilogram (mg/kg) of PCBs and arsenic concentrations slightly above site background were detected in historical soil investigations (ARCADIS 2007c). SWMU 1 does not appear to be a source of contamination to groundwater.

2.4.1.2 SWMU 2 – Tank 7

Tank 7 was a 2,000-gallon reinforced fiberglass UST located in the northwest corner of the west wing of the Tape Manufacturing Building. It was used for storage of water and waste oil associated with milling, cutting, and grinding operations. The tank was installed in 1974; however, it was only in service for 6 months in 1985. According to historical documents, the tank failed a tank tightness test (Harding ESE 2001); consequently, the tank was closed and removed in 1987 (JRE 1988). No contaminant releases from SWMU 2 were evident in historical investigations.

2.4.1.3 SWMU 3 – Chip Dock Tanks

The Chip Dock Tanks consist of four USTs (Tank 8, Tank 10, Tank 11, and Tank 12) located at the southwest corner of the Main Plant Building. All of the tanks were used to store virgin product, fuel, water, and waste oil in support of manufacturing operations. The tanks were located immediately adjacent to and south of the Chip Dock Area of the Main Plant Building where metal filings from the grinding and milling operations were temporarily stored in metal roll-off boxes on a loading dock above the tanks (Harding ESE 2001). Tank 8 was a 10,000-gallon steel UST used to store No. 1 diesel fuel and virgin Stoddard Solvent. Tank 10 was a 10,000-gallon steel UST used to store water and waste oil. Tank 11 was a 2,000-gallon steel UST, used to store light hydraulic oil. Tank 12 was a 1,000-gallon steel UST used to store gasoline.

All four tanks were installed in 1966 and, with the exception of Tank 12, were in use until 1985 and were closed and removed in 1987. Use of Tank 12 ceased in 1980. Contaminant releases were confirmed for Tank 8, Tank 10, and Tank 11; however, releases were not suspected or confirmed from Tank 12 (ARCADIS 2007c). Releases from the SWMU 3 USTs appear to be a major contributor to groundwater contamination in the Main Source Area.

2.4.1.4 SWMU 4 – Tank 9

Tank 9 was a 2,000-gallon steel UST located immediately south of the west wing of the Tape Manufacturing Building. It was used to store water and waste oil associated with lathing, milling, cutting, and grinding operations. Tank 9 was installed in 1975, and service ceased in 1978. The tank was excavated and removed in 1987. No contaminant releases from SWMU 4 were evident in historical investigations.

2.4.1.5 SWMU 5 – Former Oil Bar Tanks

The Former Oil Bar Tanks consist of six USTs located at the southeast corner of the Main Plant Building. The tanks are designated Tank 13 through Tank 18 and were last used to store waste oil in support of manufacturing operations.

All of the tanks were installed in 1955 or 1956. Tanks 13 and 14 were 850-gallon steel USTs; tanks 15 and 16 were 1,000-gallon steel USTs; and tanks 17 and 18 were 2,500- and 1,000-gallon steel USTs. These tanks were reportedly used to store waste, used, or virgin solvent, waste oil, and regular gasoline (ARCADIS 2007c). The tanks were taken out of service in 1966 and closed in place in 1982 by filling the tanks with an inert slurry material. The filled tanks and their associated piping remain in place (Harding ESE 2001). Releases from the SWMU 5 USTs appear to be a major contributor to groundwater contamination in the Main Source Area.

2.4.1.6 SWMU 10 – Former Used Oil Drum Storage Area

The Former Used Oil Drum Storage Area is a rectangular-shaped open area located between the Main Source Area and the Remote Facility. The area is approximately 120 feet long by 35 feet wide and was used to temporarily store used oil in 55-gallon drums during the early to mid-1980s. The area is underlain with gravel, and the drums were reportedly stored on wood pallets or placed directly on the gravel surface. The actual number of drums stored in the area is unknown, but it is understood that approximately 35 to 40 drums were stored in the area at any given time (ARCADIS 2007c). Relatively low concentrations of 1,4-dioxane and lead exceeding background concentrations were detected in several soil samples during historical investigations (ARCADIS 2007c). SWMU 10 does not appear to be a source of contamination to groundwater.

2.4.1.7 SWMU 11 – Former Tape Manufacturing Building Cutting Oil Recovery System

The Former Tape Manufacturing Building Cutting Oil Recovery System was a cutting oil/solids filtration system composed of a central solids filtration unit and a system of delivery and return service lines that provided cutting oil to milling operations. The system was installed in 1968 and is located inside the Tape Manufacturing Building in the southeast corner of the building. The former milling area was approximately 200 feet long by 80 feet wide and was composed of approximately 20 milling machines mounted on the concrete floor of the building. The central solids filtration unit was located in a basement area immediately south of the milling area (Harding ESE 2001).

The Former Tape Manufacturing Building Cutting Oil Recovery System was operational for only 6 months in 1968. The system was found to be ineffective at delivering and returning cutting oil to the milling machines and was taken out of service. The system was replaced with individual cutting oil delivery and solids filtration units located at each milling machine. The central solids filtration unit and associated receiving tanks remained in the basement area until the late 1970s to early 1980s, when they were permanently removed (Harding ESE 2001).

Historical investigations have detected arsenic, barium, lead, tetrachloroethene (PCE), trichloroethene (TCE), 1,4-dioxane, and PCBs in soil in excess of initial site screening levels (ARCADIS 2007c). Based on the orientation of groundwater contaminant plumes, releases from SWMU 11 appear to contribute to groundwater contamination in the Main Source Area.

2.4.1.8 SWMU 12 – Former Central Oil System and Former Temporary Collection Sumps

The Former Central Oil System was a cutting oil solids filtration system composed of a central solids filtration unit and a system of delivery and return service lines that provided cutting oil to the grinding area located in the Main Plant Building. The Central Oil System was located inside the Main Plant Building in the west central portion of the building immediately adjacent to the grinding operation area. The former grinding area measured approximately 250 feet by 120 feet and was composed of approximately 90 grinding machines mounted on the concrete floor. The Central Oil System was installed in the early to mid-1960s and operated until approximately 1993 (Harding ESE 2001).

Historical investigations have detected relatively low concentrations of 1,1-dichloroethene (DCE), PCE, TCE, benzo(a)pyrene, and thallium in soil in excess of initial site screening levels (ARCADIS 2007c). Based on the orientation of groundwater contaminant plumes, either SWMU 12 or the adjacent AOC 5 (or both) appear to contribute to groundwater contamination in the Main Source Area.

2.4.1.9 SWMU 13 – Chip Bin Containment Area

The Chip Bin Containment Area is located at the southeast corner of the Main Plant Building and is approximately 75 feet long and 15 feet wide. The area was constructed in 1993 to accommodate the temporary storage of metal chips and scrap metal from plant operations in open-top metal storage bins prior to off-site recycling. No contaminant releases from SWMU 13 were evident in historical investigations.

2.4.1.10 AOC 1 – Former AST Area

The Former Aboveground Storage Tank (AST) Area is an open concrete containment structure located approximately 150 feet south of the southwest corner of the Main Plant Building. The containment structure is approximately 75 feet long by 30 feet wide by 3 feet high and contained seven steel ASTs for product storage ranging in size from 3,000 to 6,000 gallons. Two 6,000-gallon tanks were used to store virgin and reclaimed 1,1,1-trichloroethane (TCA). Upsilon oil and heavy medium oil were stored in two 3,000-gallon tanks. Sigma oil was stored in a 5,000-gallon tank, and a 3,000-gallon tank and a 4,000-gallon tank were used as spare product tanks. The seven tanks were mounted on concrete saddles inside the containment structure; the containment structure was not covered.

The containment structure and tanks were constructed and installed in 1981 and operated until the mid-1990s. The two spare product tanks were taken out of service in 1993. The remaining five tanks were taken out of service in the mid-1990s. All seven tanks were physically removed from the area in the mid-1990s. Releases from AOC 1, including from pipelines extending north from the containment structure toward the SWMU 3 area, appear to be a major contributor to groundwater contamination in the Main Source Area.

2.4.1.11 AOC 5 – Heat Treat Basement

The Heat Treat Basement is located near the southwest corner of the Main Plant Building, just east of the Former Central Oil System (SWMU 12). The Heat Treat Basement underlies the former Heat Treat Area and served as a collection area for water and oil from the heat treat furnaces during operations.

The Heat Treat Basement was identified as an AOC during decommissioning activities for the manufacturing facility; AOC 5 was not included in the Final Current Conditions/Release Assessment (CC/RA) report (Harding ESE 2001). Investigations into the Heat Treat Basement were conducted during the Phase II RFI (MACTEC 2004). The only compound detected in soil above initial site screening levels was 1,4-dioxane (ARCADIS 2007c). However, based on the orientation of groundwater contaminant plumes, either AOC 5 or the adjacent SWMU 12 (or both) appear to contribute to groundwater contamination in the Main Source Area.

2.4.1.12 AOC 6 – Waste Treat Area

The Waste Treat Area is located in the basement of the southern end of the Main Building. The area was established to treat plating waste and other chemicals from plating tanks located on the floor above.

The Waste Treat Area was the second AOC identified during decommissioning activities for the manufacturing facility; therefore, AOC 6 was not included in the Final CC/RA report (Harding ESE 2001). The Phase II RFI examined AOC 6 (MACTEC 2004). Releases from the AOC 6 area appear to be a major contributor to groundwater contamination in the Main Source Area.

2.4.2 Remote Facility

The Remote Facility encompasses the southern portion of the Facility Parcel and includes the following SWMUs and AOCs: SWMU 6, SWMU7, SWMU 8, SWMU 9, and AOC 4.

2.4.2.1 SWMU 6 – Clean Closed Former RCRA TSD

The Clean Closed Former RCRA TSD (Closed TSD) was a hazardous waste storage and treatment area used to temporarily store and treat RCRA hazardous plating waste generated from operations in the Main Plant Building. SWMU 6 measured approximately 120 feet by 100 feet and consisted of five concrete storage areas and five concrete treatment cells. The SWMU received a clean closure certification approval from USEPA Region 8 in August 1984. Copies of the approved Closure Plan and USEPA's letter documenting closure certification are provided in the Final CC/RA report (Harding ESE 2001).

2.4.2.2 SWMU 7 – 90-Day RCRA Storage Area

The 90-day RCRA Storage Area is an enclosed building located east of the main Remote Facility building that was used for 90-day-or-less storage of RCRA hazardous waste. There is a 70-foot-by-70-foot concrete pad immediately south of the building. The building was originally constructed in the early to mid-1960s and was known as the Mirror Building. The concrete pad was originally used as a foundation for a 40-foot-diameter mirror for government-related testing activities conducted between approximately 1964 and 1966 at the Mirror Building. Between the late 1960s and early 1980s, the building was used to store equipment for use in the Main Plant Building manufacturing operations. By the early 1980s, the building was altered to conform to

RCRA requirements for units specifically designated for 90-day-or-less storage of RCRA hazardous waste (Harding ESE 2001). Hazardous waste generated from manufacturing operations was stored in 55-gallon drums inside the building in concrete-bermed areas prior to off-site disposal at an approved hazardous waste disposal facility. The concrete pad immediately south of the building was used for the storage of used waste oil in 55-gallon drums in the mid-1980s. No contaminant releases from SWMU 7 were evident in soil samples collected during historical investigations.

2.4.2.3 SWMU 8 – Former Slit Trench Area

The Former Slit Trench was an elongated earthen trench located in the southeast portion of the Remote Facility near the eastern property boundary. The trench was reportedly 115 feet long by 16 feet wide by 5 feet deep. The trench was unlined and was used for the placement of plating waste sludge generated from the Clean Closed Former RCRA TSD (SWMU 6). The trench was reportedly used between 1973 and 1975 (Harding ESE 2001).

An estimated 470 cubic yards of contaminated soil and sludge were excavated and removed from the Slit Trench in 1984. The material was disposed of at an approved off-site waste disposal facility during activities undertaken for the closure of the Cleaned Closed Former RCRA TSD (SWMU 6). Dimensions of the final excavation and the disposition of the trench after the removal action were not available in historical documents (Harding ESE 2001). Historical investigations have detected relatively low concentrations of chromium and lead in soil slightly exceeding background concentrations (ARCADIS 2007c). The absence of contamination in nearby downgradient monitoring wells suggests that SWMU 8 is not a source of contamination to groundwater.

2.4.2.4 SWMU 9 – Former Plating Waste Drum Storage Area

The Former Plating Waste Drum Storage Area is a concrete pad located immediately south of the main Remote Facility building. The pad is approximately 30 feet wide by 70 feet long and was constructed in the late 1950s or early 1960s as a foundation for cooling towers for the Remote Facility. The cooling towers were dismantled in the late 1970s and early 1980s (Harding ESE 2001). During this time, the pad was reportedly used for temporary storage of 55-gallon drums of plating waste generated from the Main Plant Building prior to treatment at the Clean Closed Former RCRA TSD (SWMU 6).

Approximately 40 cubic yards of contaminated soil were reportedly excavated and removed from an area adjacent to the concrete pad in 1984 and disposed of at an approved off-site waste disposal facility during closure of the Clean Closed Former RCRA TSD (SWMU 6) (Harding ESE 2001). Historical investigations have detected relatively low concentrations of arsenic and lead in soil slightly exceeding background concentrations (ARCADIS 2007c) and low concentrations of semi-volatile organic compounds (SVOCs). SWMU 9 does not appear to be a source of contamination to groundwater.

2.4.2.5 AOC 4 – Remote Facility

AOC 4 is a 42,000-square-foot building that was the main Remote Facility structure. The building was originally constructed in 1956 and operated until 1966 (Harding ESE 2001). In recent years, the building was used to store 55-gallon drums of virgin products used in manufacturing operations. The drums were stored in secondary containment in the northeast portion of the west wing of the building. Miscellaneous equipment and parts were also stored throughout the west wing.

Historical investigations have detected relatively low concentrations of arsenic, lead, and mercury in soil slightly exceeding background concentrations at AOC 4 (ARCADIS 2007c). Recent investigations have also detected PCE in soil at relatively low concentrations. Based on the pattern of contaminant concentrations in groundwater, the primary source of the Remote Facility PCE plume (see Section 2.6.1.2.1) appears to be in the vicinity of the AOC 4 building.

2.4.3 AOC 2 – Former Oil Collection Sump and Former Storm Water Discharge Area

The Former Oil Collection Sump and Former Storm Water Discharge Area was the primary collection and discharge point for the Facility Parcel storm water system. The sump and discharge areas are located south of the Remote Facility at the south end of the Facility Parcel (**Figure 2-3**). The sump was a metal trough approximately 12 feet long by 4 feet wide by 3 feet deep, and was partially set below-grade to accept storm water routed from the primary manufacturing area (northern half of the Facility Parcel) and the Remote Facility. The sump was installed in the early to mid-1960s and operated until the early to mid-1980s, when permanent concrete oil-water separators were installed (Harding ESE 2001).

Water entering the sump was conveyed through a 100-foot-long, 24-inch galvanized pipe, where it was discharged to the ground south of the sump. The sump discharge area is located in a topographically low-lying area that occupied the southernmost portion of the plant area south of the Remote Facility. The discharge area extended south of the 24-inch sump discharge pipe and roughly paralleled the Facility Parcel property boundary along Little Dry Creek to its terminus at the southeastern corner of the Facility Parcel property. This area is located in the 100-year flood plain of Little Dry Creek.

More than 50 soil samples were collected from AOC 2 during previous site investigations (ARCADIS 2007c). PCBs represent the primary constituent of interest, although benzo(a)pyrene has also been detected in soil samples above initial site screening levels. Relatively low concentrations of arsenic, chromium, and lead exceeding background concentrations were also detected in several soil samples during historical investigations. Historical investigations have not detected releases to groundwater from AOC 2.

2.4.4 AOC 3 – Site-wide Groundwater

Since 1987, site groundwater investigations have detected impacts resulting from releases from various locations on the Facility Parcel. Groundwater is impacted within the Facility Parcel area and extending off site, eastward toward Clear Creek. Site-wide groundwater (groundwater beneath the Facility Parcel, Perl Mack Neighborhood, and Vacant Parcel and extending to Clear Creek) has therefore been identified as an AOC due to:

- The extent of impacts to groundwater involving multiple source areas at the Facility Parcel portion of the site and
- The commingled nature of groundwater impacts as a result of natural migration and remediation measures (i.e., it is not possible to attribute all groundwater impacts to individual sources).

Groundwater quality data have been collected during numerous investigations conducted at the site as summarized in the RFI report (ARCADIS 2007c). The most recent assessment of site-wide groundwater quality was completed as part of the annual groundwater monitoring program conducted in March and April 2007 (ARCADIS 2007a). The distribution of contaminants in groundwater beneath the site is summarized in Section 2.6.

2.5 Risk Evaluation

The following sections present a summary of the risk assessment that was prepared for the Facility Parcel of the Hamilton Sundstrand Former Denver Facility. The detailed discussion, calculations, and results for the risk assessment are presented in Appendix A of this CMWP report. The risk assessment was conducted to derive site-specific health-based remedial goals (HBRGs) for the constituents detected in groundwater and soil at the site. The HBRGs were generated to be consistent with the planned future use of the Facility Parcel as a recreational area.

The HBRGs were calculated in accordance with the proposed approach summarized in the September 6, 2007 memo prepared by ARCADIS (ARCADIS 2007g) which was discussed in a September 25, 2007 meeting with CDPHE. The risk assessment approach was subsequently approved[1] by CDPHE (via e-mail) on October 11, 2007.

This risk assessment evaluated analytical data for on-site groundwater and soil collected from the Facility Parcel. Conservative screening levels were used to select COPCs for each medium, and HBRGs were derived for each COPC based on the relevant human exposure scenarios. The relevant human exposure scenarios are:

- Future child (0 to 6 year old), youth (7 to 16 year old), and adult recreational user's exposure to COPCs in surface soil (0 to 0.5 ft bgs) via incidental ingestion, dermal contact, and inhalation of wind-blown fugitive dust and vapors.
- Future child, youth, and adult recreational user's exposure to volatile COPCs in ambient air via inhalation of vapors potentially released to outdoor air from groundwater.
- Future landscape maintenance workers exposure to COPCs in surface soil (0 to 2 ft bgs) via incidental ingestion, dermal contact, and inhalation of wind-blown fugitive dust and vapors.
- Future landscape maintenance workers exposure to volatile COPCs in ambient air via inhalation of vapors potentially released to outdoor air from groundwater.

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[1] It should be noted that as of the date of this submittal, the CDPHE has not yet completed their review of the proposed trench model used in the groundwater HBRG calculations for the utility/construction worker.

- Future utility/construction workers exposure to COPCs in combined surface and subsurface soil (0 to 8 ft bgs) via incidental ingestion, dermal contact, and inhalation of dust and vapors during excavation activities.

- Future utility/construction workers exposure to COPCs by inhaling volatile COPC vapors that have volatilized from the contaminated groundwater and migrated into the ambient air of the excavated utility/construction trench.

The following sections provide a summary of the selection process for the COPCs, and the development of the HBRGs.

2.5.1 Selection of Constituents of Potential Concern

The selection of COPCs to be evaluated in the risk assessment was based on groundwater samples collected from January 2002 to September 2007, and all historical soil sample results (from 1984 through September 2007). Groundwater samples have been collected from the site since 1987. However, after a trend analysis review of the groundwater monitoring data collected over the past 5 years (January 2002 to September 2007) these data were considered more representative of current conditions than data collected prior to 2002 (i.e., in general, concentrations have been decreasing over time). The soil data set used for the COPC selection included samples collected from 0 to 9.5 feet below ground surface (ft bgs) because contact with soils deeper than this would not be expected by any of the relevant exposure scenarios. The 0 to 9.5 ft bgs depth interval is intended to represent the depth interval that future utility/construction workers could encounter during excavation activities (the exposure assumption assumes soil depths from 0 to 8 ft bgs, but all historical soil sampling data to 9.5 ft bgs was evaluated to capture a significantly larger set of analytical data for identifying COPCs).

The selection of COPCs was based on the magnitude of the measured constituent concentrations in the relevant environmental media. If the maximum detected concentration exceeded the relevant screening level, then the constituent was identified as a COPC. As discussed in the September 25, 2007 meeting with CDPHE, the COPCs were selected based on a comparison to USEPA Region 9 Preliminary Remediation Goals (PRGs) for residential soil and tap water (USEPA 2004b). The use of these screening levels for the selection of COPCs is very conservative since there is no current or planned future residential use of the site, and there is no current or planned future use of the groundwater at the site. However, the selection of COPCs does not imply that the selected constituents pose a potential human health risk, but only specifies a subset of the detected constituents to be included in the risk assessment calculations.

The comparison of the groundwater data to the screening levels resulted in the following thirty-five (35) constituents being selected as groundwater COPCs:

1,1,1-Trichloroethane
1,1,2,2-Tetrachloroethane
1,1,2-Trichloroethane
1,1-Dichloroethane
1,1-Dichloroethene
1,2,4-Trichlorobenzene
1,2,4-Trimethylbenzene
1,2-Dichloroethane
1,3,5-Trimethylbenzene
1,4-Dioxane
2-Butanone (MEK)
Benzene
Bromodichloromethane
Bromomethane
Carbon Tetrachloride
Chloroethane
Chloroform

Cis-1,2-Dichloroethene

Ethyl Methacrylate
Ethylbenzene
Isobutyl Alcohol
Methyl Tert-Butyl Ether
Methylene Chloride
Naphthalene
n-Butylbenzene
n-Propylbenzene
sec-Butylbenzene
Styrene
Tetrachloroethene
Tetrahydrofuran
Toluene
Trans-1,2-Dichloroethene
Trichloroethene
Vinyl Chloride
Xylenes (total)

The comparison of the soil data to the screening levels resulted in the following nineteen (19) constituents being selected as soil COPCs:

- 1,1,2,2-Tetrachloroethane
- 1,1,2-Trichloroethane
- 1,1-Dichloroethene
- 1,2,4-Trimethylbenzene
- 1,3,5-Trimethylbenzene
- Benzene
- Cis-1,2-Dichloroethene
- Naphthalene
- Tetrachloroethene
- Trichloroethene
- Xylenes (total)
- Benzo(a)anthracene
- Benzo(a)pyrene
- Benzo(b)fluoranthene
- Dibenzo(a,h)anthracene
- PCBs
- Arsenic
- Barium
- Copper

2.5.2 Development of Site-Specific Health-Based Remedial Goals

The calculation of HBRGs requires the assumption of acceptable “target’ risk levels for carcinogenic and non-carcinogenic effects; the calculation then results in maximum “safe” constituent concentrations based on those acceptable risk levels. An excess lifetime cancer risk of 10^{-6}, the most conservative end of the USEPA target risk range of 10^{-4} to 10^{-6}, represents an additional probability of developing cancer, over the baseline or background risk applying to the general population, of 1 in 1,000,000 due to the effect of exposure to the relevant constituent. A non-cancer hazard of 1 indicates that the exposure level is equal to the reference exposure level that is not expected to produce non-carcinogenic effects, even for sensitive individuals or subpopulations, and this non-cancer hazard is used in this assessment. For carcinogens which have available carcinogenic and non-carcinogenic toxicity values, the recommended HBRG value is the minimum of the values based on potential carcinogenic and non-carcinogenic effects.

The CDPHE approved receptor-specific exposure parameters used in the calculation of the HBRGs for the relevant exposure scenarios (i.e., maintenance worker; construction worker; and child, youth, and adult recreational users under high use and average use conditions) are presented in **Table 2-1.** A summary of the groundwater HBRGs for the relevant exposure scenarios is presented in **Table 2-2,** and a summary of the soil HBRGs for relevant exposure scenarios is presented in **Table 2-3.** These HBRGs were developed in support of the CMWP and are intended to provide input for risk management and remedial decision-making activities for the site.

2.5.3 Summary of Contamination Exceeding Health-Based Remedial Goals

ARCADIS has completed a preliminary comparison of historical soil sample analytical results to the site HBRGs presented in **Table 2-3.** As expected, very few historical soil sample analytical results exceed the soil HBRGs. The low frequency of historical soil sample analytical results exceeding HBRGs was expected because most contaminant releases at the site were from leaking USTs, pipelines, or basement-level SWMUs occurring below the relatively shallow soil depths assumed for the relevant human exposure scenarios. Concentrations of VOCs in shallow soil exceed HBRGs (or are anticipated to exceed HBRGs) and are associated with observations of shallow soil contamination in borehole logs at SWMU 5, SWMU 12/AOC 5, AOC 1, and a location in the eastern portion of the Remote Facility at boring RT-SVE-3 that is not associated with a specific SWMU or AOC. Polynuclear aromatic hydrocarbons (PAHs) were detected above HBRGs in single soil samples collected at SWMU 9 and AOC 2. PCB concentrations in shallow soil exceed HBRGs in AOC 2. **Figure 2-4** shows these areas where HBRGs are exceeded in historical soil sample results. HBRGs are also exceeded in soil samples collected at SWMU 3, SWMU 11, and AOC 6, but all these sampling locations were from sub-basement levels or excavations at depths greater than the shallow soil depths assumed for the relevant human exposure scenarios. Arsenic was detected in shallow soil samples at five locations exceeding the HBRG. However, the maximum arsenic concentration detected was 9.2 mg/kg, which only slightly exceeds the site background concentration of 7 mg/kg. It is presumed that arsenic concentrations exceeding the HBRG represent naturally occurring concentrations and not contaminant releases.

ARCADIS also completed a preliminary comparison of groundwater sample analytical results from the 2007 site-wide annual groundwater monitoring event to the site HBRGs presented in **Table 2-2.** Only a TCE concentration of 700 micrograms per liter (μg/L) at well LNAPL-1 in SWMU 3 exceeded an HBRG. In addition, the detection limit for TCE at well AOC1-3 (640 μg/L) in AOC 1 exceeded an HBRG.

2.6 Contaminant Distribution

The distribution of contaminants can be conceptualized by understanding the source areas, contaminant transport mechanisms, and impacts off site. In this section, contaminant distribution is discussed for the on-site (Facility Parcel) source areas and off-site locations (Vacant Parcel and Perl Mack Neighborhood).

2.6.1 Facility Parcel

The Facility Parcel has three generally described source areas: the Main Source Area, the Remote Facility, and AOC 2. The Main Source Area is in the northern part of the parcel and encompasses the Main Plant Building and Tape Manufacturing Building. The Remote Facility is in the south-central portion of the Facility Parcel. AOC 2 is in the southern part of the Facility Parcel. This area is considered separately from the other 13 SWMUs and 5 AOCs due to its location apart from the Remote Facility. These three source areas are discussed in more detail in the following subsections.

2.6.1.1 Main Source Area

The Main Source Area consists of the Main Plant Building, the Tape Manufacturing Building, and the adjacent area extending 200 feet south of the buildings. These buildings are physically joined, and several associated SWMUs and AOCs were the sources of most of the contaminants. Chlorinated solvents and oils were used in this area and were released in various spills and leaks over several decades from the beginning of operations in 1955 to the cessation of activity in 2004.

Solvents commingled with oil percolated through the soil and eventually reached the water table. There is an elongated zone in which LNAPLs have been observed on the water table; a groundwater plume emanates from this zone. The distribution of the COPCs in the soil, LNAPL, and groundwater are discussed below. The issue of soil vapor is also addressed.

2.6.1.1.1 Soils

As stated in Section 2.2, the soil stratigraphy at most of the Facility Parcel consists of a clay and silt layer that is 10 to 15 feet thick, underlain by sand. There is a second layer of clay lenses underlain by gravel or gravelly sand. This coarse material interfaces with the bedrock. The groundwater is unconfined; the saturated soil is often coarse material. The soil texture governs the present distribution of COPCs as well as the past migration that created the distribution.

The COPCs migrated by three mechanisms: gravity, advection, and dispersion. The gravity mechanism refers to the downward flow of LNAPL. Advection refers to the leaching of soil contaminants by the percolation of unsaturated zone water. Dispersion refers to the movement of contaminants in the vapor phase in unsaturated zone pore space.

Initially, downward motion of LNAPL by gravity was the most important migration mechanism. Some chlorinated solvents flowed independently, but most of the chlorinated COPCs were commingled with spent oil (Harding ESE 2001). The solvent-laden oil flowed downward through the porous media to the water table. As long as the fraction of oil in the soil pores was greater than the irreducible saturation, the oil continued to flow downward. When the release ceased, some oil became trapped in the soil pores, unable to overcome capillary forces. The capillary forces in smaller pores, such as in silt or clay, are greater than in sand or gravel. Thus, in finer textured soil, the critical saturation needed to overcome capillary forces is greater than in coarse material, and a higher fraction of oil was trapped in clay and silt. Hydrocarbon concentrations are also higher at sand-clay interfaces, where contaminants are delayed from entering the finer soil by the permeability contrast.

The impact to soil from the release of oil can occur in four different fashions. First, COPCs are dissolved in the oil droplets suspended in the soil matrix. Second, the COPCs are adsorbed onto the natural soil organic matter. Third, the COPCs partition into the soil pore water. Fourth, COPCs partition by Henry's Law into the vapor in the unsaturated zone pore space.

In summary, the soil underlying the historic releases from the operations of the former facility is impacted with chlorinated COPCs that are dissolved or adsorbed in oil, naturally occurring soil organic matter, soil pore water, and soil vapor. The highest concentrations of COPCs will be in the oil. The greatest oil fractions will be found in fine textured soil such as clay and silt. Water that percolates through the unsaturated zone and contacts contaminants may have some COPCs partition into it. Fortunately, water percolation through the tight clay soils in the unsaturated zone is a minor mechanism, whose contribution of COPCs to groundwater would be too small to be detected. Figure 2-5 summarizes the extent of contamination in shallow, fine-grained (silt and clay) soil beneath the contaminant release areas.

2.6.1.1.2 LNAPL (saturations, mobility, characteristics)

LNAPL has been observed floating on the water table in an elongated area that extends from the southeast corner of the Tape Manufacturing Building to the plant boundary, from the southern 200 feet of the Main Plant Building to a line 200 feet south of the building. In this report, LNAPL is considered a different source from the contamination suspended in the fine soil pores referred to above. Oil released from the facility pooled atop the groundwater table and subsequently was distributed under advective forces via capillary flow along subtle preferential pathways. The continued movement of LNAPL was restricted by capillary forces. The permeability of a formation to a non-aqueous phase liquid is equal to the total permeability multiplied by the relative permeability of the formation. Relative permeability is a value between 0 and 1 that quantifies the ability of a phase to move though a medium relative to the intrinsic permeability of that medium. Whenever two or more phases, such as oil and water, coexist in a porous medium, they “share” the permeability. Because water is the wetting phase and oil is the nonwetting phase, water is favored in this sharing of permeability. The greater the volume fraction of a phase, the greater its relative permeability. When more than one phase is present, the sum of the relative permeabilities is generally less than 1. There is a lower limit to saturation, below which a phase is immobilized by capillary forces. Such non-aqueous phase liquid is said to be “immobile” or “insular.” For this reason, LNAPL can only migrate if it is sufficiently abundant in the formation. This is known as “free phase” liquid. If the source in the soil ceases to release more LNAPL to the water table, the spread of the LNAPL will decrease its volume in the impacted pores. Eventually, the volumetric faction of LNAPL will drop to the irreducible saturation, and the spread of the LNAPL will cease. The LNAPL saturation is heterogeneous, as is the porous medium, so the motion of LNAPL in the environment is uneven, but LNAPL motion will eventually cease after the source of LNAPL is stopped.

The LNAPL plume at the Facility Parcel cannot grow or migrate because the LNAPL saturation is too low at the periphery of the plume. Although the LNAPL plume is not able to grow, and most of the LNAPL is immobile, there are pockets of free phase oil in the interior of the plume. Boreholes afford even immobile LNAPL the opportunity to flow due to the lack of capillary forces in the borehole. Therefore, LNAPL is still being removed from the formation in some of the GBS extraction wells.

At present, the most important movement of LNAPL is in the vertical direction. The water table rises and falls seasonally. It is also affected by longer historical trends, such as droughts. As the water table moves, the LNAPL moves also. Whenever the water table drops, a smearing takes place as droplets of LNAPL become immobilized and are left behind in the higher soil pores. This smear zone is a major source of contamination to groundwater. **Figure 2-5** shows the extent of the LNAPL smear zone and the area where LNAPL may accumulate in well casings.

Samples have been collected from the LNAPL. The analyses indicate that the LNAPL is composed of hydrocarbons. The chlorinated species are partitioned into the hydrocarbon matrix. This is the reason the non-aqueous phase floats at a site in which the constituents of greatest concern are chlorinated (generally dense non-aqueous phase liquids). The matrix of the LNAPL is composed of aliphatic hydrocarbons of C10 to C32. The concentrations of constituents have been measured in LNAPL samples collected from several locations within the main LNAPL plume (HLA 1991 and 1996). Detected constituents include TCA, 1,1-dichloroethane (DCA), DCE, cis-1,2-DCE, TCE, PCE, benzene, toluene, ethylbenzene, xylene, and low levels of three PCB species. Although the concentrations of the various COPCs have varied, TCA has yielded the highest detected concentration in all seven of the analyses that included chlorinated VOCs, with concentrations as high as 6.7 percent. Other COPCs with concentrations higher than 1 percent in some samples include xylene and 1,2-DCE. Ethylbenzene, DCA, DCE, and TCE are abundant in some samples. PCE was abundant (0.1 percent range) in two samples, but was not detected in five samples due to high detection limits in samples with abundant TCA. The analyses clearly show the mingling of chlorinated solvents with oil and demonstrate that TCA was the most abundant chlorinated species.

2.6.1.1.3 Groundwater

As stated previously, groundwater flows at velocities of 4 to 9 ft/day. The first water-bearing unit is unconfined, located 30 to 40 feet below the surface. The unit is highly transmissive sand with gravel and cobbles in places. Under that unit is low permeability bedrock. This confining unit is 125 feet thick at the facility. Therefore, it is sufficient to consider only the unconfined unit in this discussion of contaminant distribution.

The location of the highest concentrations in the groundwater plume within the Main Source Area coincides with the LNAPL plume. **Figure 2-6** illustrates the extent of 1,1,1-TCA, TCE, and PCE plumes beginning at the Facility Parcel and moving across the Vacant Parcel and Perl Mack Neighborhood. For the purposes of this discussion, the area of the plume is defined as the area in which Federal Maximum Contaminant Levels (MCLs) are exceeded. The groundwater plume originates 600 feet from the eastern boundary of the Facility Parcel and extends beyond the boundary into the Perl Mack Neighborhood and the Vacant Parcel. The plume is approximately 400 feet wide at its widest point and the most abundant COPC is TCA, which occurs at concentrations in the main source area as high as 65,000 μg/L. Its daughter products, DCA (produced via biological reductive dechlorination) and DCE (produced via abiotic elimination), have plumes in the Main Source Area that are approximately collocated with the TCA plume. The highest concentrations of DCA and DCE in the 2007 groundwater sampling event at the main source area were 2,700 μg/L and 4,000 μg/L, respectively. The PCE and TCE plumes have similar dimensions and locations in the Main Source Area, except that the highest concentrations tend to occur further east than the highs for TCA and its daughters. The highest PCE concentration in 2007 was 310 μg/L, and the highest TCE concentration was 700 μg/L. The plume of the main degradation product of these two chlorinated alkenes, cis-1,2-DCE, has a smaller footprint, beginning 600 feet from the boundary, but only about 200 feet wide. This daughter product is being formed via reductive dechlorination, with biodegradable hydrocarbons present in LNAPL likely serving as the primary substrate (electron donor). The highest concentration of cis-1,2-DCE in 2007 was 6,000 μg/L and located further west than the highs for PCE or TCE. Concentrations in the part of the plume overlain by LNAPL are generally higher than in the northern part of the plume.

The plume moves west to east and is intercepted by the GBS. Concentrations drop abruptly as groundwater moves west to east across the GBS, but they do not drop to MCLs as explained in a later section. Approximately 200,000 gallons of water per day are removed by the GBS. That the plume could persist for decades at these high rates of flushing indicates that the chlorinated hydrocarbons are being replenished by sources in the unsaturated zone and the LNAPL.

2.6.1.1.4 Soil Vapor

The COPCs in the soil and LNAPL, including the oil droplets in the soil and the smear zone, will partition into the unsaturated pore space in the soil. In the pore space, the COPCs can disperse in the soil vapor by diffusion. The motion is gradient-driven. Therefore, the COPCs will emanate in all directions away from the Main Source Area. The speed of the diffusive flow is governed by the diffusivity of the contaminant. Vapor diffusivity is a function of temperature, porosity, and air-filled porosity (Millington and Quirk 1961). Diffusive flow in wet clay is impeded by the lack of air-filled pore space. The capillary pressure causes these pores to retain water. Because the most impacted soil is likely to be clay or soil near the water table, the air-filled porosity is expected to be low. Therefore, the ability for COPCs to move by soil vapor transport is not very great. Further, the Henry's Law partition coefficients for the COPCs are low. The mass of COPCs in the soil vapor is relatively low, and the transport of COPCs in the soil vapor phase is inefficient. In summary, the mass of contamination residing in the soil vapor phase is relatively low and insignificant relative to concentrations in soil and groundwater. Accordingly, it is not material to the evaluation and selection of remedial technologies.

2.6.1.2 Remote Facility

The Remote Facility is located in the south central part of the Facility Parcel, away from the Main Plant Building and the Tape Manufacturing Building. This facility is geographically distinct from the Main Source Area and thus represents a second source of contamination. PCE and TCE were used in this area. The sources of the two respective COPCs are separate and distinct.

2.6.1.2.1 Groundwater

For this area, it is useful to discuss the groundwater before the soil. Only six constituents were detected in the analytical data set for groundwater at the Remote Facility in 2006 and 2007 (besides low levels of methylene chloride, a common laboratory contaminant). Of the six, only two constituents (PCE and TCE) were detected above their MCLs. There is a groundwater plume for each of these two constituents that extend beyond the boundary of the Facility Parcel into the Vacant Parcel. Figure 2-6 shows the extents of both the PCE and TCE contaminant plumes associated with the Remote Facility. The PCE plume is north of the TCE plume. There is some overlap between the PCE and TCE plumes, and they have very different shapes. Part of the reason the PCE and TCE plumes are distinct is that there exists limited amounts of organic carbon available to biodegrade PCE into TCE. This lack of natural dechlorination also explains the absence of cis-1,2-DCE detections that exceed MCLs.

The PCE plume originates at the primary Remote Facility building (AOC 4), approximately 600 feet from the eastern boundary of the Facility Parcel. The maximum PCE concentration in the 2007 sampling event was 530 μg/L. The elongated shape of the PCE plume may indicate a higher mobile porosity and speed in this area than at other parts of the site. It certainly indicates a more distinct source, probably located at the north side of the building.

The TCE groundwater plume originates 150 feet east of the Facility Parcel eastern boundary line. The plume is south of the PCE plume, and the two plumes have a limited area of overlap. The maximum concentration of TCE in this plume in the 2007 groundwater sampling event was 100 μg/L at monitoring well TP4-3. There is a second TCE plume further south originating near monitoring well AOC4-24. This plume is small, with a length of approximately 150 feet. The maximum concentration in this plume is 15 μg/L, and the plume ends before monitoring well SWMU8-4, which is more than 100 feet west of the Facility Parcel boundary.

Boring logs from wells constructed in the Remote Facility indicate that the saturated zone is composed of poorly sorted sand with gravel and cobbles. This highly transmissive soil allows groundwater to flow at speeds of 4 to 10 ft/feet day. At these rates, PCE and TCE should have been flushed from this coarse-grained unit years ago. The continued presence of PCE and TCE indicates a continuing source. The ratio between the highest concentrations and the aqueous solubility indicates that it is highly unlikely that there are non-aqueous phase liquids in the vicinity of the Remote Facility. Moreover, non-aqueous phase liquids have never been observed in this area. Thus the source is likely to be bound in the lower part of the unsaturated zone.

The GBS was recently upgraded in this area with the addition of four new extraction wells (Section 2.7.1). These wells were installed to ensure that PCE and TCE would not be able to migrate beyond the eastern boundary of the Facility Parcel.

2.6.1.2.2 Soils

The soil stratigraphy underlying the Remote Facility consists of two layers. The top layer is mostly fine-grained, consisting of silt and clay with sand. The lower layer is coarse, consisting of poorly sorted sand with gravel and cobbles. The saturated zone is almost completely in the coarse layer. Investigations of contaminants in the soil have indicated the presence of contaminants at low concentrations. The soil analytical data for the Remote Facility include 88 samples collected since 2003. No VOCs or SVOCs of concern have been detected over their initial site screening levels. The exception is one soil sample collected at boring RT-SVE-3 at 7.8 feet bgs that contained concentrations of 1,2,4-trimethylbenzene and 1,2,5-trimethylbenzene exceeding the site HBRGs and a surface soil sample collected at SWMU 9 that exceeded the HBRG for benzo(a)pyrene (see **Figure 2-4)**. Three metals have been detected above their initial screening levels including arsenic, lead, and mercury. One or more of these metals were detected above the screening level in 15 of the 88 samples. The higher metals concentrations occur at a range of depths. However, except for several arsenic concentrations that appear to be naturally occurring (see Section 2.5.3), no metals concentrations exceed the site HBRGs.

As discussed above, the persistent occurrence of PCE and TCE in groundwater indicates a source in the soil. This source has never been positively located and PCE and TCE have never been detected above HBRGs in Remote Facility soil. The groundwater data indicate that the source of PCE is possibly below the footprint of AOC 4 itself and probably close to the northern side.
The TCE groundwater plume originates from a location east of the Remote Facility and is not associated with any specific SWMU or AOC. As discussed above, the

concentrations of TCE in this plume are relatively low and are only significant in the context of the MCL for this constituent. Soil data from this area do not reveal the source of this low-level contamination, although concentrations of 1,2,4-trimethylbenzene and 1,2,5-trimethylbenzene exceeding the site HBRGs have been detected in soil at boring RT-SVE-3 in this area.

Remote Facility groundwater samples also yielded detections of TCA and cis-1,2-DCE in the 2007 annual sampling event at comparable levels, but their respective MCLs (200 μg/L and 70 μg/L) were not exceeded. The AOC 4 soil sampling events only had one detection of TCA. This detection of 1 μg/kg was located at boring AOC4-17 at a depth of 9 feet bgs. Cis-1,2-DCE was not detected in the RR borings, but was detected 10 times in the AOC 4 samples series. Eight of these detections were 1 μg/kg, and the other two detections were at 4 μg/kg and 7 μg/kg, at respective depths of 10 and 7.8 feet bgs in the boring AOC4-8. Neither the soil data nor the groundwater data indicate actionable impacts of VOCs or SVOCs in soil or groundwater besides those associated with TCE and PCE.

In addition to the four chlorinated COPCs discussed above, five other hydrocarbon VOCs have been detected in Remote Facility soils, plus two common laboratory contaminants. Like the four chlorinated species mentioned above, these detections were below initial soil screening levels (and HBRGs). In the same way, 20 SVOCs and two SVOC laboratory contaminants were detected in Remote Facility soil, but none of the detections exceeded the initial soil screening levels or HBRGs, except a detection of benzo(a)pyrene at SWMU 9. Two PCBs were detected (1242 and 1254) at borings AOC4-5 and AOC4-6, respectively. The detections were below screening levels and HBRGs.

Ten metals have been detected above background levels in soil samples collected in the area of the Remote Facility. These are arsenic, cadmium, chromium, copper, lead, mercury, selenium, silver, tin, and zinc. Only three metals have been detected above screening levels: arsenic, lead, and mercury. Four of the six arsenic detections above the initial screening level were clustered south of the building. Four detections of arsenic exceed the site's HBRGs and background in shallow soil including three samples associated with AOC 4 and one sample at SWMU 9. However, as described in Section 2.5.3, it is believed that these are naturally occurring arsenic concentrations and do not represent contaminant releases. There were 11 initial screening level exceedences of lead, and seven were clustered in the same place. However, no lead detections in shallow soil exceed the site HBRGs. Only one detection of mercury exceeded the initial screening level, but did not exceed the HBRG.

2.6.1.2.3 Soil Vapor

According to Henry's Law, one can predict that there should be finite but limited concentrations of COPCs in soil vapor in areas where these constituents have their highest groundwater concentrations. The low levels of COPCs observed in the Remote Facility area in the groundwater and soil do not support the hypothesis that soil vapor would present a significant vector for the migration of contaminants in this area. In summary, the concentrations of COPCs in the groundwater are not high enough to crate soil vapor quality issues.

2.6.1.3 AOC 2

The AOC 2 area was identified for separate consideration by this CMWP in part because of its geographical location. No COPCs were detected in the monitoring well located down gradient of the impacted soil this area in the March 2007 sampling event (except for a sub part per billion detection of a common laboratory contaminant).

No wells surrounding AOC 2 have detections of any COPCs at 1 μg/L or higher, contaminant distribution can be discussed in terms of the soil medium alone. The main COPCs in this area are the PCBs.

The stratigraphy in the southern part of the Facility Parcel is similar to that in the Remote Facility area except that it is more compressed; the silt-sand interface, bedrock, and groundwater are encountered at shallower depths. At boring AOC2-2, the upper 7.5 feet are composed of moderately firm, low plasticity silt. At 7.5 feet, the lithology changes to coarse sand with gravel and some cobbles. Bedrock is encountered at 17.5 feet bgs. Saturation occurs at the silt-sand interface.

Soil samples were collected at AOC 2 and analyzed for VOCs, semi-volatile organic compounds (SVOCs), PCBs, and metals. Several constituents were detected, but the main constituents detected above their initial screening levels were the PCB congeners Arochlor 1242 and Arochlor 1248. One detection of benzo(a)pyrene in shallow soil exceeds the site HBRG.

2.6.2 Vacant Parcel and Perl Mack Neighborhood

The Vacant Parcel and Perl Mack Neighborhood do not have sources of contamination pertinent to this remediation effort, except for the occurrence of the LNAPL smear zone extending from the Main Source Area to the western edge of the Perl Mack Neighborhood **(Figure 2-5)**. The contamination migrated laterally from the Facility

Parcel through the subsurface. The medium of primary importance in the off-site areas is the groundwater. Soil and soil vapor are nonetheless discussed in this section.

2.6.2.1 Soils

The soil stratigraphy becomes increasingly sandy moving diagonally southeast from the Facility Parcel through the Vacant Parcel (see **Figure 2-2,** geologic cross section). The surface soil changes from clay to silt underlain by clay. The clay pinches out approximately 600 feet east of the Facility Parcel boundary, and the silt layer thins and pinches out after another 600 feet. The surface soil is sand until Pecos Street, when a new layer of silt begins. The gravel at the base of the unconsolidated soil column gives way to sand at about 1,200 feet from the Facility Parcel. Thus, sand is the dominant soil type. The intermediate clay layer thins but persists throughout the trace of the geologic cross section **(Figure 2-2).** This clay layer is always about 10 feet above the water table. In the Vacant Parcel, the clay is not close enough to the groundwater to have been significantly impacted, and it does not serve as a sink for adsorption of contaminants.

Further north, along the trace of the geologic cross section through the southern part of the Perl Mack Neighborhood and along West 68th Avenue, the surface soil is a continuous silt layer. The saturated zone is predominantly gravel, with some clay east of Pecos Street. Through most of the trace, the lower part of the unsaturated zone is gravel. The exception is in the area west of Fern Drive, where clay comes within 4 feet of a water table measured in April 2000. April is part of the 3-month season in which groundwater is lowest.

In summary, the gravel in the lower part of the stratigraphy in the Vacant Parcel and the Perl Mack Neighborhood have high transmissivity in the saturated zone and make the lower part of the unsaturated soil column an unlikely receptacle for groundwater-borne contamination. The exception is the area in the Perl Mack Neighborhood closest to the Facility Parcel, where the smear zone extends beyond the Facility Parcel eastern boundary.

2.6.2.2 Groundwater

The groundwater plume from the Main Source Area propagated into the Perl Mack Neighborhood and the Vacant Parcel. The Remote Facility groundwater plume propagated into the Vacant Parcel only. Figure 2-6 shows that the TCA plume (and daughter products) reaches the Perl Mack Neighborhood, flows to the east-southeast, and extends some 500 feet before it dissipates. A plume containing the daughter products (DCA, DCE, as well as cis-1,2-DCE) resumes at Pecos Street and continues in a southeasterly direction to the Lower Clear Creek Canal. The break in the plume can be explained in terms of the history of the GBS. The portion of the PCE and TCE plume east of Pecos Street is the remnant of migration that predated the installation of the GBS in 1992 and its enhancement in 1994. The concentrations in the western part of the plume in the Perl Mack Neighborhood are generally less than one tenth of their peak values in the early 1990s.

The PCE and TCE plumes in the off-site areas have two components, one from the Main Source Area and another from the Remote Facility. The PCE plumes join just south of the corner of West 68th Avenue and Morrison Drive. The plume flows southeast toward the Lower Clear Creek Canal with a gap in the Vacant Parcel west of Pecos Street. The TCE plume is similar, but recent remedial activities in the western part of the Vacant Parcel (the Phase I Vacant Parcel in-situ ERD system, see Section 5.1.1) have divided the plume; the MCL exceedences zone from the Remote Facility and the one in the Perl Mack Neighborhood from the Main Source Area are not contiguous with the main part of the plume in the Vacant Parcel. Also, there is no gap in the plume in the area immediately west of Pecos Street.

The discussion of contaminant distribution in groundwater from the Remote Facility (2.6.1.2.1) noted that the PCE and TCE plumes were distinct. The PCE plume is north of the TCE plume. The geographic situation of the two plumes continues in the Vacant Parcel, where the TCE can be found at locations south of the southern extent of the PCE. It was also pointed out in that section that cis-1,2-DCE is not abundant at the Remote Facility and that there are no MCL exceedences for cis-1,2-DCE in this area. Given the limited amount of organic carbon available to biodegrade, or naturally dechlorinate the PCE and TCE, it is not surprising that there are no detections of cis-1,2-DCE in the entire western segment of the Vacant Parcel from the facility boundary to Pecos Street.

The groundwater flow properties of the Vacant Parcel and the Perl Mack Neighborhood have been studied extensively through the monitoring of groundwater levels, computer modeling and a tracer study. The saturated zone is composed of sand and gravel. The hydraulic conductivity of the saturated zone in the Perl Mack Neighborhood and most of the Vacant Parcel is very high, about 300 ft/day (ARCADIS 2007b). The gradient has an average value of 0.005 in much of this area, and groundwater velocities are approximately 5 ft/day. The tracer study demonstrated that the groundwater-bearing unit is heterogeneous. Groundwater velocities can be 10 ft/day or greater in preferred flow paths. The tracer test indicated that the mobile porosity of the formation was approximately 7 percent with a range of plus or minus 3 percent. Under these conditions, contaminants would be rapidly flushed from the preferable flow paths. The COPCs would move from the less mobile pore space to the more mobile pore space by diffusion. Using a value of 35 percent for total porosity and 7 percent for mobile porosity, one can compute a retardation factor of 5. If groundwater moves at a rate of 5 ft/day, then the COPCs could be flushed from the Perl Mack Neighborhood and the Vacant Parcel at a rate of approximately 1 foot per day. This conclusion is corroborated by the history of the concentrations of the chlorinated hydrocarbons in the off-site wells.

In the Vacant Parcel, the hydraulic conductivity diminishes toward the south and east to 65 ft/day and 20 ft/day. There is a pocket of finer-textured lithology at well GW-49 east of Pecos Street, where the conductivity is 0.05 ft/day. In this area, contaminants are expected to flush out at a slower rate. The concentrations of the COPCs are closer to their respective MCLs in this area. In the Vacant Parcel east of Pecos Street, TCA and DCA did not exceed their MCLs in any monitoring well in the March 2007 sampling event. The highest concentration of DCE in the eastern part of the Vacant Parcel was 28 μg/L in well GW-54 compared to its MCL of 7 μg/L. The highest concentration of cis-1,2-DCE in this area was 97 μg/L in GW-54; the MCL for this constituent is 70 μg/L. In the March 2007 sampling event, the highest TCE concentration was 40 μg/L in GW-54 compared to an MCL of 5 μg/L. PCE was the only COPC to have its maximum in a well other than GW-54 in the March 2007 sampling event. Its highest yielded concentration was 31 μg/L at GW-47 compared to the MCL of 5 μg/L. The concentration of PCE at GW-54 was 14 μg/L. Thus, the potential for flushing of COPCs in groundwater in the eastern part of the impacted area is lower, but four of the six main COPCs are relatively close to their cleanup target concentrations, and two COPCs meet their targets.

The concentrations of COPCs in the off-site areas have been influenced by the GBS. In the early 1990s, the concentration of TCA was as high as 11,000 μg/L and 17,000 μg/L on Jordan Drive in samples collected from TP-14 and TP-15, respectively. By 1996, the concentrations were at or below 700 μg/L in both wells. In the October 2001 sampling event, the concentrations were 170 μg/L and 120 μg/L in the respective wells. In 2002, a drought hindered the efficiency of the GBS, and concentrations in these wells increased to 400 μg/L and 300 μg/L in subsequent years. As of July 2007, the concentration of TCA in TP-15 was 72 μg/L.

The performance of the GBS was improved beginning in May 2006 in four ways. Pumping rates have been optimized in key wells, well rehabilitation frequency has been increased, certain pumps and other hardware have been replaced, and wells have been added in the southern portion of the barrier. SVE has recently begun in the stagnant zone under Zuni Street. These changes have the effect of preventing the plume from re-supplying itself with chlorinated hydrocarbons. This will allow the high-velocity groundwater to begin to flush the plume away. It is expected that the zone of MCL exceedences should recede eastward from the Facility Parcel boundary at a rate of 1 ft/day. When conditions within the Facility Parcel allow the deactivation of the GBS, groundwater flow rates will increase by more than 50 percent according to the groundwater model (ARCADIS 2007b).

In summary, the groundwater concentrations of the COPCs in the southwestern part of the Perl Mack Neighborhood and in the Vacant Parcel are elevated with respect to MCLs, but are substantially lower than they were when operation of the GBS was initiated in 1992. Contamination migrated off site from the Main Source Area and the Remote Facility. The model predicts that upon substantive, or near-complete, removal of the source, the off-site areas have the potential to self-remediate by flushing the high-velocity groundwater at a rate of 5 ft/day. In the areas of lower hydraulic conductivity in the eastern part of the Vacant Parcel, the removal of contamination by flushing will be slower, but the concentrations of COPCs in this area are lower and closer to their remediation target values.

2.6.2.3 Soil Vapor

According to Henry’s Law, concentrations of hydrocarbons in the groundwater will seek to achieve equilibrium with the air in the unsaturated pore space. In the past, when concentrations of chlorinated hydrocarbons were one to two orders of magnitude higher than they are today, measurable quantities of COPCs in the soil vapor would have been possible. As groundwater concentrations decline, the concentrations of COPCs in the soil vapor are also expected to decline. Soil vapor transport is by diffusion, an inefficient transport mechanism. The source of the soil vapor contamination is the groundwater. Thus, eliminating the groundwater issues will resolve the soil vapor issues.

2.7 Current Mitigation Systems

Currently, there are three existing mitigation systems in operation at the site. The GBS was installed to extract contaminated groundwater that was migrating from the Facility Parcel eastward towards the Perl Mack Neighborhood and the Vacant Parcel. A Seepage Water Remediation System was installed to treat groundwater surfacing in seeps in the eastern portion of the site. Finally, Indoor Air Mitigation Systems have been maintained to ensure adequate indoor air quality in the surrounding Perl Mack Neighborhood. The following subsections describe these operating mitigation systems.

2.7.1 Groundwater Barrier System

A GBS was selected as an appropriate remedy to intercept and treat groundwater contaminant plumes present at the site. The GBS became operational in April 1992 with continuous 24-hour-per-day operations. The purpose of the GBS is to capture and treat extracted groundwater containing VOCs and recover LNAPL from the surface of the water table. The planning, permitting, and design of the GBS were developed between October 1990 and September 1992 (HLA 1991).

The original GBS was composed of six groundwater extraction wells, three of which (EXW-2, EXW-5, and EXW-6) are equipped with LNAPL recovery equipment. In February and October 1994, five groundwater extraction wells were added to the GBS, two of which (EXW-9 and EXW-10) are equipped with LNAPL recovery equipment. An ultra filtration unit designed to remove emulsified oil from groundwater extracted by several wells was also added to the system (Harding ESE 2001). In 2006, ARCADIS added four extraction wells to the southern end of the GBS to enhance capture of the TCE and PCE plumes migrating from sources in the Remote Facility. As previously described, operation of the GBS was also upgraded in 2006 by optimizing pumping rates in key wells, increasing the frequency of well rehabilitation and replacing certain pumps and operational hardware.

The GBS operates by pumping groundwater from the shallow aquifer to the groundwater treatment facility through double-walled piping. Extracted groundwater is filtered (bag filters) to remove solids and then undergoes air stripping to remove VOCs to below permitted discharge concentrations before being discharged to an outfall located on Little Dry Creek. A portion of the extracted groundwater is filtered and pretreated as necessary using the ultra filtration unit. LNAPL recovered by the skimmer pumps is pumped through dedicated double-walled LNAPL lines to a temporary storage drum enclosed within a secondary-containment area located adjacent to the groundwater treatment facility. Following temporary storage, LNAPL is transported off site for disposal as a hazardous waste.

Water levels in all extraction wells and selected monitoring wells are monitored weekly to evaluate plume capture performance. In order to ensure effective treatment, system effluent is sampled weekly, monthly, bi-monthly, or quarterly to comply with State of

Colorado General Permit for Groundwater Remediation number COG-315146. System influent is sampled quarterly for compliance with facility-wide State of Colorado Air Pollution Control Construction Permit number 95AD779. Influent concentrations are used to calculate air emission rates from the groundwater treatment plant air stripper unit. Overall, ARCADIS estimates that approximately 11,000 pounds of chlorinated VOCs have been removed from groundwater captured by the GBS since the start of continuous operation in 1992. In total, nearly one billion gallons of water have been captured and treated by the system.

2.7.2 Seepage Water Remediation System

The Seepage Water Remediation System is designed to capture and treat contaminated groundwater issuing from seeps near the eastern boundary of the Vacant Parcel. The system has been in operation since November 1995 and includes three gravel sump collection locations extending from near South Pond to Kalcevic Gulch that pump seep water to a central treatment facility. At the treatment facility, water is filtered to remove particulates and then undergoes air stripping to remove VOCs. Effluent from the air stripper is pumped to a discharge outfall located on Kalcevic Gulch. Discharge is under the same permit as the GBS system (permit number COG-315146).

2.7.3 Indoor Air Mitigation Systems

Hamilton Sundstrand initiated an extensive indoor air testing program in October 2000 due to the potential for indoor air contamination in the Perl Mack Neighborhood east of the Facility Parcel (MACTEC 2003). The concern resulted from groundwater beneath a portion of the neighborhood exhibiting low concentrations of chlorinated VOCs (CVOCs). One of the primary concerns with the presence of CVOCs in groundwater is that they can volatilize from the groundwater and migrate upward through the soil in the soil vapor. If the volatilized CVOCs reach the ground surface beneath a house or other building, they can move into indoor air, increasing the potential for human exposure and causing a potential short-term and/or long-term human health risk.

The air testing program concentrated on the Perl Mack Neighborhood and was voluntary for the residents of the area. Indoor air quality was measured in 128 individual homes. Indoor air in only one of the homes yielded a concentration of one CVOC of concern above the Hamilton Sundstrand Voluntary Action Level (MACTEC 2003). However, Hamilton Sundstrand installed and operated individual home sub slab depressurization (ventilation) systems (similar to radon mitigation systems) in 70 homes. The systems were sampled quarterly until indoor air concentrations were below the decision criteria for two consecutive quarters, whereupon no further sampling was conducted. ARCADIS now assumes responsibility for maintenance of the sub slab depressurization systems.

3.0 Corrective Measure Objectives

CMOs are the standards established for the corrective measures selected for remediation of contamination at the Hamilton Sundstrand site. The CMOs are developed based on public health and environmental criteria and site-specific information. The primary qualitative CMO for the site is the protection of human health and the environment. A general CMO for the site that will continue throughout the corrective measures process is compliance with existing permits and agreements including the groundwater remediation permit for the GBS and Seeps Water Remediation System, adherence to the surface water augmentation agreement, and compliance with the existing air permit. Quantitative CMOs identified or developed as part of this CMWP are standards, such as Federal MCLs and the site-specific HBRGs that must be met to ensure the required protectiveness. The following sections summarize the site CMOs for the Perl Mack Neighborhood, Vacant Parcel, and Facility Parcel.

3.1 Perl Mack Neighborhood and Vacant Parcel

The qualitative CMO for the Perl Mack Neighborhood and Vacant Parcel is to protect human health and the environment by remediating contamination in groundwater migrating beneath the areas from contaminant sources located on the Facility Parcel. CDPHE approved an NFA request for the Vacant Parcel in February 2007, based on the understanding that Carma, as the master developer of the property, is contractually obligated to ensure that passive vapor mitigation systems will be included in any building constructed on the property (CDPHE 2007a). Although an NFA request has been approved for the Vacant Parcel, a quantitative CMO for groundwater for the Perl Mack Neighborhood and Vacant Parcel has been established to remediate contamination to meet Federal MCLs. **Table 2-3** summarizes MCLs for the site groundwater COPCs.

Contamination in soil that remains a source of continued contamination to groundwater is generally restricted to the Facility Parcel; however, a relatively small volume of contaminated soil has been observed in soil borings east of the Facility Parcel along the western edge of the Perl Mack Neighborhood (primarily beneath Zuni Street). As described in Section 2.6, it is possible that the leading edge of the LNAPL plume reached across the Facility Parcel boundary prior to the installation of the GBS, leaving this remnant of the contaminant smear zone on the western edge of the Perl Mack Neighborhood. This soil contamination is restricted to a thin interval above the current water table surface and is at least 30 feet bgs. Due to the depth of this soil contamination, it is not subject to the HBRGs established for soil contamination beneath the Facility Parcel (Section 2.5). However, a qualitative CMO has been established for this soil contamination to reduce COPC concentrations to the extent that it is incapable of continuing to release COPCs to groundwater at concentrations exceeding groundwater remedial goals (MCLs). No direct measurement of COPC concentrations in soil is proposed; rather, the measurement of contaminant concentrations remaining in groundwater will determine whether COPCs have been adequately removed from this contaminated soil.

3.2 Facility Parcel

Qualitative CMOs for the Facility Parcel were described in the ICAP Application as follows:

- The reduction of concentrations in soil to levels that are protective for planned future potential recreational uses and open space
- The reduction of soil and groundwater concentrations so that MCLs can be maintained at the eastern Facility Parcel property boundary without the use of an active groundwater remedy (i.e., the GBS). Once it is determined an active groundwater remedy is no longer necessary, the GBS will be decommissioned.

Institutional controls are in place on the Facility Parcel property in the form of an environmental covenant that restricts future land use to recreational and open space purposes only (Hamilton Sundstrand 2007). The environmental covenant also places limitations on future structures and buildings and the use of groundwater from the shallow (tributary) alluvial aquifer on the Facility Parcel. The land use restrictions required by the environmental covenant have been considered in the calculation of HBRGs for soil and groundwater on the Facility Parcel as summarized in Section 2.5 of this report.

The following sections describe quantitative CMOs for Facility Parcel groundwater and soil based on the calculation of risk-based remedial goals and contractually mandated requirements. Qualitative CMOs for residual LNAPL that may be left in place following the implementation of selected remedial technologies are also described.

3.2.1 Facility Parcel Groundwater

Quantitative CMOs for groundwater for the Facility Parcel include reducing COPC concentrations in groundwater to meet MCLs at the downgradient (eastern) Facility Parcel boundary. **Table 2-3** summarizes MCLs for site groundwater COPCs. Groundwater remediation beneath the Facility Parcel must also meet risk-based criteria appropriate for recreational land use. Section 2.5, Risk Evaluation, summarizes the calculation of HBRGs for groundwater beneath the Facility Parcel and **Table 2-3** summarizes the HBRGs.

3.2.2 Facility Parcel Soil

Qualitative CMOs for soil for the Facility Parcel include reducing COPC concentrations to the extent that contaminated soil does not continue to release COPCs to groundwater at concentrations exceeding groundwater remedial goals (MCLs at the eastern Facility Parcel boundary or risk-based goals beneath the parcel). A previous study of the leaching potential of contaminated, fine-grained soil typical of shallow depth intervals at the site concluded that the soils could not leach COPCs to groundwater at concentrations that would exceed MCLs at the eastern Facility Parcel boundary. This study is included in this CMWP as **Appendix B.** However, it is possible that more heavily contaminated soil may be uncovered at the site than was analyzed as part of the leaching potential evaluation, especially beneath the Main Plant Building. Although no quantitative CMO is currently proposed for this possibility, ARCADIS may remediate heavily contaminated soil uncovered during future demolition activities that could potentially leach COPCs to groundwater in concentrations exceeding groundwater remedial goals.

Quantitative CMOs for soil for the Facility Parcel include risk-based remedial goals as described in Section 2.5, Risk Evaluation. HBRGs were calculated for specific soil depth intervals using potential receptor exposure assumptions. **Table 2-2** summarizes the HBRGs for the Facility Parcel.

3.2.3 Facility Parcel Residual LNAPL

Some LNAPL may remain in place following the remediation of soil and groundwater contamination on the Facility Parcel. The qualitative CMO for the remediation of LNAPL is to render the material inert by reducing contaminant concentrations to the extent that any remaining residual LNAPL is incapable of continuing to release COPCs to groundwater at concentrations exceeding groundwater remedial goals (MCLs at the eastern Facility Parcel boundary or risk-based goals beneath the parcel) or pose any other unacceptable risk to human health or the environment. While COPC concentrations in residual LNAPL may be measured during remediation to gauge treatment system performance, direct COPC cleanup standards for remaining LNAPL are not proposed; rather, the measurement of contaminant concentrations remaining in groundwater will determine whether COPCs have been adequately removed from any remaining residual LNAPL.

4.0 Corrective Measures Technology Screening

The previous sections of this CMWP have generally defined the nature and extent of impacts at the site. These sections have also identified key implementation and performance requirements that must be considered by and ultimately incorporated into the CMWP remedy. This section of the CMWP will outline the process used to evaluate potential corrective measures and develop remediation alternatives capable of meeting the CMOs established in Section 3.0. For the Hamilton Sundstrand site, the remediation alternatives will entail groupings of compatible corrective measures (i.e., a technology and/or process), implemented in a manner designed to meet the CMOs established for the site.

The *corrective measure* terminology, as it applies to this CMWP, generally refers to a range of naturally occurring, enhanced, and/or engineered processes that can be used to reduce COPC concentrations to acceptable levels and/or eliminate potential exposure pathways. The complexity of individual corrective measure implementation can vary, but generally entails various in-situ and/or ex-situ processes, broadly characterized as physical, biological, or chemical in nature. No individual corrective measure, standing alone, is likely to meet all of the established CMOs for the Hamilton Sundstrand site. As such, the remedial alternatives developed for evaluation by this CMWP will require implementation of several integrated corrective measures. The process used to identify which corrective measures should be considered as part of a remedial alternative is described herein.

The first step towards developing the remedial alternatives entailed identification and screening of individual corrective measures using standard RCRA evaluation criteria. The screening process is then used to narrow the list of potential corrective measures down to a subset of preferred technologies and/or processes capable of attaining one or all of the CMOs established in Section 3.0. Where compatible, these preferred corrective measures are then grouped to develop a variety of remediation alternatives capable of meeting CMOs for particular areas of the site. The remainder of this section

(1) further describes the approach used to screen corrective measures and develop remedial alternatives for subsequent evaluation (Section 4.1); (2) provides summaries and brief descriptions of the individual corrective measures considered for each area of the site (Section 4.2); and (3) presents the results of the screening process in context of remedial alternatives (i.e., technology and process groupings) that ARCADIS has developed for each area of the site. These remediation alternatives will be evaluated further in Section 6 of this CMWP.

4.1 Corrective Measure Screening Approach

The corrective measures identification and screening process is used to develop reasonable remediation alternatives for a particular site. For the Hamilton Sundstrand site, many of the individual corrective measures that were considered by ARCADIS are applicable to more than one area and more than one type of affected media. The relative effectiveness of a corrective measure largely depends on what the associated technology/process entails (i.e., treatment mechanisms) and its capability to be implemented at a particular site. More often than not, there are multiple technologies/processes capable of meeting the same cleanup goals for a given project. However, relative cost and timeliness for meeting these goals can vary significantly for these competing technologies. As such, all of these factors are considered as part of the corrective measures screening process.

The corrective measures ARCADIS identified for subsequent screening and evaluation are described in context of each area of the site in the following section (Section 4.2). Professional judgment and experience with cleanups at similar sites was also used to identify individual corrective measures that are potentially applicable to the Hamilton Sundstrand site. The individual corrective measures are evaluated based on their potential effectiveness, site-specific implementability considerations, and relative cost. Based on this evaluation, the individual corrective measure is either rejected or retained for further consideration in development of a remedial alternative. The corrective measure screening criteria are defined as follows:

- Applicability: The measure of how well a specific corrective measure can be applied to the area of concern without creating or perpetuating circumstances where additional treatment would be required. Some areas of the site are characterized as having multiple areas of concern; with multiple types of affected media (e.g., soil types, groundwater, LNAPL). As such, the first step in the corrective measures screening and evaluation process requires identification of how the individual corrective measure would be applied at this particular site. The applicability evaluation criterion primarily qualifies how the corrective measure will be applied at particular areas of the site. It also identifies some of the limitations of the associated technology or process.

- Effectiveness: The measure of the corrective measure's ability to reduce the toxicity, mobility, and volume of the COPCs over both short-term and long-term periods. Effectiveness is also largely based on the degree of protection offered to human health and the environment. Where applicable, the effectiveness of each corrective measure considered for the site is evaluated for each of the affected media in a given area of the site.
- Implementability: The measure of how easily the corrective measure can be implemented at the site with regard to technical feasibility, health and safety, and administrative considerations. Technical feasibility refers to the ability to construct, operate, and meet technology-specific requirements until the remedial action is complete. Administrative considerations may include regulatory restrictions; permitting; and availability of treatment, capacity, and any other requirements for specific equipment or personnel.
- Cost: This screening criterion is used primarily for comparison purposes. For the purpose of this screening-level evaluation, engineering cost estimates are used to arrive at a range of probable costs for implementing the described corrective measure. These estimates are qualitative and are generally limited to evaluation of the predominant cost items associated with the corrective measure implementation. When evaluating corrective measures, the relative costs are used to further assess corrective measure feasibility. It is used as a differentiator where multiple corrective measures are qualified as similarly effective or desirable. In the cases where there are large differences in cost among corrective measures (i.e., order of magnitude) the cost evaluation criteria may result in elimination of a particular corrective measure from further consideration.

4.2 Corrective Measures Identification and Screening

A variety of corrective measures has been identified for consideration by this CMWP. Most of these corrective measures entail application of similar highly effective technologies and processes. While these corrective measures can be applied to several areas of the site, their relative measure of effectiveness, implementability, and cost can vary significantly depending on where and how the corrective measure is applied. The following sections (1) identify the corrective measures considered for each area of the site, (2) describe how and where these individual corrective measures could be applied, and (3) evaluate the relative suitability of each corrective measure in context of the aforementioned corrective measure screening evaluation criteria. Section 4.2.1 identifies and screens the corrective measures ARCADIS has identified for the Perl Mack Neighborhood. Section 4.2.2 summarizes those corrective measures evaluated for the Vacant Parcel. The corrective measures screening evaluation for the Facility Parcel is summarized in Section 4.2.3.

4.2.1 Perl Mack Neighborhood

There are two affected media subject to corrective measure consideration in the Perl Mack Neighborhood, groundwater, and soil. The CMO for groundwater in the Perl Mack is to meet MCLs. ARCADIS has also proposed a qualitative CMO for soil to mitigate residual soil impacts to the extent necessary to prevent COPCs from dissolving into groundwater at levels that exceed MCLs. The following sections summarize the corrective measures screening evaluation for each of these media. Comprehensive evaluation of applicable corrective measure screening criteria for the Perl Mack Neighborhood is provided in **Table 4-1**.

4.2.1.1 Groundwater

The CMO for groundwater in the Perl Mack Neighborhood is to meet MCLs. Consideration of groundwater corrective measures to meet this CMO assumes that the conservative existing mitigation systems for mitigating indoor air concerns are maintained until the Perl Mack Neighborhood groundwater CMOs have been met and maintained. Corrective measure evaluation also assumes that CMOs for the upgradient Facility Parcel have been (or are being) met and that operation of the GBS will continue until MCLs have been met at the eastern Facility Parcel boundary.

The following corrective measures were screened and evaluated for the groundwater under the Perl Mack Neighborhood:

- Monitored Natural Attenuation (MNA)

MNA is a process in which COPCs are allowed to naturally attenuate via a combination of sorption, diffusion, dispersion, biodegradation, and abiotic degradation mechanisms. Attenuation progress is monitored in accordance with a performance monitoring plan and subsequent analysis of degradation and attenuation parameters is used to verify that CMOs are being met. MNA is typically considered when the hydrogeological and geochemical environments already exist in a manner that is conducive to attenuation (USEPA 2004a); for example, once the potential for source contribution has been mitigated and data suggest plume stability. MNA was considered for this area with the expectation that, following optimization of the existing GBS, additional COPC mass contributions from the upgradient source areas would no longer be able to adversely affect groundwater under the neighborhood. As a result, the small area of dissolved COPCs beneath the neighborhood would attenuate naturally. ARCADIS has identified MNA as a potential corrective measure for addressing groundwater impacts beneath the Perl Mack Neighborhood. While potentially effective, this corrective measure was eliminated from further evaluation at this time due to the potential presence of residual contamination in saturated soils beneath Zuni Street.

- Air sparging with soil vapor extraction (AS/SVE)

AS with SVE is an effective corrective measure for removing volatiles from subsurface soils as well as dissolved mass in the groundwater. The process entails injection of ambient air into the saturated zone. The injected air volatilizes (i.e., strips) and flushes the volatile and semi-volatile COPCs from the groundwater into the unsaturated zone where they can be physically removed using soil vapor extraction (Suthersan 1997). In addition, the less volatile COPCs may be degraded aerobically. For the Perl Mack Neighborhood, AS would occur in the area directly west of the eastern Facility Parcel boundary where residual contamination may be present, and the placement of SVE wells would extend farther east into the neighborhood.

- In-situ ERD

In-situ ERD was identified as a viable corrective measure given its demonstrated effectiveness at remediating CVOCs. In-situ ERD relies on the same attenuation mechanisms described above for MNA. Consideration of in-situ ERD as a corrective measure would entail implementation such that enhanced biodegradation is the primary attenuation mechanism. Desorption and dispersion are secondary processes. The ERD process consists of injecting a carbohydrate solution into the subsurface to provide a food source for the indigenous bacteria within the subsurface. An anaerobic reducing environment is created through the bacteria’s natural respiration process. The chlorinated COPCs are degraded either metabolically (part of the microbial respiration process) or co-metabolically (not part of the microbial respiration process, but degraded via enzymes excreted from the microorganisms) (Suthersan and Payne 2005). During the process of dechlorination, methanogenic conditions must be achieved to degrade some chlorinated hydrocarbons, creating the potential to accumulate methane in the subsurface. Monitoring and potentially engineering controls would be required to mitigate these concerns under existing buildings during ERD implementation. In-situ ERD has been identified as a potentially viable corrective measure for addressing groundwater impacts beneath the Perl Mack Neighborhood. A Phase I interim corrective measure, described in Section 5.1.2, has been implemented in order to assess the overall effectiveness of in-situ ERD to meet all of the groundwater CMOs for the Perl Mack neighborhood.

- In-situ thermal heating

For the Perl Mack Neighborhood, in-situ thermal heating has been considered as a corrective measure because biological degradation reactions occur faster under higher temperatures, and heating promotes hydrolysis of TCA. Hydrolysis is a chemical transformation in which the chlorinated compound reacts with water and a new, most often less toxic, compound is formed. TCA can be degraded anaerobically; however, hydrolysis is the intrinsically preferred degradation pathway. By introducing heat into the reaction, the rate at which the natural transformation occurs can be increased. The general objective would be to raise the temperature of the affected groundwater by approximately 10^{o}C to increase the rate of hydrolysis by a factor of 2.5 (Suthersan 1997). For the Perl Mack Neighborhood, this would likely entail either injection/recirculation of heated water or injection of steam. Effectiveness of this corrective measure is highly dependent on the ability to heat the entire aquifer. Unless a similar corrective measure is implemented as part of the Main Source Area remedy on the Facility Parcel, the associated infrastructure needs and power costs for implementing this corrective measure in the Perl Mack Neighborhood are significantly greater than those of competing corrective measures. This corrective measure was eliminated from further consideration primarily due to implementation and cost concerns, particularly with regard to potential health and safety consequences from introducing a heated underground system in residential areas.

- Groundwater extraction and treatment

This corrective measure would entail expansion of the existing GBS for purposes of extracting COPC impacted groundwater from beneath the entire Perl Mack Neighborhood. This would be accomplished either through installation of additional pumping wells, or conversion of the existing Phase I ERD remediation wells for groundwater extraction. Extracted water would be pumped to the existing GWTP on the Facility Parcel for ex situ treatment via air stripping, and subsequent discharge under the existing NPDES permit. Implementation of this measure will begin to reduce COPC concentrations in groundwater immediately; however, the time required to achieve all CMOs could prove excessive if residual source mass is present. Absent a quantitative and detailed understanding of the stagnant zone created by the existing system, efficiency of this corrective measure is highly dependant on hydrogeologic variability and the ensuing ability to maximize COPC mass removal using groundwater extraction wells.

- In-situ chemical oxidation

In-situ chemical oxidation (ISCO) was considered as a corrective measure because of proven effectiveness in degrading chlorinated compounds. For the Perl Mack Neighborhood, this corrective measure would entail injection of sodium or potassium persulfate into the affected reaches of the aquifer to create reactions with the COPCs and chemically alter them to less toxic compounds. However, a byproduct of these chemical reactions is heat and/or significant gas production. Effectiveness of this corrective measure is highly dependent on the ability to cost-effectively deliver enough oxidant to overcome natural oxidant scavengers and contact the affected media (Suthersan and Payne 2005). While potentially very effective, this corrective measure was eliminated from for further evaluation at this time due primarily to implementation and cost concerns that arise as a result of COPC concentrations in soils and potential health and safety consequences from introducing a heated underground system in residential areas .

- Zero valent iron

Zero valent iron (ZVI) was considered a viable technology based on proven effectiveness in chemically reducing chlorinated hydrocarbons. ZVI is installed in the saturated subsurface perpendicular to groundwater flow direction as a permeable reactive barrier (PRB), maximizing groundwater contact time with the reactive media. Within the ZVI reactive zone, many reactions take place that may directly or indirectly destroy contaminants (Suthersan and Payne 2005). Implementation of this corrective measure would likely necessitate installation of multiple PRBs, each requiring substantially intrusive installation work within the neighborhood. While potentially effective, this corrective measure was eliminated from further evaluation at this time due primarily to implementation and cost concerns.

- EHC™

EHC™ is a mixture of ZVI and organic carbon that can be used to trigger both biotic and abiotic reductive dechlorination reactions. Implementation of this corrective measure is virtually identical to use of ZVI alone. While ZVI permeable reactive barriers are effective at reducing chlorinated contaminants, the addition of EHC™ induces both biotic and abiotic reduction reactions (Adventus 2006). Generally speaking, this corrective measure is likely more effective than ZVI alone; it is also relatively less expensive than ZVI alone. While potentially very effective, this corrective measure presents significant feasibility concerns with regard to implementation, and is considerably more expensive than the other Perl Mack corrective measures.

4.2.1.2 Soil

The soil in the Perl Mack Neighborhood does not have a quantifiable CMO; however, small quantities of residual smear-zone soil impacts have been identified beneath Zuni Street, just east of the Facility Parcel boundary. These impacts have potential to adversely affect aqueous phase COPC concentrations under fluctuating water table conditions. Because most of the residual soil impacts are under a main thoroughfare, other more invasive forms of soil remediation (e.g., excavation, ex-situ bioremediation) were discarded from consideration by this evaluation. Therefore, only in-situ technologies were evaluated as potentially feasible corrective measures:

- SVE

SVE is an effective technology to remove volatiles from the vadose zone. A vacuum is applied to the soil to induce the controlled flow of air and remove volatile and some semi-volatile organic contaminants from the soil (Suthersan 1997). For the Perl Mack Neighborhood, implementation would be relatively simple because all of the SVE wells, equipment, and associated infrastructure are already installed as part of existing VBS interim corrective measures. This corrective measure was retained for evaluation and VBS enhancement considerations due to potential effectiveness, implementability, and cost.

- AS with SVE

AS with SVE is an effective corrective measure for removing volatiles from affected soils within the saturated zone of the aquifer. The process entails injection of ambient air into the saturated reaches of the aquifer. The injected air volatilizes (i.e., strips) the volatile COPCs from the saturated zone into the unsaturated zone where they can be physically removed using soil vapor extraction (Suthersan 1997). The addition of oxygen also enhances aerobic biodegradation of non-chlorinated contaminants that may be residing within the saturated soil pores. This corrective measure was retained for further evaluation due to proven effectiveness, implementability, and cost.

- SVE/in-situ steam injections

Steam injection with SVE is similar to AS, with the addition of heat. The steam strips the volatiles from the subsurface soils where they can then be removed by soil vapor extraction (TerraTherm 2007). The addition of heat will also be effective in hydrolyzing TCA, contributing to the overall effectiveness of complementary groundwater remediation efforts. While potentially very effective, this corrective measure presents significant feasibility concerns with regard to implementation, and is more costly than other Perl Mack corrective measures. Relative cost concerns are minimized, however, provided this corrective measure is implemented in conjunction with similar corrective measures for the Facility Parcel. Health and safety is a primary concern with regards to implementation of this corrective measure. By introducing a heated and potentially high pressure underground system, the potential for harmful health and safety consequences increase and this consideration was also a reason for elimination.

4.2.2 Vacant Parcel

The CMOs for the Vacant Parcel apply to groundwater only. CDPHE has already issued a NFA determination for the Vacant Parcel, contingent on requirements that sub-slab passive vapor barrier systems are incorporated into subsequent property redevelopment plans. Consideration of groundwater corrective measures to meet the Vacant Parcel CMO assumes that the existing mitigation system (the Seeps Water Remediation System) for mitigating surface water concerns is maintained until the Vacant Parcel groundwater CMOs have been reached. Corrective measure evaluation also assumes that CMOs for the upgradient Facility Parcel have been (or are being) met and that operation of the GBS system will continue until MCLs have been met at the eastern Facility Parcel boundary.

The following sections describe the corrective measures screened for groundwater in the Vacant Parcel. **Table 4-2** summarizes each of these corrective measures individually.

4.2.2.1 Groundwater

The quantitative CMO for groundwater for the Vacant Parcel is to remediate groundwater contamination to meet MCLs. The following corrective measures were screened and evaluated for purposes of meeting this CMO.

- MNA

MNA is a process in which COPCs are allowed to naturally attenuate via a combination of sorption, diffusion, dispersion, biodegradation, and abiotic degradation mechanisms. Attenuation progress is monitored in accordance with a performance monitoring plan and subsequent analysis of degradation and attenuation parameters is used to verify that CMOs are being met. MNA is typically considered when the hydrogeological and geochemical environments already exist in a manner that is conducive to attenuation (USEPA 2004a), for example, once potential for source contribution has been mitigated and data suggests plume stability. MNA was considered for this area with the expectation that, following optimization of the existing GBS, additional COPC mass contributions from the upgradient source areas would no longer be able to affect groundwater in the Vacant Parcel. As a result, the area of dissolved COPCs would attenuate naturally. ARCADIS has identified MNA as a potential corrective measure for addressing groundwater impacts in the Vacant Parcel. While potentially effective, this corrective measure was eliminated from further evaluation at this time due to the timing of residential redevelopment activities.

- Groundwater extraction and treatment

Augmentation and expansion of the existing pump and treat system was identified given the historical effectiveness of this technology at this site. This corrective measure would entail expansion of the existing GBS for purposes of removing COPC impacted groundwater from beneath the Vacant Parcel. Demonstrated technologies and processes already in use at the site would be utilized. Air stripping has been demonstrated as an effective method of removing COPCs, and installation of additional wells is easily implemented. Implementation of this measure will begin to reduce COPC concentrations in groundwater immediately. However, a large number of groundwater extraction wells would need to be installed at the Vacant Parcel in order to achieve adequate coverage of the groundwater contaminant plume. This corrective measure would also require significant expansion of the existing groundwater treatment plant. This corrective measure was eliminated from further consideration for the Vacant Parcel primarily due to relative effectiveness and cost compared to competing corrective measures.

- AS with SVE

AS with SVE is an effective corrective measure for removing volatiles from subsurface soils as well as dissolved mass in the groundwater. The process entails injection of ambient air into the saturated reaches of the aquifer. The injected air strips the volatile COPCs from the groundwater into the unsaturated zone where they can be physically removed using soil vapor extraction (Suthersan 1997). For the Vacant Parcel, implementation would likely entail use of AS curtains, as opposed to complete well-to-well coverage of the entire aqueous phase COPC plumes. Nevertheless, a large number of AS/SVE wells would need to be installed at the Vacant Parcel in order to adequately meet the groundwater CMO. This corrective measure was retained for further evaluation due to proven effectiveness.

- In-situ ERD

In-situ ERD was identified as a viable corrective measure given its demonstrated effectiveness at remediating CVOCs. In-situ ERD relies on the same attenuation mechanisms described earlier. Consideration of in-situ ERD as a corrective measure would entail implementation such that enhanced biodegradation is the primary attenuation mechanism. Desorption and dispersion are secondary processes. The ERD process consists of injecting a carbohydrate solution into the subsurface to provide a food source for the indigenous bacteria within the subsurface. For this corrective measure, a relatively larger dose of carbohydrate would be used than that considered for the Perl Mack Neighborhood. Through the bacteria's natural respiration process, an anaerobic reducing environment is created. The chlorinated COPCs are degraded either metabolically (part of the microbial respiration process) or co-metabolically (not part of the microbial respiration process, but degraded via enzymes excreted from the microorganisms) (Suthersan and Payne 2005). In-situ ERD is a highly implementable corrective measure for groundwater treatment. During the process of dechlorination, methanogenic conditions must be achieved to degrade some chlorinated hydrocarbons. In-situ ERD has been identified as a potentially viable corrective measure for addressing groundwater impacts beneath the Vacant Parcel area. A Phase I interim corrective measure, described in Section 5.1.1, has been implemented to further assess the feasibility of achieving CMOs in the Vacant Parcel using ERD.

- ZVI

ZVI was considered a potentially viable technology for the Vacant Parcel based on proven effectiveness in chemically reducing chlorinated hydrocarbons. ZVI is installed in the saturated subsurface perpendicular to groundwater flow direction as a PRB, maximizing groundwater contact time with the reactive media. Within the ZVI reactive zone, many reactions take place that may directly or indirectly destroy contaminants (Suthersan and Payne 2005). Implementation of this corrective measure would likely necessitate installation of multiple PRBs, each requiring substantially intrusive installation work within the neighborhood. While potentially effective in certain lithologies, this corrective measure was eliminated from further evaluation for full-scale implementation due primarily to cost concerns.

- EHC™

EHC™ is a mixture of ZVI and organic carbon that can be used to trigger both biotic and abiotic reductive dechlorination reactions. Implementation of this corrective measure is virtually identical to use of ZVI alone. While ZVI permeable reactive barriers are effective at reducing chlorinated contaminants, the addition of EHC™ induces both biotic and abiotic reduction reactions (Adventus 2006). Generally speaking, this corrective measure is likely more effective than ZVI alone; it is also relatively less expensive than ZVI alone. While potentially very effective in certain lithologies, this corrective measure was eliminated from further evaluation for full-scale implementation due primarily to cost concerns.

4.2.3 Facility Parcel

As described in previous sections of this CMWP, the Facility Parcel comprises 13 SWMUs and five AOCs. Collectively, these SWMUs and AOCs comprise the historical source areas suspected of releasing COPCs into the environment. Through investigation and subsequent risk evaluation, ARCADIS has determined that COPC contributions from some of these SWMUs and AOCs are minimal and will not impede ability to meet established CMOs for the Facility Parcel. As such, no corrective action is necessary for attaining regulatory closure determinations at select SWMUs and AOCs (Section 7).

Previous investigation and evaluation efforts have identified similarities, with regard to nature, type, and co-mingling of COPC releases, among the remaining SWMUs and AOCs. As such, the remedial alternatives developed by this CMWP will be designed to meet CMOs for multiple SWMUs and AOCs. Remedial alternatives will be developed to address three separate areas within the Facility Parcel: the Main Source Area, the Remote Facility, and AOC 2. Section 3 describes the CMOs developed for the Facility Parcel.

The following sections describe the corrective measures screened for the Facility Parcel. **Table 4-3** summarizes each of these corrective measures individually.

4.2.3.1 Main Source Area

Corrective measure implementation for the Main Source Area requires consideration of technologies suitable for remediating existing groundwater, soils, and LNAPL concerns. Both qualitative and quantifiable CMOs have been established for groundwater, soils, and LNAPL. Quantifiable CMOs require that MCLs are met in groundwater at the eastern Facility Parcel boundary and that risk-based COPC concentrations are met in groundwater underlying the Main Source Area. Soils require remediation to the extent necessary to meet acceptable risk-based criteria for allowable COPC concentrations in shallow soils. Additionally, all affected soils will also need to be remediated to the extent that remaining COPC concentrations in soil are not impeding a remedial alternative’s ability to meet groundwater CMOs. Similar to soils, LNAPL will need to be treated until rendered inert so that any residual LNAPL is no longer impeding the ability to meet the groundwater CMO. The following sections describe the corrective measures evaluated for purposes of meeting these CMOs.

4.2.3.1.1 Groundwater

The CMOs for groundwater in the Main Source Area require remediation to meet both MCLs along the eastern edge of the Facility Parcel and allowable risk-based concentrations in groundwater beneath the Main Source Area. In order to meet those CMOs, source area impacts will need to be remediated. Source area remediation will entail implementation of complementary corrective measures capable of mitigating soils and LNAPL to the extent necessary that dissolution of COPCs from these media no longer adversely affect groundwater. Implementation of these groundwater corrective measures assumes that the established CMOs for soils and LNAPL have been or are being met. Consideration of these corrective measures also assumes that interim measures at the Facility Parcel boundary remain operational until all Main Source Area groundwater CMOs have been met. The following corrective measures were screened for remediation of the impacted groundwater in the Main Source Area:

- MNA

For the Main Source Area, consideration of MNA as a corrective measure assumes concurrent implementation of corrective measures capable of meeting established CMOs for soil and LNAPL. Provided the soil and LNAPL CMOs have been met, aqueous-phase COPC concentrations will eventually naturally attenuate. This corrective measure is relatively less effective than competing corrective measures; however, it is easily implemented and potentially viable as long as the groundwater CMOs can be met in a reasonable time frame. While potentially effective, this corrective measure was eliminated from further evaluation due to the length of time necessary to complete cleanup.

- AS with SVE

AS with SVE is an effective corrective measure for removing volatiles from groundwater and affected soils within the saturated zone of the aquifer. The process entails injection of ambient air into the saturated reaches of the aquifer. The injected air strips the volatile chlorinated compounds from the saturated zone into the unsaturated zone where they can be physically removed using soil vapor extraction. The addition of oxygen also enhances aerobic biodegradation of non-chlorinated contaminants that may be residing within the saturated soil pores. This corrective measure was retained for further evaluation due to proven effectiveness and cost relative to competing corrective measures. Pilot-scale testing, described in Section 5.2, has been implemented to further assess the feasibility of achieving CMOs in the Facility Parcel using AS with SVE.

- In-situ ERD

In-situ ERD was identified as a potentially viable corrective measure given its demonstrated effectiveness at remediating CVOCs. In-situ ERD is a highly implementable corrective measure for groundwater treatment; however, ERD is less effective in the Main Source Area due to the presence of the petroleum-based LNAPL. The best way to remove chlorinated COPCs from LNAPL is to weather/breakdown the LNAPL. Relative effectiveness concerns precluded further consideration of the ERD corrective measure for remediation of groundwater in the Main Source Area.

- ZVI

ZVI was considered as a corrective measure based on proven effectiveness in chemically reducing chlorinated hydrocarbons. ZVI is installed in the saturated subsurface perpendicular to groundwater flow direction as a PRB, maximizing groundwater contact time with the reactive media. Within the ZVI reactive zone, many reactions take place that may directly or indirectly destroy contaminants (Suthersan and Payne 2005). Implementation of this corrective measure would likely necessitate installation of multiple PRBs, each requiring substantially intrusive installation work within the Facility Parcel. While potentially effective, this corrective measure was eliminated from further evaluation at this time due primarily to implementation and cost concerns.

4.2.3.1.2 Soil

The soil media for the Main Source Area has both qualitative and quantitative CMOs. Qualitatively, all soil that could potentially leach COPCs into groundwater and prevent groundwater CMOs from being reached requires remediation. Additionally, quantitative risk-based CMOs have been developed for shallower soils. A more detailed discussion of the risk-based goals is found in Section 2.5. Effectiveness of the Main Source Area corrective measures is highly dependent on distribution of COPC impacts and soil characteristics. For the purposes of this screening evaluation, soils requiring remediation have been broadly described as either fine-grained or coarse-grained. The fine-grained descriptor applies to the shallow, unsaturated vadose zone soils. The coarse-grained descriptor refers to impacted smear-zone soils, which include those saturated below the water table, soils located within the capillary fringe, and unsaturated soils within the upper reaches of the smear zone. The following corrective measures have been considered for remediation of soils within the Main Source Area.

- Large Scale Excavation

For the Main Source Area, large-scale excavation as a corrective measure would entail complete excavation of all affected soil media, followed by either ex-situ treatment on site using land farming, in-situ aeration, or off-site disposal at an appropriate landfill. Ex-situ land farming would entail treatment via induced volatilization and enhanced biological degradation. Land farming consideration assumes that soils will be treated to meet CMOs and subsequently backfilled in the excavation. In-situ aeration would consist of leaving impacted soil in place, turning the soil over to volatize COPCs, and then using that soil as backfill once sampling confirms CMOs are achieved. While potentially highly effective, there are significant implementation concerns associated with this corrective measure. Large-scale excavation as a corrective measure was precluded from further consideration in the Main Source Area, primarily due to implementability and cost concerns relative to competing corrective measures.

- Small Scale Excavation

For the Main Source Area, the small-scale excavation corrective measure would entail excavation of shallower, fine-grained soils for purposes of meeting the established soil CMOs. This corrective measure is easily implemented and relatively more cost-effective than competing corrective measures also capable of meeting CMOs in the fine-grained soils. Small-scale excavation is the presumptive corrective measure for fine-grained soils beneath the Main Source Area that exceed risk-based goals. Excavated soils may either be treated on site via land farming, in situ aeration, or disposed at an appropriate off-site landfill. Small scale excavation would likely occur during building demolition, especially within potential highly-impacted source areas, such as sumps, floor drains, and former tank storage areas. Any excavation would involve development of a soil management plan to provide detailed information on treatment, and/or transport, disposal, and manifesting procedures are followed. In addition, a dust control plan would be developed to help prevent short term exposures to nearby residents.

- AS with SVE

Soil vapor extraction is an effective technology to remove volatiles from the vadose zone. A vacuum is applied to the soil to induce the controlled flow of air and remove volatile and some semi-volatile organic contaminants from the soil (Suthersan 1997). The induced flow of air across affected soils also serves to stimulate aerobic degradation of petroleum hydrocarbons. AS with SVE is an effective corrective measure for removing volatiles from affected soils within the saturated zone of the aquifer. The process entails injection of ambient air into the saturated reaches of the aquifer. The injected air volatilizes (i.e., strips) the volatile COPCs from the saturated zone into the unsaturated zone where they can be physically removed using soil vapor extraction (Suthersan 1997). The addition of oxygen also enhances aerobic biodegradation of non-chlorinated contaminants that may be residing within the saturated soil pores. This corrective measure was selected for pilot testing in the Main Source Area, described in Section 5.2, to further evaluate effectiveness, implementability, and cost. While AS with SVE is appropriate for coarse-grained soil, it would likely have limited effectiveness for treating shallow, fine-grained soils.

4.2.3.1.3 LNAPL

The qualitative CMO for the remediation of residual LNAPL is to reduce the leachable COPC concentrations to the extent that any remaining residual LNAPL is rendered inert and is incapable of continuing to release contaminants to groundwater at concentrations exceeding MCLs. The following corrective measures were evaluated to address the LNAPL:

- In-situ electrical resistance heating

The electrical resistance heating (ERH) technology incorporates heating of contaminated materials to enhance the removal of CVOCs and Non-aqueous phase liquid (NAPL). By applying heat to the contaminated media, the viscosity and surface tension of the LNAPL will decrease, thus facilitating collection and subsequent removal from the subsurface. COPC mass removal would occur through concurrent ERH, vapor extraction, and liquids extraction. While considered primarily for purposes of removing LNAPL, this corrective measure is also applicable for treating groundwater. The saturated zone would need to be heated to 100 ºC, and the deep vadose zone would need to be heated to 80 ºC. Pneumatic and hydraulic control would be critical when using this method in order to prevent the spread of contamination. The application of heat would also help degrade TCA via hydrolysis (Beyke 2006). Relative effectiveness and implementability are largely affected by soil type. This corrective measure is not well suited for treating LNAPL in the coarse-grained soils. While potentially highly effective for mitigating LNAPL in the fine-grained soils, the ERH corrective measure has been precluded from further consideration, primarily due to implementability and cost concerns relative to competing corrective measures.

- ZVI/Clay Mixing

ZVI/Clay stabilization was considered a viable corrective measure for both fine- and coarse-grained soils based on proven effectiveness in chemically reducing chlorinated hydrocarbons and stabilizing LNAPL. ZVI and bentonite clay would be mixed with affected soils in situ using large-diameter augers. The bentonite would immobilize/stabilize any residual LNAPL, and the ZVI would treat any leachable chlorinated COPCs. The ability to advance large-diameter augers through the coarse-grained soil presents a significant implementability obstacle for this corrective measure. ZVI/Clay Mixing as a corrective measure was precluded from further consideration in the Main Source Area, primarily due to implementability concerns and potential cost relative to competing corrective measures.

- Steam-Enhanced SVE

Application of steam-enhanced SVE within the Main Source Area was considered primarily for purposes of treating LNAPL. This corrective measure would entail controlled injection of steam to enhance volatilization of COPCs from LNAPL. Steam is injected into the saturated zone, similar to air sparge. The heat from the steam enhances volatilization from groundwater and any residual LNAPL within both saturated and unsaturated coarse-grained soils. Volatilized chlorinated and petroleum hydrocarbons are subsequently removed from the subsurface using SVE. The addition of heat will also be effective in hydrolyzing TCA. Steam-enhanced SVE is being considered primarily for purposes of mitigating LNAPL; however, this corrective measure is also applicable for treating soils and groundwater. This corrective measure was retained for further evaluation.

- Surfactant Flooding

The surfactant flooding corrective measure entails injecting both surfactant and alcohol into the subsurface to increase the mobility of the residual LNAPL. Injected chemicals and the mobilized LNAPL would be subsequently removed through groundwater extraction wells, and the extracted liquids would either be treated on site or disposed of at an appropriate off-site facility. The addition of alcohol may also promote biological degradation (Suthersan and Payne 2005). This corrective measure also has applicability for treating soils and groundwater. While potentially effective, this corrective measure was precluded from further consideration, primarily due to implementability concerns and potential cost relative to competing corrective measures.

4.2.3.2 Remote Facility

There are two affected media under evaluation for remediation in the Remote Facility, groundwater and soils. The CMO for groundwater entails meeting MCLs at the eastern Facility Parcel boundary. Soils will require remediation to the extent necessary so that groundwater CMOs are achieved in a timely and cost-effective manner. The following sections describe the corrective measures screened for Remote Facility. **Table 4-3** further summarizes screening evaluation criteria for each of these corrective measures.

4.2.3.2.1 Groundwater

The CMOs for groundwater in the Remote Facility are to meet MCLs along the eastern edge of the Facility Parcel. In order to meet those CMOs, the following corrective measures were identified and evaluated for the Remote Facility:

- MNA

As previously described for the Perl Mack Neighborhood and Vacant Parcels, the MNA corrective measure relies upon natural attenuation to meet groundwater CMOs. MNA was considered for this area with the expectation that residual soil impacts that are contributing to groundwater concerns would be addressed through implementation of a complementary corrective measure for soils. Once COPC concentrations in source area soils have been reduced, the aqueous phase COPC plumes will attenuate naturally. ARCADIS has identified MNA as a potential corrective measure for addressing groundwater impacts in the Remote Facility. While potentially effective, this corrective measure was eliminated from further evaluation due to the length of time necessary to complete cleanup.

- AS with SVE

As previously described for the Perl Mack Neighborhood and Vacant Parcels, AS with SVE will be an effective corrective measure for removing volatiles from subsurface soils as well as dissolved mass in the groundwater. For the Remote Facility, implementation would likely entail use of sparge curtains as opposed to complete well-to-well AS well coverage across the entire groundwater plume. The groundwater CMO for the remote facility would be met in a timelier manner than relying on MNA alone. This corrective measure was chosen for remedial alternative consideration, mainly for ease of implementability and anticipated effectiveness.

- In-situ ERD

As previously described for the Perl Mack Neighborhood and Vacant Parcels, in-situ ERD was identified as a viable corrective measure given its demonstrated effectiveness at remediating CVOCs. The ERD process consists of injecting a carbohydrate solution into the subsurface to provide a food source for the indigenous bacteria within the subsurface. Through the bacteria’s natural respiration process, an anaerobic reducing environment is created and the COPCs are dechlorinated (Suthersan and Payne 2005). In-situ ERD is a highly implementable corrective measure for groundwater treatment; however, the amount of carbohydrate required to adequately dechlorinate the groundwater on the Remote Facility has the potential to exacerbate biofouling concerns during operation of the GBS. In order to implement this corrective measure at the Remote Facility, extraction wells in the southern portion of the GBS would need to be de-activated or significant modifications would need to be made to the GBS treatment process. Implementing this corrective measure also presumes that residual soil impacts will be addressed with a complementary soils corrective measure and that similar ERD corrective measures will be implemented on the downgradient Vacant Parcel. The in-situ ERD corrective measure has been identified as a potentially viable corrective measure for addressing groundwater impacts in the Remote Facility and will be further evaluated based on ease of implementation and effectiveness.

- ISCO

In-situ chemical oxidation was also considered as a corrective measure because of proven effectiveness in degrading chlorinated compounds. For the Remote Facility, this corrective measure would entail injection of sodium or potassium permanganate and/or activated persulfate into the affected reaches of the aquifer, to create reactions with the COPCs, and to chemically reduce them to less toxic compounds (Suthersan and Payne 2005). Effectiveness of this corrective measure is highly dependent on the ability to cost-effectively deliver enough oxidant to overcome natural oxidant scavengers and contact the affected media (i.e., a large number of wells). This corrective measure also assumes that a complementary corrective measure for remediating residual soil impacts is implemented as part of the resulting remedial alternative. The ISCO corrective measure will be further evaluated based on effectiveness although its cost is high relative to similarly effective competing corrective measures.

4.2.3.2.2 Soil

Affected soils in the vicinity of the Remote Facility have both qualitative and quantitative CMOs. Qualitatively, all soil that could potentially leach into groundwater and prevent groundwater CMOs from being reached must be remediated. Quantitatively, risk-based remedial goals have been developed using potential receptor exposure assumptions. A more detailed discussion of the risk-based goals is found in Section 2.5. The following two corrective measures were considered for the Remote Facility.

- SVE

SVE is an effective technology to remove volatiles from coarse-grained soil in the vadose zone and is particularly well suited for this area of the site. For the Remote Facility, this corrective measure can be easily implemented through modification and enhancement of existing systems and installation of a relatively small number of SVE wells. SVE is the presumptive corrective measure for addressing Remote Facility soils and has been selected for pilot testing, described in Section 5.2, to further evaluate effectiveness.

§ Small Scale Excavation

Small-scale excavation of potential source areas has been considered as a potentially viable corrective measure for addressing soil concerns at the Remote Facility. Evaluation of characterization data collected to date has identified a benzo(a)pyrene detection in a single surface soil sample at SWMU 9 at the HBRG limit. Additional investigation will be conducted at SWMU 9 and remediation, if necessary, may be accomplished by small scale excavation. This corrective measure could also prove highly effective if other shallower, localized source areas are discovered in the Remote Facility during building demolition activities. Small-scale excavation of source areas, if found, will be further evaluated based on ease of implementation and effectiveness.

4.2.3.3 AOC 2

As discussed in previous sections of this CMWP, provided AOC 2 soils remain undisturbed, there is no regulatory basis for remediating these soils (ARCADIS 2007c). CMOs for AOC 2 soils are mostly qualitative, but quantitative CMOs will also apply assuming affected soil media is disturbed. A more detailed discussion of the AOC 2 soil CMOs is found in Section 2.5. The following corrective measures were identified as applicable to AOC 2:

§ No action

The no action corrective measure, as applied to AOC 2, would require use of administrative and potentially engineering controls to ensure that PCB-affected soils remain undisturbed. Effectiveness is largely determined by the type of controls considered, and implementation cost may be subject to ongoing maintenance and monitoring of engineering controls. The no action corrective measure will be further considered for inclusion in the AOC 2 remediation alternatives.

§ Large-scale excavation

For the AOC 2 area, the large-scale excavation corrective measure entails complete removal and off-site disposal of affected soils in order to meet established risk-based CMOs for soil. Relative cost associated with implementation of this corrective measure at AOC 2 is much higher than that of competing corrective measures. However, this corrective measure is the most effective at meeting CMOs for soil. As such, the large-scale excavation corrective measure will be further considered for inclusion in the AOC 2 remediation alternatives.

- Small-scale excavation

For the AOC 2 area, the small-scale excavation corrective measure entails removal and off-site disposal of soils within a utility corridor right-of-way. This corrective measure is aimed at mitigating potential exposure pathways in the event that potentially affected soils are disturbed. Evaluation of characterization data from the right-of-way data has not identified any soils having COPC concentrations that require mitigation to meet the risk-based CMOs for soil. The small-scale excavation corrective measure will be further considered for inclusion in the AOC 2 remediation alternatives.

4.3 Corrective Measures Alternatives

Section 4.2 summarized the screening level evaluation of potential corrective measures ARCADIS has considered for the Hamilton Sundstrand site. Those corrective measures identified for further consideration will be grouped with complementary corrective measures for purposes of developing viable corrective measure alternatives, each believed capable of meeting the established CMOs for the Perl Mack Neighborhood, Vacant Parcel, and Facility Parcel.

4.3.1 Perl Mack Neighborhood

The alternatives derived from the corrective measure screening evaluation for the Perl Mack Neighborhood are:

- Corrective Measure Alternative 1
  - SVE
  - AS
- Corrective Measure Alternative 2
  - SVE
  - In-situ ERD

4.3.2 Vacant Parcel

The alternatives derived from the corrective measure screening evaluation for the Vacant Parcel are:

- Corrective Measure Alternative 1
  - In-situ ERD

- Corrective Measure Alternative 2
    - SVE
    - AS

4.3.3 Facility Parcel

Corrective Measure Alternatives have been developed for each of the primary areas of concern within the Facility Parcel, which includes the Main Source Area, the Remote Facility, and AOC 2. The alternatives for each area are presented below.

4.3.3.1 Main Source Area

The alternatives derived from the corrective measure screening evaluation for the Main Source Area are:

- Corrective Measure Alternative 1
    - Small-scale excavation
    - SVE
    - AS
- Corrective Measure Alternative 2
    - Small-scale excavation
    - SVE
    - Steam Injection

4.3.3.2 Remote Facility

The alternatives derived from the corrective measure screening evaluation for the Remote Facility are:

- Corrective Measure Alternative 1
    - Small-scale excavation (if necessary)
    - SVE
- Corrective Measure Alternative 2
    - Small-scale excavation (if necessary)
    - SVE
    - AS

- Corrective Measure Alternative 3
    - Small-scale excavation (if necessary)
    - SVE
    - In-situ ERD

- Corrective Measure Alternative 4
    - Small-scale excavation (if necessary)
    - SVE
    - ISCO

4.3.3.3 AOC 2

The alternatives derived from the corrective measure screening evaluation for AOC 2 are:

- Corrective Measure Alternative 1
    - Large-scale excavation
- Corrective Measure Alternative 2
    - Small-scale excavation
- Corrective Measure Alternative 3
    - No action

5.0 Interim Corrective Measures and Pilot-Scale Studies

The following sections describe interim corrective measures and pilot-scale studies implemented at the Hamilton Sundstrand site under the ICAP Application. Interim corrective measures were selected to expedite the implementation of those technologies that were likely to be incorporated into a final remedy for the site. Similarly, pilot-scale tests were implemented to evaluate the efficacy of promising technologies as potential remedial alternatives that were also likely to be incorporated into a final remedy for the site. As such, evaluation of the performance of the interim corrective measures and pilot-scale studies is an important component to the assessment and selection of final corrective measures.

Interim corrective measures include the Phase I in-situ ERD systems installed in the Vacant Parcel and Perl Mack Neighborhood, the perimeter VBS completed along the eastern boundary of the Facility Parcel, and expansion of the perimeter VBS to enhance contaminant source removal under Zuni Street. Pilot-scale tests include short-term and long-term AS/SVE or SVE-only tests conducted in the Facility Parcel, Main Source Area, and Remote Facility. **Figure 5-1** shows the locations of all interim corrective measures and pilot-scale studies.

5.1 Interim Corrective Measures

The following sections describe the interim corrective measures implemented at the site.

5.1.1 Phase I ERD System – Vacant Parcel

In-situ ERD was selected as an interim corrective measure for groundwater in the Vacant Parcel. Because of the width of the plume and fast groundwater velocity, an injection trench was utilized for delivery of carbohydrates instead of vertical injection wells. The trench was installed in three 200-foot segments with 4-inch perforated high density polyethylene (HDPE) piping and connected to the mixing system at the Groundwater Treatment Facility. An injection test was performed in September of 2006 to evaluate the injectability of the trench segments; approximately 900 gallons of a dilute total organic carbon (TOC) solution (molasses) was injected. Flow rate and injection pressure data were monitored. The results were utilized for planning the full-scale injection events.

The first full injection event occurred in October 2006 with the injection of 100,000 gallons of a TOC amended solution into each trench segment. The initial concentration of TOC in the injection solution was approximately 1,000 milligram per liter (mg/L). Performance monitoring of the six new monitoring wells, as well as existing wells (GW-62, GW-43, and GW-61), occurred monthly (**Figure 5-1**). These data were used to assess the effectiveness of the IRZ and adjust injection parameters including TOC concentration, frequency, and injection volumes. A decrease in TCE and PCE concentrations and an increase in cis-1,2-DCE in the downgradient wells (T1P-1S/D)was observed by day 90, indicating that ERD technology was successful. Table 5-1 summarizes the data that have been collected to date for the Phase I study. This interim measure is ongoing, and monthly injections and performance monitoring are in effect.

In January of 2008, the frequency of molasses injections was increased to twice per month. Each injection is followed by a continuous flush of clean water to prevent bio-fouling of the trench and to push the injected TOC further into the formation for increased microbial activity downgradient.

5.1.2 Phase I ERD – Perl Mack Neighborhood

In-situ ERD was also selected as an interim corrective measure in the Perl Mack Neighborhood. Four remediation wells and six performance monitoring wells were installed in the neighborhood along Jordan Drive and Fern Drive **(Figure 5-1**). These wells were connected to the mixing system within the groundwater treatment facility. An injection test occurred in September 2006 to assess the injectability of a carbohydrate solution (molasses); approximately 900 gallons of a dilute TOC solution were injected into well PM-4. Flow rate and injection pressure were monitored and the results used for planning the full-scale injections.

The first full injection event occurred in October 2006 with the injection of 44,000 gallons of a dilute TOC solution into PM-2. The initial concentration of TOC was lower than that used in the Vacant Parcel (approximately 50 mg/L TOC vs. 1,000 mg/L TOC). ERD reactions occur under strongly reduced aquifer conditions, and methane is often formed. Because these injections were occurring in a residential area, it was important to better understand how quickly the aquifer would become anaerobic to control methane production. Various engineering controls were put into place to monitor methane, if present, in the vadose zone. Five vapor points were installed to 15 feet bgs, mimicking below-basement conditions. These points were monitored monthly for methane as part of the performance monitoring network. After the initial injection event, approximately 44,000 gallons of a 50 mg/L TOC solution were injected into each of the four wells (PM-1-4) on a monthly basis. Performance of the six new wells, as well as existing wells TP-15, GW-63, GW-64, and GW-11, was monitored monthly. These data were used assess the effectiveness of the In-situ reactive zone (IRZ) and adjust injection parameters including TOC concentration, frequency, and injection volumes. Some decreases in PCE and TCE have been observed throughout the performance monitoring network, a slight increase in cis-1,2-DCE in a select few monitoring wells, and fluctuations in the TCA concentrations. Together with the low concentrations of methane and the lack of significant concentrations of daughter products, it can be concluded that degradation is minimal or not occurring at this low dosage of TOC. An increase in TOC concentration could increase the degradation rates. The fluctuations in concentration are most likely due to biosurfactant effects. During the creation of IRZs, the natural biosurfactants increase, resulting in desorption of contaminants that are sorbed to the aquifer media. This creates an increase in dissolved mass within the IRZ. In addition to the biosurfactant effects, fermentation of the molasses results in the creation of by-products such as alcohols and ketones. These by-products increase the solubilization of the sorbed contaminants by cosolvency effects (Suthersan and Payne 2005). **Table 5-2** summarizes the performance monitoring data that have been collected to date in the Perl Mack Neighborhood.

In April through June 2007, a bromide tracer test was conducted in the Perl Mack Neighborhood to further evaluate the aquifer characteristics such as mobile porosity, aquifer conductivity, and groundwater velocity. This information was used to support changes in interim-measure operations and make future decisions on remediation in this area. The tracer test consisted of injecting approximately 44,000 gallons of a bromide tracer solution into well PM-2 on Jordan Drive on April 30, 2007. Bromide concentrations in groundwater were monitored in a set of wells on Jordan Drive and Fern Drive. Two monitoring methods were employed: the collection of samples for analysis at a commercial laboratory and in-situ bromide probe measurements. Monitoring continued for 42 days and concluded on June 11, 2007.

The tracer study corroborated the groundwater flow model in revealing a high flow velocity with a general easterly flow direction and average velocity of 5 to 10 ft/day. Local and temporal speeds outside this range were observed (up to 15 ft/day). The tracer test confirmed that the injection points were outside of the stagnation zone that is typically located immediately downgradient of a pump and treat system (the GBS). The results showed that the area around the injection point is heterogeneous, and that flow is locally governed by high conductivity channel features. Thus, the area of influence is not an ellipse, but an irregular zone indicative of channelized flow. Any reagent injected in this area can travel large distances in these high-flow channels and will require time to diffuse into areas of lower mobility. The mobile porosity was estimated to be between 2 percent and 12 percent. In summary, the tracer revealed a heterogeneous flow regime governed by high conductivity, preferential flow channels.

Throughout the first step of the Phase I implementation, no methane was detected in the vapor points or headspace of the monitoring wells. In an effort to increase contaminant degradation rates in the neighborhood, the TOC dose in the injection solution was increased from 50 mg/L to 500 mg/L in August 2007. However, subsequent monitoring in the performance wells indicated that dissolved methane concentrations were reaching levels that could potentially produce elevated levels of methane in the vadose zone. Although vadose zone monitoring indicated that concentrations were lower than the LEL in the vapor phase (0.2 parts per million (ppm) relative to 45,000 ppm), in order to ensure protection of the neighborhood, ERD injections were suspended pending further data interpretation. Based on the evaluation of the existing data from both the lower TOC dosing (50 mg/L) and the higher TOC dosing, (500 mg/L), the lower TOC dosing will be used for any future ERD implementation in order to remain protective of existing housing in the Perl Mack Neighborhood.

5.1.3 Perimeter Vapor Barrier System

The perimeter VBS interim measure was constructed to prevent the potential migration of soil vapor containing CVOCs across the Facility Parcel eastern boundary toward the Perl Mack Neighborhood and Vacant Parcel. In early 2006, Hamilton Sundstrand conducted a soil vapor mitigation pilot study along the eastern boundary of the Facility Parcel north of the Groundwater Treatment Facility (MACTEC 2006). At that time, four SVE wells with the infrastructure and equipment necessary to operate the northern half of the perimeter VBS were installed. In October 2006, four additional SVE wells were installed to complete the southern half of the perimeter VBS. These four additional SVE wells are actually multiphase extraction wells that also operate as groundwater extraction wells to enhance operation of the GBS (see Section 2.7.1). The northern half of the system has been in continuous operation since August 2006 while continuous operation of the southern half was added in December 2006.

The perimeter VBS creates a continuous negative pressure zone along the eastern boundary of the Facility Parcel to prevent the migration of potentially contaminated soil vapor. Although the system has the capacity to operate up to eight SVE wells, only four wells are currently operated to maintain the continuous negative pressure boundary; including wells VEW-1, VEW-4, EXW-7C, and EXW-11C **(Figure 5-1).** System performance measurements are collected weekly including measurements of vapor flow rates and vacuum pressures as well as the vacuum induced in nearby monitoring wells to ensure that a continuous negative pressure boundary is maintained. Vapor samples are collected quarterly for laboratory analysis to evaluate the concentration of contaminants in extracted vapors and to calculate contaminant mass removal rates and the cumulative contaminant mass removed. As of September 2007, the cumulative mass of total VOCs removed by SVE wells VEW-1 and -2 is 603 pounds (VEW-2 was operated initially but was shut down in November 2006 and replaced by operating VEW-1). VEW-4 has removed 426 pounds of total VOCs. The total mass removed by the combination of SVE wells EXW-7C and EXW-11C adjacent to the Remote Facility is 53 pounds. The relatively greater mass removed by wells VEW-1, -2, and -4 is due to their proximity to the Main Source Area and indicates that SVE operation in this area is removing contaminant source material.

5.1.4 Vapor Barrier System Expansion

Expansion of the perimeter VBS includes the installation of three additional SVE wells (VEW-6, -7, and -8) immediately east of existing VBS wells VEW-1 and VEW-4 (Figure 5-1). The objective of expanding the VBS is to enhance the remediation of contaminant source material where the smear zone has been identified extending under Zuni Street (Section 2.6.2). Expansion of the VBS system is designed to enhance the removal of contaminant source material downgradient of the GBS and upgradient of the Phase I in-situ ERD interim corrective measure currently operating in the Perl Mack Neighborhood (Section 5.1.2). Ultimately, remediation of this contaminant source material is necessary to allow complete remediation of contaminants dissolved in groundwater by the Perl Mack ERD system. Implementation of this interim corrective measure is described in ARCADIS (2007d).

New SVE wells VEW-6, -7, and -8 were installed in September 2007, and distribution piping hookups were completed in October 2007. The expanded VBS interim corrective measure began full operation in November 2007. Evaluating remediation of the contaminant source material will include monitoring the rate and cumulative mass of CVOCs removed in extracted vapor and assessing changes in CVOC concentrations in groundwater in selected monitoring wells.

5.2 Pilot-Scale Studies

SVE, potentially enhanced with AS operation, was identified early during the corrective measures technology identification process as a technology that could potentially remediate contaminant source material on the Facility Parcel to meet the project CMOs. The viability of SVE was further supported by observations from early operation of the perimeter VBS suggesting that the northern half of the system was removing contaminant source material from the Main Source Area (Section 5.1.3). The following sections describe the implementation of pilot-scale studies designed to evaluate the effectiveness of SVE and AS/SVE operation on the Facility Parcel.

5.2.1 Short-Term AS/SVE Pilot Test

Short-term AS/SVE pilot tests were completed December 13 through 19, 2006. The short-term AS/SVE pilot tests included SVE-only, AS-only, and combined AS/SVE operation at three test areas. The three test areas included the Remote Facility TCE and PCE groundwater contaminant plume source areas and the Main Source Area (near SWMU 5). **Figure 5-1** shows all pilot testing locations. The tests were conducted as described in the Remote Facility short-term AS/SVE work plan (ARCADIS 2006c) and addendum work plan describing the Main Source Area test (ARCADIS 2006a). The objectives of the short-term pilot tests were to determine the radius of influence (ROI) surrounding AS and SVE wells and the optimal pressure (or vacuum) and air flow requirements for AS/SVE operation. Due to the similarities in geology among the three areas, the combined pilot testing results represent the range of AS/SVE performance that may be expected across most of the former Hamilton Sundstrand facility site. Samples of extracted vapors were also collected to evaluate the rate of contaminant mass removal achieved during initial operation of AS/SVE systems.

The AS ROI achieved during short-term testing at all three locations was approximately 10 feet, which is consistent with the ROI expected given a saturated aquifer thickness of approximately 10 feet. Stable sparge air flow measured during the short-term tests ranged from 15.6 to 24.7 standard cubic feet per minute (SCFM) at blower pressures of 7.5 to 11 pounds per square inch (PSI).

SVE vacuum ROIs were measured in excess of 100 feet during short-term pilot testing, which is consistent with the highly permeable nature of alluvial materials just above the water table surface and observations from operating the facility's perimeter vapor barrier system (see Section 5.1.3). No induced vacuum was measured in shallow, low-permeable soil, indicating that the shallow low-permeable soil is a boundary to air flow. Vapor flow and wellhead vacuum measurements varied with SVE well construction, but ranged from 34 to more than 200 SCFM flow at between 8 and 35 inches of water vacuum. Pneumatic conductivity calculations indicated that one soil pore volume of vapor was exchanged every 24 hours to distances ranging from 70 to 82 feet from the SVE wells (at a flow rate of 60 SCFM).

Contaminant mass removal rates were calculated from extracted vapor sample analytical results and SVE flow rates measured during both SVE-only and combined AS/SVE testing at all three short-term pilot test areas. Removal rates were relatively low at the Remote Facility TCE and PCE areas during SVE-only testing (0.13 and 0.44 pounds per day (lb/day), respectively) and removal rates either remained the same or dropped during AS/SVE testing. The lack of any increase measured during AS/SVE testing is not surprising given that the SVE ROI was much greater than the AS ROI and any increase from sparge operation would have been difficult to measure. The percentage of total detectable VOCs removed during AS/SVE operation was about 59 percent (by volume) TCE and 35 percent TCA from the TCE Area and nearly 97 percent PCE from the PCE Area.

Removal rates at the Main Area were10.6 lb/day during SVE-only testing and 12.4 lb/day during AS/SVE testing. The removal rate during AS/SVE testing increased partly due to an increased vapor flow rate, but consistent increases in contaminant concentrations in the vapor sample indicate that AS operation may have enhanced the removal rate. The percentage of total detectable VOCs removed during AS/SVE operation was about 50 percent (by volume) TCA, 10 percent cis-1,2-DCE, 7 percent TCE, and 11 percent PCE.

5.2.2 Main Source Area Long-Term AS/SVE Pilot Test

Long-term AS/SVE pilot testing was completed in the Main Source Area between March and September 2007. The AS/SVE pilot test area was located west of SWMU 5 **(Figure 5-1**). The primary source of continued contamination to groundwater in this area are CVOCs bound in lubricating and cutting oils, including TCA, PCE, TCE, and their degradation products. The lubricating and cutting oils exist as a residual (non-drainable) LNAPL occurring in the contaminant smear zone as described in Section 2.6.1. Mobile (recoverable) LNAPL also accumulate in some well casings in this area. The primary objective of long-term AS/SVE pilot testing in the Main Source Area was to evaluate whether the technology can adequately remove CVOCs from groundwater, soil, and LNAPL to the extent that any remaining CVOCs will not exceed MCLs at the property boundary. The test was conducted as described in the Main Contaminant Source Area long-term AS/SVE work plan (ARCADIS 2007e).

As previously described, short-term AS/SVE pilot testing was completed in December 2006 to provide design information for full-scale systems, including evaluating the ROI to be expected surrounding AS and SVE wells, and specifications for mechanical equipment to provide sufficient air pressure (or vacuum) and air flow. The long-term AS/SVE pilot test focused on evaluating the removal of CVOCs from groundwater, soil, and LNAPL. As such, the following tasks were completed in support of this evaluation:

<u>Task 1 – Evaluate changes in CVOC concentrations in groundwater and LNAPL</u>. Pre-test sampling established baseline concentrations of contaminants in groundwater and recoverable LNAPL (LNAPL that accumulates in well casings) in “report card” wells within the AS/SVE pilot test area. Groundwater and recoverable LNAPL were re-sampled after a period of continuous AS/SVE operation (approximately 3 months) to evaluate changes in contaminant concentrations.

<u>Task 2 – Evaluate changes in VOC concentrations in soil (residual LNAPL)</u>. Soil in the contaminant “smear zone” was evaluated for residual LNAPL distribution and

concentrations of CVOCs before the start of AS/SVE operations and after a period of continuous AS/SVE operation (approximately 3 months) to evaluate changes in contaminant concentrations.

Task 3 – Monitor the rate of contaminant mass removal and aerobic biodegradation. Emission rates and contaminant concentrations in extracted vapors were evaluated throughout AS/SVE operation to monitor the removal of CVOCs from the subsurface environment. A biodegradation respiration test was conducted when the system was temporarily shut down to collect samples to address Tasks 1 and 2 after 3 months of continuous operation to evaluate the rate of aerobic biodegradation stimulated by AS/SVE operation. In addition, concentrations of carbon dioxide (CO_2) were measured in extracted vapors to monitor the rate of aerobic biodegradation.

The long-term AS/SVE pilot test system included one SVE well surrounded by eight AS wells installed west of SWMU 5. Simultaneous with AS/SVE testing adjacent to SWMU 5, SVE-only operation was tested near AOC 1 by converting an existing groundwater monitoring well (LNAPL5,3) to SVE operation. The objective of adding SVE-only testing near AOC 1 was to evaluate SVE-only versus combined AS/SVE operation, and to test operation within a contaminant release area (AOC 1) compared to operation in an area affected primarily by LNAPL present in the smear zone (west of SWMU 5). Baseline soil, groundwater, and LNAPL sampling was completed in March 2007 (no baseline soil sampling was conducted near SVE well LNAPL5,3) and SVE operation was initiated March 28, 2007. Operation of the AS system was added on April 9, 2007. Soil, groundwater, and NAPL were re-sampled following continuous AS/SVE operation in late June 2007. Additional soil samples were also collected in late August 2007. Monitoring of emission rates and contaminant mass removal for pilot testing purposes continued through August 2007, although the systems currently continue to operate.

5.2.2.1 Changes in Contaminant Concentrations in Groundwater and NAPL

Baseline groundwater samples and samples collected after about 3 months of continuous AS/SVE operation were obtained from four “report card” wells, including MW-OBS-5, SWMU5-3, SWMU5-4, and TP-4. The same set of baseline and post-operation groundwater analyses were performed on samples collected from two wells in the SVE-only test area, including wells AOC1-3 and TP-2. All baseline and post-operation groundwater samples were analyzed for VOCs and total petroleum hydrocarbons (TPH) as gasoline-range organics (GRO), diesel-range organics (DRO), and motor oil-range organics (MRO).

Reductions in the concentrations of VOCs were significant in all baseline/post-operation groundwater sample pairs. Reductions in the concentrations of the primary CVOCs ranged from 67 percent to 97 percent in the AS/SVE test area and 57 percent to 63 percent in the SVE-only test area. Changes in TPH concentrations were much more variable, with some sample pairs showing reductions and others showing increases between baseline and post-operation sampling results. **Table 5-3** summarizes baseline and post-operation groundwater sample analytical results for the primary CVOC compounds and TPH.

Baseline and post-AS/SVE LNAPL samples were obtained from well MW-OBS-5. The reduction in total CVOC concentrations was 98 percent between the baseline and post-operation samples, suggesting that AS/SVE is capable of removing CVOCs from the oily LNAPL. **Table 5-3** also summarizes baseline and post-operation LNAPL sample analytical results for the primary CVOC compounds. Fluid properties analyses were also compared between the post-operation LNAPL sample collected from well MW-OBS-5 and an LNAPL sample collected from nearby well SWMU5-4 in October 2006. The post-operation LNAPL sample measured an increase in viscosity ranging between 26 percent and 41 percent, depending on the temperature at which the viscosity was measured. The increase in viscosity suggests the removal of lighter, more volatile compounds (solvents) from the LNAPL due to operation of the AS/SVE system.

5.2.2.2 Changes in Contaminant Concentrations in Soil (residual LNAPL)

Thirteen baseline soil samples were collected from boreholes used to install AS wells for the long-term AS/SVE pilot test. All soil samples were collected from the contaminant smear zone just above the water table surface. Following 3 months of continuous AS/SVE operation (by late June 2007), 16 soil samples were collected from borings installed adjacent to the AS wells (within several feet). These post-operation soil samples were also collected from the contaminant smear zone as close as possible to the depths where the original baseline soil samples were collected. All baseline and post-operation soil samples were analyzed for VOCs and TPH (GRO, DRO, and MRO). Additional soil samples were also collected in late August 2007 from borings drilled adjacent to existing well AOC1-3 in the SVE-only test area and adjacent to historical boring SR-3 (which was collected before the SVE pilot study) in the combined AS/SVE test area. Post-operation analytical results from these soil samples were compared to historical soil sampling results from when well AOC1-3 was installed (October 2003) and when boring SR-3 was completed (October 2006).

Reductions in the concentrations of VOCs were significant in all baseline/post-operation soil sample pairs. Reductions in the concentrations of the primary CVOCs ranged from 84 percent to 100 percent in the AS/SVE test area. Reductions in the SVE-only testing area were similar, except for a sample pair collected in shallow low-permeability soil about 15.5 to 17 feet bgs. Very little reduction was observed in this sample pair, which was consistent with observations from the short-term AS/SVE pilot test that the shallow low-permeability soil is a boundary to air flow. Similar to the groundwater sample pairs, changes in TPH concentrations in the soil sample pairs were much more variable, with some sample pairs showing reductions and others showing increases between baseline and post-operation sampling results. In general, however, most soil sample pairs showed a decrease in the volatile GRO fraction between baseline and post-operation sample pairs. **Table 5-4** summarizes baseline and post-operation soil sample analytical results for the primary CVOC compounds and TPH (note: DCA and DCE concentrations are not included in **Table 5-4** because they were never or only rarely detected in the soil samples).

5.2.2.3 Rate of Contaminant Mass Removal and Aerobic Biodegradation

The rate of vapor flow extracted by the SVE wells was tracked throughout the long-term AS/SVE pilot test, and laboratory analysis of extracted vapor samples was conducted approximately monthly. Relatively high vapor extraction rates were maintained briefly during initial SVE-only operation to evaluate maximum contaminant mass removal rates (41 SCFM at SVE-1 and 30 SCFM at LNAPL5,3). Throughout most of the long-term AS/SVE pilot test, extracted vapor flow was controlled to restrict the SVE ROI to a confined area. The SVE ROI was also controlled by the use of passive SVE vent wells surrounding the test areas used to supply makeup air to the SVE systems. In general, extracted vapor flow was maintained between 30 to 33 SCFM at SVE-1 (roughly matching the rate of injected air flow from the AS system) and between 17 to 20 SCFM at LNAPL5,3. However, SVE operation was again maximized starting in late July 2007, after critical pilot-study data had been collected, to the maximum capacity of the SVE blower. At that time, the flow rate was increased to about 105 SCFM at SVE-1. However, only a minimal increase in flow from 17 to 19 SCFM was measured at LNAPL5,3.

The rate of contaminant mass removal from SVE well LNAPL5,3, located within a contaminant release area, exceeded 55 lb/day of total VOCs during initial operation. The mass removal rate dropped to 7 to 8 lb/day by mid June 2007, and was not significantly increased in late July 2007 after maximizing SVE blower flow. The cumulative mass of total VOCs removed by mid September 2007 exceeded 2,000 pounds. Approximately 95 percent of the total VOCs removed were of the six primary site CVOCs with 86 percent of the total mass being TCA. **Figure 5-2** summarizes the rate and cumulative mass of VOCs removed by SVE well LNAPL5,3 during the long-term pilot test.

The rate of contaminant mass removal from SVE well SVE-1, operated to focus contaminant removal from the smear zone only, exceeded 15 lb/day of total VOCs during initial operation. The mass removal rate dropped to 1 lb/day or less by mid May 2007, and was increased to about 3 lb/day in late July 2007 by maximizing the SVE blower operation. The cumulative mass of total VOCs removed by mid September 2007 was 350 pounds. Approximately 88 percent of the total VOCs removed were composed of the six primary site CVOCs with 70 percent of the total mass being TCA. **Figure 5-3** summarizes the rate and cumulative mass of VOCs removed by SVE well SVE-1 during the long-term pilot test.

The aerobic biodegradation of petroleum hydrocarbons (the lubricating and cutting oils that form the bulk of the LNAPL) stimulated by AS/SVE operation was estimated from respiration testing completed during a temporary system shutdown after approximately 3 months of continuous system operation. In addition, aerobic biodegradation rates were calculated from periodic measurements of CO_2 concentrations in extracted vapors collected during system operation. Respiration testing involves monitoring changes in the ratio of oxygen and CO_2 concentrations in soil vapor samples collected from monitoring wells within the AS/SVE or SVE-only testing areas after system shutdown. The respiration testing results indicated that biodegradation rates of 0.8 and 1.6 lb/day were occurring near (assuming a 40-foot ROI) SVE wells LNAPL5,3 and SVE-1, respectively, after approximately 3 months of continuous system operation. The biodegradation rates were likely higher in the vicinity of SVE-1 than LNAPL5,3 because more biodegradable petroleum hydrocarbons are present near SVE-1, as supported by field observations and laboratory data. The relatively low biodegradation rates at both areas suggested that most of the readily bioavailable organics have largely been degraded near the SVE wells where pore volume exchange rates have been greatest. This observation was supported by the much greater rate of biodegradation calculated from oxygen and CO_2 concentrations measured in vapor samples collected in well LNAPL8,3, located 75 feet west of SVE-1, where the pore volume exchange rate was much lower.

Aerobic biodegradation rates exceeding 30 lb/day were calculated from periodic measurements of CO_2 concentrations in extracted vapors from both testing areas. In addition, CO_2 concentrations remained relatively constant throughout operation of the pilot test, indicating that a relatively consistent rate of biodegradation was maintained. The much greater rate of biodegradation estimated from CO_2 concentrations in extracted vapors (relatively to the respiration testing results) is due, at least in part, to the much greater area of biodegradation represented by the extracted vapor measurements. That is, CO_2 in the extracted vapors is being pulled from the maximum extent of the system ROI. Although vapor extraction was controlled throughout most of the test, induced vacuum could still be measured more than 100 feet from the SVE wells. Consequently, biodegradation rates estimated from respiration testing results apply to a small ROI of 40 feet, where pore volume exchange rates have been greatest, while rates calculated from CO_2 concentrations in extracted vapors apply to a much greater ROI exceeding 100 feet. Presumably, readily bioavailable organics have not been largely degraded at greater distances from the SVE wells where pore volume exchange rates are much lower and where robust biodegradation continued to occur throughout the duration of the pilot test.

5.2.3 Remote Facility Long-Term SVE Pilot Test

Long-term SVE operation will be tested at two locations at the Remote Facility including a suspected source area for PCE contamination to groundwater and a separate location suspected as a source area for TCE contamination to groundwater **(Figure 5-1).** The objective of long-term SVE pilot testing at the Remote Facility is to evaluate whether the technology can adequately remove CVOCs from soil to the extent that any remaining CVOCs will not leach to groundwater in concentrations that will exceed MCLs at the property boundary and to clean the site sufficiently to allow recreational land use. The PCE and TCE contaminant source areas are defined based on elevated contaminant concentrations in groundwater. SVE systems have been constructed in areas of highest contaminant concentrations in groundwater where contaminant releases are assumed to have occurred and where contaminants may remain in unsaturated zone soil and the capillary fringe. Long-term pilot testing will evaluate whether SVE is capable of adequately removing this continuing source of contamination to groundwater without implementing enhancement technologies such as AS. Implementation of the Remote Facility long-term SVE pilot test is described in ARCADIS (2007f).

As previously described in Section 5.1.3, the southern portion of the perimeter VBS, which is adjacent to a portion of the TCE source area (extraction well EXW-11C), has operated continuously since December 2006. Analytical results from groundwater samples collected in March 2007 indicate that TCE concentrations in groundwater are decreasing in the vicinity of the perimeter VBS well when compared to April 2006 and previous historical analytical results. This decrease in TCE concentrations in groundwater that may be attributed to SVE operation indicates that expansion and long-term testing of SVE across the TCE and PCE source areas is warranted. The long-term SVE pilot test will focus on evaluating the removal of CVOCs from soil and the resulting effect on contaminant concentrations in groundwater. Tasks to be completed include monitoring the rate and cumulative mass of CVOCs removed in extracted vapor and assessing changes in CVOC concentrations in groundwater in selected monitoring wells.

Existing SVE wells EXW-11C (also used for the perimeter VBS) and RP-SVE-1 (installed for the short-term AS/SVE pilot test described in Section 5.2.1) will be used for the Remote Facility long-term SVE pilot test. New SVE wells RT-SVE-1, -2, and -3 **(Figure 5-1)** were installed in September 2007, and distribution piping hookups were completed in October 2007. The Remote Facility long-term SVE pilot test began operation in November 2007 and performance monitoring of the system is currently being conducted.

6.0 Corrective Measure Alternatives Evaluation and Comparison

Section 4 of this CMWP summarized the corrective measure screening evaluation process used to assess and develop a variety of corrective measure alternatives (CMAs) for the Perl Mack Neighborhood, Vacant Parcel, and Facility Parcel. Each CMA entails implementation of one or more complementary and technically viable corrective measure that, when implemented collectively and in context with ongoing interim measures, can be expected to meet the established CMOs. Section 5 summarized results from interim corrective measures and recent pilot testing activities that ARCADIS has implemented in order to further qualify the relative effectiveness of some of the key individual corrective measures that are being considered as components to these CMAs. A minimum of two CMAs have been identified for each area of the Hamilton Sundstrand site, all of which are being considered as viable corrective measure groupings, capable of meeting CMOs. That being the case, further consideration needs to be given to each of these CMAs in order to identify the preferred CMAs for the site.

This section compares and evaluates each of the CMAs developed in Section 4 against each other and in context of traditional RCRA corrective action evaluation criteria. Section 6.1 describes the evaluation approach, including descriptions of criteria, and Section 6.2 summarizes the comparative evaluation of these criteria for each of the CMAs developed in Section 4. Subsequent sections of this CMWP will establish the preferred CMAs for each area of the site (Section 7) and outline the proposed approach for implementing and monitoring the preferred CMAs in a manner that facilitates meeting all established CMOs in a timely manner (Section 8).

6.1 Evaluation Approach

There are three minimum performance criteria that the EPA has determined all CMAs should achieve (USEPA 2002). Additionally, there are balancing or evaluation criteria that can be used to identify the best overall CMA for meeting the minimum performance criteria. The three primary performance criteria used to evaluate the CMAs are summarized as follows:

- Protection of Human Health and the Environment: CMAs must be protective of human health and the environment. Remedies may also include corrective measures necessary to ensure the CMA is protective, but are not directly related to media cleanup, source control, or management of wastes.
- Attainment of CMOs: CMAs will be required to attain and maintain media cleanup standards as dictated by the CMOs presented in Section 3.
- Control of Source Releases: A critical objective in any CMA must be to stop further environmental degradation by controlling or eliminating further releases that may pose a threat to human health and the environment. Unless source control measures are taken, efforts to clean up releases may be ineffective or may require continuous cleanup. Therefore, an effective source control program is essential to ensure the long-term effectiveness of the corrective action program.

Each CMA was also evaluated for its ability to meet the following technical decision factors detailed below (USEPA 2002):

- Long-Term Reliability and Effectiveness: Each CMA was evaluated in terms of its anticipated life span, whether the CMA has been used effectively under analogous site conditions, whether failure of any one corrective measure in the CMA will have an immediate impact on receptors, and whether the CMA will have the flexibility to accommodate any unforeseeable changes at the site.
- Reduction in the Toxicity, Mobility, or Volume of Contamination: Generally, the preferred CMAs are those that are capable of eliminating or substantially reducing the toxicity, mobility, and volume of contaminants. The irreversibility of the treatment and the quantity and type of residual material produced are also considered in the evaluation. The amount of reduction is evaluated by comparing

initial site conditions to expected post-implementation conditions and estimating how much the CMAs reduce the toxicity, volume, or mobility of the contaminants.

- Short-Term Effectiveness: This factor evaluates the ability of the CMA to protect workers, local community, and the environment during the implementation phases. This factor is particularly relevant when remediation activities are conducted in populated areas or where waste characteristics are such that risks to workers or to the environment are high and special protective measures are needed.
- Implementability: The ability to implement a technology will often determine its usefulness in a CMA. State or local approvals or restrictions may increase the amount of time needed to implement a corrective measure or even preclude certain approaches. Information considered when assessing implementability includes:
    - The administrative activities needed to implement the CMA, such as permits, rights of way, offsite approvals, and the length of time required to complete these activities;
    - Ease of implementation (e.g., construction) and the time required for implementation;
    - The availability of adequate offsite treatment, storage capacity, disposal services, or needed technical services and materials; and
    - The availability of technologies identified in each CMA.
- Cost: Cost is a relative measure in this evaluation, as additional site-specific information is needed for a more detailed cost analysis. Only order-of-magnitude cost differences would result in the elimination of a CMA.
- Community Acceptance: The CMAs were evaluated based past concerns raised by the affected community and the degree to which the community would accept the recommended remedial alternative(s).
- State Acceptance: The CMAs were evaluated based on the degree to which they are expected to be acceptable by the CDPHE.

6.2 Evaluation and Comparison of Alternatives

A variety of CMAs are considered viable remediation alternatives for this site, the relative effectiveness, implementability, cost, and measure of stakeholder acceptance will vary. CMA evaluation tables have been prepared in order to summarize relative performance expectations for the previously identified CMAs. The CMAs for the Perl Mack Neighborhood are evaluated in **Table 6-1**, and the Vacant Parcel CMAs evaluation is summarized in **Table 6-2**. Comparative evaluations of CMAs developed for each of the three Facility Parcel areas – the Main Source Area, the Remote Facility, and AOC 2 – are provided as **Tables 6-3 through 6-5**, respectively.

The CMA evaluation tables include numeric rankings for each corrective measure alternative to assist in the selection of preferred alternatives as summarized in Section 7. Each alternative has been assigned a qualitative numeric ranking for each of the evaluation categories. The rankings are intended to assess the relative ability for each alternative to address the CMOs. Numeric rankings are based on a scale of one to five and have been assigned as follows:

1. Low
2. Moderately Low
3. Moderate
4. Moderately High
5. High

The sum total of all category rankings has been used to produce a weighted score, which represents the relative feasibility of each alternative to meet the CMOs for the site.

7.0 Selected Corrective Measure Alternatives

The previous section summarized the methodology and results of the Corrective Measure Alternatives evaluation for the three main areas of the site. This evaluation has been used to identify the preferred CMAs for addressing soil and groundwater impacts within the Perl Mack Neighborhood, the Vacant Parcel, and the three area groupings of the Facility Parcel (i.e., the Main Source Area, the Remote Facility, and AOC 2). Most of the individual SWMUs and AOCs identified are contained within the Main Source Area and Remote Facility. Section 2.4 of this CMWP summarized each SWMU and AOC in context of its location within either the Main Source Area or Remote Facility. Only AOC 2, an area of PCB contamination in soil at the south end of the Facility Parcel, and AOC 3, site-wide groundwater, have been distinguished separately. Evaluation of historical site characterization data in context of allowable risk-based COPC concentrations and qualitative CMOs has determined that eight SWMUs do not need to be specifically remediated:

- SWMU 1
- SWMU 2

- SWMU 4
- SWMU 6
- SWMU 7
- SWMU 8
- SWMU 10
- SWMU 13

The five remaining SWMUs and six AOCs, will be addressed through implementation of the proposed CMAs. **Tables 7-1 and 7-2** summarize corrective action determinations for each of the 13 SWMUs and six AOCs. Where corrective action is necessary, these tables identify the CMAs proposed for purposes of attaining CMOs.

Each of the CMAs evaluated for implementation are potentially viable alternatives. Closer examination of relative effectiveness, implementability, acceptability, and cost for the CMAs has been used to further qualify relative CMA viability for purposes of identifying the preferred CMAs for the site. The proposed CMAs for the site are summarized in the subsections below. Section 7.1 presents the proposed CMA for the Perl Mack Neighborhood. The preferred CMA for the Vacant Parcel is discussed in Section 7.2, and the proposed CMAs for the Facility Parcel are presented in Section 7.3. Section 7.4 provides further rationale for seeking regulatory closure determinations on the 9 SWMUs that will not require further remediation. Section 8 will further describe how these proposed CMAs will be implemented.

7.1 Perl Mack Neighborhood

The proposed CMA for the Perl Mack Neighborhood, described as CMA1 in **Table 6.1**, entails SVE coupled with AS. This CMA will be used to meet the established CMOs for the Perl Mack Neighborhood while serving to meet the regulatory closure objectives established for AOC 3, site-wide groundwater. In order to meet this objective, this CMA will address residual soil impacts to the extent necessary to ensure residual COPC concentrations in soil are no longer contributing to groundwater concerns.

Recent enhancements to operation of the GBS have resulted in decreasing CVOC concentrations in some Perl Mack Neighborhood monitoring wells. As a result, corrective measures in the neighborhood will be implemented to best address the remaining CVOCs affecting groundwater. SVE will be implemented followed by AS (if necessary) to reduce residual CVOC concentrations in soil that in turn affect groundwater. If the GBS enhancements combined with SVE alone result in a significant reduction in the concentrations of CVOCs in groundwater, AS may not be implemented. Groundwater analytical data collected for performance evaluation will be used to determine if AS is necessary to meet CMOs. This CMA can also be easily modified to accommodate ERD, in the event ERD becomes the preferred groundwater alternative as remediation progresses, as described by CMA2.

7.2 Vacant Parcel Area

The proposed CMA, described as CMA1 in **Table 6.2**, for the Vacant Parcel entails continued operation of ERD. This CMA is primarily intended to assist in meeting the regulatory closure objectives established for AOC 3, site-wide groundwater. In order to meet this objective, this CMA will entail continued injections, as well as monitoring, to ensure residual COPC concentrations in groundwater are attenuating~~,~~ absent upgradient contributions from the Facility Parcel. This CMA will be implemented in conjunction with operation of the current mitigation systems on the Facility Parcel, previously described in Section 2.7 of this CMWP.

The need for treatment in lower-permeable soil occurring east of Pecos Street will be determined as the established ERD reactive zone continues to migrate eastward from the existing injection trench. If additional treatment is needed east of Pecos Street to achieve closure, remediation may include the use of iron or other additives with the carbon injections. A remedial design will be determined at a later date and submitted to CDPHE for approval.

7.3 Facility Parcel

Remediation efforts on the Facility Parcel entail implementation of CMAs to address contaminant sources and associated impacts in three separate areas, the Main Source Area, the Remote Facility, and AOC 2. Proposed CMAs for each of these areas, as described in the following subsections, are intended to address soil and groundwater impacts and thereby meet regulatory closure requirements for the four SWMUs and six AOCs of ~~r~~emediation concern at the site.

7.3.1 Main Source Area

As described in Section 2.4, there are nine SWMUs currently identified as potential sources within the area designated as the Main Source Area. Subsequent evaluation of these SWMUs has determined that five have not contributed to soil and groundwater contamination at the site, including SWMU 1, SWMU 2, SWMU 4, SWMU 10, and SWMU 13. The basis for no further corrective action at these SWMUs will be discussed in Section 7.4. There are four remaining SWMUs within the Main Source Area that will require corrective action. These are: SWMU 3, SWMU 5, SWMU 11, SWMU 12, AOC 1, AOC 3, AOC 5, and AOC 6. The proposed CMA is intended to meet established CMOs for soil, LNAPL, and groundwater, and thus attain regulatory closure of the four SWMUs and six AOCs associated with Main Source Area. Once the groundwater CMOs have been met, operation of the GBS will no longer be necessary, and it can be decommissioned.

The proposed CMA, described as CMA1 in **Table 6.3**, for the Main Source Area entails small-scale excavation of source area soils, use of SVE to minimize COPC concentrations in LNAPL and unsaturated smear zone soils, and air sparging to (1) reduce COPC concentrations in LNAPL and saturated smear zone soils, and (2) actively treat COPC impacted groundwater. Small-scale excavation was the chosen corrective measure for treatment of shallower, fine grained soils because it is the most effective method at eliminating potential direct-exposure pathways for human health protection. This CMA will also mitigate residual soil impacts to the extent they no longer exacerbate groundwater concerns. The decision to implement SVE in conjunction with air sparging for this CMA is supported by favorable results from a combined AS/SVE pilot test conducted in the Main Source area (Section 5). The pilot test operated for five months, from March 2007 through August 2007; numerous soil and groundwater samples were collected throughout the study to gage the effectiveness of the technology. For groundwater and affected smear zone soils, substantial reductions were seen in COPC LNAPL, soil, and groundwater concentrations as a result of the combined AS/SVE operation. It is anticipated that AS/SVE will prove effective at mitigating COPC contributions from residual LNAPL and soil in smear zone soils. Ultimately whether or not these contributions to groundwater are sufficiently mitigated will be subject to performance monitoring assessments concurrent with implementation this CMA. In the event more aggressive corrective measures are necessary to treat both the unsaturated, and saturated smear zone impacts, this CMA can be adapted to accommodate additional corrective measures to enhance performance, most notably steam injection consistent with implementation as described by CMA2 in **Table 6.3**.

7.3.2 Remote Facility Area

As described in Section 2.4, there are four SWMUs currently identified as potential source areas within the area designated as the Remote Facility, including SWMU 6, SWMU 7, SWMU 8, and SWMU 9. Subsequent evaluation of these SWMUs has determined that they either have not contributed, or are no longer contributing, to soil and groundwater contamination concerns at the site. The exception is SWMU 9 where a single historical soil sample detected benzo(a)pyrene at the HBRG limit. Additional investigation of this benzo(a)pyrene detection is warranted and possibly remediation by small scale excavation depending on the results of additional investigation. The basis for no further corrective action at the other three SWMUs will be discussed in Section 7.4. Residual source contributions from the Remote Facility areas are contributing factors to two of the six AOCs, including AOC 3 and AOC 4. The proposed CMA is intended to meet established CMOs for soil and groundwater, and thus attain regulatory closure of the two AOCs associated with Remote Facility.

The proposed CMA, described as CMA1 in **Table 6.4**, for the Remote Facility area entails small-scale excavation of source area soils, if necessary, following building demolition, coupled with SVE. This CMA is intended to achieve the CMOs and regulatory closure objectives established for AOC 3 and AOC 4. In order to meet these objectives, this CMA will address residual soil impacts to the extent necessary to ensure residual COPC concentrations in soil are no longer contributing to groundwater concerns.

Small-scale excavation was the chosen corrective measure for treatment of shallower, fine grained soils because it is the most effective method for eliminating potential direct-exposure pathways for human health protection. This corrective measure will also remove residual soil impacts as a continuing source of groundwater concerns. SVE is the presumptive remedy for addressing residual soil impacts at depth. SVE wells and associated infrastructure are currently installed in the Remote Facility, and the SVE system is expected to reduce further COPC contaminant contributions to groundwater. At minimum, SVE is proposed for implementation as the corrective measure of choice for meeting established qualitative CMOs for soil within the Remote Facility. Although it is possible that groundwater CMOs can be met by addressing residual soil impacts through SVE alone, if this proves to be insufficient, then ARCADIS will quickly begin air sparging as a complement to SVE. AS can be readily implemented in this portion of the site in the event performance monitoring determines that implementation of SVE alone does not result in a sufficient and timely reduction of groundwater contamination (CMA2). This CMA can also be modified to implement an alternative corrective measure such as ERD (CMA3) or in situ chemical oxidation (CMA4) as described in **Table 6.4**.

7.3.3 AOC 2

AOC 2 is located in the general vicinity of the Remote Facility; however the contaminant source characteristics and resulting impacts are sufficiently different that this AOC is best handled separately. Initial screening evaluations have identified detections for benzo(a)pyrene and arsenic, chromium, and lead in soils above background, however the primary COPC for this AOC is PCBs (benzo(a)pyrene also exceeds the site HBRG in one location). The apparent source for COPCs in soils is a former oil-collection sump and an adjacent storm water discharge area. Historical investigations have not identified any resulting impact on groundwater.

Currently the preferred CMA, described as CMA1 in **Table 6.5**, for AOC 2 entails excavation of potentially affected soils. While conservative, and much more expensive to implement than competing corrective measures, this CMA is being proposed for purposes of facilitating re-development of the Facility Parcel as a whole. Current understanding of Facility Parcel redevelopment plans suggest these soils may be subject to disturbance. Excavation is presumed to be relatively more viable in the event future disturbance of affected soils can be anticipated, such as utility installation, etc. That being the case, excavation, while more costly, will mitigate potential exposures

7.4 No Further Action Basis for Remaining SWMUs

ARCADIS has determined that eight of the 13 SWMUs previously identified as potential source areas either have not contributed, or are no longer significantly contributing, to environmental impacts at the site. As such, no further corrective action is anticipated for five of the SWMUs located within the Main Source Area, and three SWMUs located in the vicinity of the Remote Facility. A brief description of the regulatory closure basis for each of these SWMUs is summarized below. Section 7.4.1 discusses the five SWMUs available for closure in the Main Source Area. Section 7.4.2 discusses the three SWMUs available for closure in the Remote Facility area.

7.4.1 Main Source Area SWMUs

No further corrective action is anticipated for the following Main Source Area SWMUs:

- SWMU 1

SWMU 1, Tank 6, was a 10,000-gallon steel UST used for water and waste oil storage that was closed and removed in 1992. No soil sample analytical results exceed site HBRGs and previous soil sampling appears to have been adequate to evaluate potential releases from the SWMU. There is no evidence of an impact to groundwater at this SWMU.

- SWMU 2

SWMU 2, Tank 7, was a 2,000-gallon reinforced fiberglass UST used for water and waste oil storage that was closed and removed in 1987. No soil sample analytical results exceed site HBRGs and previous soil sampling appears to have been adequate to evaluate potential releases from the SWMU. There is no evidence of an impact to groundwater at this SWMU.

SWMU 4, Tank 9, was a 2,000-gallon steel UST used for water and waste oil storage that was closed and removed in 1987. No soil sample analytical results exceed site HBRGs and previous soil sampling appears to have been adequate to evaluate potential releases from the SWMU. There is no evidence of an impact to groundwater at this SWMU.

- SWMU 10

SWMU 10, the Former Used Oil Drum Storage Area, was a gravel pad used to temporarily store used oil in 55-gallon drums during the early to mid 1980s. No soil sample analytical results exceed site HBRGs and previous sampling appears to have been adequate to evaluate potential releases from the SWMU. There is no evidence of an impact to groundwater at this SWMU.

- SWMU 13

SWMU 13, the Chip Bin Containment Area, was a bermed asphalt pad used to temporarily store metal chips and scrap metal in open-top metal storage bins prior to off-site recycling. No soil sample analytical results exceed site HBRGs and previous soil sampling appears to have been adequate to evaluate potential releases from the SWMU. Although contaminated groundwater exists beneath this SWMU, the contaminant sources appear to be releases from other SWMUs and AOCs located to the west (upgradient) and there is no evidence of an impact to groundwater at this SWMU 13.

7.4.2 Remote Facility SWMUs

No further corrective action is anticipated for the following Remote Facility Area SWMUs:

- SWMU 6

SWMU 6, the Closed TSD was a hazardous waste storage and treatment area used to temporarily store and treat RCRA hazardous plating waste. SWMU 6 received a clean closure certification approval from USEPA Region 8 in August 1984. Soil sampling was completed to document clean closure in 1983 and no additional investigation of the SWMU was subsequently implemented. There does not appear to be any concern that the closure investigation was inadequate or that the previous clean closure certification was inappropriate.

- SWMU 7

SWMU 7, the 90-day RCRA Storage Area, includes a concrete-bermed area inside a building and adjacent outside concrete pad. The enclosed concrete-bermed area was used for the 90-day storage of hazardous waste contained in 55-gallon drums while the outside pad was used to temporarily store used oil in 55-gallon drums. No soil sample analytical results exceed site HBRGs and previous soil sampling appears to have been adequate to evaluate potential releases from the SWMU. Although contaminated groundwater exists beneath a portion of this SWMU, the contaminant source appears to be releases associated with AOC 4 located to the west (upgradient) and there is no evidence of an impact to groundwater at this SWMU 7.

- SWMU 8

SWMU 8, the Former Slit Trench, was an earthen trench used for the placement of plating waste sludge generated from SWMU 6 between 1973 and 1975. An estimated 470 cubic yards of contaminated soil and sludge were excavated and removed from the trench in 1984. Subsequent soil sampling investigations have not detected contaminant concentrations exceeding site HBRGs and these investigations appear to have been adequate to evaluate any potential contamination remaining at the SWMU. Low concentrations of TCE in groundwater, probably below MCLs, may occur beneath SWMU 8, but the source of TCE contamination appears to be west (upgradient) of SWMU 8. Throughout this relatively small plume, TCE concentrations are well below site HBRGs and the plume dissipates to concentrations below MCLs upgradient of the Facility Parcel eastern boundary.

8.0 Corrective Action Implementation

The previous section of this CMWP identified the Corrective Measure Alternatives (CMAs) proposed by ARCADIS for meeting CMOs across the site. This section summarizes how these CMAs will be implemented in the Perl Mack Neighborhood, the Vacant Parcel, and the three specific areas of the Facility Parcel. Collectively, the proposed CMAs share many similarities and as such, implementation methods will be similar. Generally speaking, corrective action implementation site wide will entail (1) limited excavation of soils in former source areas on the Facility Parcel in order to meet risk-based direct-exposure criteria and to mitigate potential for further impact of groundwater, (2) SVE to treat impacted soils at depth to the extent necessary to prevent further impact of groundwater, and (3) implementation of corrective measures to enhance groundwater as necessary.

Corrective measures vary depending on site proximity and relative implementation concerns. All proposed corrective actions presume ongoing operation of existing mitigation systems - including operation of the barrier systems along the eastern Facility Parcel boundary, and operation of the Seeps Water Collection System - until such time CMOs have been met. Corrective action implementation in the Perl Mack Neighborhood and the Vacant Parcel is described in Section 8.1 and Section 8.2, respectively. Corrective action implementation in the three areas of the Facility Parcel is described in Section 8.3.

Following CDPHE approval of the proposed corrective actions, ARCADIS will prepare implementation work plans for submittal to CDPHE that will summarize system specifications, corrective action implementation, performance monitoring, and assessment objectives for purposes of ensuring CMOs are met. These implementation work plans are described in Section 8.4.

8.1 Perl Mack Neighborhood

The proposed Corrective Action for the Perl Mack neighborhood will entail implementation of SVE and AS. Preliminary implementation of this alternative is currently underway. In addition, upgrades to the existing GBS are currently under evaluation to ensure that contaminated groundwater is not escaping the system and re-contaminating the neighborhood.

The SVE corrective measure will be implemented as a part of ongoing operation of the VBS interim measure on the Facility Parcel. Modification of the existing VBS for purposes of enhancing COPC mass removal from soils beneath the Perl Mack Neighborhood is currently underway. SVE implementation consists of installation of additional wells, located, designed, and constructed to optimize mass removal and extend the area of SVE influence eastward beneath the Perl Mack Neighborhood. The results of these efforts will be assessed in the short-term through monitoring of groundwater and extracted vapors. Pending evaluation of groundwater conditions, further expansion of SVE to other areas of the Perl Mack Neighborhood will be considered. ARCADIS previously installed additional SVE wells and conveyance piping along Jordan Avenue.

The AS corrective measure will entail installation of AS wells along Zuni Street as the beginning of a phased implementation, depending on the success of GBS enhancements and SVE-only operation. Groundwater conditions will continue to be monitored using existing monitoring wells. Descriptions of groundwater performance monitoring wells, monitoring parameters, and monitoring frequency will be included in a implementation work plan. Performance monitoring and assessment objectives will be developed for purposes of ensuring that AS meets groundwater CMOs. Assessment criteria will be established for purposes of triggering implementation of expanded operations or an alternate groundwater corrective measure, such as resuming ERD injections, in the event performance monitoring determines AS is insufficient for meeting groundwater CMOs.

In summary, the step-wise approach to remediating the Perl Mack Neighborhood will involve (1) enhancements to the GBS to better capture site groundwater, (2) use of SVE, (3) use of AS if determined that residual mass is present, and (4) possible use of low-concentration ERD injections, if appropriate and necessary.

8.2 Vacant Parcel Area

The proposed Corrective Action for the Vacant Parcel will entail continued implementation of ERD in the context of recent interim measure GBS enhancements.

As described in Section 2.7.1, ARCADIS recently installed four additional groundwater extraction wells for to enhance groundwater capture at the southern portion of the GBS. Post-enhancement GBS performance monitoring has determined these additional wells are effective at preventing further migration of aqueous phase COPCs from the Remote Facility to groundwater beneath the Vacant Parcel.

The ERD corrective measure will entail continued operation of the existing system and monitoring groundwater conditions using existing monitoring wells. Groundwater performance monitoring wells, monitoring parameters, and monitoring frequency will be described in the subsequently prepared implementation work plan. Performance monitoring and assessment objectives will be developed for purposes of ensuring groundwater CMOs are attainable using ERD. Assessment criteria will be established for purposes of (1) modifying ERD operations, (2) determine if expansion of the ERD system is appropriate, and/or (3) triggering implementation of an alternate groundwater corrective measure in the event performance monitoring determines the current ERD system configuration is insufficient for meeting groundwater CMOs in all areas of the Vacant Parcel in a timely manner.

8.3 Facility Parcel

Corrective Action at the Facility Parcel will consist of the proposed CMAs for the Main Source Area, the Remote Facility, and AOC 2. Collectively, corrective action in these three areas will address remediation of COPC releases to soil and groundwater attributed to five of the 13 SWMUs and all previously identified AOCs on the Facility Parcel. ARCADIS has determined that no further corrective action is necessary for eight of the SWMUs at the site. Section 7 described the basis for these no further action determinations. ARCADIS assumes that CDPHE to approve closure of these SWMUs upon approval of this CMWP. Corrective Action implementation on the Facility Parcel is further described below, in context of the Main Source Area, the Remote Facility, and AOC 2.

8.3.1 Main Source Area

The proposed Corrective Action for the Main Source Area will involve source area excavation (if necessary) following building demolition and AS/SVE implementation. Preliminary implementation of this alternative is currently underway.

Source area excavation with either off-site disposal or on-site treatment will be used to mitigate further transport of COPCs to groundwater. This corrective measure will be implemented concurrent with building demolition and will adhere to objectives and decision criteria that will be established by a separate Interim Corrective Measure Work Plan. This plan will detail soil sampling methodology and assessment criteria that will be used to assess performance and verify that both quantitative and qualitative soil CMOs are met. Building demolition will soon commence at the site before this CMWP is reviewed and approved by CDPHE. The Interim Corrective Measure Work Plan is necessary to guide the evaluation and management of contaminated soil that may be most easily accessed as buildings are demolished and before backfilling and final grading of the site is completed.

The SVE corrective measure will be implemented through ongoing operation of the VBS interim measure on the Facility Parcel boundary, and through installation of additional SVE systems designed to treat affected soils at depth throughout the entire Main Source Area. Design and installation of the additional SVE systems is currently underway and ARCADIS anticipates phased implementation in context of building demolition. Initial SVE expansion will occur in areas requiring minimal demolition activity. Subsequent SVE expansion phases will address areas presently occupied by buildings subject to decommissioning and demolition activity. Performance monitoring of the SVE corrective measure will include evaluation of SVE emissions, mass removal rates, the extent of vacuum and flow propagation, and operational data useful for optimizing technology performance.

The need for supplemental treatment of residual LNAPL as well as groundwater is anticipated. Based largely on favorable performance observations from the combined SVE/AS pilot test (Section 5.2.2), air sparging is proposed as the corrective measure of choice for enhancing SVE treatment and treating saturated smear-zone impacts and groundwater. Similar to SVE, AS will be implemented in a phased manner. The initial AS implementation phase will entail installation of AS injection wells and associated infrastructure in the immediate vicinity of SWMU 3 and AOC 1. Additional AS systems will be installed in any adjacent comparably affected areas of the Main Source Area as building demolition allows. Subsequent AS implementation phases will focus on installation of additional AS systems in areas having lesser impacts (i.e., relatively lower LNAPL saturations and relatively lower COPC concentrations) to the extent necessary that all soil, LNAPL, and groundwater CMOs for the Main Source Area are effectively met. Performance of the AS corrective measure will be monitored by evaluating biodegradation, groundwater quality, enhanced SVE mass removal rates, groundwater elevation fluctuations, injection flow rates and pressures, and operational data useful for optimizing technology performance. An implementation work plan will be prepared summarizing design criteria and detailing performance monitoring objectives as well as assessment criteria for purposes of triggering implementation of alternate groundwater corrective measures in the event performance monitoring determines AS is insufficient for meeting groundwater CMOs.

8.3.2 Remote Facility Area

The proposed Corrective Action for the Remote Facility will entail, at a minimum, source area excavation, if contaminated soil is uncovered during building demolition activities and if warranted based on additional investigation of SWMU 9, and SVE with contingent implementation of air sparging, ISCO, or ERD as warranted. Preliminary implementation of this alternative is currently underway.

As described in Section 2.6.1.2, the suspected TCE and PCE source areas in the Remote Facility have not been clearly defined, rather these source areas have been inferred based on COPC distribution in groundwater. In the case of the PCE source area, it is reasonable to expect source area soils may be identified during demolition of the Remote Facility buildings. The soil excavation corrective measure for the Remote Facility is expected to consider on-site treatment, and/or off-site disposal for purposes of (1) managing potential risk-based exposure concerns, and (2) mitigating further dissolution of COPCs to groundwater. This corrective measure will be implemented concurrent with building demolition. Excavation, management, dust control, treatment, and off-site disposal will adhere to objectives and decision criteria that will be established in the Interim Corrective Measure Work Plan. This plan will also detail soil sampling methodology and assessment criteria that will be used to assess performance and verify that both quantitative and qualitative soil CMOs are met.

The SVE corrective measure will be implemented as a result of (1) ongoing operation of the VBS interim measure on the Facility Parcel boundary, and (2) through installation of additional SVE systems in presumed PCE and TCE source areas of the Remote Facility. Concurrent with GBS enhancement efforts at the end of 2006, ARCADIS installed multi-phase extraction wells for the added purpose of extending the VBS to match the southern reaches of the GBS. These additional wells were designed, and constructed with the intention of maximizing mass removal in the vicinity of the TCE source area. Additional SVE systems have been installed upgradient of the VBS, to expand SVE treatment westward and encompass the TCE and PCE source areas. The expanded SVE systems in the Remote Facility became fully operational in November of 2007.

In the event implementation of additional groundwater corrective measures is necessary, ARCADIS will install AS systems for purposes of enhancing physical removal of COPCs from groundwater. At a minimum, the initial AS implementation phase will entail installation of one or more sparge-curtains, consisting of vertical injection wells oriented perpendicular to groundwater flow. Additional clusters of AS wells may be installed in the vicinity of the source areas to enhance desorption and volatilization of residual smear-zone impacts below the water table. Additional AS systems will be installed to target treatment of aqueous phase COPCs downgradient of source areas to the extent necessary that all soil and groundwater CMOs for the Remote Facility are effectively met in a timely manner. Performance monitoring of the AS corrective measure will primarily entail evaluation of enhanced SVE mass removal rates, groundwater elevation fluctuations, air injection flow rates and pressures, and operational data useful for optimizing technology performance. Implementation of the AS alternative will be described, as necessary, in subsequent addendums to the Long-Term SVE Work Plan (ARCADIS 2007e).

Alternately, ERD will be considered in lieu of AS, in the event subsequent design considerations determine (1) ERD is more cost effective, and (2) implementation of ERD is more consistent with implementation of corrective measures implemented on the downgradient Vacant Parcel. Finally, ISCO may also be considered for purposes of enhancing groundwater treatment to more effectively meet the established CMOs for groundwater. In the event ISCO is used, ARCADIS foresees this as a polishing step, most likely implemented in potentially problematic areas of the Remote Facility, subsequent to AS treatment efforts. Implementation of the ERD or ISCO alternatives, if necessary, will be described in a subsequent addendum to the Long-Term SVE Work Plan (ARCADIS 2007e). .

8.3.3 AOC 2

The proposed Corrective Action for AOC 2 (located south of the Remote Facility Area) will entail excavation of affected soils to the extent necessary to manage potential risk-based exposure concerns from near-surface soils. This corrective measure will likely be implemented concurrent with source area excavation of soils elsewhere in the Remote Facility. Excavation, management, dust control, and off-site disposal will adhere to objectives and decision criteria that will be established by a separate implementation work plan. This plan will also detail soil sampling methodology and assessment criteria that will be used to assess performance and verify that quantitative soil CMOs are met.

8.4 Implementation Work Plans

Following CDPHE approval of this CMWP, ARCADIS will prepare implementation work plans for purposes of (1) summarizing design criteria, (2) ensuring effective implementation of these corrective actions, and (3) ensuring all CMOs are met. An Interim Corrective Measure Work Plan will be developed to describe procedures for managing contaminated soil uncovered during building demolition activities or any other potentially contaminated soil requiring remediation, such as at SWMU 9. In general, these plans will include:

- Descriptions of how corrective actions are intended to meet area specific corrective measure implementation objectives; and
- Discussion of performance criteria used to assess interim performance and attainment of CMOs.

The Interim Corrective Measure Work Plan will describe:

- Anticipated methodology for managing excavated soils;
- Proposed treatment methods;

- Decision processes that will be used to make transportation and off-site disposal determinations;
- Soil sampling methodology;
- Dust control procedures; and
- Assessment criteria to determine when both qualitative and quantitative soil CMOs have been met.

The implementation work plans will summarize the corrective measure design basis and applicable design criteria for purposes of ensuring (1) application is consistent with this CMWP, and (2) implementation adheres to any applicable, or relevant and appropriate CDPHE requirements. The work plans will also describe any necessary periodic reporting on corrective action performance and any documentation necessary to facilitate no further action determinations by CDPHE. Finally, the implementation work plans will describe performance monitoring activities including:

- Which monitoring wells will be used for performance monitoring purposes;
- Description of monitoring parameters in context of the applied corrective measure;
- Groundwater sampling methodology;
- Anticipated monitoring frequency;
- Assessment criteria for purposes of triggering implementation of alternate groundwater corrective measures; and
- Assessment criteria for purposes of determining when groundwater CMOs have been met.

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Tables

Table 2-1. Proposed Receptor-Specific Exposure Parameters, Hamilton Sundstrand Facility, Denver, Colorado.

			High-Use Recreational User						Average-Use Recreational User						Maintenance		Construction	
Parameter	**Symbol**	**units**	**Child**		**Youth**		**Adult**		**Child**		**Youth**		**Adult**		**Worker**		**Worker**	
General Factors																		
Averaging Time (cancer)	ATc	days	25,550	[a]	25,550	[a]	25,550	[a]	25,550	[a]	25,550	[a]	25,550	[a]	25,550	[a]	25,550	[a]
Averaging Time (noncancer)	ATnc	days	2,190	[a]	3,650	[a]	10,950	[a]	2,190	[a]	2,190	[a]	10,950	[a]	9,125	[a]	42	[a]
Body Weight	BW	kg	15	[e]	45	[e]	70	[b,c]	15	[e]	45	[e]	70	[b,c]	70	[b,c]	70	[b,c]
Exposure Frequency	EF	days/year	100	[h]	130	[g]	100	[h]	12	[j]	50	[i]	12	[j]	250	[b,c]	30	[k]
Exposure Duration	ED	years	6	[b,c]	10	[g]	30	[b,c]	6	[b,c]	6	[i]	30	[b,c]	25	[b,c]	1	[k]
Groundwater - Inhalation of Volatiles																		
Breathing Rate	BRgw	m^3/day	—		—		—		—		—		—		—		20	[b,c]
Soil - Ingestion (Oral)																		
Incidental Soil Ingestion Rate	IRs	mg/day	200	[c,f]	200	[c,f]	100	[c]	200	[c,f]	100	[c,f]	50	[c]	50	[c]	330	[f]
Fraction Ingested from Souce	FI	unitless	1		1		1		1		1		1		1		1	
Soil - Dermal Contact																		
Exposed Skin Surface Area	SSAs	cm^2	2,800	[d,f]	4,800	[L]	5,700	[d,f]	2,800	[d,f]	4,800	[L]	5,700	[d]	3,300	[d]	3,300	[f]
Soil-to-Skin Adherence Rate	SAR	mg/cm^2/day	0.2	[d,f]	0.2	[d,f]	0.07	[d,f]	0.2	[d,f]	0.2	[d,f]	0.07	[d]	0.2	[d]	0.3	[f]
Soil - Inhalation of Dust and Vapor																		
Breathing Rate	BRs	m^3/day	8	[n]	14	[m]	20	[c]	8	[n]	14	[m]	20	[c]	20	[b,c]	20	[b,c]

[a] The averaging time for cancer risk is the expected lifespan of 70 years expressed in days.
The averaging time for non-cancer hazard is the total exposure duration expressed in days.

[b] USEPA (1989).

[c] USEPA (1991).

[d] USEPA (2004).

[e] USEPA (1997).

[f] USEPA (2002)

[g] High-use recreational youth assumed to be 7 to 16 year old who accesses the site an average of 4 days/week for 33 weeks/year (i.e., 8 months: March thru October) for recreational activities.

[h] High-use recreational adult and child assumed to access the site an average of 3 days/week for 33 weeks/year (i.e., 8 months: March thru October) for recreational activities.

[i] Average-use recreational youth assumed to be a 7 to 13 year old who accesses the site 1 to 2 days a week for 33 weeks/year (i.e., 8 months: March thru October) for recreational activities.

[j] Average-use recreational adult and child assumed to access the site 1 to 2 days a month for 8 months/year for recreational activities.

[k] Exposure frequency based on a one-month construction project.

[L] Skin surface area averaged across gender for exposure while wearing a short-sleeved shirt, shorts and shoes (USEPA, 1997).

[m] Age-weighted average over gender from recommended inhalation rates of 9 -11 year olds (males 14 m^3/day; females 13 m^3/day), 12-14 year olds (males 15 m^3/day; females 12 m^3/day), and 15-18 year olds (males 17 m^3/day; females 12 m^3/day). (USEPA, 1997).

[n] Age-weighted average from recommended inhalation rates of 6.8 m^3/day, 8.3 m^3/day, and 10m^3/day for age groups of 1-2 years old, 3-5 years old, and 6-8 years old, respectively (USEPA, 1997).

cm	Centimeter.	m	Meter.
kg	Kilogram.	mg	Milligram.

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Table 2-2. Summary of Soil Health Based Remedial Goals (HBRGs) for Maintenance Worker, Construction Worker and Recreational User Exposure Scenarios, Hamilton Sundstrand Facility, Denver, Colorado.

HBRGs for Soil:

Chemical of Potential Concern	Health-Based Remedial Goals for Soil Exposure (mg/kg)[a]							
	Maintenance Worker	Construction Worker	High Use Recreational User			Average Use Recreation User		
			Child	Youth	Adult	Child	Youth	Adult
Volatile Organic Compounds								
1,1,2,2-Tetrachloroethane	1.0E+00	1.7E+02	4.1E+00	3.6E+00	1.9E+00	1.0E+01	1.7E+01	5.0E+00
1,1,2-Trichloroethane	NA	1.4E+02	NA	NA	NA	NA	NA	NA
1,1-Dichloroethene	NA	3.8E+02	NA	NA	NA	NA	NA	NA
1,2,4-Trimethylbenzene	NA	6.2E+01	NA	NA	NA	NA	NA	NA
1,3,5-Trimethylbenzene	NA	5.4E+01	NA	NA	NA	NA	NA	NA
Benzene	1.7E+00	1.2E+02	7.7E+00	6.5E+00	3.2E+00	1.9E+01	2.9E+01	8.2E+00
cis-1,2-Dichloroethene	2.0E+02	1.7E+02	2.2E+02	3.1E+02	4.5E+02	5.6E+02	8.2E+02	1.1E+03
Naphthalene	NA	1.4E+02	NA	NA	NA	NA	NA	NA
Tetrachloroethene	1.5E+00	1.2E+02	3.7E+00	4.0E+00	2.7E+00	9.2E+00	2.3E+01	7.8E+00
Trichloroethene	1.2E-01	2.2E+01	5.8E-01	4.8E-01	2.3E-01	1.5E+00	2.1E+00	5.8E-01
Xylenes, total	8.4E+02	7.2E+02	1.0E+03	1.3E+03	1.9E+03	2.5E+03	3.5E+03	4.7E+03
Semivolatile Organic Compounds								
Benzo(a)Anthracene	2.3E+00	1.8E+02	3.2E+00	3.7E+00	5.4E+00	8.0E+00	2.3E+01	2.0E+01
Benzo(a)pyrene	2.3E-01	1.8E+01	3.2E-01	3.7E-01	5.4E-01	8.0E-01	2.3E+00	2.0E+00
Benzo(b)fluoranthene	2.3E+00	1.8E+02	3.2E+00	3.7E+00	5.4E+00	8.0E+00	2.3E+01	2.0E+01
Dibenzo(a,h)anthracene	2.3E-01	1.8E+01	3.2E-01	3.7E-01	5.4E-01	8.0E-01	2.3E+00	2.0E+00
PCBs	8.3E-01	1.0E+01	1.1E+00	1.3E+00	1.9E+00	2.9E+00	8.2E+00	7.0E+00
Metals								
Arsenic	1.8E+00	8.2E+01	2.0E+00	2.6E+00	3.5E+00	4.9E+00	2.0E+01	1.6E+01
Barium	1.7E+05	5.9E+04	5.1E+04	1.1E+05	3.8E+05	1.3E+05	5.3E+05	1.5E+06
Copper	4.5E+04	1.2E+04	1.1E+04	2.5E+04	1.0E+05	2.7E+04	1.3E+05	5.1E+05

[a] Minimum of the HBRGC for Cancer Effects and HBRGNC for Non-Cancer Effects.

mg/kg - Milligrams per kilogram.

PCBs - Polychlorinated Biphenyls.

NA - Not applicable because the maximum detected concentration for the soil depth of concern (i.e., 0-2 or 0-0.5 ft bgs) is less than the screening level.

Table 2-3. Summary of Preliminary Groundwater Health Based Remedial Goals (HBRGs) for Maintenance Worker, Construction Worker and Recreational User Exposure Scenarios, UTC Hamilton Sundstrand Facility, Denver, Colorado.

	Health-Based Remedial Goals for Groundwater Exposure (mg/L)[a] [b]								
Chemical	Maintenance Worker	Construction Worker	High Use Recreational User			Average Use Recreation User			Federal MCL
			Child	Youth	Adult	Child	Youth	Adult	
Volatile Organic Compounds									
1,1-Dichloroethane	2.0E+04	4.7E+03	2.4E+04	3.2E+04	4.6E+04	6.1E+04	8.4E+04	1.1E+05	-
1,1-Dichloroethene	1.6E+03	3.4E+01	2.0E+03	2.6E+03	3.6E+03	4.9E+03	6.7E+03	9.1E+03	7.0E-03
cis-1,2-Dichloroethene	2.0E+03	4.7E+01	2.4E+03	3.1E+03	4.5E+03	6.0E+03	8.2E+03	1.1E+04	7.0E-02
Tetrachloroethene	6.8E+00	1.1E+01	3.4E+01	2.7E+01	1.3E+01	8.5E+01	1.2E+02	3.2E+01	5.0E-03
1,1,1-Trichloroethane	7.0E+04	1.5E+03	8.4E+04	1.1E+05	1.6E+05	2.1E+05	2.9E+05	3.9E+05	2.0E-01
1,1,2-Trichloroethane	3.9E+01	7.9E+01	1.9E+02	1.5E+02	7.3E+01	4.9E+02	6.7E+02	1.8E+02	5.0E-03
Trichloroethene	5.8E-01	2.7E+00	2.9E+00	2.3E+00	1.1E+00	7.3E+00	9.9E+00	2.7E+00	5.0E-03
1,1,2,2-Tetrachloroethane	2.9E+01	1.7E+02	1.5E+02	1.2E+02	5.5E+01	3.7E+02	5.0E+02	1.4E+02	-
1,2,4-Trichlorobenzene	1.2E+03	3.3E+01	1.5E+03	2.0E+03	2.8E+03	3.8E+03	5.2E+03	7.0E+03	7.0E-02
1,2,4-Trimethylbenzene	2.7E+02	6.0E+00	3.2E+02	4.3E+02	6.0E+02	8.1E+02	1.1E+03	1.5E+03	-
1,2-Dichloroethane	1.4E+01	1.6E+01	7.1E+01	5.6E+01	2.6E+01	1.8E+02	2.4E+02	6.6E+01	5.0E-03
1,3,5-Trimethylbenzene	2.0E+02	4.5E+00	2.5E+02	3.2E+02	4.6E+02	6.1E+02	8.4E+02	1.1E+03	-
1,4-Dioxane	4.3E+03	1.5E+04	2.2E+04	1.7E+04	8.1E+03	5.4E+04	7.4E+04	2.0E+04	-
2-Butanone (MEK)	2.3E+06	8.8E+04	2.8E+06	3.7E+06	5.3E+06	7.0E+06	9.7E+06	1.3E+07	-
Benzene	1.3E+01	2.5E+01	6.6E+01	5.2E+01	2.4E+01	1.6E+02	2.2E+02	6.1E+01	5.0E-03
Bromodichloromethane	3.8E+01	2.2E+02	1.9E+02	1.5E+02	7.2E+01	4.8E+02	6.6E+02	1.8E+02	-
Bromomethane	1.9E+02	4.4E+00	2.3E+02	3.1E+02	4.3E+02	5.8E+02	7.9E+02	1.1E+03	-
Carbon tetrachloride	1.7E+00	7.5E+00	8.3E+00	6.6E+00	3.1E+00	2.1E+01	2.9E+01	7.8E+00	5.0E-03
Chloroethane	2.2E+01	9.7E+01	1.1E+02	8.5E+01	4.0E+01	2.7E+02	3.7E+02	1.0E+02	-
Chloroform	5.5E+00	2.8E+01	2.8E+01	2.2E+01	1.0E+01	6.9E+01	9.5E+01	2.6E+01	-
Ethyl methacrylate	2.8E+02	5.8E+00	3.4E+02	4.4E+02	6.3E+02	8.4E+02	1.2E+03	1.6E+03	-
Ethylbenzene	3.1E+04	6.9E+02	3.7E+04	4.9E+04	7.0E+04	9.3E+04	1.3E+05	1.7E+05	7.0E-01
Isobutyl alcohol	5.6E+06	4.1E+05	6.7E+06	8.9E+06	1.3E+07	1.7E+07	2.3E+07	3.1E+07	-
Methyl tert-Butyl Ether	3.5E+03	2.0E+04	1.7E+04	1.4E+04	6.5E+03	4.4E+04	6.0E+04	1.6E+04	-
Methylene chloride	4.6E+02	2.4E+03	2.3E+03	1.8E+03	8.6E+02	5.7E+03	7.9E+03	2.1E+03	-
Naphthalene	1.7E+03	4.2E+01	2.1E+03	2.7E+03	3.8E+03	5.1E+03	7.1E+03	9.6E+03	-
n-Butylbenzene	2.6E+03	5.7E+01	3.2E+03	4.2E+03	6.0E+03	8.0E+03	1.1E+04	1.5E+04	-
n-Propylbenzene	2.6E+03	5.7E+01	3.2E+03	4.2E+03	6.0E+03	8.0E+03	1.1E+04	1.5E+04	-
sec-Butylbenzene	1.9E+03	3.9E+01	2.3E+03	3.0E+03	4.2E+03	5.7E+03	7.8E+03	1.1E+04	-
Styrene	8.7E+04	6.0E+03	1.0E+05	1.4E+05	2.0E+05	2.6E+05	3.6E+05	4.9E+05	1.0E-01
Tetrahydrofuran	2.4E+03	1.8E+04	1.2E+04	9.6E+03	4.5E+03	3.0E+04	4.2E+04	1.1E+04	-
Toluene	1.6E+05	3.5E+03	1.9E+05	2.5E+05	3.5E+05	4.7E+05	6.5E+05	8.8E+05	1.0E+00
trans-1,2-Dichloroethene	1.6E+03	3.6E+01	1.9E+03	2.5E+03	3.6E+03	4.8E+03	6.6E+03	9.0E+03	1.0E-01
Vinyl chloride	2.1E+00	9.4E+00	1.1E+01	8.4E+00	4.0E+00	2.7E+01	3.7E+01	9.9E+00	2.0E-03
Xylenes, total	3.8E+03	7.7E+01	4.6E+03	6.0E+03	8.6E+03	1.1E+04	1.6E+04	2.1E+04	1.0E+01

[a] Minimum of the HBRGC for Cancer Effects and HBRGNC for Non-Cancer Effects.

[b] Calculated using volatilization factor (VF) for vapor migration from groundwater to outdoor (ambient) air for the maintenance worker and recreational user and a VF for vapor migration from groundwater to a construction trench for the construction worker.

MCL - Maximum Contaminant Level

- Denotes no MCL established for compound

Table 4.1- Technology Screening, Perl Mack Neighborhood, UTC Hamilton Sundstrand Facility, Denver, Colorado.

Corrective Measure	Media		Media Applicability	Effectiveness	Implementability	Relative Cost	References
	Ground-water	Soil					
Monitored Natural Attenuation (MNA)	X		MNA was considered for GW with the expectation that following optimization of the existing GBS, additional COPC mass contributions from the upgradient source areas would no longer be able to affect groundwater under the neighborhood. Assuming there are no contributions to GW impacts from residual contamination in saturated soils beneath the neighborhood, the small area of dissolved COPCs would naturally attenuate.	MODERATE Relatively effective assuming little or no residual contamination in saturated zone soils; main driver is schedule.	HIGH Easily implemented. Performance monitoring would be required to assess the efficiency of the natural biodegradation in the subsurface. Suggested four consecutive quarters of sampling and then re-assess the corrective measure.	LOW Low cost associated with this technology.	▪United States Environmental Protection Agency (USEPA). 2004. Performance Monitoring of MNA Remedies for VOCs in Ground Water. National Risk Management Research Center, Cincinnati, OH. April.
Air Sparging (AS) with Soil Vapor Extraction (SVE)	X	X	The AS system injects ambient air into the saturated reaches of the aquifer. The injected air volatilizes and flushes the volatile and semi-volatile COPCs from the groundwater into the unsaturated zone, where they are extracted by the SVE system. AS would occur in the area directly west of the eastern Facility Parcel boundary where residual contamination may be present, and the placement of SVE wells would extend farther east into the neighborhood.	HIGH Is an effective technology assuming well installations can target affected areas of concern. Indoor air considerations must be taken into account under the neighborhood.	MODERATE Proper well spacing may become a concern if it turns out there is significant sorbed mass in saturated soils beyond Zuni St.	MODERATE Additional infrastructure is required.	▪ Suthersan, S.S. Ph.D., and Payne, F.C. PhD. 2004. In Situ Remediation Engineering. CRC Press, LLC. Boca Raton, Florida.
In-Situ Enhanced Reductive Dechlorination (ERD)	X		ERD consists of injecting a carbohydrate solution into the subsurface to provide a food source for the indigenous bacteria within the subsurface. Through the bacteria's natural respiration process, an anaerobic reducing environment is created and the contaminants are dechlorinated.	HIGH Proven effective in remediating chlorinated volatile organic compounds (CVOCs).	HIGH ERD infrastructure is already installed; however, a significant amount of TOC would need to be injected in order to dechlorinate all COPCs. The large volume of TOC injected creates a concern over methane generation.	LOW Infrastructure already installed. Primary cost drivers are carbon ammendments and those related to operation and maintenance of the existing ERD system	▪ Suthersan, S.S. Ph.D., and Payne, F.C. PhD. 2004. *In Situ* Remediation Engineering. CRC Press, LLC. Boca Raton, Florida.
In-Situ Thermal Heating	X		This technology has been used to promote hydrolysis to remediate 1,1,1-trichloroethane (TCA). Hydrolysis is a chemical transformation in which the chlorinated compound reacts with water and a new, most often less toxic, compound is formed. By introducing heat into the reaction, the rate at which the transformation occurs is increased. This method would consist of heating water to a temperature of approximately 100 ºF and then injecting it into the subsurface.	MODERATE Hydrolysis works, but would need to heat the entire aquifer to increase the temperature enough for the reaction to take place.	LOW In order to maximize effectiveness, would need to apply high temperatures over a large distance, this creates a large power demand. Introduction and use of heat beneath residential areas presents potential health and safety concerns.	HIGH Capital costs, 6 phase heating strategy all lead to a high power investment.	▪ Suthersan, S.S. Ph.D., and Payne, F.C. PhD. 2004. *In Situ* Remediation Engineering. CRC Press, LLC. Boca Raton, Florida.
Groundwater Extraction and Treatment	X		This corrective measure would entail expansion of the existing GBS for purposes of extracting COPC impacted groundwater from beneath the entire Perl Mack Neighborhood. This would be accomplished either through installation of additional pumping wells, or conversion of the existing Phase I ERD remediation wells for groundwater extraction. Extracted water would be pumped to the existing GWTP on the Facility Parcel for ex situ treatment via air stripping, and subsequent discharge under the existing NPDES permit.	MODERATE Effectiveness depends largely on hydrogeologic variability and whether or not residual COPC mass is sorbed to saturated zone soils.	MODERATE Would need to modify existing remediation wells as well as install some additional infrastructure.	MODERATE Need new pump tied into the existing system. Capital expense will be relatively minor, but given potentially long treatment duration, O&M costs will be significant.	▪ Suthersan, S.S. 1997. Remediation Engineering: Design Concepts. CRC Press, Boca Raton, FL.
In-Situ Chemical Oxidation	X		Entails injecting sodium or potassium permanganate in the affected reaches of the aquifer, to create reactions with the COPCs, and chemically reduce them to less toxic compounds.	MODERATE Highly dependant on the ability to cost effectively deliver enough oxidant to overcome natural oxidant scavengers and contact affected media.	MODERATE Minor modifications to infrastructure are required. The effectiveness of oxidant delivery will drive cost. Exothermic reactions beneath residential areas presents potential health and safety concerns.	MODERATE May require additional installations, and chemical costs are likely significant	▪ Suthersan, S.S. Ph.D., and Payne, F.C. PhD. 2004. *In Situ* Remediation Engineering. CRC Press, LLC. Boca Raton, Florida.
Zero Valent Iron (ZVI) Permeable Reactive Barrier (PRB)	X		A ZVI-PRB is installed in the saturated subsurface perpendicular to groundwater flow direction allowing for the longest contact time. Within the ZVI reactive zone, many reactions take place that may directly or indirectly destroy contaminants. The degradation process involves abiotic reductive halogenation on the granular iron surface, with the iron acting as an electron source. The result is the transformation of halogenated VOCs to ethene, ethane, methane and the release of halide ions into solution.	HIGH Proven effectiveness in chemically reducing chlorinated hydrocarbons.	LOW Installation of multiple PRBs would likely be needed, with each requiring substantially intrusive installation work within the neighborhood.	HIGH Vendor estimate for ZVI-PRB technology at the site = $897,000. This estimate is based on cost data from other sites and current quoted prices from granular iron suppliers.	▪Environmental Technologies Inc. 2007. Letter to Kimberely Schrupp, ARCADIS. September 11, 2007.
EHC™ with ZVI	X		EHC™ is a controlled release complex organic carbon. When mixed with ZVI, EHC™ can be used to trigger both biotic and abiotic reductive dechlorination reactions. Implementation of this corrective measure is virtually identical to use of ZVI alone. Generally speaking, this corrective measure is likely more effective than ZVI alone; it is also relatively less expensive than ZVI alone.	HIGH EHC™ has a longevity of approximately 12-60 months. The Florida Dept of Environmental Protection recognizes EHC™ products as viable means by which to remediate sites in Florida.	LOW Injections are recommended in the top-down direction using an injection tip that directs the slurry horizontally. Injections are to be distributed evenly over the targeted depth interval using a vertical injection spacing of approximately 2-4 feet. EHC™ is available in solid and aqueous formulations and is manufactured according to site-specific needs and conditions.	HIGH Manufacturer's (EHC) cost = $2.00/lb; total EHC cost estimated at $95,000. Primary cost driver is the ZVI components, presumably less ZVI will be required since used with EHC.	▪Adventus Americas, Inc. 2006. EHC™ Environmental Remediation Products. [Web Page]. Located at: http://www.adventusgroup.com/products/ehc.shtml. Accessed September 7, 2007. ▪Florida Dept of Environmental Protection. 2005. Letter to Jim Mueller, Adventus Americas, Inc. September 7, 2005.
Soil Vapor Extraction / In-situ Steam Injections	X	X	Similar to AS with SVE but with the addition of heat. The steam strips the volatiles from the subsurface soils where they can then be removed by the SVE system. Addition of heat will also be effective at hydrolyzing TCA impacts in groundwater.	HIGH Proven effective technology (Terra Therm 2007).	MODERATE All SVE wells are already installed in the neighborhood, but injecting enough steam may pose a problem. Also, the steam must remain at high temperatures in order to volatilize the entire plume of contamination. Introduction and use of heat beneath residential areas presents potential health and safety concerns.	HIGH All SVE wells installed; however cost of heating steam to point where temperature will not significantly decrease through subsurface will be costly.	▪Terra Therm, Inc. 2007. Process Description (ISTD). [Web Page]. Located at: http://www.terratherm.com/technology/process.htm. Accessed: September 7, 2007.

Table 4.2 - Technology Screening, Vacant Parcel, UTC Hamilton Sundstrand Facility, Denver, Colorado.

Corrective Measure	Media		Media Applicability	Effectiveness	Implementability	Relative Cost	References
	Ground-water	Soil					
Monitored Natural Attenuation (MNA)	**X**		MNA was considered for GW with the expectation that following optimization of the existing GBS, additional COPC mass contributions from the upgradient source areas would no longer be able to affect groundwater under the Vacant Parcel. As a result, the dissolved COPC plumes would naturally attenuate.	MODERATE Relatively effective; main concern is schedule impact on residential development in the Vacant Parcel.	HIGH Easily implemented.	LOW Low cost associated with this technology.	▪United States Environmental Protection Agency (USEPA). 2004. Performance Monitoring of MNA Remedies for VOCs in Ground Water. National Risk Management Research Center, Cincinnati, OH. April.
Groundwater Extraction and Treatment	**X**		This corrective measure would entail expansion of the existing GBS for purposes of removing COPC impacted groundwater from beneath the Vacant Parcel. Demonstrated technologies and processes already in use at the site would be utilized. Air stripping has been demonstrated as an effective method of removing COPCs, and installation of additional wells is easily implemented. Implementation of this measure will begin to reduce COPC concentrations in groundwater immediately	MODERATE Effectiveness largely dictated by number of wells. Potentially effective; main concern is schedule impact on residential development in the Vacant Parcel.	LOW Would need to install significant number of wells and infrastructure to accommodate plume size. Likely to necessitate significant expansion and upgrade of above ground treatment facilities.	HIGH Significant capital costs to install systems. O&M costs are also substantially high relative to other CMs. Cost prohibitive.	▪ Suthersan, S.S. 1997. Remediation Engineering: Design Concepts. CRC Press, Boca Raton, FL.
Air Sparging (AS) with Soil Vapor Extraction (SVE)	**X**		The AS system injects ambient air into the saturated reaches of the aquifer. The injected air volatilizes and flushes the volatile and semi-volatile COPCs from the groundwater into the unsaturated zone, where they are extracted by the SVE system. For the Vacant Parcel, implementation would likely entail use of AS curtains, as opposed to complete well-to-well coverage of the entire aqueous phase COPC plumes.	HIGH Is an effective technology; however, indoor air considerations must be taken into account under the Vacant Parcel.	MODERATE Proper well spacing is a large concern for the Vacant Parcel. As a result, a significant number of AS/SVE wells would be required for this application.	HIGH Significant amount of additional infrastructure is required.	
In-Situ Enhanced Reductive Dechlorination (ERD)	**X**		ERD consists of injecting a carbohydrate solution into the subsurface to provide a food source for the indigenous bacteria within the subsurface. Through the bacteria's natural respiration process, an anaerobic reducing environment is created and the contaminants are dechlorinated.	HIGH Proven effective in remediating chlorinated volatile organic compounds (CVOCs).	HIGH Phase I structure are already installed; however, a significant amount of TOC would need to be injected in order to dechlorinate all COPCs. The large volume of TOC injected creates a concern over methane generation.	LOW Majority of infrastructure already installed. Primary cost drivers are carbon ammendments and those related to operation and maintenance of the existing ERD system	▪ Suthersan, S.S. Ph.D., and Payne, F.C. PhD. 2004. *In Situ* Remediation Engineering. CRC Press, LLC. Boca Raton, Florida.
Zero Valent Iron (ZVI) Permeable Reactive Barrier (PRB)	**X**		A ZVI-PRB is installed in the saturated subsurface perpendicular to groundwater flow direction allowing for the longest contact time. Within the ZVI reactive zone, many reactions take place that may directly or indirectly destroy contaminants. The degradation process involves abiotic reductive halogenation on the granular iron surface, with the iron acting as an electron source. The result is the transformation of halogenated VOCs to ethene, ethane, methane and the release of halide ions into solution.	HIGH Proven effectiveness in chemically reducing chlorinated hydrocarbons.	MODERATE Installation of multiple PRBs would likely be needed for full-scale application. Easier implemented on a smaller scale.	HIGH Potentially very expensive to install, depending on the number of PRBs required; significant amount of intrusive work, and significant costs associated with emplacment of ZVI.	▪Environmental Technologies Inc. 2007. Letter to Kimberely Schrupp, ARCADIS. September 11, 2007.
EHC™ with ZVI	**X**		EHC™ is a controlled release complex organic carbon. When mixed with ZVI, EHCTM can be used to trigger both biotic and abiotic reductive dechlorination reactions. Implementation of this corrective measure is virtually identical to use of ZVI alone. Generally speaking, this corrective measure is likely more effective than ZVI alone; it is also relatively less expensive than ZVI alone.	HIGH EHC™ has a longevity of approximately 12-60 months. The Florida Dept of Environmental Protection recognizes EHC™ products as viable means by which to remediate sites in Florida.	MODERATE Injections are recommended in the top-down direction using an injection tip that directs the slurry horizontally. Injections are to be distributed evenly over the targeted depth interval using a vertical injection spacing of approximately 2-4 feet. EHC™ is available in solid and aqueous formulations and is manufactured according to site-specific needs and conditions.	HIGH Similar installation costs as ZVI alone, potentially a little less.	▪Adventus Americas, Inc. 2006. EHC™ Environmental Remediation Products. [Web Page]. Located at: http://www.adventusgroup.com/products/ehc.shtml. Accessed September 7, 2007. ▪Florida Dept of Environmental Protection. 2005. Letter to Jim Mueller, Adventus Americas, Inc. September 7, 2005.

Table 4.3 - Technology Screening, Facility Parcel, UTC Hamilton Sundstrand Facility, Denver, Colorado.

Corrective Measure	Affected Media							Area and Media Applicability	Effectiveness	Implementability	Relative Cost	References
	Main Source Area				Remote Facility		AOC2					
	Groundwater	Fine Grained Soils	Coarse Grained Soils	LNAPL	Groundwater	Soils	Soils					
Monitored Natural Attenuation (MNA)	X				X			MNA was considered for GW with the expectation that it would be implemented along with CMs effective for treating COPCs in soils and LNAPL to the extent residual mass concentrations no longer impact groundwater.	MODERATE Relatively effective; main driver is schedule.	HIGH Easily implemented.	LOW Low cost associated with this groundwater technology.	•United States Environmental Protection Agency (USEPA). 2004. Performance Monitoring of MNA Remedies for VOCs in Ground Water. National Risk Management Research Center, Cincinnati, OH. April.
Air Sparging (AS) with Soil Vapor Extraction (SVE)	X		X	X	X	X		The AS system injects ambient air into the saturated reaches of the aquifer. The injected air volatilizes and flushes the volatile and semi-volatile COPCs from the groundwater into the unsaturated zone, where they are extracted by the SVE system. The addition of oxygen also enhances aerobic biodegradation of non-chlorinated contaminants that may be residing within the saturated soil pores.	HIGH Demonstrated technolgy that is well souited for the site hydrogeology. Pilot tests have demonstrated ability to reduce COPC concentrations in soil, groundwater, and LNAPL	MODERATE A large number of wells would need to be installed.	MODERATE Implementation of additional wells will increase cost.	▪ Suthersan, S.S. Ph.D., and Payne, F.C. PhD. 2004. In Situ Remediation Engineering. CRC Press, LLC. Boca Raton, Florida.
In-Situ Enhanced Reductive Dechlorination (ERD)	X				X			ERD consists of injecting a carbohydrate solution into the subsurface to provide a food source for the indigenous bacteria within the subsurface. Through the bacteria's natural respiration process, an anaerobic reducing environment is created and the contaminants are dechlorinated.	HIGH Proven effective in remediating chlorinated volatile organic compounds (CVOCs). ERD is less effective in the Main Source Area due to the presence of the petroleum-based LNAPL.	MODERATE Additional wells would need to be installed for the Remote Facility area. Potential concern with carbon loading to the GBS.	MODERATE TO HIGH For the Remote Facility area, installation and O&M costs are estimated at $100,000. Likely ineffective/cost prohibitive in Main Source Area	▪ Suthersan, S.S. Ph.D., and Payne, F.C. PhD. 2004. *In Situ* Remediation Engineering. CRC Press, LLC. Boca Raton, Florida.
Zero Valent Iron (ZVI) Permeable Reactive Barrier (PRB)	X							A ZVI-PRB is installed in the saturated subsurface perpendicular to groundwater flow direction allowing for the longest contact time. Within the ZVI reactive zone, many reactions take place that may directly or indirectly destroy contaminants. The degradation process involves abiotic reductive halogenation on the granular iron surface, with the iron acting as an electron source. The result is the transformation of halogenated VOCs to ethene, ethane, methane and the release of halide ions into solution.	HIGH Proven effectiveness in chemically reducing chlorinated hydrocarbons.	MODERATE Installation of multiple PRBs would likely be needed, with each requiring substantially intrusive installation work within the Main Source Area.	HIGH Anticipated installation costs are very high, based on cost data from other sites and current quoted prices from granular iron suppliers.	•Environmental Technologies Inc. 2007. Letter to Kimberely Schrupp, ARCADIS. September 11, 2007.
Large Scale Excavation		X	X				X	For the Main Source Area, large-scale excavation as a corrective measure would entail complete excavation of all affected soil media, followed by either ex-situ treatment on site using land farming, in-situ aeration, or off-site disposal at an appropriate landfill. For AOC2, this CM would entail complete excavation of PCB impacted soils followed by off-site treatment (inceneration) and/or disposal at an appropriate facility.	HIGH Highly effective	LOW TO MODERATE Readily implemented in AOC2. More difficult to implement in the Main Source Area due to numerous concerns: air emissions, potential exposure risks, dust migration, demolition constraints	HIGH Anticipated costs are relatively high, with significant uncertainties	
Small Scale Excavation		X	X			X	X	For the Main Source Area, the small-scale excavation corrective measure would entail excavation of shallower, fine-grained soils for purposes of meeting the established soil CMOs. This corrective measure could be used at the Remote Facility if shallower, localized source areas are discovered during building demolition activities. For the AOC 2 area, the small-scale excavation corrective measure entails removal and off-site disposal of soils within a utility corridor right-of-way.	HIGH Highly effective	HIGH Shallow excavation and disposal is readily implementable. Timing is contingent on demolition schedule	MODERATE Anticipated costs are moderately high. Shallower excavations present fewer cost uncertainties than the Large Scale Excavation CM	
In-Situ Electrical Resistance Heating (ERH)	X	X	X	X				Heating of contaminated materials enhances the removal of COPCs and NAPL. By applying heat to the contaminated media, the viscosity and surface tension of NAPL is reduced, thus facilitating removal. Mass removal would occur through concurrent ERH, vapor extraction and liquids extraction. The saturated zone would need to be heated to 100ºC and the deep vadose zone would need to be heated to 80ºC.	LOW TO HIGH Effectiveness largely dependant on soil type; more effective for fine grain soils.	MODERATE TO LOW Difficulties may arise due to the temperature standards required for the measure to be effective. Pneumatic and hydraulic control would be critical when using this corrective measure to prevent the spread of contamination. More readily implemented in fine grained soil applications	HIGH Requires installation of a significant number of wells and associated treatment infrastructure	•Beyke, Gregory, P.E. 2006. Enhance Removal of Separate Phase Viscous Fuel by Electrical Resistance Heating. Thermal Remediation Service, Inc. (White Paper).
Zero Valent Iron (ZVI)/Clay Mixing		X	X					ZVI and bentonite clay would be mixed with affected soils in situ using large diameter augers. The bentonite would immobilize/stabilize any residual LNAPL, and the ZVI would treat any leachable chlorinated COPCs.	HIGH Excellent treatment for sorbed mass contamination. Good treatment in the targeted zone for residual NAPL.	MODERATE TO LOW Buildings must be demolished and utilities re-routed in treatment area. The ability to advance large-diameter augers through the coarse-grained soil presents a concern; more readily implemented in the fine grained shallow soil than at depth.	HIGH Relatively high; will depend largely on scale of application; significant cost uncertainites for full scale application	▪ Suthersan, S.S. 1997. Remediation Engineering: Design Concepts. CRC Press, Boca Raton, FL.

Table 4.3 - Technology Screening, Facility Parcel, UTC Hamilton Sundstrand Facility, Denver, Colorado.

	Affected Media											
	Main Source Area				Remote Facility		AOC2					
Corrective Measure	Groundwater	Fine Grained Soils	Coarse Grained Soils	LNAPL	Groundwater	Soils	Soils	**Area and Media Applicability**	**Effectiveness**	**Implementability**	**Relative Cost**	**References**
Soil Vapor Extraction / In-Situ Steam Injections	X		X	X				This corrective measure would entail controlled injection of steam to enhance volatilization of COPCs from LNAPL. Steam is injected into the saturated zone, similar to air sparge. The heat from the steam enhances volatilization from groundwater and any residual LNAPL within both saturated and unsaturated coarse-grained soils. Volatilized chlorinated and petroleum hydrocarbons are subsequently removed from the subsurface using SVE. Steam-enhanced SVE is being considered primarily for purposes of mitigating LNAPL; however, this corrective measure is also applicable for treating coarse grained soils and groundwater.	HIGH Highly effective, demonstrated technology.	MODERATE Requires installation of a large number of wells and associated treatment infrastructure; similar in complexity to AS/SVE	HIGH Requires significant well installation and infrastructure costs	•Terra Therm, Inc. 2007. Process Description (ISTD). [Web Page]. Located at: http://www.terratherm.com/technology/process.htm. Accessed: September 7, 2007.
Surfactant Flooding				X				Surfactant flooding includes injecting both surfactant and alcohol into the subsurface to strip and volatilize VOCs and mobilize NAPL. Injections would take place in a series of wells positioned where a sweep of the NAPL source zone would occur. The chemical flood and the solubilized or mobilized NAPL would be removed through extraction wells and the liquids would be treated on-site or disposed of off-site. Addition of alcohol may also promote biological degradation.	MODERATE Provides good enhancement for removal of residual and mobile NAPL.	MODERATE TO LOW There is potential for difficulties when treating or disposing of produced water.	HIGH Relatively high cost; requires significant injection infrastructure; treatment plant upgrades are very likely; significant uncertainty.	• Suthersan, S.S. Ph.D., and Payne, F.C. PhD. 2004. In Situ Remediation Engineering. CRC Press, LLC. Boca Raton, Florida.
In-situ Chemical Oxidation					X			Entails injecting sodium or potassium permanganate in the affected reaches of the aquifer, to create reactions with the COPCs, and chemically reduce them to less toxic compounds.	MODERATE Highly dependant on the ability to cost effectively deliver enough oxidant to overcome natural oxidant scavengers and contact affected media.	MODERATE Minor modifications to infrastructure are required. The effectiveness of oxidant delivery will drive cost.	LOW Will require additional installations (potentially significant), and chemical costs are likely significant	• Suthersan, S.S. Ph.D., and Payne, F.C. PhD. 2004. In Situ Remediation Engineering. CRC Press, LLC. Boca Raton, Florida.
Soil Vapor Extraction (SVE)						X		Removes volatiles from the vadose zone by creating a vacuum in the subsurface; volatile and some semi-volatile organic contaminants are removed. This CM is being considered for deeper Remote Facility soils, and presumes concurrent implementation of MNA, AS, ISCO, or ERD	HIGH Highly effective technology for remediating soils impacted by chlorinated VOCs, particularly in this type of geology	HIGH Long-term pilot test is currently underway. If successful, the pilot scale system can be easily upgraded for full-scale operation	LOW Full-scale operation will require additional SVE wells. Existing pilot scale equipment can accommodate full-scale scenario	• Suthersan, S.S. 1997. Remediation Engineering: Design Concepts. CRC Press, Boca Raton, FL.
No Action							X	The no action corrective measure only applies to AOC 2, and would require use of administrative and potentially engineering controls to ensure that PCB-affected soils remain undisturbed. This corrective measure would only be used if the risk evaluation provided evidence that the direct exposure human health risks are acceptable and that the leachability would not compromise groundwater.	MODERATE Relatively effective; dependant on type of controls. Physical/engineering controls are more effective than administrative controls alone.	HIGH Easily implemented.	LOW Low cost associated with this technology.	

Table 5.1 Summary of VOC Data for Vacant Parcel, UTC Hamilton Sundstrand Facility, Denver, Colorado.

Well	Sample Date	1,1,1-Trichloroethane µg/L	1,1-Dichloroethane µg/L	1,1-Dichloroethene µg/L	cis-1,2-Dichloroethene µg/L	Tetrachloroethene µg/L	Trichloroethene µg/L
Federal MCL		200		7	70	5	5
GW-43	4/17/2006	17	<1.0	1.40	3.10	**92 E**	**54**
GW-43	10/25/2006	10	<10	<10	<10	**168**	**38**
GW-43	11/1/2006	8.40	<4.0	<4.0	1.5 J	**110**	**28**
GW-43	11/14/2006	9.90	<5.0	0.79 J	2.1 J	**97**	**27**
GW-43	12/12/2006	1.7 J	5.10	0.53 J	1.8 J	**69**	**24**
GW-43	1/4/2007	0.65 J	7.80	0.75 J	2.1 J	**60**	**35**
GW-43	3/15/2007	<0.16	12	0.85 J	23	**11**	**31**
GW-43	4/9/2007	0.75 J	10	0.86 J	51	2.50	2.80
GW-43	7/9/2007	<0.16	2.70	0.25 J	30	0.83 J	0.30 J
GW-62	4/17/2006	33	<1.0	2.90	4.80	1.60	**100 E**
GW-62	10/17/2006	30	<10	<10	7	<10	**74**
GW-62	11/1/2006	11	0.52 J	1.10	3.40	0.52 J	**35**
GW-62	11/14/2006	4.5 J	<20	<20	<20	<20	**19 J**
GW-62	12/12/2006	<6.7	1.2 J	<6.7	<6.7	<6.7	**5.8 J**
GW-62	1/4/2007	<0.64	1.7 J	<0.56	0.74 J	<0.80	**10**
GW-62	1/25/2007	<1.1	4.5 J	<0.93	1.3 J	<1.3	**24**
GW-62	3/15/2007	<0.64	1.2 J	<0.56	1.7 J	<0.80	**5.2**
GW-62	4/9/2007	<1.6	<1.6	<1.4	3.7 J	<2.0	<1.6
GW-62	7/9/2007	<0.32	2.40	1.0 J	12	<0.40	**13**
MW-A	10/17/2006	20	27.00	<10	**95**	**6**	<20
MW-A	12/13/2006	<4.0	<4.0	<4.0	0.84 J	1.2 J	<4.0
MW-A	1/4/2007	<0.16	<0.16	<0.14	0.20 J	0.64 J	<0.16
MW-A	3/15/2007	<3.2	<3.2	<2.8	<3.0	<4.0	<3.2
MW-A	4/9/2007	<3.2	<3.2	<2.8	<3.0	<4.0	<3.2
MW-A	7/9/2007	<1.6	<1.6	<1.4	<1.5	<2.0	<1.6
T1P-1D	10/16/2006	<30	<10	<10	<10	**193**	**10.0**
T1P-1D	11/1/2006	2.7 J	<4.0	<4.0	1.4 J	**120**	**7.1**
T1P-1D	11/14/2006	3.0 J	<10	<10	1.6 J	**120**	**8.3 J**
T1P-1D	12/12/2006	0.90 J	1.7 J	<5.0	1.3 J	**100**	**9.5**
T1P-1D	1/4/2007	<0.64	1.9 J	<0.56	1.1 J	**82**	**11.0**
T1P-1D	3/15/2007	<0.16	2.90	0.32 J	51	**7.1**	2.80
T1P-1D	4/9/2007	<0.32	3.20	0.37 J	60	2.60	2.70
T1P-1S	10/16/2006	<30	<10	<10	<10	**135**	**9.0**
T1P-1S	11/1/2006	2.6 J	<4.0	<4.0	1.3 J	**130**	**7.2**
T1P-1S	11/14/2006	2.5 J	<5.0	<5.0	1.3 J	**110**	**8**
T1P-1S	12/12/2006	<5.0	2.5 J	<5.0	1.4 J	**110**	**11**
T1P-1S	1/4/2007	<0.64	2.0 J	<0.56	1.2 J	**83**	**11**
T1P-1S	3/15/2007	<0.32	2.40	<0.28	52	1.1 J	0.38 J
T1P-1S	4/9/2007	<0.32	3.40	0.34 J	64	3.80	1.6 J
T1P-2	10/16/2006	<30	<10	<10	<10	<10	<20
T1P-2	11/1/2006	<1.0	<1.0	<1.0	<1.0	0.36 J	0.53 J
T1P-2	11/14/2006	<1.0	<1.0	<1.0	<1.0	0.26 J	0.58 J
T1P-2	12/12/2006	<1.0	<1.0	<1.0	<1.0	0.37 J	0.53 J
T1P-2	1/4/2007	<0.16	<0.16	<0.14	<0.15	0.22 J	0.74 J
T1P-2	3/15/2007	<0.16	<0.16	<0.14	<0.15	0.25 J	0.72 J
T1P-2	4/9/2007	<0.16	<0.16	<0.14	<0.15	<0.20	0.39 J
T1P-3	10/16/2006	20	<10	<10	<10	**5**	**62**
T1P-3	1/4/2007	14	0.49 J	1.6 J	2.80	4.2	**50**
T1P-3	3/15/2007	17	0.67 J	2.10	3.50	**5.5**	**58**
T1P-3	4/9/2007	16	1.10	1.20	3.20	**7.4**	**60**
T1P-3	6/12/2007	6.2	4.60	0.96 J	2.20	**8.5**	**40**
T1P-3	7/9/2007	5.1	4.80	0.98 J	2.50	**8.6**	**36**
T1P-3	8/2/2007	2.9	3.80	0.56 J	8.10	**6.4**	**18**
T1P-3	8/29/2007	2.5	3.60	0.56 J	11	4.6	**17**
T1P-4	10/16/2006	<30	<10	<10	7	**79**	**5**
T1P-4	4/9/2007	2.6	0.77 J	0.80 J	4	**66**	**9.7**
T1P-4	6/12/2007	2.1	0.76 J	0.69 J	7.2	**28**	**8.6**
T1P-4	7/9/2007	3	1.10	0.97 J	11	**54**	**15**
T1P-4	8/2/2007	2.8	0.92 J	1.10	11	**59**	**15**
T1P-4	8/29/2007	1.8	0.95 J	0.76 J	12	**30**	**16**
T1P-5	10/16/2006	<30	<10	<10	<10	**23**	**33**
T1P-5	4/9/2007	12	0.38 J	2.10	1.50	**32**	**50**
T1P-5	8/29/2007	10	0.40 J	1.80	1.90	**26**	**45**

Notes	
Bold	Results above Colorado Basic Standards for Groundwater (BSG)
Shaded	Concentrations prior to ERD injections
µg/L	micrograms per liter
E	Concentration exceeds instrument calibration ra
J	Concentration detected above method detection limit but below contract required detection limit

Table 5.2 Summary of VOC Data for Perl Mack Neighborhood, UTC Hamilton Sundstrand Facility, Denver, Colorado.

Well	Sample Date	1,1,1-Trichloroethane µg/L	1,1-Dichloroethane µg/L	1,1-Dichloroethene µg/L	cis-1,2-Dichloroethene µg/L	Tetrachloroethene µg/L	Trichloroethene µg/L
Federal MCL		**200**		**7**	**70**	**5**	**5**
GW-63	8/17/2005	88	7	**8.6**	5.7	**12**	**12**
GW-63	4/17/2006	6.8	2.8	1.9	<1.0	1.5	<1.0
GW-63	1/25/2007	54	5.8	5.4	3.2	**7.9**	**6.1**
GW-63	2/27/2007	53	4.7	**7.3**	3.5	**7.9**	**6.4**
GW-63	4/2/2007	50	4.6	4.9	3.1	**8.3**	**6.2**
GW-63	4/27/2007	47	5	4.5	2.4	**7.4**	**5.4**
GW-63	7/3/2007	37	4.4	4.2	1.7	**5.1**	3.6
GW-63	7/24/2007	33	3.9	3.9	1.7	4.3	2.9
GW-64	8/17/2005	7.3	3.3 J	2 J	<5	1.7 J	0.95 J
GW-64	4/17/2006	130 E	8.3	**13**	10	**22**	**19**
GW-64	1/25/2007	160	11	**16**	18	**25**	**22**
GW-64	2/27/2007	**240**	14	**24**	57	**31**	**28**
GW-64	4/2/2007	180	11	**17**	32	**27**	**23**
GW-64	4/27/2007	**200**	12 J	**17 J**	30	**26**	**21**
GW-64	7/3/2007	170	10	**18**	24	**27**	**20**
GW-64	7/24/2007	**220**	13	**22**	39	**35**	**24**
PMP-1	10/13/2006	**330 M2**	15	**20**	21	**53**	**36**
PMP-1	11/14/2006	**250**	12	**13**	27	**34**	**30**
PMP-1	12/19/2006	160 E	8.4	**11**	34	**20**	**15**
PMP-1	1/25/2007	**370**	22	**13**	**120**	**27**	**29**
PMP-1	2/26/2007	**420**	25	**23**	**170**	**24**	**30**
PMP-1	4/2/2007	**450**	26	**19 J**	**140**	**36**	**34**
PMP-1	4/27/2007	**240**	13 J	**12 J**	45	**31**	**23**
PMP-1	7/3/2007	**660**	45	**26**	**230**	**31**	**32**
PMP-1	7/24/2007	**290**	19	**12**	**89**	**18**	**17**
PMP-2	10/18/2006	**330**	15	**24**	27	**47**	**33**
PMP-2	11/14/2006	**240**	11	**15**	24	**35**	**26**
PMP-2	12/19/2006	160	9.2	**9.7**	52	**15**	**14**
PMP-2	1/25/2007	**460**	27	**17 J**	**160**	**35**	**38**
PMP-2	2/26/2007	**580**	32	**33**	**220**	**32**	**39**
PMP-2	4/2/2007	**410**	25	**16 J**	**140**	**32**	**32**
PMP-2	4/27/2007	**230**	13 J	**11 J**	47	**28**	**21**
PMP-2	7/2/2007	**560**	39	**21**	**190**	**28**	**30**
PMP-2	7/24/2007	**550**	34	**20**	**190**	**24**	**25**
PMP-3	10/18/2006	**540**	33	**34**	**141**	**57**	**47**
PMP-3	11/14/2006	**490**	30	**21**	**150**	**46**	**43**
PMP-3	12/19/2006	170	15	**11**	65	**10**	**14**
PMP-3	1/25/2007	**310**	44	**11 J**	**180**	**10 J**	**24**
PMP-3	2/26/2007	120	29	**7.8**	**92**	3.5 J	**10**
PMP-3	4/2/2007	140	34	6.3	**120**	2.7 J	**9.3**
PMP-3	4/27/2007	**480**	36 J	**21 J**	**190**	**16 J**	**25 J**
PMP-3	7/2/2007	130	38	**7.2**	**120**	4.3 J	**7.4**
PMP-3	7/24/2007	45	15	2.7	51	2.2	3.6
PMP-4	10/18/2006	**1100**	129	**37**	**553**	**37**	**51**
PMP-4	1/25/2007	6.3	51	2.4	52	1.2 J	5.2
PMP-4	2/26/2007	17	31	2.9	43	1.5 J	4.1
PMP-4	4/2/2007	8.3	18	1.3	26	0.74 J	2.1
PMP-4	4/27/2007	19	13	1.4	26	0.96 J	2.6
PMP-4	7/3/2007	26	13	2.6	33	1.9	2.5
PMP-4	7/24/2007	6.3	5.2	1.1	14	0.82 J	0.98 J
PMP-5	10/18/2006	**320**	22	**25**	51	**45**	**35**
PMP-5	1/25/2007	**240**	32	**11**	**130**	**21**	**26**
PMP-5	2/26/2007	**240**	32	**15**	**120**	**15**	**23**
PMP-5	4/3/2007	**230**	26	**9.6 J**	**130**	**13**	**19**
PMP-5	4/27/2007	**250**	29	**11 J**	**120**	**10 J**	**17 J**
PMP-5	7/3/2007	**460**	42	**17 J**	**210**	**19 J**	**22**
PMP-5	7/24/2007	**320**	41	**14**	**180**	**11**	**15**
PMP-6	10/18/2006	20	10	<10	35	**11**	**<20**
PMP-6	1/25/2007	2.6	5.2	0.67 J	9.2	3	**15**
PMP-6	2/27/2007	6.9	4.9	1.7	16	3.1	**11**
PMP-6	4/2/2007	5	5.4	1.5	16	1.7	4.4
PMP-6	4/27/2007	2.1	6	1.5	16	1.1	2.4
PMP-6	7/2/2007	6.6	6.1	2.2	18	0.92 J	1.5
PMP-6	7/24/2007	7	4.8	2.6	19	0.93 J	1.2
TP-15	4/20/2006	**340**	14	**26**	22	**56**	**39**
TP-15	12/19/2006	160	8.6	**21**	10	**36**	**19**
TP-15	1/26/2007	53	3	**8.9**	3.6	**12**	**8.9**
TP-15	2/26/2007	99	5.5	**16**	6.8	**20**	**15**
TP-15	4/2/2007	130	9.3	**19**	9.8	**28**	**21**
TP-15	4/27/2007	56	6.4	**7.9**	5.2	**14**	**9.4**
TP-15	7/3/2007	120	11	**16**	12	**23**	**16**
TP-15	7/24/2007	72	11	**11**	8.1	**18**	**11**

Notes	
Bold	Results above Colorado Basic Standards for Groundwater (BSG)
Shaded	Concentrations prior to ERD injections
µg/L	micrograms per liter
E	Concentration exceeds instrument calibration r
J	Concentration detected above method detection limit but below contract required detection limit

Table 5.3 Summary of Baseline and Post-Operation Groundwater and LNAPL Analytical Data

GROUNDWATER Sample		SVE-1											
		MW-OBS-5			SWMU5-3			SWMU5-4			TP-4		
Constituent	units	Baseline '07	Post-Test	% Red. w/Base	Baseline '07	Post-Test	% Red. w/Base	Baseline '07	Post-Test	% Red. w/Base	Baseline '07	Post-Test	% Red. w/Base
1,1,1-Trichloroethane	µg/L	6,400	290	95%	1,400	470	66%	1,100	38	97%	860	260	70%
1,1-Dichloroethane	µg/L	1,300	14	99%	66	29	56%	32	1.7	95%	44	15	66%
1,1-Dichloroethene	µg/L	440	4.9	99%	170	12	93%	120	0.38	100%	140	6	96%
1,2-Dichloroethene (total)	µg/L	2,300	16	99%	280	120	57%	520	14	97%	91	33	64%
Tetrachloroethene	µg/L	51	3.3	94%	<13	<4.0	69%	11	0.28	97%	<10	<2.0	80%
Trichloroethene	µg/L	44	5.2	88%	24	8.6	64%	69	0.58	99%	31	5	84%
Total Primary CVOCs	µg/L	**10,535**	**333**	**97%**	**1,940**	**640**	**67%**	**1,852**	**55**	**97%**	**1,166**	**319**	**73%**
TPH-Diesel Range Organics	mg/L	5,300	180	97%	100	180	-80%	80	1.3	98%	15	230	-1433%
TPH-Gasoline Range Organics	mg/L	20	1.5	93%	1.8	3.4	-89%	1.7	0.18	89%	0.9	0.29	68%
TPH-Motor Oil Range Organics	mg/L	5,700	170	97%	110	180	-64%	88	1.2	99%	18	260	-1344%
Total TPH	mg/L	**11,020**	**352**	**97%**	**212**	**363**	**-72%**	**170**	**3**	**98%**	**34**	**490**	**-1346%**

LNAPL Sample		SVE 1		
		M2-OBS-5*		
Constituent	units	March '07	June '07	% Red. w/Mar
1,1,1-Trichloroethane	µg/L	2,000,000	36,000	98%
1,1-Dichloroethane	µg/L	71,000	690	99%
1,1-Dichloroethene	µg/L	94,000	1,300	99%
1,2-Dichloroethene (total)	µg/L	94,000	860	99%
Tetrachloroethene	µg/L	130,000	3,400	97%
Trichloroethene	µg/L	18,000	890	95%
Total Primary CVOCs	µg/L	**2,407,000**	**43,140**	**98%**
TPH-Diesel Range Organics	mg/kg	660,000	590,000	11%
TPH-Gasoline Range Organics	mg/kg	54,000	1,300	98%
TPH-Motor Oil Range Organics	mg/kg	5700	170	97%
Total TPH	mg/kg	**719,700**	**591,470**	**18%**

NOTES	
µg/L	microgram per liter
mg/L	milligram per liter
CVOCs	Chlorinated Volatile Organic Compounds; Analyte Grouping
TPH	Total Petroleum Hydrocarbons; Analyte Grouping
NS	No sample collected

GROUNDWATER Sample		LNAPL 5,3					
		TP-2			AOC1-3		
Constituent	units	Baseline '07	Post-Test	% Red. w/Base	Baseline '07	Post-Test	% Red. w/Base
1,1,1-Trichloroethane	µg/L	5,200	1,900	63%	65,000	26,000	60%
1,1-Dichloroethane	µg/L	110	36	67%	640	220	66%
1,1-Dichloroethene	µg/L	620	71	89%	6,800	520	92%
1,2-Dichloroethene (total)	µg/L	460	370	20%	<600	<150	75%
Tetrachloroethene	µg/L	<40	<20	50%	<800	<200	75%
Trichloroethene	µg/L	59	58	2%	<640	<160	75%
Total Primary CVOCs	µg/L	**6,449**	**2,769**	**57%**	**72,440**	**26,740**	**63%**
TPH-Diesel Range Organics	mg/L	94	100	-6%	NS	130	
TPH-Gasoline Range Organics	mg/L	6.6	2.5	62%	NS	12	
TPH-Motor Oil Range Organics	mg/L	68	66	3%	NS	37	
Total TPH	mg/L	**169**	**169**	**0%**		**179**	

Table 5.4 Summary of Baseline and Post-Operation Soil Analytical Data

SVE-1

Borehole ID		AS-2	AS-2	Percent Difference	AS-3	AS-3	Percent Difference	AS-3	AS-3	Percent Difference	AS-4	AS-4	Percent Difference	AS-4	Percent Difference	AS-5	AS-5	Percent Difference
Sample Date		Mar-07	Jun-07		Mar-07	Jun-07		Mar-07	Jun-07		Mar-07	Jun-07		Jun-07		Mar-07	Jun-07	
Sample Depth (feet bgs)		32-33	32-34		30-31	30.5-31.5		32-32.8	32.5-33.5		32.5-34.5	32-33		34-36		30-31	30-30.8	
Lithology		SW	SW		SW/SP	SW/SP		SC/SW	SC/SW		SW/GW	SC		SW		SW/SP	SW/SP	
Constituent	**Units**																	
1,1,1-Trichloroethane	µg/kg	54000	73	100%	6400	1.7	100%	15000	0.64	100%	74000	4600	94%	25	100%	11000	34	100%
1,2-Dichloroethene (total)	µg/kg	2300	<24	99%	250	<0.57	100%	2000	<0.65	100%	3400	86	97%	<23	99%	540	<23	96%
Tetrachloroethene	µg/kg	<770	<29	96%	4400	<0.6	100%	1000	<0.69	100%	370	470	-27%	<29	92%	13000	54	100%
Trichloroethene	µg/kg	<650	<25	96%	330	<0.24	100%	450	<0.27	100%	650	170	74%	<25	96%	1000	<24	98%
Total Primary CVOCs	**µg/kg**	**57720**	**151**	**100%**	**11380**	**1.7**	**100%**	**18450**	**0.64**	**100%**	**78420**	**5326**	**93%**	**25**	**100%**	**25540**	**88**	**100%**
TPH-Diesel Range Organics	mg/kg	4900	6500	-33%	4400	1.8	100%	3300	2.5	100%	4500	2600	42%	4100	9%	1400	4200	-200%
TPH-Gasoline Range Organics	mg/kg	520	110	79%	370	0.48	100%	440	<0.35	100%	1100	270	75%	60	95%	99	390	-294%
TPH-Motor Oil Range Organics	mg/kg	5500	7900	-44%	4600	<4.1	100%	3600	<4.2	100%	4900	3000	39%	4000	18%	1700	5200	-206%
Total TPH	**mg/kg**	**10920**	**14510**	**-33%**	**9370**	**2.28**	**100%**	**7340**	**2.5**	**100%**	**10500**	**5870**	**44%**	**8160**	**22%**	**3199**	**9790**	**-206%**

Borehole ID		AS-5	AS-5	Percent Difference	AS-5	AS-5	Percent Difference	AS-6	AS-6	Percent Difference	AS-6	Percent Difference	AS-7	AS-7	Percent Difference
Sample Date		Mar-07	Jun-07		Mar-07	Jun-07		Mar-07	Jun-07		Jun-07		Mar-07	Jun-07	
Sample Depth (feet bgs)		32-33.2	32.5-33.5		34-35	34.6-36		30-31	29.6-30.7		32.7-33.7		30-31	29-30	
Lithology		SW	SW/SM		SW/GW	SW		SW	SW		SW		SW	SW/SC	
Constituent	**Units**														
1,1,1-Trichloroethane	µg/kg	8400	<41	100%	59000	<21	100%	4900	570	88%	100	98%	5000	62	99%
1,2-Dichloroethene (total)	µg/kg	360	<45	88%	5500	<23	100%	150	<23	85%	<23	85%	370	<23	94%
Tetrachloroethene	µg/kg	920	<56	94%	810	<28	97%	7500	1500	80%	80	99%	5300	1200	77%
Trichloroethene	µg/kg	210	<48	77%	340	<24	93%	380	33	91%	<24	94%	1700	92	95%
Total Primary CVOCs	**µg/kg**	**9890**	**0**	**100%**	**65650**	**0**	**100%**	**12930**	**2103**	**84%**	**180**	**99%**	**12370**	**1354**	**89%**
TPH-Diesel Range Organics	mg/kg	2500	7100	-184%	20000	4300	79%	4200	8300	-98%	3700	12%	5200	5800	-12%
TPH-Gasoline Range Organics	mg/kg	430	220	49%	1500	68	95%	580	730	-26%	300	48%	390	220	44%
TPH-Motor Oil Range Organics	mg/kg	2800	8500	-204%	21000	4400	79%	4800	9700	-102%	4500	6%	5800	7300	-26%
Total TPH	**mg/kg**	**5730**	**15820**	**-176%**	**42500**	**8768**	**79%**	**9580**	**18730**	**-96%**	**8500**	**11%**	**11390**	**13320**	**-17%**

NOTES	
µg/kg	microgram per kilogram
mg/kg	milligram per kilogram
CVOCs	Chlorinated Volatile Organic Compounds; Analyte Grouping
TPH	Total Petroleum Hydrocarbons; Analyte Grouping
bgs	below ground surface
NS	Not sampled
CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays
ML	Inorganic silts, very fine sands, rock flour, silty or clayey fine sands with slight plasticity
SC	Clayey sands, sand-clay mixtures
SM	Silty sands, sand-silt mixtures
SP	Poorly-graded sands or gravelly sands, little or no fines
SW	Well-graded sand or gravelly sands, little or no fines
GW	Well-graded gravels or gravel-sand mixtures, little or no fines

Table 5.4 Summary of Baseline and Post-Operation Soil Analytical Data (con't)

SVE-1

Borehole ID		AS-7	AS-7	Percent Difference	AS-7	Percent Difference	AS-8	AS-8	Percent Difference	AS-8	AS-8	Percent Difference	AS-8	AS-8	Percent Difference
Sample Date		Mar-07	Jun-07		Jun-07		Mar-07	Jun-07		Mar-07	Jun-07		Mar-07	Jun-07	
Sample Depth (feet bgs)		34-34.8	32-33.5		35-36.2		30-31	29.5-30.5		32.5-33.5	32-33.5		34-35	35-36	
Lithology		SW	SW/SC		SW		SW/SC	SM/SW		SW	SC/SM		SW	SW	
Constituent	**Units**														
1,1,1-Trichloroethane	µg/kg	16000	36	100%	110	99%	6500	26	100%	13000	160	99%	40000	<21	100%
1,2-Dichloroethene (total)	µg/kg	880	<23	97%	<24	97%	350	<24	93%	640	<23	96%	1900	<23	99%
Tetrachloroethene	µg/kg	160	<29	82%	<29	82%	13000	110	99%	4200	34	99%	1100	<29	97%
Trichloroethene	µg/kg	190	<5	97%	<25	87%	3100	<25	99%	3600	44	99%	1500	<24	98%
Total Primary CVOCs	**µg/kg**	**17230**	**36**	**100%**	**110**	**99%**	**22950**	**136**	**99%**	**21440**	**238**	**99%**	**44500**	**0**	**100%**
TPH-Diesel Range Organics	mg/kg	2300	760	67%	2400	-4%	4200	880	79%	4800	5900	-23%	2600	2400	8%
TPH-Gasoline Range Organics	mg/kg	700	65	91%	17	98%	220	410	-86%	340	430	-26%	460	100	78%
TPH-Motor Oil Range Organics	mg/kg	2500	1000	60%	2600	-4%	4800			5400	7000	-30%	2900	2400	17%
Total TPH	**mg/kg**	**5500**	**1825**	**67%**	**5017**	**9%**	**9220**	**1290**	**86%**	**10540**	**13330**	**-26%**	**5960**	**4900**	**18%**

Borehole ID		SR-3	PVSB-3	Percent Difference	SR-3	PVSB-3	Percent Difference	SR-3	PVSB-3	Percent Difference
Sample Date		10/31/06	8/20/07		10/31/06	8/20/07		10/31/06	8/20/07	
Sample Depth (feet bgs)		24-25	22.5-23.5		30.5	30-31		35	35-36	
Lithology		SM/ML	SP/SC		SW	SW		SW	SW	
Constituent	**Units**									
1,1,1-Trichloroethane	µg/kg	2200	100	95%	6,900	100	99%	1,700	83	95%
1,2-Dichloroethene (total)	µg/kg	<4700	<23	100%	<13,000	<23	100%	<2,300	<26	99%
Tetrachloroethene	µg/kg	6800	660	90%	2,100	660	69%	2,600	50	98%
Trichloroethene	µg/kg	<4700	<24	99%	<13,000	<24	100%	<2,300	<28	99%
Total Primary CVOCs	**µg/kg**	**18400**	**807**	**96%**	**35,000**	**807**	**98%**	**8,900**	**187**	**98%**
TPH-Diesel Range Organics	mg/kg	NS	1700		NS	3,300		NS	2,600	
TPH-Gasoline Range Organics	mg/kg	NS	3400		NS	1,200		NS	200	
TPH-Motor Oil Range Organics	mg/kg	NS	370		NS	3,300		NS	3,100	
Total TPH	**mg/kg**	NS	**5470**		NS	**7,800**		NS	**5,900**	

LNAPL5,3

Borehole ID		AOC1-3	PVSB-2	Percent Difference	AOC1-3	PVSB-2	Percent Difference
Sample Date		10/14/03	6/1/07		10/14/03	8/20/07	
Sample Depth (feet bgs)		17	15.5-16.5		24	23-24	
Lithology		CL	CL/SC		SP	SW	
Constituent	**Units**						
1,1,1-Trichloroethane	µg/kg	55,000	42,000	24%	18,000	47	100%
1,2-Dichloroethene (total)	µg/kg	8.6	<130	-1412%	14	<0.43	97%
Tetrachloroethene	µg/kg	1,100	2,800	-155%	34	1	97%
Trichloroethene	µg/kg	44	160	-264%	13	<0.25	98%
Total Primary CVOCs	**µg/kg**	**56,153**	**45,090**	**20%**	**18,061**	**49**	**100%**
TPH-Diesel Range Organics	mg/kg	NS	2,500		NS	0.42	
TPH-Gasoline Range Organics	mg/kg	NS	21		NS	4.8	
TPH-Motor Oil Range Organics	mg/kg	NS	650		NS	<10	
Total TPH	**mg/kg**	NS	**3,171**		NS	**5**	

NOTES	
µg/kg	microgram per kilogram
mg/kg	milligram per kilogram
CVOCs	Chlorinated Volatile Organic Compounds; Analyte Grouping
TPH	Total Petroleum Hydrocarbons; Analyte Grouping
bgs	below ground surface
NS	Not sampled
CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean cla
ML	Inorganic silts, very fine sands, rock flour, silty or clayey fine sands with slight plasticity
SC	Clayey sands, sand-clay mixtures
SM	Silty sands, sand-silt mixtures
SP	Poorly-graded sands or gravelly sands, little or no fines
SW	Well-graded sand or gravelly sands, little or no fines
GW	Well-graded gravels or gravel-sand mixtures, little or no fines

Table 6.1 Corrective Measures Alternative Evaluation and Comparison - Perl Mack Neighborhood

CMA Evaluation Criteria	CM Alternative 1: Soil Vapor Extraction (SVE) and Air Sparging (AS)		CM Alternative 2: Soil Vapor Extraction (SVE) and In-Situ Enhanced Reductive Dechlorination (ERD)	
Minimum Criteria	**Comparative Evaluation**	**Ranking**	**Comparative Evaluation**	**Ranking**
Protection of Human Health and the Environment	Interim Measures are in place to ensure protection until such time that Perl Mack Neighborhood CMOs are attained; Considered protected once CMOs have been met for both the Perl Mack neighborhood and the Facility Parcel	High 5	Interim Measures are in place to ensure protection until such time that Perl Mack Neighborhood CMOs are attained; Considered protected once CMOs have been met for both the Perl Mack neighborhood and the Facility Parcel	High 5
Attainment of CMOs	All established CMOs for this area will be attained through implementation of this CMA.	High 5	All established CMOs for this area will be attained through implementation of this CMA.	High 5
Control of the Source of Release	There are no sources within this area. However, any residual soil and LNAPL impacts beneath the neighborhood will be addressed through SVE. Additionally, the GBS and VBS interim measures will remain in operation, mitigating potential for further impact from upgradient source areas until such time that CMOs for the Facility Parcel are met.	High 5	There are no sources within this area. However, any residual soil and LNAPL impacts beneath the neighborhood will be addressed through SVE. Additionally, the GBS and VBS interim measures will remain in operation, mitigating potential for further impact from upgradient source areas until such time that CMOs for the Facility Parcel are met.	High 5
Decision Factors	**Comparative Evaluation**	**Ranking**	**Comparative Evaluation**	**Ranking**
Long-Term Reliability and Effectiveness	Volatiles are removed from subsurface soils as well as dissolved mass in groundwater. Active treatment system O&M and monitoring will be necessary until such time that CMOs have been met. Presumably, long-term performance monitoring will not be necessary. Once CMO's have been met, natural attenuation processes will continue, and conditions will only continue to improve	High 5	Volatiles are removed from subsurface soils as well as dissolved mass in groundwater. Active treatment system O&M and monitoring will be necessary until such time that CMOs have been met. Presumably, long-term performance monitoring will not be necessary. Once CMO's have been met, natural attenuation processes will continue, and conditions will only continue to improve	High 5
Reduction in the Toxicity, Mobility, or Volume of Contamination	Contamination in soils and groundwater is volatilized and removed from the subsurface by the AS/SVE system. Primarily a physical treatment process with secondary treatment via enhanced aerobic biodegradation. Residual LNAPL mobility, contaminant concentrations, and contaminant volume is reduced.	High 5	Residual VOCs in soil vapors and sorbed to unsaturated zone soil are physically removed via the SVE system. Aqueous phase contaminant toxicity, concentrations, and volume are reduced through enhanced reductive dechlorination processes.	High 5
Short-Term Effectiveness	Short installation period required. There will be no loss of performance to existing interim measures as a result of implementation activities. Time required to meet CMOs is comparable to CMA2	High 5	Does not require any additional installations and all SVE wells/infrastructure is already installed. There will be no loss of performance to existing interim measures (i.e., GBS and VBS) as a result of implementation activities. Short-term effectiveness artificially limited by need to limit formation/accumulation of methane. Time required to meet CMOs is comparable to CMA1.	Moderately High 4
Implementability	Requires installation of AS wells and additional SVE wells and associated infrastructure/equipment. Performance monitoring requirements are likely less onerous than competing CMAs, but O&M requirements are more onerous.	Moderate 3	Can rely on existing installations and infrastructure for implementation. Will require ongoing injections through existing infrastructure, and relatively more onerous performance monitoring than CMA1. Methane accumulation concerns will likely require enhancement of existing engineering controls.	Moderately High 4
Community Acceptance	Very likely acceptable, but potential disturbance during installation may raise concerns	Moderately High 4	Most likely acceptable, but methane accumulation possibilities may raise concern (relatively more so than on the Vacant Parcel)	Moderate 3
State Acceptance	Demonstrated technologies, reasonable implementation requirements and performance expectations.	High 5	Demonstrated technologies, reasonable implementation requirements and performance expectations	Moderately High 4
Relative Cost	Requires installation of AS wells and additional SVE wells and associated infrastructure/equipment. Performance monitoring requirements are likely less onerous than CMA2. O&M costs are relatively higher than CMA2.	Moderate 3	SVE system installation needs are similar too CMA1. No further ERD system installations required. Costs associated with injecting carbohydrate are relatively higher than CMA2. Performance monitoring and minimal O&M is anticipated.	Moderately High 4
Conclusions	A very viable CMA. Likely more effective than CMA2 assuming significant amount residual source material is present in the saturated zone. Potentially more difficult and expensive CMA to implement than CMA2.	Overall 45	A very viable CMA. Need to manage/mitigate methane concerns in residential area will impact this CMA's short-term effectiveness and implementability, relative to non-residential applications. Nonetheless, because ERD infrastructure is already installed, this CMA is likely less expensive and less onerous than CMA1.	Overall 44

Table 6.2 Corrective Measures Alternative Evaluation and Comparison - Vacant Parcel

CMA Evaluation Criteria	CM Alternative 1: In-situ Enhanced Reductive Dechlorination (ERD)		CM Alternative 2: Soil Vapor Extraction (SVE) and Air Sparge (AS)	
Minimum Criteria	**Comparative Evaluation**	**Ranking**	**Comparative Evaluation**	**Ranking**
Protection of Human Health and the Environment	Interim Measures are in place to ensure protection until such time that Vacant Parcel CMOs are attained; Additionally, development plans will incorporate passive vapor barriers into construction of dwellings.	High 5	Interim Measures are in place to ensure protection until such time that Vacant Parcel CMOs are attained; Additionally, development plans will incorporate passive vapor barriers into construction of dwellings.	High 5
Attainment of CMOs	All established CMOs for this area will be attained through implementation of this CMA.	High 5	All established CMOs for this area will be attained through implementation of this CMA.	High 5
Control of the Source of Release	There are no sources within this area. The GBS and VBS interim measures will remain in operation, mitigating potential for further impact from upgradient source areas until such time that CMOs for the Facility Parcel are met.	High 5	There are no sources within this area. The GBS and VBS interim measures will remain in operation, mitigating potential for further impact from upgradient source areas until such time that CMOs for the Facility Parcel are met.	High 5
Decision Factors	**Comparative Evaluation**	**Ranking**	**Comparative Evaluation**	**Ranking**
Long-Term Reliability and Effectiveness	Active treatment system O&M and monitoring will be necessary until such time that CMOs have been met. Additional performance monitoring may be required. Once CMO's have been met, natural attenuation processes will continue, and conditions will only continue to improve	High 5	Performance monitoring will be required until such time that groundwater CMOs have been met. Once CMO's have been met, natural attenuation processes will continue, and conditions will only continue to improve.	High 5
Reduction in the Toxicity, Mobility, or Volume of Contamination	Aqueous phase contaminant toxicity, concentrations, and volume are reduced through enhanced reductive dechlorination processes. Also relies on natural attenuation processes of desorption, diffusion, and dispersion	High 5	Contamination in groundwater is volatilized and removed from the subsurface by the AS/SVE system. Primarily a physical treatment process. Contaminant concentrations, and contaminant volume is reduced. Also relies on natural attenuation processes of desorption, diffusion, and dispersion.	Moderately High 4
Short-Term Effectiveness	Interim injection infrastructure is already installed which can be utilized for the full-scale system. Time to meet CMOs is shorter than that anticipated for CMA2.	High 5	Once installed and fully operational, AS/SVE is expected to successfully meet CMOs relatively quickly. Ultimately, short-term effectiveness will depend on the scale/extent of the AS installation. Time to become fully operational is significantly greater than CMA1, which may result in a longer overall time to meet CMOs than CMA1	Moderate 3
Implementability	Interim injection infrastructure is already installed which can be utilized for the full-scale system. Will require ongoing injections through existing infrastructure. Methane accumulation is less of a concern (relative to the Perl Mack Parcel).	Moderately High 4	Would require design, installation, and operation of numerous AS and SVE wells. SVE would likely entail near-complete coverage of the aqueous phase plume, AS would be implemented through sparge curtains. Significantly greater O&M requirements than CMA1	Moderate 3
Community Acceptance	Moderately high probability of acceptance.	Moderately High 4	Moderate probability of acceptance. Requires installation of significantly more infrastructure than CMA1, which may present relatively greater impact on redevelopment activities.	Moderate 3
State Acceptance	NFA already issued, Probability of CDPHE acceptance is high.	High 5	NFA already issued, As such, probability of CDPHE acceptance is very high.	High 5
Relative Cost	No further installations anticipated. Costs associated with injecting carbohydrate are relatively lower than O&M requirements of CMA2. O&M costs anticipated to be relatively minor. Performance monitoring is anticipated.	Moderately High 4	Significantly higher capital installation and O&M costs than CMA1. Performance monitoring likely comparable to CMA1	Moderately Low 2
Conclusions	A very viable CMA. Relatively less expensive and less onerous than CMA2.	Overall 47	Potentially viable CMA. Relatively more difficult to implement and significantly more costly than CMA1.	Overall 40

Table 6.3 Corrective Measures Alternative Evaluation and Comparison - Facility Parcel, Main Source Area

CMA Evaluation Criteria	CM Alternative 1: Small-Scale Excavation, Soil Vapor Extraction (SVE) and Air Sparge (AS)		CM Alternative 2: Small-Scale Excavation and Steam-Enhanced Soil Vapor Extraction (SVE)	
Minimum Criteria	**Comparative Evaluation**	**Ranking**	**Comparative Evaluation**	**Ranking**
Protection of Human Health and the Environment	Direct exposure soil pathways are eliminated through excavation. Meeting quantitative groundwater CMOs ensures human health and the environment are adequately protected from any residual contamination. Meeting qualitative soil/LNAPL CMOs ensures long-term viability of the CMA.	High 5	Direct exposure soil pathways are eliminated through excavation. Meeting quantitative groundwater CMOs ensures human health and the environment are adequately protected from any residual contamination. Meeting qualitative soil/LNAPL CMOs ensures long-term viability of the CMA.	High 5
Attainment of CMOs	CMA is intendend to meet all established CMOs. Excavation will primarily meet risk based goals for direct soil exposure. SVE and AS intended to meet qualitative LNAPL/soil CMOs and quantitative groundwater CMOs	High 5	CMA is intendend to meet all established CMOs. Excavation will primarily meet risk based goals for direct soil exposure. Steam enhanced SVE intended to meet qualitative LNAPL/soil CMOs and quantitative groundwater CMOs	High 5
Control of the Source of Release	Excavation will entail removal of source materials in fine-grained soils. SVE/AS intended to reduce source contributions from unsaturated and saturated smear-zone to groundwater. Existing interim measures will prevent further migration until such time CMOs are met.	High 5	Excavation will entail removal of source materials in fine-grained soils. Steam-enhanced SVE intended to reduce source contributions from unsaturated and saturated smear-zone to groundwater. Existing interim measures will prevent further migration until such time CMOs are met. Potential impact on interim measure effectiveness during initial implementation efforts - may exacerbate groundwater concerns in Perl Mack neighborhood.	Moderately High 4
Decision Factors	**Comparative Evaluation**	**Ranking**	**Comparative Evaluation**	**Ranking**
Long-Term Reliability and Effectiveness	Assuming all qualitative and quantitative CMOs are met, this CMA is considered reliable and effective long-term.	High 5	Assuming all qualitative and quantitative CMOs are met, this CMA is considered reliable and effective long-term.	High 5
Reduction in the Toxicity, Mobility, or Volume of Contamination	CMA intended to reduce toxicity, mobility, and volume of contamination to the extent necessary that all qualitatitve and quantitative CMOs are met. Relatively less complete/aggressive than CMA2.	Moderately High 4	CMA intended to reduce toxicity, mobility, and volume of contamination to the extent necessary that all qualitatitve and quantitative CMOs are met. Relatively more complete/aggressive than CMA1.	High 5
Short-Term Effectiveness	Direct soil exposure CMOs will be met very quickly. Pilot studies indicate SVE/AS is potentially very effective at meeting qualitative soil/LNAPL CMOs. AS will continue to expedite groundwater treatment once soil/LNAPL CMOs have been met.	Moderately High 4	Direct soil exposure CMOs will be met very quickly. Steam enhanced SVE will be very effective at meeting qualitative soil/LNAPL CMOs, as well as all groundwater CMOs in a relatively short period.	High 5
Implementability	Requires building demolition prior to excavation, installation of approximately 30 SVE wells and as many as 600 AS wells. Most likely AS will be implemented in a phased manner, with ongoing evaluation of performance to determine if well-to-well AS coverage is necessary. SVE/AS can be partially implemented prior to demolition.	Moderately High 4	Requires building demolition prior to excavation. Number of wells required likely comparable to CMA1, but construction requirements are more robust. Will likely necessitate upgrades to the GWTP to accomodate recirculation and ex-situ treatment. Relatively more significant infrastructure requirements. Presumes agressive/robust treatment is necessary to meet CMOs feasibly.	Moderate 3
Community Acceptance	Moderately high probability of acceptance. May require contingencies to enhance long-term performance and expedite meeting CMOs if necessary.	High 5	Moderate probability of acceptance. Potential concerns with short-term diminished performance of interim measures.	Moderate 3
State Acceptance	Moderately high probability of acceptance. May require contingencies to enhance long-term performance and expedite meeting CMOs if necessary.	High 5	Moderate probability of acceptance. Potential concerns with short-term diminished performance of interim measures.	Moderate 3
Relative Cost	Excavation and performance monitoring costs assumed similar to CMA2. AS installation and performance monitoring costs highly dependant on actual number of wells required to meet CMOs. Capital infrastructure costs are significantly less than CMA2 .	Moderately High 4	Excavation and performance monitoring costs assumed similar to CMA1. SVE installation costs are relatively higher than CMA1. Steam injection installation will be higher than AS alone (CMA1). Requires significant capital infrastructure and GWTP upgrade costs.	Low 1
Conclusions	Preferred CMA for the Main Source area. Relative cost warrants implementation of CMA1 initially, provided CMA1 is implemented in a manner that can be enhanced as necessary.	Overall 46	Potentially a very viable CMA. Costs relative to CMA1 is significantly higher, and may not be necessary.	Overall 39

Table 6.4 Corrective Measures Alternative Evaluation and Comparison - Facility Parcel, Remote Facility

CMA Evaluation Criteria	CM Alternative 1: Small-Scale Excavation and Soil Vapor Extraction (SVE)		CM Alternative 2: Small-Scale Excavation, Soil Vapor Extraction (SVE) and Air Sparging (AS)		CM Alternative 3: Small-Scale Excavation, Soil Vapor Extraction (SVE) and In-situ Enhanced Reductive Dechlorination (ERD)		CM Alternative 4: Small-Scale Excavation, Soil Vapor Extraction (SVE) and in-Situ Chemical Oxidation (ISCO)	
Minimum Criteria	**Comparative Evaluation**	**Ranking**	**Comparative Evaluation**	**Ranking**	**Comparative Evaluation**	**Ranking**	**Comparative Evaluation**	**Ranking**
Protection of Human Health and the Environment	Direct exposure soil pathways are eliminated through excavation as necessary. Meeting quantitative groundwater CMOs ensures human health and the environment are adequately protected from any residual contamination. Meeting qualitative soil CMOs ensures long-term viability of the CMA.	High 5	Direct exposure soil pathways are eliminated through excavation as necessary. Meeting quantitative groundwater CMOs ensures human health and the environment are adequately protected from any residual contamination. Meeting qualitative soil CMOs ensures long-term viability of the CMA.	High 5	Direct exposure soil pathways are eliminated through excavation as necessary. Meeting quantitative groundwater CMOs ensures human health and the environment are adequately protected from any residual contamination. Meeting qualitative soil CMOs ensures long-term viability of the CMA.	High 5	Direct exposure soil pathways are eliminated through excavation as necessary. Meeting quantitative groundwater CMOs ensures human health and the environment are adequately protected from any residual contamination. Meeting qualitative soil CMOs ensures long-term viability of the CMA.	High 5
Attainment of CMOs	Quantitative soil CMOs are attained through excavation. Qualitative soil CMOs are attained through SVE. Groundwater CMOs are attained through source reduction.	High 5	Quantitative soil CMOs are attained through excavation. Qualitative soil CMOs are attained through SVE. Groundwater CMOs are attained through AS.	High 5	Quantitative soil CMOs are attained through excavation. Qualitative soil CMOs are attained through SVE. Groundwater CMOs are attained through ERD.	High 5	Quantitative soil CMOs are attained through excavation. Qualitative soil CMOs are attained through SVE. Groundwater CMOs are attained through ISCO.	High 5
Control of the Source of Release	Potential contribution from PCE and TCE sources are controlled via excavation and SVE. Existing interim measures will prevent further migration until such time all Facility Parcel CMOs are met.	High 5	Potential contribution from PCE and TCE sources are controlled via excavation and SVE. Existing interim measures will prevent further migration until such time all Facility Parcel CMOs are met.	High 5	Potential contribution from PCE and TCE sources are controlled via excavation and SVE. Existing VBS interim measures will prevent further vapor migration until such time all Facility Parcel CMOs are met. Implementation likely assumes inactivating southern portion of GBS and concurrent implementation of ERD on the Vacant Parcel.	Moderately High 4	Potential contribution from PCE and TCE sources are controlled via excavation and SVE. Existing interim measures will prevent further migration until such time all Facility Parcel CMOs are met.	High 5
Decision Factors	**Comparative Evaluation**	**Ranking**	**Comparative Evaluation**	**Ranking**	**Comparative Evaluation**	**Ranking**	**Comparative Evaluation**	**Ranking**
Long-Term Reliability and Effectiveness	Assuming all qualitative and quantitative CMOs are met, this CMA is considered reliable and effective long-term.	High 5	Assuming all qualitative and quantitative CMOs are met, this CMA is considered reliable and effective long-term.	High 5	Assuming all qualitative and quantitative CMOs are met, this CMA is considered reliable and effective long-term.	High 5	Assuming all qualitative and quantitative CMOs are met, this CMA is considered reliable and effective long-term.	High 5
Reduction in the Toxicity, Mobility, or Volume of Contamination	CMA intended to reduce toxicity, mobility, and volume of contamination to the extent necessary that all qualitatitve and quantitative CMOs are met. Competing CMAs may prove more effective.	Moderately High 4	CMA intended to reduce toxicity, mobility, and volume of contamination to the extent necessary that all qualitatitve and quantitative CMOs are met. Relatively more effective than CMA1, comparable to CMA3 and CMA4.	High 5	CMA intended to reduce toxicity, mobility, and volume of contamination to the extent necessary that all qualitatitve and quantitative CMOs are met. Relatively more effective than CMA1, comparable to CMA2 and CMA4.	High 5	CMA intended to reduce toxicity, mobility, and volume of contamination to the extent necessary that all qualitatitve and quantitative CMOs are met. Relatively more effective than CMA1, comparable to CMA2 and CMA3.	High 5
Short-Term Effectiveness	Excavation and SVE will prove very effective at meeting soil CMOs relatively quickly. Source reduction alone, while presumed effective, is relatively less effective than competing CMAs in the short-term.	Moderately High 4	Excavation and SVE will prove very effective at meeting soil CMOs relatively quickly. AS presumed to be effective once qualitative soil CMOs have been met. Relatively more effective than CMA1, comparable to CMA3 and CMA4.	High 5	Excavation and SVE will prove very effective at meeting soil CMOs relatively quickly. ERD presumed to be effective once qualitative soil CMOs have been met. Relatively more effective than CMA1, comparable to CMA2 and CMA4.	High 5	Excavation and SVE will prove very effective at meeting soil CMOs relatively quickly. AS presumed to be effective once qualitative soil CMOs have been met. Relatively more effective than CMA1, comparable to CMA2 and CMA3.	High 5
Implementability	Excavation assumes prior demolition of buildings. SVE is readily implemented. Excavation and SVE implementation similar for all CMAs.	High 5	Excavation assumes prior demolition of buildings. SVE is readily implemented. Excavation and SVE implementation similar for all CMAs. Requires installation of AS wells, most likely as sparge curtains, as well as associated O&M and performance monitoring.	Moderately High 4	Excavation assumes prior demolition of buildings. SVE is readily implemented. Excavation and SVE implementation similar for all CMAs. Requires installation of ERD injection wells, periodic carbohydrate injections, and associated O&M and performance monitoring. In order to offset potential biofouling concerns with the GBS/GWTP, implementation assumes southern GBS wells will be de-activated and ERD in the Remote Facility is performed concurrently with ERD in the Vacant Parcel.	Moderately High 4	Excavation assumes prior demolition of buildings. SVE is readily implemented. Excavation and SVE implementation similar for all CMAs. Requires installation of ISCO injection wells/infrastructure. ISCO most likely implemented in a targeted manner, near source areas and where groundwater COPCs are highest, as opposed to complete plume coverage. Entails periodic O&M and performance monitoring.	Moderately Low 2
Community Acceptance	Moderately high probability of acceptance, assuming contingencies are available to enhance performance and expedite meeting CMOs if necessary.	Moderately High 4	High probability of acceptance.	High 5	High probability of acceptance. Implementation of ERD on the Vacant Parcel is not likely, but is an acceptable technology. Requires modification to existing performance of GBS interim measures	High 5	High probability of acceptance.	High 5
State Acceptance	Moderately high probability of acceptance, assuming contingencies are available to enhance performance and expedite meeting CMOs if necessary.	Moderately High 4	High probability of CDPHE acceptance.	High 5	High probability of acceptance. Implementation of ERD on the Vacant Parcel is not viewed as necessary, but is an acceptable technology. Requires modification to existing performance of GBS interim measures	High 5	High probability of CDPHE acceptance.	High 5
Relative Cost	Excavation and SVE implementation costs are comparable for all CMAs. Additional costs for performance monitoring. CMA1 significantly less expensive to implement than competing CMAs	High 5	Excavation and SVE implementation costs are comparable for all CMAs. Additional costs for AS infrastructure and associated O&M and monitoring. Potentially less expensive than CMA4.	Moderately Low 2	Excavation and SVE implementation costs are comparable for all CMAs. Additional costs for injection infrastructure, carbohydrate injection and associated O&M and monitoring. Potentially less expensive than CMA2 and CMA4.	Moderate 3	Excavation and SVE implementation costs are comparable for all CMAs. Additional costs for injection infrastructure, reagent injections and associated O&M and monitoring. Likely the most expensive CMA	Low 1
Conclusions	Preferred CMA for the Remote Facility. Additionally, this CMA can be easily adapted to implement CMs from competing CMAs, as needed.	Overall 46	Relative cost warrants implementation of CMA1 initially. CMA1 can be easily converted to CMA2 as necessary.	Overall 46	Potentially a very viable CMA. Relative implementation concerns are more pronounced with this CMA. ERD can still be considered as a viable contingency CM, as needed.	Overall 46	Potentially a very viable CMA. Relative cost concerns are more pronounced with this CMA. ISCO can still be considered as a viable contingency CM, as needed.	Overall 43

Table 6.5 Corrective Measures Alternative Evaluation and Comparison - Facility Parcel, AOC 2

CMA Evaluation Criteria	CM Alternative 1: Complete Excavation		CM Alternative 2: Limited Excavation with Controls		CM Alternative 3: No Action with Controls	
Minimum Criteria	**Comparative Evaluation**	**Ranking**	**Comparative Evaluation**	**Ranking**	**Comparative Evaluation**	**Ranking**
Protection of Human Health and the Environment	No regulatory basis for removal. However COPC concentrations assume limited excavation is necessary to meet risk based exposure scenarios in utility right-of-way. Complete excavation entails conservative removal of all potentially affected soils, outside of utility right-of-way as well.	High 5	No regulatory basis for removal. However COPC concentrations assume limited excavation is necessary to meet risk based exposure scenarios in utility right-of-way.	Moderately High 4	Assuming affected soils remain undisturbed, there is no regulatory basis for removal. Administrative and engineering controls will be used to eliminate exposure pathways.	Moderate 3
Attainment of CMOs	All CMOs are attained through implementation of this CMA	High 5	All CMOs are attained through implementation of this CMA. Excavation to extent necessary to eliminate disturbance/exposure during redevelopment. Administrative/engineering controls to ensure protection from residual impacts below risk-based CMOs.	High 5	All CMOs are attained through implementation of this CMA. Administrative/engineering controls to ensure protection from residual impacts below risk-based CMOs.	High 5
Control of the Source of Release	Alternative has no affect on the source area. Affected soils are not contributing to soil and groundwater concerns elsewhere on the Site. Potential exposure pathways for residual soil impacts are controlled.	High 5	Alternative has no affect on the source area. Affected soils are not contributing to soil and groundwater concerns elsewhere on the Site. Potential exposure pathways for residual soil impacts are controlled.	High 5	Alternative has no affect on the source area. Affected soils are not contributing to soil and groundwater concerns elsewhere on the Site. Potential exposure pathways for residual soil impacts are controlled.	High 5
Decision Factors	**Comparative Evaluation**	**Ranking**	**Comparative Evaluation**	**Ranking**	**Comparative Evaluation**	**Ranking**
Long-Term Reliability and Effectiveness	Complete excavation of the contaminated media would provide a large degree of long-term effectiveness and reliability.	High 5	Long-term reliability contingent primarily on implementation of administrative controls.	Moderately High 4	Long-term reliability contingent primarily on implementation of both engineering and administrative controls.	Moderate 3
Reduction in the Toxicity, Mobility, or Volume of Contamination	Complete excavation primarily reduces the volume of the contamination, but consequently also reduces the toxicity and mobility of the contamination.	High 5	Any and all administrative/engineering controls used at the site will minimize the potential for mobility and exposure. Excavation procedures reduce the volume, and therefore the toxicity and mobility of contamination as well.	Moderately High 4	Any and all administrative/engineering controls used at the site will minimize the potential for mobility and exposure.	Moderate 3
Short-Term Effectiveness	Very effective in meeting CMOs in the short term	High 5	Very effective in meeting CMOs in the short term	High 5	Very effective in meeting CMOs in the short term	High 5
Implementability	Requires building demolition prior to implementation. Easily implemented, albeit significantly more onerous in the short-term than competing CMAs	Moderately Low 2	Requires building demolition prior to implementation. Easily implemented, entails excavation in utility right-of-ways, potential engineered cover in remaining areas.	Moderately High 4	Will likely entail a combination of engineered covers in addition to administrative controls to prevent future disturbance of affected soils.	High 5
Community Acceptance	High probability of acceptance.	High 5	Moderately high probability of acceptance.	Moderately High 4	Moderate probability of acceptance.	Moderate 3
State Acceptance	Moderate probability of CDPHE acceptance. Most likely viewed as unnecessary complication to meeting site-wide closure objectives.	Moderate 3	Moderate probability of CDPHE acceptance. Most likely viewed as unnecessary complication to meeting site-wide closure objectives.	Moderate 3	Moderately high probability of CDPHE acceptance. No regulatory basis for remediation. May require long term monitoring and O&M	Moderately High 4
Relative Cost	Cost for a complete excavation is greater than the limited excavation and no action alternatives. No monitoring, O&M, or administration costs.	Moderately Low 2	Incurred costs depend largely on the size of the area excavated and controls controls. Some monitoring and O&M may be necessary.	Moderate 3	Engineering controls are assumed to be minimal. May ential limited O&M and monitoring. Overall significantly less expensive than competing CMAs	High 5
Conclusions	Preferred CMA for the AOC2 at this time. Subject to change based on development and demolition requirements.	Overall 42	Potentially a very viable CMA.	Overall 41	Potentially a very viable CMA.	Overall 41

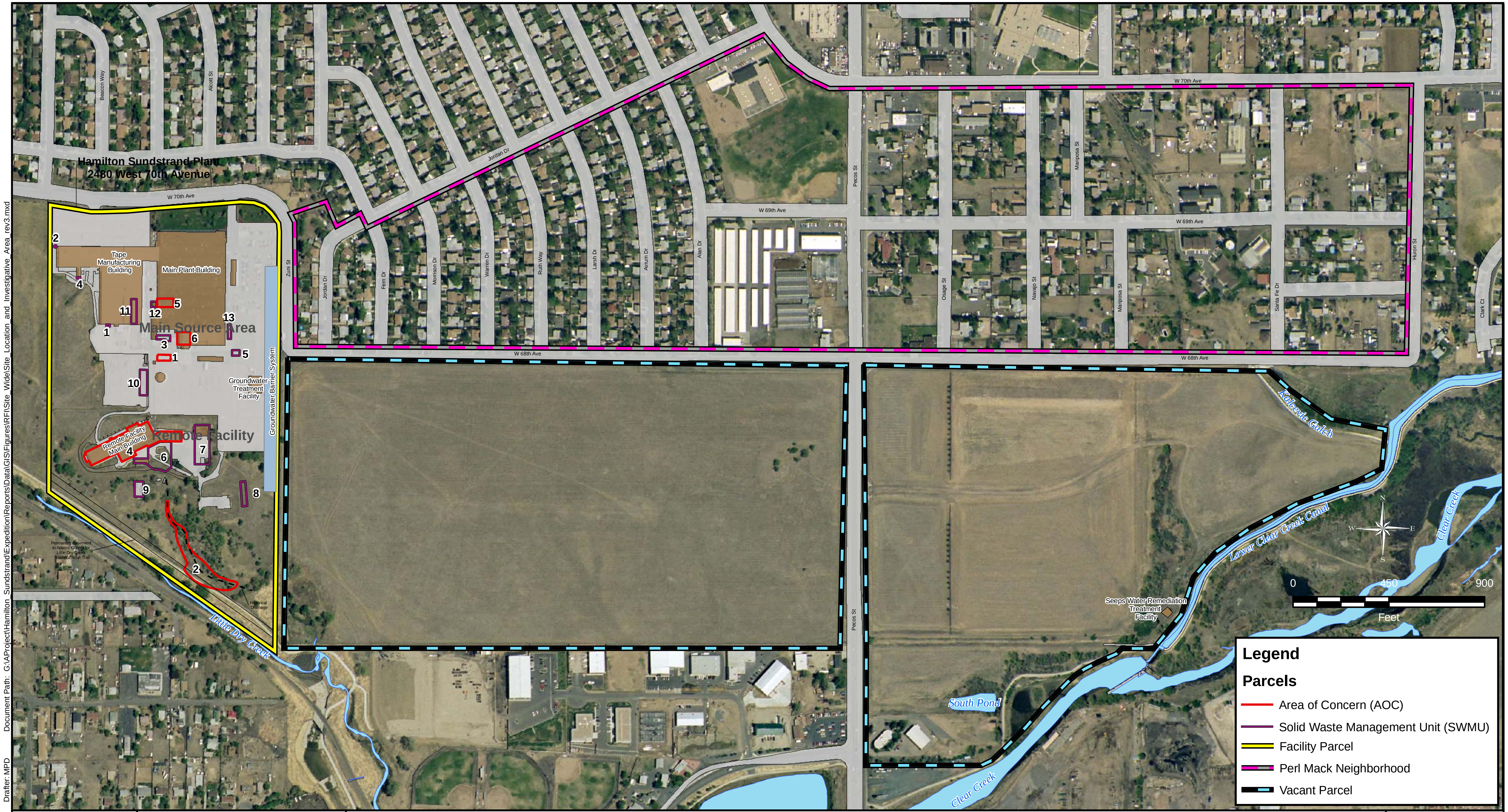
Table 7-1 Corrective Action Determinations for SWMUs on the Facility Parcel

SWMU Number	Facility Parcel Areas		Tank ID or Area		General Location	Unit Description and Use	Status	Release History	Corrective Action Determination
	Main Source	Remote Facility							
1	X		Tank 6		Immediately South of Tape Manufacturing Building	Underground storage tank used to store water and waste oil from lathing, milling, cutting, and grinding operations.	Removed and closed in 1992; ceased use in 1985.	Confirmed release to soil; however, confirmation soil sampling after tank and impacted soil removal indicated soil remediation objectives were achieved.	No Further Action
2	X		Tank 7		Northwest corner of Tape Manufacturing Building	Underground storage tank used to store water and waste oil from lathing, milling, cutting, and grinding operations.	Removed and closed in 1987; only used for 6 months during 1985.	Suspected release to soil; failed tank tightness test. Confirmation soil sampling after tank and impacted soil removal indicated soil remediation objectives were achieved.	No Further Action
3	X		Chip Dock Area	Tank 8	Southwest corner of Main Plant Building	Underground storage tank used to store water and waste oil from lathing, milling, cutting, and grinding operations. Stoddard Solvent for degreasing in Main Plain Building.	Removed and closed in 1987; use ceased in 1985.	Release to soil confirmed.	Corrective Action will entail limited source area excavation, if necessary, coupled with AS/SVE
				Tank 10	Southwest corner of Main Plant Building	Underground storage tank used to store water and waste oil from the Main Plain Building.	Removed and closed in 1987; use ceased in 1985.	Release to soil confirmed.	
				Tank 11	Southwest corner of Main Plant Building	Underground storage tank used to store light hydraulic oil for degreasing in Main Plant Building.	Removed and closed in 1987; use ceased in 1985.	Release to soil confirmed.	
				Tank 12	Southwest corner of Main Plant Building	Underground storage tank used to store gasoline for fueling in Main Plant Building.	Closed in place in 1991 (slurried); ceased use in 1980.	No confirmed release to soil.	
4	X		Tank 9		Immediately south of the west wing of the Tape Manufacturing Building.	Underground storage tank used to store water and waste oil from lathing, milling, cutting, and grinding operations in the Tape Manufacturing Building.	Removed and closed in 1987; use ceased in 1978.	Release to soil confirmed; however, confirmation soil sampling after tank and impacted soil removal indicated soil remediation objectives were achieved.	No Further Action
5	X		Former Oil Bar Tanks	Tanks 13 & 14	Southeast corner of Main Plant Building	Underground storage tanks used to store waste oil from the Main Plant Building operations.	Closed in place in 1981 (slurried); ceased use in 1980.	Release to soil confirmed.	Corrective Action will entail limited source area excavation, if necessary, coupled with AS/SVE
				Tanks 15 & 16	Southeast corner of Main Plant Building	Underground storage tanks used to store waste oil from the Main Plant Building operations. May have also been used to store virgin solvents.	Closed in place in 1982 (slurried); ceased use in 1966.	Release to soil confirmed.	
				Tank 17	Southeast corner of Main Plant Building	Underground storage tanks used to store waste oil from the Main Plant Building operations. May have also been used to store virgin solvents.	Closed in place in 1982 (slurried); ceased use in 1966.	Release to soil confirmed.	
				Tank 18	Southeast corner of Main Plant Building	Underground storage tanks used to store waste oil from the Main Plant Building operations. May have also been used to store regular gasoline for fueling plant vehicles.	Closed in place in 1982 (slurried); ceased use in 1966.	Release to soil confirmed.	
6		X	Clean Closed Former RCRA TSD		Remote Facility	Five treatment cells within three tanks and five storage areas to treat and store plating wastes from the Main Plant Building.	Certified RCRA clean closed by EPA Region 8 in a letter dating August 1984.	Release to soil confirmed; however, confirmation soil sampling indicated soil remediation objectives were achieved.	No Further Action
7		X	90-day RCRA Storage Area		Remote Facility	Enclosed building currently used to store less than 90-day RCRA hazardous waste; previously used for the storage of new and used equipment. Operated as Mirror Building from apporximately 1964 to 1966. Adjacent concrete pad origianlly used as a foundation to support 40-ft diameter mirror. Later used for pilot-sclae plating waste treatment and to store waste oil in drums.	Inactive	Release to soil suspected from drums stored on concrete pad. However, soil sampling from within the SWMU indicates that any potential release did not exceed soil remediation objectives.	No Further Action
8		X	Former Slit Trench Area		Remote Facility	Elongated earthen trench used for placement of plating waste sludge from Clean Closed Former RCRA TSD (SWMU 6).	Inactive; soil remediation conducted in 1984.	Release to soil confirmed. However, post-remediation soil sampling from within the SWMU indicates that no soil contamination remains exceeding remediation objectives.	No Further Action
9		X	Former Plating Waste Drum Storage Area		Remote Facility	Concrete slab used to store 55-gallon drums of plating waste sludge from the Clean Closed Former RCRA TSD. Slab was originally constructed in the late 1950s or early 1960s as a foundation for cooling towers for the Remote Facility.	Inactive; soil remediation conducted in 1984.	Release to soil confirmed.	Corrective Action will entail additional soil sampling to evaluate previous detection of benzo(a)pyrene at HBRG limit and possibly small-scale excavation to remove any confirmed soil contamination
10	X		Former Used Oil Drum Storage Area		South of Main Plant Building	Rectangular shpaed open area located on eastern boundary of former west parking lot used to store waste oil in 55-gallon drums.	Inactive	Release to soil suspected. However, soil sampling from within the SWMU indicates that any potential release did not exceed soil remediation objectives.	No Further Action
11	X		Former Tape Manufacturing Building and Cutting Oil Recovery System		Southeast corner of Tape Manufacturing Building	Solids filtration unit; above-grade waste oil storage in 55-gallon grade metal tanks; sub-grade piping and a sub-grade sump to supply virgin cutting oil and remove and filter waste cutting oil from the grinding area.	Inactive	Release to soil suspected.	Corrective Action will entail limited source area excavation, if necessary, coupled with AS/SVE
12	X		Former Central Oil System and Former Temporary Collection Sumps		West central portion of the Main Plant Building	Solids filtrate unit; above-grade metal troughs and receiver tanks; sub-grade and above-grade piping and sub-grade sumps; used to supply virgin cutting oil and remove and filter waste cutting oil from the grinding area.	Inactive	Release to soil suspected.	Corrective Action will entail limited source area excavation, if necessary, coupled with AS/SVE
13	X		Chip Bin Containment Area		Southeast corner of Main Plant Building	Outdoor area for temporary storage of metal chips and fillings (in bins) from the grinding operations. Gravity drain to sump for collection of fluids from bins.	Inactive	Release to soil suspected. However, soil sampling from within the SWMU indicates that any potential release did not exceed soil remediation objectives.	No Further Action

Table 7-2 Corrective Action Determinations for Identified AOCs

AOC Number	Facility Parcel Areas		Perl Mack Neighborhood	Vacant Parcel	Tank ID or Area	General Location	Unit Description and Use	Status	Release History	Corrective Action Determination
	Main Source	Remote Facility								
1	X				Former Above-ground Sorage Tank Area	South of the southwest corner of the Main Plant Building	Open containment structure used to store virgin oils, virgin solvent, and reclaimed solvent in seven above-ground storage tanks.	Inactive	Release to soil suspected.	Corrective Action will entail limited source area excavation, if necessary, coupled with AS/SVE
2		X			Former Oil Collection Sump and Former Storm Water Discharge Area	Southeast portion of the Site	Primary collection sump for historical storm water system that drained the north, west, and central portions of the Main Plant site area, and the eastern portion of the Remote Facility. Collected water was drained via corrugated steel pipe (24-inch diameter, 100-ft long) and discharge on the ground in the southeast portion of the site.	Inactive and abandoned	Release to soil confirmed.	Anticipated Corrective Action will entail complete excavation and removal of affected soils exceeding HBRGs
3	X	X	X	X	Site wide groundwater					Corrective Action will entail limited source area excavation, if necessary, coupled with AS/SVE or SVE in source areas on Facility Parcel, SVE augmented with AS in Perl Mack Neighborhood, and continued implementation of ERD in Vacant Parcel
4		X			Remote Facility Main Building	Remote Facility	Testing of cryogenic pumps using liquid gases, testing of Accessory Power Units (APUs), materials handling and testing of OTTO fuel.	Inactive	Release to soil suspected.	Corrective Action will entail limited source area excavation, if necessary, coupled with SVE; implementation of AS, ERD, or ISCO contingent on performance
5	X				Heat Treatment Basement	Southwest corner of the Main Plant Building, just east of the Centrail Oil Systems basement (SWMU 12).	Collection area for water and oil from the heat treat furnaces during operations. The northern wall of the Heat Treat Basement is isolated from the Heat Treat Basement floor by an isolation joint filled with a felt material. The joint between the floor and the north wall was observed to be filled with an oily liquid during one visit. There is a lack of knowledge of the structural construction of the foundation in this area.	Inactive	Release to soil suspected.	Corrective Action will entail limited source area excavation, if necessary, coupled with AS/SVE
6	X				Waste Treat Area	The basement of the southeast corner of the Main Plant Building	Area was established to treat plating waste from plating tanks located on the floor above. Some acid, caustic, metals, or cyanide may have been released. In the southwest corner of the area, two concrete formed pools formerly contained an acid bath and an alkaline bath.	Inactive	Release to soil suspected.	Corrective Action will entail limited source area excavation, if necessary, coupled with AS/SVE

Figures



Legend

Parcels

- Area of Concern (AOC)
- Solid Waste Management Unit (SWMU)
- Facility Parcel
- Perl Mack Neighborhood
- Vacant Parcel

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Drafter: MPD

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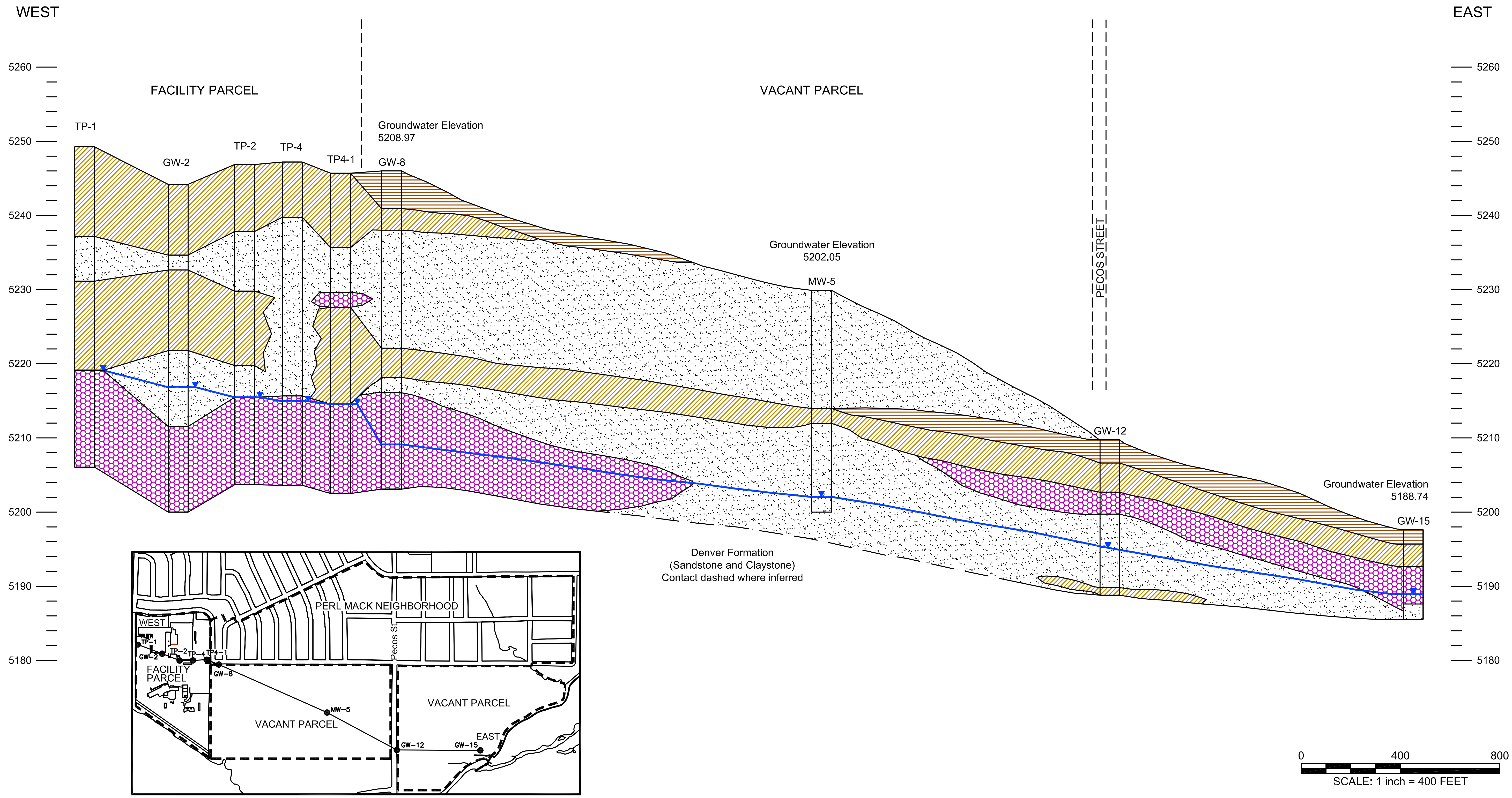
Site Location

Hamilton Sundstrand
Denver, Colorado

Project Number
GP000UTC.C000

Drawing Date
09/20/2007

Figure
2-1



CROSS SECTION LOCATION

VERTICAL EXAGGERATION = 30

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D. Applegate

Project Manager
A. Steckelburg

Task Manager
A. Steckelburg

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LEGEND

▨ CLAY
▨ GRAVEL
▨ SAND
▨ SILT
WATER TABLE ELEVATION DATA FROM APRIL 29, 2000

Geologic Cross Section

Hamilton Sundstrand
Denver, Colorado

Project Number
GP000UTC.C000

Drawing Date
SEPT 21, 2007

Figure
2-2

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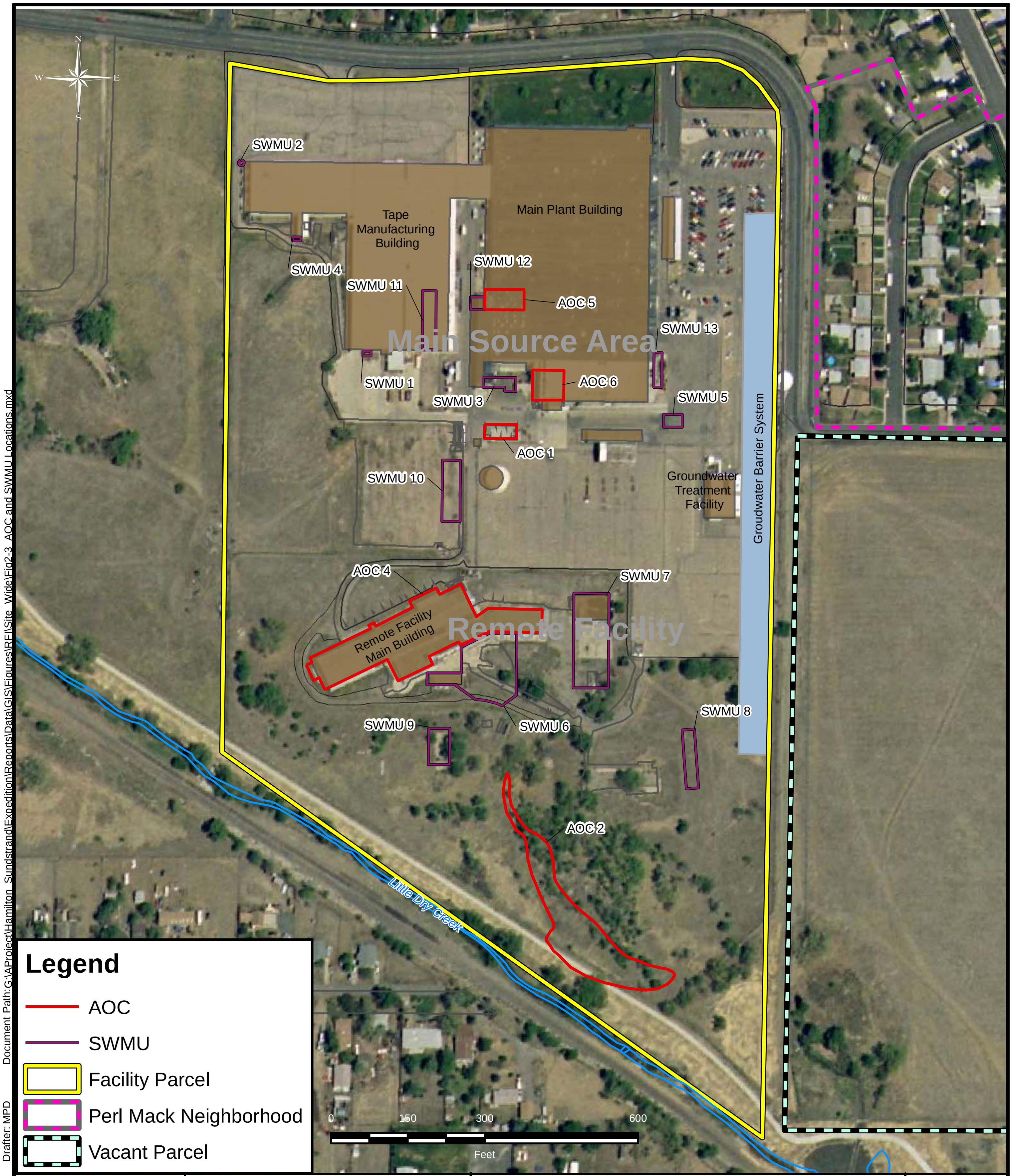

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Program Manager Allan Steckelberg	ARCADIS	SWMU and AOC Locations	FIGURE
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Technical Review Mark Lupo			

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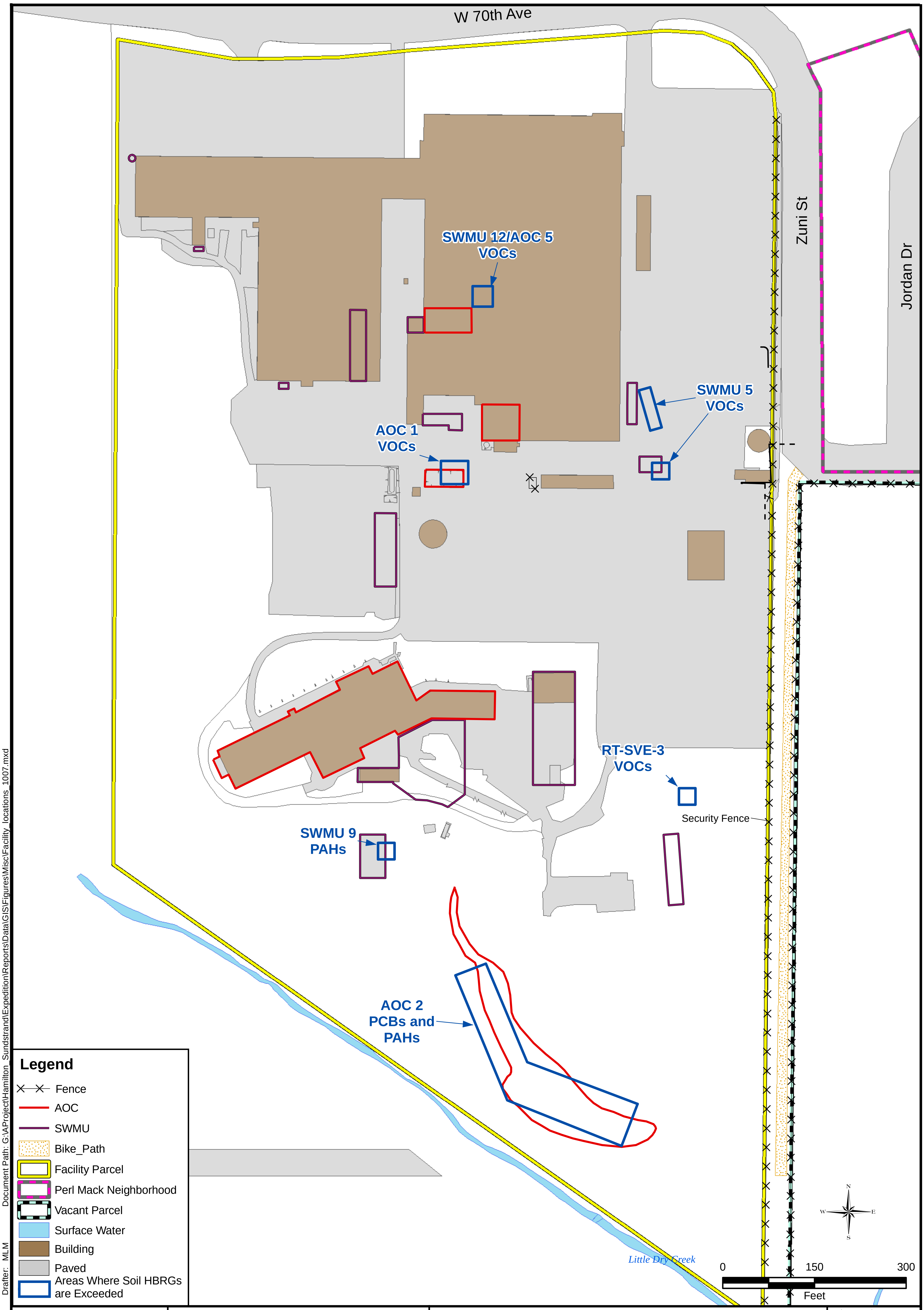

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Areas Where Health-Based Remedial Goals are Exceeded in Historical Soil Sample Analytical Results

Hamilton Sundstrand
Denver, Colorado

Project Number
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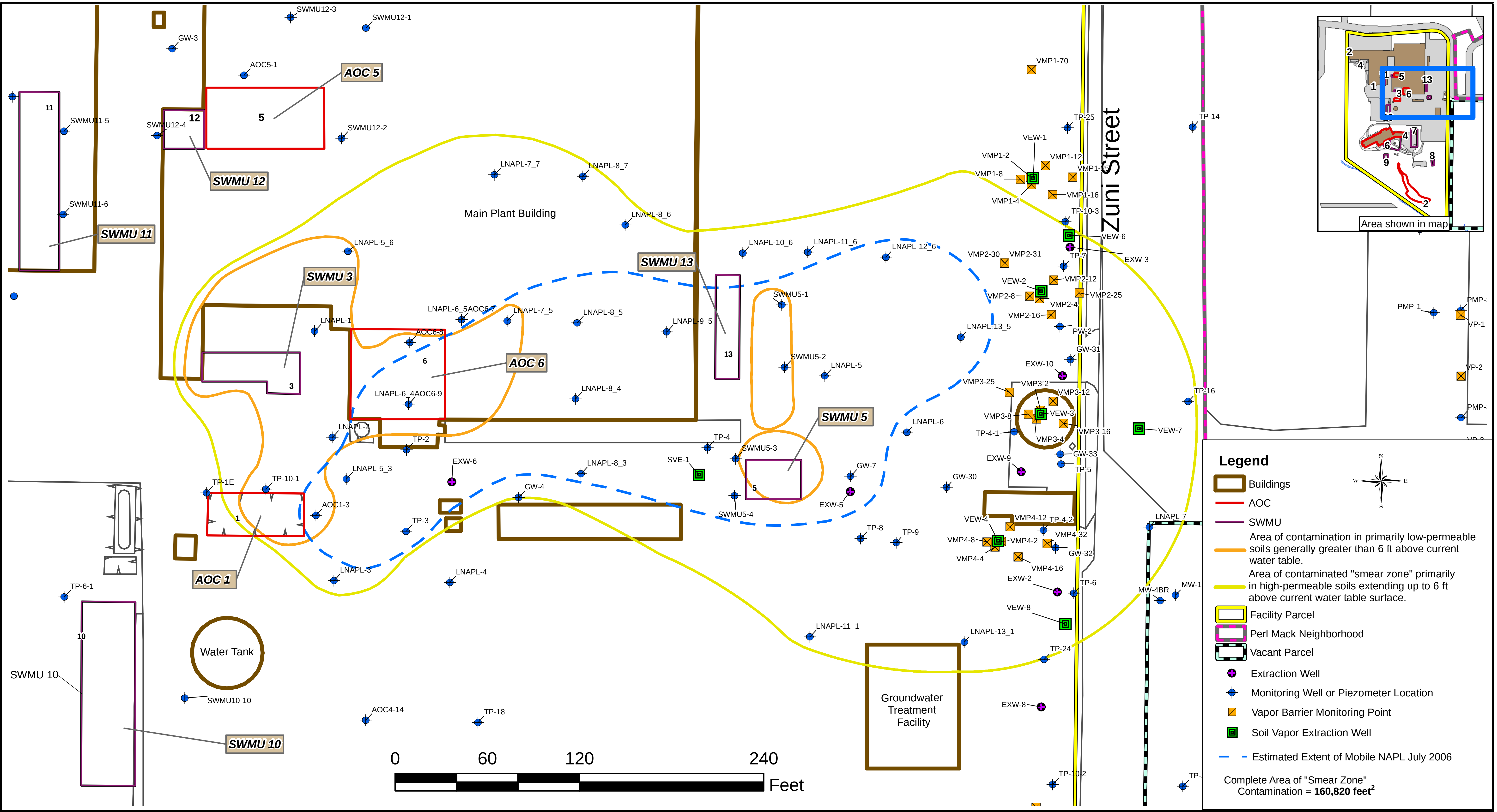
Drawing Date
10/31/2007

Figure
2-4



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Summary of Soil & LNAPL Contamination
Main Source Area

Hamilton Sundstrand
Denver, Colorado

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Drawing Date	09/27/2007
Figure	2-5

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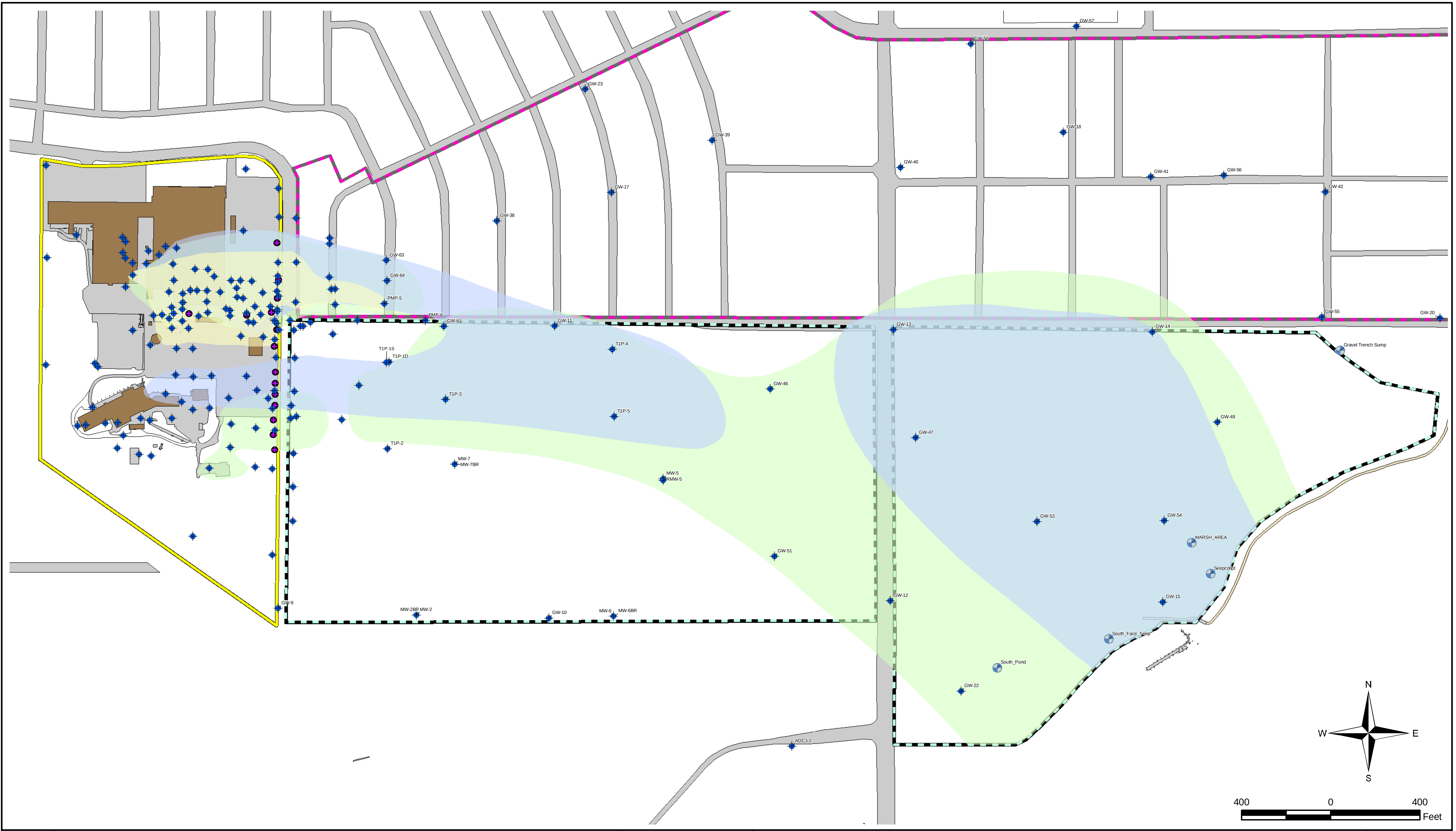

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Legend

🟨	1,1,1-TCA Exceeding Colorado Basic Standards for Groundwater
🟦	PCE Exceeding Colorado Basic Standards for Groundwater
🟩	TCE Exceeding Colorado Basic Standards for Groundwater

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Extent of PCE, TCE, and 1,1,1-TCA Contaminant Plumes
April 2007

Hamilton Sundstrand
Denver, Colorado

Project Number
GP000UTC.C000

Drawing Date
08/29/2007

Figure
2-6

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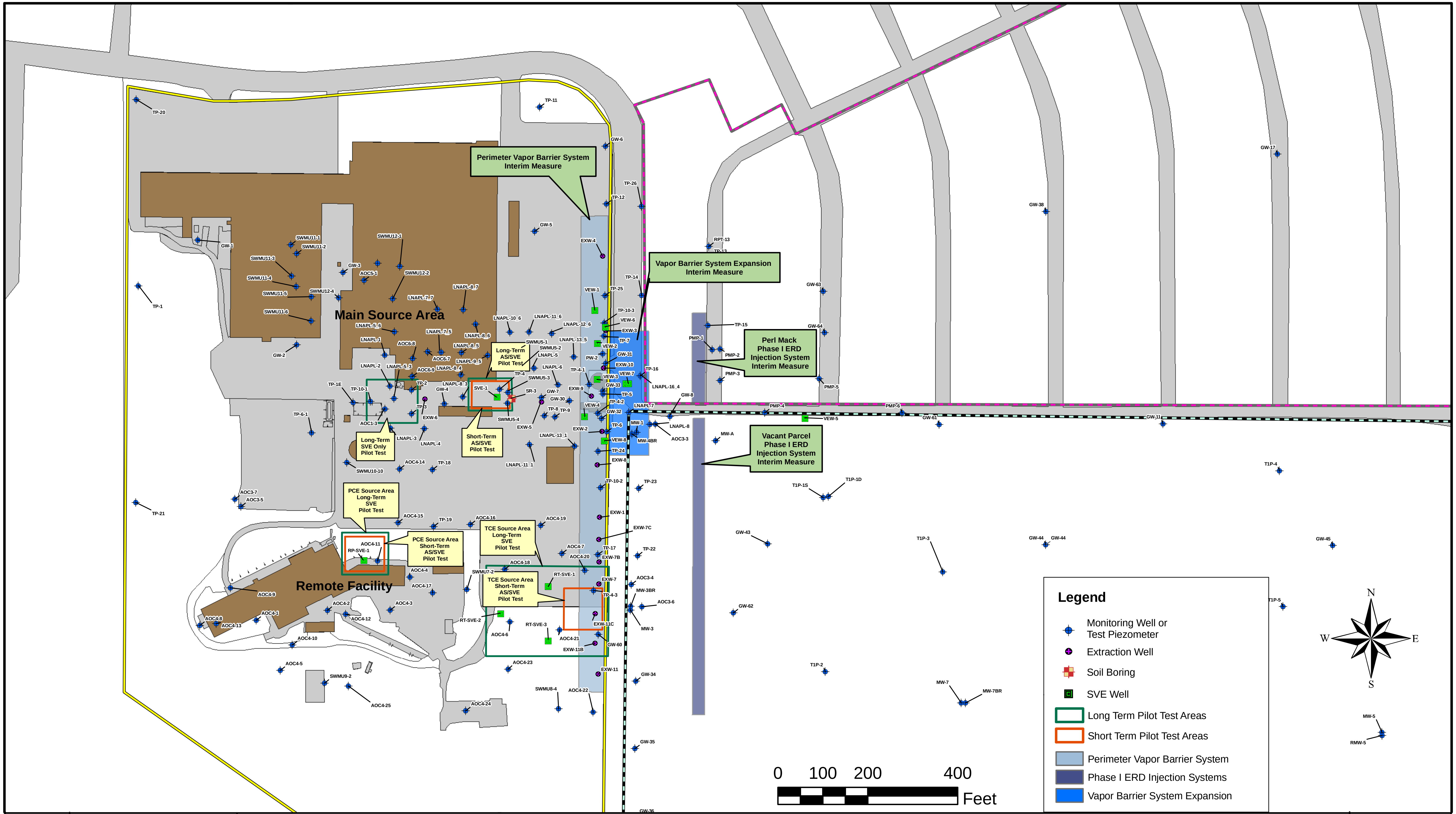

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Interim Measure & Pilot Test Areas

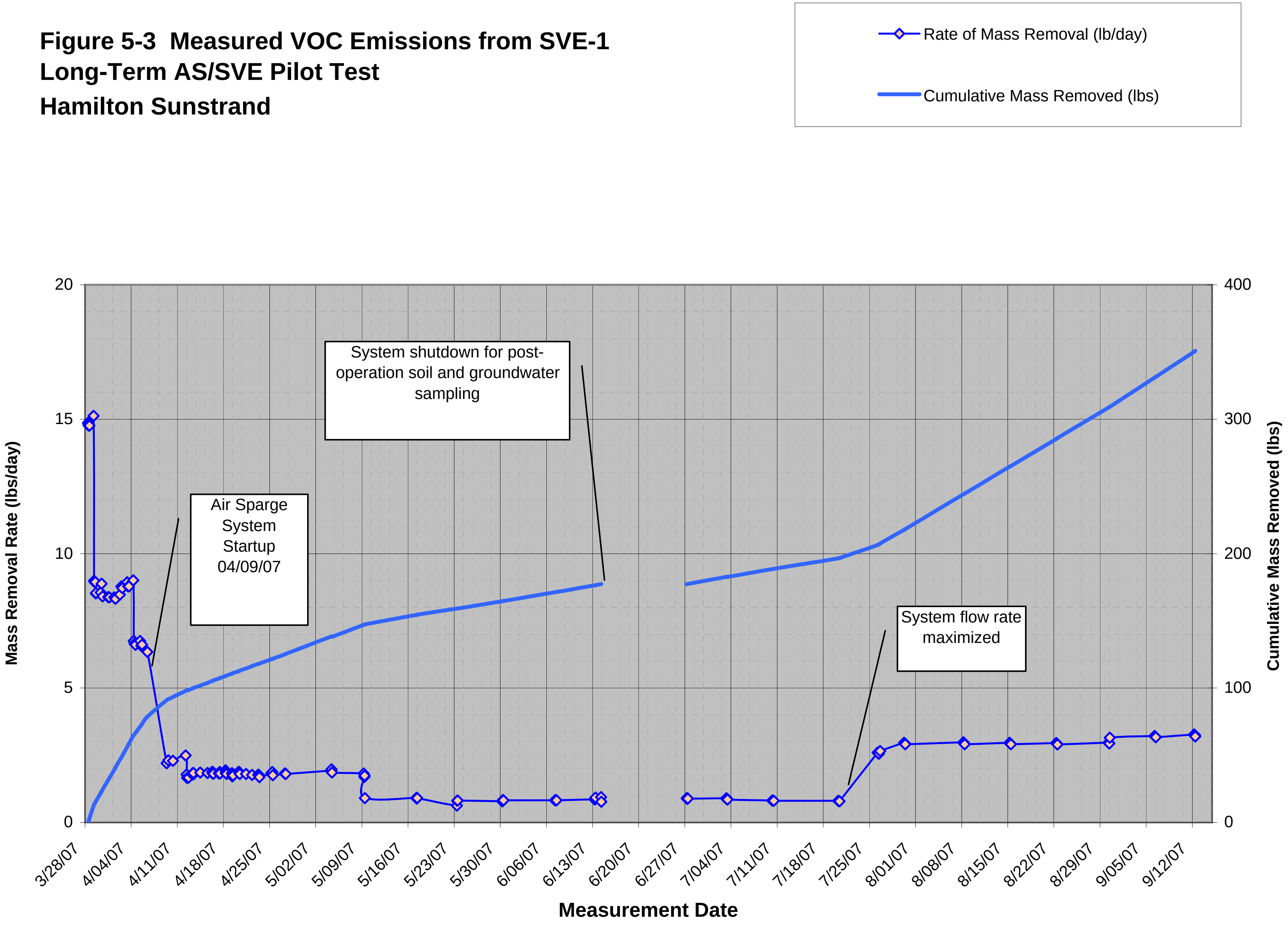
Hamilton Sundstrand
Denver, Colorado

Project Number
GP000UTC.C000

Drawing Date
09/27/2007

Figure
5-1

Figure 5-3 Measured VOC Emissions from SVE-1
Long-Term AS/SVE Pilot Test
Hamilton Sunstrand

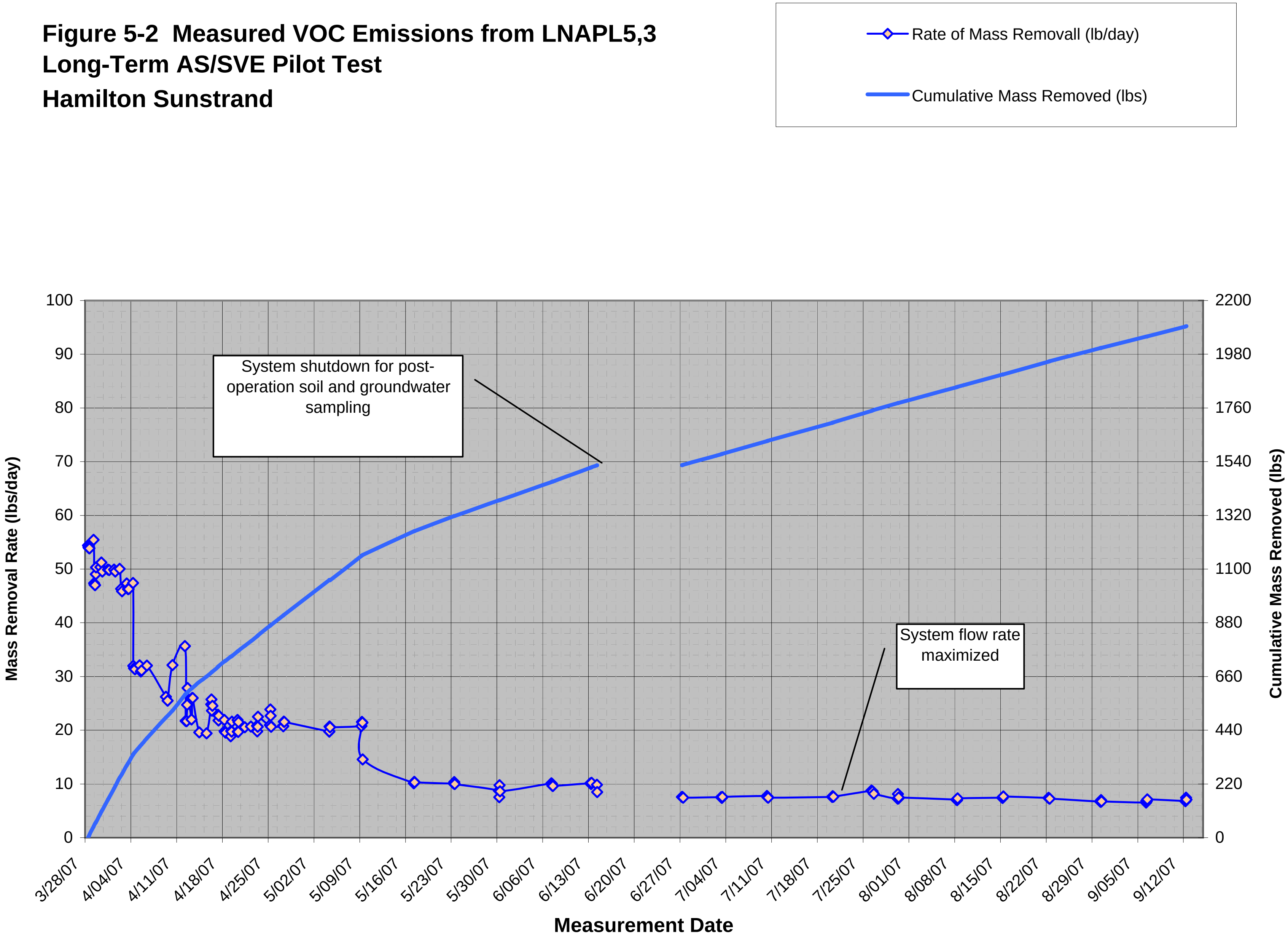


Air Sparge System Startup 04/09/07

System shutdown for post-operation soil and groundwater sampling

System flow rate maximized

Figure 5-2 Measured VOC Emissions from LNAPL5,3
Long-Term AS/SVE Pilot Test
Hamilton Sunstrand



Appendix A

APPENDIX A

Risk Assessment of the Facility Parcel

Hamilton Sundstrand Former Denver Facility, Denver, Colorado

23 January 2008

Risk Assessment of the Facility Parcel

Hamilton Sundstrand Former
Denver Facility
Denver, Colorado

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Our Ref.:
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Date:
23 January 2008

Table of Contents

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Figures

1. Introduction

This report presents the human health risk assessment (HHRA) for the Facility Parcel at the Hamilton Sundstrand Former Denver Facility, in Denver, Colorado. This HHRA has been prepared by ARCADIS U.S., Inc. (ARCADIS) for the Facility Parcel (the Site) located at the Hamilton Sundstrand Former Denver Facility. This HHRA was developed in support of the Corrective Measures Work Plan for the Site and the results are intended to provide input for the risk management and remedial decision-making for the Site.

This HHRA characterizes potential risks in a manner consistent with the risk assessment principles and practices established by the U.S. Environmental Protection Agency (USEPA) Risk Assessment Guidance for Superfund (RAGS) (USEPA, 1989), and additional USEPA standards and guidance (USEPA, 1985; 1990, 1991a, b; 1992b; 1993; 1997; 1999; 2000; 2004b; 2005a).

The methods and approach used in this HHRA, and specifically the methods used to calculate health-based remedial goals (HBRGs), are consistent with the HBRG protocol discussed with, and approved by, the Colorado Department of Public Health and Environment (CDPHE) in a meeting on September 25, 2007. The Site is currently non-operational and there are no workers currently on-site. Therefore, the calculated HBRGs presented in this HHRA are based on the planned future use of the Site as a recreational area.

1.1 Organization of the Risk Assessment

The methodology and results of the HHRA are presented in nine sections, including this introduction. The subsequent sections are organized as follows:

- Site Characterization (Section 2): Provides a description of the Site and site features, and provides a brief history of the Site.
- Chemical Characterization (Section 3): Identifies and summarizes the occurrence of chemicals in soil and groundwater, and identifies chemicals of potential concern (COPCs).
- Exposure Assessment (Section 4): Presents the conceptual site exposure model that is used to identify exposure routes and discusses potential human exposure pathways and potential human receptors at the Site.

- Toxicity Assessment (Section 5): Identifies pertinent toxicological values for COPCs.
- Risk Characterization (Section 6): Provides the receptor and pathway-specific HBRG calculations and comparison to Site COPC concentrations.
- Uncertainties in the HHRA (Section 7): Discusses the uncertainties in the HHRA process.
- Summary and Conclusions (Section 8): Summarizes the results of the HHRA.
- References (Section 9): Provides complete citations for all documents used in the preparation of this HHRA.

2. Site Characterization

The information in this section is based on information contained in the RCRA Facility Investigation Summary Report for the Site (ARCADIS, 2007). This section describes the Site (i.e., Facility Parcel) and history and provides information regarding previous environmental investigations, and the environmental setting for the Site as well as the adjacent property (i.e., Vacant Parcel).

2.1 Site History

Based on a 1954 aerial photograph of the Site and a 1950 United States Geological Survey (USGS) 7.5-minute quadrangle map (EDR, 2000), the Site (i.e., Facility Parcel) was undeveloped and used for agricultural purposes prior to 1955 (Harding ESE, 2001a).

The Hamilton Sundstrand Former Denver Facility was constructed in 1955 and originally consisted of the main manufacturing plant (Main Plant Building) in the north-central portion of the property (Figure 2-1). The Tape Manufacturing Building was constructed in 1966 as a west wing to the Main Plant Building. Hamilton Sundstrand manufactured components for aerospace assemblies that include drive generators, fuel pumps, gears, turbines, actuators, electrical housings, and windings. The Main Plant Building and, to a lesser degree, the Tape Manufacturing Building housed machining, grinding, lapping/superfinish, heat treating, plating, electrochemical machining (ECM), electrical discharge machining (EDM), deburring, degreasing, cleaning, electron beam welding (EBW), gas torch welding, painting, cutting, and testing operations used to support the manufacturing process (Harding ESE, 2001a). The plant ceased operations in April 2004.

The Remote Facility, constructed in 1956 and operated until 1966, is located in the southern portion of the Facility Parcel area. The Remote Facility was used to test cryogenic pumps using liquid gases, to test Accessory Power Units (APUs) for use as power generators on space vehicles in the U.S. space exploration program, and for material handling and combustion testing of Otto Fuel for a U.S. Navy-sponsored torpedo testing program (Harding ESE, 2001a).

During operations in recent years, the Remote Facility was mostly vacant and unused except for the storage of approximately 75 to 100 55-gallon drums of virgin products used in the Main Plant and Tape Manufacturing Building operations. The 55-gallon drums were stored in secondary containment in the northeast portion of the west wing of the Remote Facility. Miscellaneous equipment and equipment parts were also stored in various portions of the west wing of the Remote Facility (Harding ESE, 2001a).

Hamilton Sundstrand announced a phased closure of the Denver plant In October 2002. ARCADIS was contracted to decommission the Main Plant Building and the Tape Manufacturing Building in August 2003. Decommissioning included removal of process piping and equipment and solid and hazardous waste; cleaning, recycling, reusing, and disposing of non-hazardous industrial waste; limited areas of asbestos repair and abatement; and polychlorinated biphenyl (PCB) characterization, removal, and disposal. After final cleaning, confirmation rinse samples collected from walls and floors were analyzed. Approximately 777 tons of waste were generated, disposed of, recycled, or reused during the 9-month decommissioning project. The plant ceased production activities in April 2004. Decommissioning was completed by ARCADIS in May 2004. Details of the decommissioning are presented in the *Hamilton Sundstrand Decommissioning Completion Report* (ARCADIS, 2004).

2.2 Site Investigations

Field investigations of the Hamilton Sundstrand Former Denver Facility and surrounding areas were conducted as detailed in the 2001 Residential Work Plan and the 2003 and 2004 Non-Residential RFI Work Plans approved by the USEPA (Harding ESE, 2001b; MACTEC, 2003; 2004). Results from these investigations were used to fill identified data gaps, supplement the existing Conceptual Site Model, and determine the nature and extent of potential impacts to soil and groundwater at the Site. The nature and extent of impacts were determined based on initial site screening levels, derived from the most stringent appropriate state and federal published standards.

Comparison of Site soil data with initial Site screening levels resulted in the identification of COPCs for certain solid waste management units (SMWUs) and areas of concern (AOCs). These COPCs have been retained for this HHRA.

An overview of historical and ongoing investigations is presented in the Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI) Report (ARCADIS, 2007) for the Site. Detailed information regarding environmental samples collected and analyzed during the Site investigations are discussed in Section 3.

2.3 Environmental Setting

2.3.1 Location

The Site (i.e., Facility Parcel) is located at 2480 West 70th Avenue in Denver, Colorado, as shown on Figure 2-1. The Site consists of the 43-acre original plant area. The adjacent Vacant Parcel consists of 138 acres of acquired property located east of the Site. The Site and Vacant Parcel are located in the eastern half of Section 5, Township 3 South, Range 68 West in Adams County, Colorado.

The Site and Vacant Parcel are bounded to the north by West 70th and West 68th Avenues. The eastern portion of the Vacant Parcel is bounded by Huron Street and by the Lower Clear Creek Canal. The western portion of the Site is bounded by adjacent land and Little Dry Creek. The southern portion is bounded by adjacent land and the Lower Clear Creek Canal at the southeast limits of the Vacant Parcel.

2.3.2 Physical Setting

The Site and Vacant Parcel topography slopes to the east toward Little Dry Creek, Clear Creek, and Lower Clear Creek Canal. The topography decreases from an elevation of approximately 5,250 feet above mean sea level (amsl) in the northwestern part of the Site to approximately 5,175 feet amsl along the southeastern portion of the Vacant Parcel. The Site is elevated approximately 75 feet above Clear Creek and is located approximately 0.5 mile northwest of Clear Creek. Clear Creek flows from southwest to northeast and ultimately discharges to the South Platte River approximately 6 miles east of the Site. Little Dry Creek, located along the southwestern boundary of the Site, discharges to Clear Creek approximately 1 mile south of the Site. The topography in the eastern portion of the Vacant Parcel (east of Pecos Street and South of West 68th Avenue) has been modified slightly by grading and construction activities associated with the Seepage Water Remediation System (Harding ESE, 2001a).

A 100-year flood plain extends to the north approximately 400 feet from Little Dry Creek into the Site. West of Pecos Street, surface water drainage is to the southeast toward the adjacent southern properties. For the Vacant Parcel east of Pecos Street, surface drainage is toward the surface water containment berms and various inlet structures located upgradient of Clear Creek and Lower Clear Creek Canal. Berms extend vertically to approximately 5,181 feet amsl (Harding ESE, 2001a).

2.3.3 Regional Geology

The geologic descriptions and interpretations of the regional area discussed in this subsection are based on USGS 7.5-minute topographic maps (USGS, 1980) and geologic maps (Lindvall, 1979; 1980) of the Arvada and Commerce City quadrangles.

The Investigative Area overlies a former paleochannel and paleoterrace which are oriented parallel to the present-day northeast-southwest trending Clear Creek. The Clear Creek paleochannel is approximately 1 mile wide and underlies Clear Creek. At the north side of the Clear Creek paleochannel, the bedrock rises steeply and levels off to form a paleoterrace approximately 0.25 to 0.5 mile wide (Lindvall, 1979). Unconsolidated deposits cover the paleochannel, paleoterrace, and the bedrock uplands.

Upland surficial deposits in the region are predominantly unconsolidated alluvial and wind-blown deposits. These deposits are relatively thin; generally 25 feet thick or less; are composed of fine sands and silts; and may have considerable amounts of clay, silty clay, and calcareous material (Lindvall, 1979). These higher-permeability alluvial sediments locally control the occurrence and movement of groundwater.

Stream valleys (Little Dry Creek and Clear Creek) are locally filled with stream-deposited (fluvial) sands, silts, gravels, and cobbles. The thicknesses of the fluvial deposits may be 50 feet or more (Lindvall, 1979). The channel deposits in Little Dry Creek include the Piney Creek Alluvium overlying the Louviers Alluvium. The Piney Creek Alluvium is composed of interbedded sand, silt, and clay. The Louviers Alluvium is composed of coarse sand, gravel, cobbles, and occasional boulders. Contorted lenses of clay and silt may also be present (Lindvall, 1979). The channel deposits in Clear Creek include the Slocum Alluvium and the Post-Piney Creek Alluvium as surficial units overlying the Louviers Alluvium. The Slocum Alluvium is composed of pebbly clay and silt interlayered with gravel, cobbles, and boulders. The Post-Piney Creek Alluvium is composed of clay, silt, sand, and small amounts of gravel (Lindvall, 1979).

Regionally, the underlying bedrock consists of green-blue claystone or olive-gray sandstone units of the Denver Formation. The bedrock surface slopes east-southeast beneath the Investigative Area and is located at a depth of 40 to 50 feet bgs. A few localized areas have bedrock depths shallower or deeper than 40 to 50 feet bgs.

3. Chemical Characterization

This section describes the process followed for selecting COPCs. Detailed information describing the distribution of chemicals observed in environmental media is also discussed in this section.

3.1 Selection of Chemicals of Potential Concern

The first step of the HHRA process consists of compiling and evaluating investigation data to select the COPCs. To date, remedial efforts have focused on six chemicals: 1,1-dichloroethane; 1,1-dichloroethene; 1,2-dichloroethene; tetrachloroethene; 1,1,1-trichloroethane; and trichloroethene. In addition to these six chemicals, polychlorinated biphenyls (PCBs) have also been identified as COPCs in soil at the Area of Concern 2 (AOC2). However, prior to development of the HBRGs, all available data were reviewed to identify additional COPCs.

The available data were evaluated in accordance with USEPA guidance (USEPA, 1989 and 1992b). Prior to the COPC selection, sample results were handled as follows:

- For duplicate sample pairs, the higher detected concentration was conservatively used. If both sample results were non-detect, the lower sample quantitation limit (SQL) was used. If one sample result was detected and the other sample result was non-detect, the detected concentration was used.

- Samples that were diluted were evaluated on a sample-by-sample basis. Generally, if a concentration exceeds the upper level of the calibration range of the laboratory instrument, that sample is diluted. The diluted detected concentration is typically the more accurate measurement; however, dilutions also raise detection limits so for non-detects, the original (undiluted) detection limit is more accurate. Therefore, for this evaluation if a sample was diluted, the diluted detected result was retained; if the original result was non-detect, the original reporting limit was retained.

- For samples that were re-analyzed, the re-analyzed result was retained over the original result.

The selection of COPCs was based on the magnitude of the measured chemical concentrations in the relevant environmental media. If the maximum detected concentration exceeded the relevant screening level, then the chemical was identified as a COPC. As discussed in the September 25, 2007 meeting with CDPHE, the

COPCs were selected based on a comparison to USEPA Region 9 Preliminary Remediation Goals (PRGs) for residential soil and tap water (USEPA, 2004a). The use of these screening levels for the selection of COPCs is very conservative since there is no current or planned future residential use of the Site, and there is no current or planned future use of the groundwater at the Site. However, the selection of COPCs does not imply that the selected chemicals pose a potential human health risk, but only specifies a subset of the detected chemicals to be included in the risk assessment calculations.

Following USEPA (1993) guidance, PRGs based on non-carcinogenic effects were adjusted by a factor of 0.1 to account for the potential additive effects of exposure to multiple chemicals. The adjusted PRGs are presented for comparison to observed concentrations as discussed in subsequent sections (USEPA, 1993).

The residential soil PRGs were identified as appropriate health-based screening levels for soil because the initial future land use of the Facility Parcel is not intended for commercial/industrial use but includes recreational use by both children and adults. Although the Facility Parcel will not be re-developed for residential land use, the residential PRGs were used for screening since recreational PRGs are not available. In addition, the assumptions (i.e., exposure pathways and exposure factors) that the USEPA used in calculating the residential soil PRGs are protective of all other potential receptors identified at the Site. COPCs identified using the residential soil PRGs are protective of all potential soil exposure scenarios at the Site.

Based on these criteria, the chemicals identified in Tables 3-1 through 3-4 for soil and groundwater were selected as COPCs. It should be noted that the tables in the following sections detailing the COPC selection process only present chemicals that were detected in the given medium. Chemicals that were analyzed for but not detected are not included in the COPC selection process. The table below summarizes the list of analytical parameters by media.

	Analyte Group				
Sample Matrix	VOCs	SVOCs	Metals	PCBs	Herbicides
Soil	X	X	X	X	X
Groundwater	X	X	X	X	

VOCs - Volatile organic compounds
SVOCs- Semivolatile organic compounds
PCBs – Polychlorinated biphenyls

3.2 Soil Samples

In accordance with the approach summarized in the September 6, 2007 memo prepared by ARCADIS which was discussed in a September 25, 2007 meeting with CDPHE and subsequently approved by CDPHE (via e-mail) on October 11, 2007, soil samples collected at the Site were separated into three depth intervals applicable to each receptor scenario: the recreational user, the maintenance worker, and the construction or utility worker. Each exposure scenario is further discussed in Section 4. The soil depth intervals appropriate for each receptor are explained below:

- Future child, youth, and adult recreational users would be expected to contact the surficial horizon of the soil column; in this case the 0 to 0.5 ft bgs depth interval is considered appropriate.

- Future landscape maintenance workers would be expected to contact surface soil in the top 2 feet of the soil column (i.e., 0 to 2 ft bgs).

- Future construction workers would be expected to contact surface soil and subsurface soil while repairing and/or installing underground utilities/piping/footings, etc. Therefore, the depth interval is based on available utility corridor information for the area, and will encompass the typical excavation depth (for example if piping exists at 7 ft bgs), then the top 8 feet (which includes an additional 1 foot of over-excavation) of the soil column is considered appropriate.

The selection of soil COPCs evaluated in this risk assessment is based on a total of 159 soil samples ranging in depths from 0 to 9.5 ft bgs. The samples were collected between May 1984 and September 2007 to investigate potential impacts to soil. The soil sample locations are shown on Figure 3-1. Soil samples were analyzed for VOCs, SVOCs, PCBs, herbicides, and metals. Although exposure pathways are only evaluated to 8 ft bgs (see Section 4.1.2), soil sample analytical results from the Site's database were queried to 9.5 ft bgs to provide a robust data set to select COPCs. However, it should also be noted that many soil samples identified in the database as collected from 0 to 9.5 ft bgs were actually collected from the base of excavations or from borings drilled through sub-grade basement floors. Many of these soil samples were obtained from depths greater than 9.5 feet below the existing elevation grade. Nevertheless, the analytical results were used to evaluate the Site COPCs.

The summary of soil data and the COPC selection process for each depth interval (i.e., 0 to 0.5 ft bgs, 0 to 2 ft bgs, and 0 to 9.5 ft bgs) are provided in Tables 3-1 through 3-3.

The comparison of the soil data (0 to 9.5 ft bgs) to the screening levels resulted in the following nineteen (19) chemicals being selected as soil COPCs:

1,1,2-Trichloroethane	1,1,2,2-Tetrachloroethane
1,1-Dichloroethene	Benzo(a)anthracene
1,2,4-Trimethylbenzene	Benzo(a)pyrene
1,3,5-Trimethylbenzene	Benzo(b)fluoranthene
Benzene	Dibenzo(a,h)anthracene
Cis-1,2-Dichloroethene	PCBs
Naphthalene	Arsenic
Tetrachloroethene	Barium
Trichloroethene	Copper
Xylenes	

Note in Table 3-3 that manganese was analyzed and detected one time in soil collected from the Site. The detected concentration (224 mg/kg) did exceed the USEPA Region 9 screening level (180 mg/kg) and due to the low occurrence, a site-specific UTL could not be calculated for manganese. Therefore, in the absence of a site-specific background value, the mean background concentration for manganese in Colorado surface soils of 343 mg/kg reported by the USEPA (2005b) was used as a surrogate concentration to represent natural background conditions. The detected concentration of 224 mg/kg did not exceed the USEPA background value of 343 mg/kg and therefore manganese was not selected as a COPC and was not further evaluated in this HHRA.

3.3 Groundwater Samples

The selection of groundwater COPCs evaluated in this risk assessment is based on groundwater samples collected from January 2002 to September 2007. Groundwater samples have been collected from the Site since 1987. However, after a review of the data, which included a trend analysis, the groundwater monitoring data collected over the past 5 years (January 2002 to September 2007) were considered more representative of current conditions than data collected prior to 2002 because in general, concentrations have been decreasing over time.

Groundwater was collected from 143 wells including 31 AOC wells, 54 GW wells, 5 monitoring wells (MW) and several temporary wells (TP), and solid waste management unit (SWMU) wells (Figures 3-1 and 3-2). Groundwater samples were analyzed for VOCs, SVOCs, metals and PCBs. However, for this HHRA, only VOCs are evaluated in groundwater because the only complete groundwater exposure pathway identified for the Site's planned use as a recreational area is inhalation of vapors that may migrate from groundwater to outdoor air and into a construction trench. Exposure pathways are further discussed in Section 4.

Table 3-4 presents a summary of the groundwater data and the COPC selection process. The comparison of the groundwater data to the screening levels resulted in the following thirty-five (35) chemicals being selected as groundwater COPCs:

1,1,1-Trichloroethane	Ethyl Methacrylate
1,1,2,2-Tetrachloroethane	Ethylbenzene
1,1,2-Trichloroethane	Isobutyl Alcohol
1,1-Dichloroethane	Methyl Tert-Butyl Ether
1,1-Dichloroethene	Methylene Chloride
1,2,4-Trichlorobenzene	Naphthalene
1,2,4-Trimethylbenzene	n-Butylbenzene
1,2-Dichloroethane	n-Propylbenzene
1,3,5-Trimethylbenzene	sec-Butylbenzene
1,4-Dioxane	Styrene
2-Butanone (MEK)	Tetrachloroethene
Benzene	Tetrahydrofuran
Bromodichloromethane	Toluene
Bromomethane	Trans-1,2-Dichloroethene
Carbon Tetrachloride	Trichloroethene
Chloroethane	Vinyl Chloride
Chloroform	Xylenes
Cis-1,2-Dichloroethene	

4. Exposure Assessment

The purpose of the exposure assessment is to evaluate the ways receptors might be exposed to chemicals at a site. Without exposure there is no risk; thus, the exposure assessment is a key element of the risk assessment. The assessment of exposure includes characterization of the physical environment, identification of exposure pathways (including migration pathways, exposure points, and exposure routes), and identification of potentially exposed individuals and populations. The following sections present a conceptual site model (CSM) developed for the Site.

4.1 Conceptual Site Model

The CSM incorporates the site-specific analytical data with chemical-specific fate and transport information to identify migration pathways, and activity and use patterns to identify the unique receptors and exposure pathways. The following sections identify potential receptors and describe the potential exposure pathways that were used to develop the exposure scenarios for the Site.

4.1.1 Potential Receptors

In accordance with the approach summarized in the September 6, 2007 memo and subsequently approved by CDPHE (via e-mail) on October 11, 2007, and based on the anticipated future land use for the Facility Parcel as a recreational area, the following potential receptors have been selected for evaluation:

- High-Use and Average-Use Future Child Recreational User;
- High-Use and Average-Use Future Youth (adolescent) Recreational User;
- High-Use and Average-Use Future Adult Recreational User;
- Future Adult Landscape Maintenance Worker (e.g., personnel involved with mowing, fence maintenance, vegetation management, and landscaping); and
- Future Adult Construction/Utility Worker (e.g., personnel involved with excavation activities).

4.1.2 Exposure Pathways

An exposure pathway consists of the following four elements: (1) a source and mechanism of chemical release to the environment, (2) a retention or transport medium for the released chemical, (3) a point of potential contact by the receptor with the impacted medium (the exposure point), and (4) a route of exposure to the receptor at the exposure point (e.g., ingestion, inhalation, or dermal contact). If any of these elements did not exist, the exposure pathway was considered incomplete and will not be further evaluated in this HHRA.

As discussed previously, there is no current human health exposure to media on-site and the planned future use of the Site will be a recreational area. Therefore, health-based remedial goals calculated in this HHRA for the Site are consistent with recreational and open space future use. As a result, potential risks to hypothetical future residents on the Facility Parcel associated with exposure to soil and groundwater were not evaluated in this HHRA. Additionally, the restrictive deed covenant prevents future installation of potable or non-potable water wells on the Site (no wells for potable or non-potable use currently exist at the facility). All drinking water for the Site and surrounding area is provided by the Denver municipal system. These conditions are unlikely to change in the foreseeable future. Given these conditions, exposure pathways associated with potable use (e.g., ingestion) and non-potable use (e.g., dermal contact) of groundwater were not evaluated in this HHRA.

The depth to groundwater at the Site is approximately 30 to 40 feet bgs. Because the water table is deeper than 15 feet bgs, it is unlikely that an excavation worker would come in direct contact with ponded groundwater that might enter a construction/utility trench intersecting the water table. Therefore, exposure via dermal contact and inhalation of vapors volatilizing from ponded groundwater was not evaluated in this HHRA. Although it is unlikely that an excavation worker would come in direct contact with ponded groundwater in a trench, there is still a potential for the construction/utility worker to inhale VOC vapors that have volatilized from the contaminated groundwater and migrated upward through the overlying soil into the air of the construction trench. Therefore, construction worker exposure via inhalation of VOC vapors was evaluated in this HHRA.

Once the Site is redeveloped, children and adults are likely to use the property for recreational purposes. Recreational users of the property would only contact the surface soil; it is unlikely that they will contact soil deeper than 6 inches (0.5 ft bgs). Maintenance workers will be involved in maintaining the property though planting and maintaining landscaping, mowing, fence maintenance and other activities designed to maintain the property and keep the park useable. Therefore, it is possible they will contact soils within the top 2 ft bgs. Finally, construction and/or utility workers may be exposed to chemicals in both surface and subsurface soils (0 to 8 ft bgs).

The complete and potentially complete exposure pathways are summarized below:

- Future child (0 to 6 year old), youth (7 to 16 year old), and adult recreational users may be exposed to COPCs in surface soil (0 to 0.5 ft bgs) via incidental ingestion, dermal contact, and inhalation of wind-blown fugitive dust and vapors.
- Future child, youth, and adult recreational users may be exposed to volatile COPCs in ambient air via inhalation of vapors potentially released to outdoor air from groundwater.
- Future landscape maintenance workers may be exposed to COPCs in surface soil (0 to 2 ft bgs) via incidental ingestion, dermal contact, and inhalation of wind-blown fugitive dust and vapors.
- Future landscape maintenance workers may be exposed to volatile COPCs in ambient air via inhalation of vapors potentially released to outdoor air from groundwater.
- Future construction/utility workers may be exposed to COPCs in combined surface and subsurface soil (0 to 8 ft bgs) via incidental ingestion, dermal contact, and inhalation of dust and vapors during excavation activities.
- Future construction/utility workers may be exposed to COPCs by inhaling volatile COPC vapors that have volatilized from the contaminated groundwater and migrated into the ambient air of the excavated utility/construction trench.

4.2 Exposure Factors

This HHRA is based on evaluation of reasonable maximum exposure (RME), or high end, exposure scenarios and average exposure scenarios. The RME approach has been defined by USEPA in two guidance documents, *Guidelines for Exposure Assessment* (USEPA, 1992a) and *Risk Assessment Guidance for Superfund* (RAGS) (USEPA, 1989). The 1992 guidelines define the concept of RME (using the term High End Exposure [HEE] scenario) as a potential estimate of the individual exposure for those persons at the upper end of an exposure distribution. For the purposes of this report, the RME evaluation has been constructed with reasonable maximum variables that are consistent with the risk evaluation envisioned by the USEPA guidance. RME assumptions were estimated for each potential exposure pathway using standard default assumptions (USEPA, 1989; 1991a; 1991b; 1997) and site-specific information. Values for exposure parameters are summarized in Table 4-1. Supporting information for the exposure factors for the future maintenance worker, future construction worker and future recreational user, including references and rationales, are provided in Table 4-1.

4.2.1 Physical and Chemical Properties

The environmental fate and transport of chemicals are dependent on the physical and chemical properties of the chemicals, the environmental transformation processes affecting them, and the medium through which the chemicals are migrating. The physical and chemical property information that was used to evaluate potential exposure to the COPCs detected in environmental media at the Site was compiled for each of the COPCs detected during the Site investigations. The physical and chemical properties, including molecular weight, water solubility, Henry's Law constant, diffusivity in air and water, organic-carbon partition coefficient (Koc), and the melting point for COPCs are presented in Table 4-2.

4.2.2 Particulate Emissions from Soil

The calculation of a site-specific particulate emission factor (PEF) for wind-blown fugitive dust (PEFwind) was performed using a site-specific air dispersion factor (Q/Cwind). The facility parcel is approximately 43 acres. USEPA (2002) default input parameters were used for the fraction of vegetative cover, and equivalent threshold value of wind-speed and function dependent upon wind-speed. The mean annual wind speed for Denver, Colorado was obtained from the National Oceanographic and Atmospheric Administration (NOAA, 1998). The PEFwind was used to estimate particulate emissions for the maintenance worker, construction/utility worker and recreational scenarios (Table 4-3).

4.2.3 Volatilization Factors from Soil

To evaluate emission of volatiles from soil, chemical-specific volatilization factors (VFs) were calculated using USEPA (2002) guidance. The VF equation can be broken into two separate models: a model to estimate the emissions and a model to estimate the dispersion (reduced to the term Q/C) that simulates the dispersion of contaminants in ambient air. The site-specific dispersion term Q/C was calculated assuming the same size and location as those used for calculating the PEF. Default parameters were used for soil characteristics (USEPA, 2002). The derivation of VFs for fugitive VOCs are provided in Table 4-4.

4.2.4 Dermal Absorption of COPCs in Soil

Dermal absorption efficiencies (ABSd) are used to reflect desorption of the chemical from soil and the absorption of the chemical across the skin. The ABSd are chemical-specific, however, general factors for classes of compounds have been recommended by USEPA (2004b). The chemical-specific ABSd values are provided on the toxicity value tables as appropriate (Section 5).

4.2.5 Volatile Emissions from Groundwater to Construction Trench

Due to the volatile nature of the COPCs in groundwater, a potential exposure route for construction/utility workers is inhalation of COPCs volatilized from groundwater. To estimate the VOC emission rates from groundwater concentrations, the Virginia Department of Environmental Quality's (VDEQ) trench model (VDEQ, 2006) was used. The VDEQ trench model can be used to estimate ambient air concentrations of VOCs in a trench when depth to groundwater is greater than 15 ft bgs and deeper than the bottom of the trench (i.e., no direct contact). Trench model equations are presented in the HBRG equation definition table for the construction worker exposure to groundwater vapor scenario. The HBRGs are further discussed in Section 6.

5. Toxicity Assessment

Human health risk assessment is based on two general categories of toxic effects—non-carcinogenic and carcinogenic. Chemical-specific toxicity values are used to calculate potential risks for these two types of effects.

The chemical-specific toxicity values used in the HBRG calculations were obtained from USEPA Region 9 (2004a). Other USEPA sources (e.g., IRIS [Integrated Risk Information System]) were used to obtain up-to-date toxicity values if toxicity information has been updated since the USEPA Region 9 PRG table publication (October 2004). All sources are consistent with CDPHE risk assessment guidance and chemical-specific policy.

5.1 Cancer Toxicity Values

Cancer slope factors (CSFs) and weight-of-evidence classifications were compiled for COPCs. The CSF is defined as a plausible upperbound estimate of the probability of a response per unit intake of a chemical over a lifetime. The weight-of-evidence classification describes the likelihood that a chemical is a human carcinogen, based on the supporting evidence of carcinogenicity in human and animal studies (USEPA, 2005a). Cancer toxicity information for COPCs is provided in Tables 5-1 (ingestion and dermal) and 5-2 (inhalation).

5.2 Non-Cancer Toxicity Values

The benchmark value for non-carcinogenic effects is the reference dose (RfD) (USEPA, 1989). Chronic RfDs are used to assess long-term exposures ranging from 7 years to a lifetime. Tables 5-3 (ingestion and dermal) and 5-4 (inhalation) present the chronic toxicity values, target organs/critical effects, and USEPA's confidence levels for COPCs at the Site. Typically, subchronic RfDs are used to evaluate the potential for adverse health effects associated with exposure to chemicals over a period of 2 weeks to 7 years. Subchronic RfDs were used to calculate the short-term construction/utility worker HBRGs. If a subchronic RfD was not available, the chronic RfD (if available) was used. This is a conservative measure that may lead to overly-conservative HBRGs. Tables 5-5 (ingestion and dermal) and 5-6 (inhalation) present the subchronic toxicity values, target organs/critical effects, and USEPA's confidence levels for COPCs at the Site.

5.3 Dermal Toxicity Values

In general, toxicity values are available for oral and inhalation pathways. Toxicity values for dermal exposures have not yet been developed by the USEPA. For this reason, the oral toxicity values (RfD_o and CSF_o) and the oral absorption efficiency (ABS_{GI}) were used to derive adjusted toxicity values (RfD_a and CSF_a) (adjusted to the absorbed dose) for use in assessing dermal exposure (USEPA, 1989; 2004b):

$$RfD_a = RfD_o \times ABS_{GI}$$

$$CSF_a = CSF_o / ABS_{GI}$$

The oral toxicity adjustment values are provided in Tables 5-1 and 5-3.

6. Risk Characterization

Potential risks to human health are evaluated quantitatively by calculating HBRGs and comparing them to current Site conditions in soil and groundwater. HBRGs were calculated in general accordance with CDPHE Resource Conservation and Recovery Act (RCRA) Integrated Corrective Action Plan (ICAP) Application Guidance Document and Checklist (January 2000), State of Colorado Proposed Soil Remediation Objectives Policy Document (1997), and the CDPHE Corrective Action Guidance Document (May 2002), as well as other applicable and appropriate state and USEPA Risk Assessment Guidance for Superfund (RAGS) guidance (e.g., RAGS Part B [USEPA 1991b]).

The calculation of HBRGs requires the assumption of acceptable “target’ risk levels for carcinogenic and non-carcinogenic effects; the calculation then results in maximum “safe” chemical concentrations based on those acceptable risk levels. A cancer risk of 10^{-6}, the most conservative end of the USEPA target risk range of 10^{-4} to 10^{-6}, represents an additional probability of developing cancer, over the baseline or background risk applying to the general population, of 1 in 1,000,000 due to the effect of exposure to the relevant chemical. A non-cancer hazard of 1 indicates that the exposure level is equal to the reference exposure level that is not expected to produce non-carcinogenic effects, even for sensitive individuals or subpopulations, and this non-cancer hazard is used in this assessment. For carcinogens which have available carcinogenic and non-carcinogenic toxicity values, the recommended HBRG value is the minimum of the values based on potential carcinogenic and non-carcinogenic effects.

The CDPHE approved receptor-specific exposure parameters used in the calculation of the HBRGs for the relevant exposure scenarios (i.e., maintenance worker; construction worker; and child, youth, and adult recreational users under high use and average use conditions) are presented in Table 4-1. The equations that were used to calculate HBRGs for soil and groundwater for all receptors are shown in Tables 6-1 through 6-3.

A summary of the soil HBRGs for the relevant exposure scenarios is presented in Table 6-4, and a summary of the groundwater HBRGs for relevant exposure scenarios is presented in Table 6-5. The HBRG calculations for each scenario are provided in Tables 6-6 through 6-21. These HBRGs are intended to provide input for risk management and remedial decision-making activities for the Site.

6.1 Comparison of Soil HBRGs to Soil Data

Detected soil concentrations for each COPC in each depth interval (i.e., 0 to 2 ft bgs, 0 to 8 ft bgs, and 0 to 0.5 ft bgs,) were compared to the appropriate HBRGs to determine if concentrations in on-site soils post-redevelopment would be acceptable for hypothetical future receptors (i.e., future maintenance worker, future construction/utility worker, and future recreational user). The lowest HBRG for the recreational users was compared to the maximum concentration in the 0 to 0.5 ft bgs depth interval. If the maximum concentration is below the applicable HBRG for a given scenario, it indicates that exposure to soil containing that COPC is below the regulatory acceptable risk level. If however, the detected concentration is greater than the appropriate HBRG, then additional evaluation of that sample point with respect to its physical location and current status (i.e., has the sampling location been recently altered via building removal, etc.) should be considered, as well as the potential to develop a more representative exposure area concentration (e.g., average concentration or 95 percent upper confidence limit (UCL) concentration).

As described in Section 3.2, many soil samples identified in the Site’s analytical results database as collected at shallow depths (e.g., less than 9.5 ft bgs), were actually obtained from the base of excavations or from borings drilled through sub-grade basement floors. All soil samples identified as collected from 0 to 9.5 ft bgs were used to evaluate COPCs, even though many of these samples were actually obtained from depths exceeding 9.5 feet below the existing elevation grade. However, the true depth of soil data relative to the existing elevation grade (and the presumed post-redevelopment final elevation grade) must be considered when comparing to soil HBRGs. As a result, relatively few soil samples have detected COPC concentrations exceeding HBRGs. Shallow soil contamination is limited because most chemical releases were from underground storage tanks (USTs), buried piping, or areas in building basements deeper than 8 ft bgs. Table 6-22 presents a summary of detected soil concentrations that exceed their applicable HBRG.

6.2 Comparison of Groundwater HBRGs to Groundwater Data

Maximum groundwater concentrations were compared to the appropriate HBRGs to determine if concentrations in groundwater beneath the Site post-redevelopment would be acceptable for future receptors (i.e., future maintenance worker, future construction/utility worker, and future recreational user) breathing VOC vapors could potentially migrate from groundwater to outdoor air or into a construction trench. If the maximum groundwater concentration is below the applicable HBRG for a given scenario, it indicates that exposure to COPC vapors in outdoor air is below the regulatory acceptable risk level. If however, the maximum concentration is greater than the HBRG, additional evaluation of the groundwater data (e.g., spatial and temporal attributes) should be considered, as well as the potential to develop a more representative exposure area concentration (e.g., average concentration or 95 percent upper confidence limit (UCL) concentration). The comparison of maximum concentrations to HBRGs for all scenarios is presented in Tables 6-23 through 6-26.

6.2.1 Groundwater HBRGs for Maintenance Worker Exposure

Maximum groundwater concentrations were compared to the HBRGs calculated for the future maintenance worker (Table 6-23). HBRGs were exceeded for the following chemicals: 1,1,2,2-tetrachloroethane, 1,1-dichloroethene, 1,2,4-trimethylbenzene, 1,3,5-trimethylbenzene, benzene, chloroethane, chloroform, cis-1,2-dichloroethene, methylene chloride, tetrachloroethene, trichloroethene, and vinyl chloride.

6.2.2 Groundwater HBRGs for Construction Worker Exposure

Maximum groundwater concentrations were compared to the HBRGs calculated for the future construction worker (Table 6-24). HBRGs were exceeded for the following chemicals: 1,1,1-trichloroethane, 1,1,2,2-tetrachloroethane, 1,1-dichloroethene, 1,2,4-trimethylbenzene, 1,3,5-trimethylbenzene, benzene, chloroform, cis-1,2-dichloroethene, ethyl methacrylate, ethylbenzene, naphthalene, n-butylbenzene, n-propylbenzene, sec-butylbenzene, tetrachloroethene, trichloroethene, and xylenes.

6.2.3 Groundwater HBRGs for Recreational User Exposure

6.2.3.1 Average Use Recreational User

Maximum groundwater concentrations were compared to the minimum HBRGs calculated for the future average use recreational user (Table 6-25). HBRGs were exceeded for the following chemicals: 1,1,2,2-tetrachloroethane, 1,1-dichloroethene, 1,2,4-trimethylbenzene, 1,3,5-trimethylbenzene, benzene, chloroform, cis-1,2-dichloroethene, tetrachloroethene, and trichloroethene. The recreational receptor with the minimum HBRG is identified below:

Chemical	*Recreational Receptor with Minimum HBRG*
1,1,2,2-Tetrachloroethane	*Adult*
1,1-Dichloroethene	*Child*
1,2,4-Trimethylbenzene	*Child*
1,3,5-Trimethylbenzene	*Adult*
Benzene	*Child*
Chloroform	*Adult*
cis-1,2-Dichloroethene	*Child*
Tetrachloroethene	*Adult*
Trichloroethene	*Adult*

6.2.3.2 High Use Recreational User

Maximum groundwater concentrations were compared to the minimum HBRGs calculated for the future high use recreational user (Table 6-26). HBRGs were exceeded for the following chemicals: 1,1,2,2-tetrachloroethane, 1,1-dichloroethene, 1,2,4-trimethylbenzene, 1,3,5-trimethylbenzene, benzene, chloroform, cis-1,2-dichloroethene, tetrachloroethene, and trichloroethene. The recreational receptor with the minimum HBRG is identified below:

Chemical	*Recreational Receptor with Minimum HBRG*
1,1,2,2-Tetrachloroethane	*Adult*
1,1-Dichloroethene	*Child*
1,2,4-Trimethylbenzene	*Child*

1,3,5-Trimethylbenzene	*Child*
Benzene	*Adult*
Chloroform	*Adult*
cis-1,2-Dichloroethene	*Child*
Tetrachloroethene	*Adult*
Trichloroethene	*Adult*

6.2.4 Comparison of Groundwater HBRGs to 2007 Groundwater Sampling Data

Groundwater concentrations from the most recent site-wide groundwater sampling event were compared to the minimum HBRGs calculated for all future receptors. Groundwater samples for the 2007 annual monitoring event were collected during March and April 2007 from 146 monitoring wells located across the entire Site. Only trichloroethene at a concentration of 0.7 mg/L from a sample collected at well LNAPL-1 (Figure 3-1) was determined to exceed the lowest HBRG of 0.58 mg/L (for the maintenance worker scenario). The observation of HBRGs being exceeded at only one location in the most recent set of site-wide groundwater analytical data is consistent with historical trends of generally deceasing chemical concentrations over time.

7. Uncertainties

All risk assessments involve the use of assumptions, judgments, and incomplete data to varying degrees that contribute to the uncertainty of the final estimates of risk. Uncertainties result both from the use of assumptions or models in lieu of actual data and from the estimation of risk-related parameters, and may result in calculated HBRGs overestimating or underestimating the actual risk. Based on the uncertainties described below, this risk assessment should not be construed as presenting an absolute estimate of risk to persons potentially exposed to chemicals present at the Site. A consideration of the uncertainty attached to various aspects of the risk assessment process allows one to better interpret the risk assessment results and understand the potential adverse effects on human health. In general, the primary sources of uncertainty are associated with environmental sampling and analysis, the exposure assessment, and the toxicological data. The following subsections present the uncertainties associated with this HHRA.

7.1 Uncertainties Associated with the Sampling and Analysis

The selection of COPCs was based upon the results of the sampling and analytical program established for the Site. The factors that contribute to the uncertainties associated with the identification of COPCs are inherent in the data collection and data evaluation processes, including appropriate sample locations, adequate sample quantities, laboratory analyses, data validation, and treatment of validated samples.

A comparison of maximum detected chemical concentrations to USEPA Region 9 PRGs was conducted. Chemicals whose maximum concentrations were below their respective screening levels were not carried through the assessment. It is unlikely that this screening would have excluded chemicals that would be of concern, based on the conservative exposure assumptions and toxicity criteria that are the basis of the screening levels. Although following this methodology does not provide a quantitative risk estimate for all chemicals, it focuses the assessment on the chemicals accounting for the greatest risks.

7.2 Uncertainties Associated with the Exposure Assessment

The exposure assessment is a single step in the risk assessment process that uses a wide array of information sources and techniques. In the absence of site-specific data, assumptions and inferences are often made, which lead to varying degrees of uncertainties. Sources of uncertainty in exposure assessment include the degrees of completeness and confidence in (1) chemical concentration estimation (related to field measurement and modeling parameter estimation); (2) time of contact identification (for example, exposure scenario characterization, target population identification, and population stability over time); and, (3) the methodology for chemical intake calculation.

Assuming that the concentration in the bulk medium (soil or groundwater) is the same as the exposure concentration is a source of potential uncertainty in the exposure analysis. Environmental sampling was designed to assess the most likely impacted portion of the Site, and thus is biased toward high concentrations.

7.3 Uncertainties Associated with the Toxicity Assessment

Toxicity assessment is a critical step in the development of risk estimates for potentially exposed populations. If no toxicity data are available, there are few options to evaluate risks, except using structure-activity relationships or awaiting more data. In general, the principal sources of uncertainty associated with toxicity values used in this HHRA include: (1) using dose-response information from animal studies to predict effects in humans; (2) using dose-response information from effects observed at high tested doses to predict the adverse effects that may occur following human exposure to the low levels; (3) using dose-response information from short-term exposure studies to predict the effects of long-term exposures and vice versa; and, (4) using the dose-response information from homogeneous animal populations or healthy human populations to predict the effects likely to be observed in the general population consisting of individuals with a wide range of sensitivities.

In addition to the use of extrapolated toxicity data, another area of uncertainty in this HHRA is the use of oral toxicity data to evaluate dermal exposure. Differences between oral and dermal pathways are chemical specific. However, the calculated dermal risks are expected to be very conservative, and therefore, overly protective of human health (USEPA, 2004b).

Finally, subchronic toxicity values were unavailable for several COPCs and therefore chronic RfDs were used to evaluate a subchronic pathway likely overestimating the potential hazard.

7.4 Uncertainties Associated with Risk Characterization

Chemicals exceeding HBRGs were identified based on the assumption that the current conditions would remain stable throughout the exposure period and that future receptors would be regularly and periodically exposed for a period of years. This simplifies reality because natural attenuation processes are expected to reduce chemical concentrations over time. If the source is eliminated or reduced, natural attenuation processes will reduce chemical concentrations and the likelihood of exposure, thus reducing exposure concentrations for the hypothetical future exposure scenarios. For example, it is highly unlikely that receptors would be exposed to maximum chemical concentrations in surface soils for such an extended period of time.

8. Summary and Conclusions

The HHRA for the Hamilton Sundstrand Former Denver Facility was prepared consistent with the approved HBRG protocol discussed with, and approved by, CDPHE in a meeting on September 25, 2007 and via email on October 11, 2007, and USEPA guidance. The HHRA compares maximum concentrations of COPCs in soil and groundwater at the Site to calculated HBRGs.

8.1 Summary of Chemicals of Potential Concern

One of the first steps in selecting COPCs was to evaluate the sample data collected at the Site. Sample collection, analysis, and validation aspects of the data collection were reviewed to ensure data were valid for use in the risk assessment following USEPA guidance. The sample screening process and samples used to determine the COPCs in soil and groundwater are briefly discussed below.

The selection of soil COPCs evaluated in this risk assessment is based on a total of 159 soil samples ranging in depths from 0 to 9.5 ft bgs. The samples were collected between May 1984 and September 2007 to investigate potential impacts to soil. Soil samples were analyzed for VOCs, SVOCs, PCBs, herbicides and metals. Samples collected at the Site were separated into three depth intervals applicable to each receptor scenario: the recreational user, the maintenance worker, and the construction or utility worker. The soil depth intervals appropriate for each receptor are explained below:

- Future child, youth, and adult recreational users would be expected to contact the surficial horizon of the soil column (0 to 0.5 ft bgs depth interval).

- Future landscape maintenance workers would be expected to contact surface soil in the top 2 feet of the soil column (i.e., 0 to 2 ft bgs).

- Future utility/construction workers would be expected to contact surface soil and subsurface soil while repairing and/or installing underground utilities/piping/footings, etc. (i.e., 0 to 8 ft bgs).

The selection of groundwater COPCs evaluated in this risk assessment is based on groundwater samples collected from January 2002 to September 2007. Groundwater was collected from 143 wells. Groundwater samples were analyzed for VOCs, SVOCs, metals and PCBs. Only VOCs were evaluated in groundwater based on the identified exposure pathways and the future land use of the Site.

The second step in the COPC selection process was to compare the maximum detected chemical concentrations in each media (and soil depth interval) to health-based screening levels. USEPA Region 9 PRGs for residential soil and tap water were used as the screening levels for soil and groundwater, respectively. Chemicals detected at concentrations greater than the PRGs were identified as COPCs. The following COPCs were identified:

Soil[1]: 1,1,2,2- tetrachloroethane, 1,1,2-trichloroethane, 1,1-dichloroethene, 1,2,4-trimethylbenzene, 1,3,5-trimethylbenzene, benzene, cis-1,2-dichloroethene, naphthalene, tetrachloroethene, trichloroethene, xylenes, benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, dibenzo(a,h)anthracene, PCBs, arsenic, barium, and copper.

Groundwater: 1,1,1-trichloroethane, ethyl methacrylate, 1,1,2,2-tetrachloroethane, ethylbenzene, 1,1,2-trichloroethane, isobutyl alcohol, 1,1-dichloroethane, methyl tert-butyl ether, 1,1-dichloroethene, methylene chloride, 1,2,4-trichlorobenzene, naphthalene, 1,2,4-trimethylbenzene, n-butylbenzene, 1,2-dichloroethane, n-propylbenzene, 1,3,5-trimethylbenzene, sec-butylbenzene, 1,4-dioxane, styrene, 2-butanone (MEK), tetrachloroethene, benzene, tetrahydrofuran, bromodichloromethane, toluene, bromomethane, trans-1,2-dichloroethene, carbon tetrachloride, trichloroethene, chloroethane, vinyl chloride, chloroform, xylenes, and cis-1,2-dichloroethene.

8.2 Exposure Assessment

The assessment of exposure includes characterization of the physical environment, identification of exposure pathways (including migration pathways, exposure points, and exposure routes), and identification of potentially exposed individuals and populations. A conceptual site model was developed which identified potential receptors as well as characterized potentially complete or incomplete exposure pathways.

In accordance with the approach summarized in the September 6, 2007 memo and subsequently approved by CDPHE (via e-mail) on October 11, 2007, and based on the anticipated future land use for the Facility Parcel as a recreational area, the following complete and potentially complete exposure pathways were identified:

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[1] These COPCs were identified for the construction scenario based on soil collected from 0 to 9.5 feet bgs. This is the most conservative scenario for soil exposure.

- Future child (0 to 6 year old), youth (7 to 16 year old), and adult recreational users may be exposed to chemicals of potential concern (COPCs) in surface soil (0 to 0.5 ft bgs) via incidental ingestion, dermal contact, and inhalation of wind-blown fugitive dust and vapors.

- Future child, youth, and adult recreational users may be exposed to volatile COPCs in ambient air via inhalation of vapors potentially released to outdoor air from groundwater.

- Future landscape maintenance workers may be exposed to COPCs in surface soil (0 to 2 ft bgs) via incidental ingestion, dermal contact, and inhalation of wind-blown fugitive dust and vapors.

- Future landscape maintenance workers may be exposed to volatile COPCs in ambient air via inhalation of vapors potentially released to outdoor air from groundwater.

- Future utility/construction workers may be exposed to COPCs in combined surface and subsurface soil (0 to 8 ft bgs) via incidental ingestion, dermal contact, and inhalation of dust and vapors during excavation activities.

- Future utility/construction workers may be exposed to COPCs by inhaling volatile COPC vapors that have volatilized from the contaminated groundwater and migrated into the ambient air of the excavated utility/construction trench.

8.3 Toxicity Assessment

The human toxicity assessment was performed in order to identify numerical toxicity criteria with which to assess human health exposures. Quantitative dose-response data were taken from USEPA Region 9 (2004a). Other USEPA sources (e.g., IRIS) were used if toxicity information has been updated since the USEPA Region 9 PRG table publication (October 2004). All sources are consistent with CDPHE risk assessment guidance and chemical-specific policy.

For non-cancer health effects, chemical-specific RfDs were compiled. Chronic RfDs were used to assess long-term exposures ranging from 7 years to a lifetime. Subchronic RfDs were used to evaluate the potential for adverse health effects associated with exposure to chemicals over a period of 2 weeks to 7 years. Subchronic RfDs were used to calculate the short-term construction worker HBRGs.

For cancer endpoints, chemical-specific CSFs and weight-of-evidence classifications were compiled.

Whenever possible, route-specific toxicity values have been used. However, toxicity values for dermal exposures have not yet been developed by USEPA; therefore, the oral toxicity values and the gastrointestinal absorption efficiency (ABS_{GI}) were used to derive adjusted toxicity values (adjusted to the absorbed dose) for use in assessing dermal exposure (USEPA, 2004b).

8.4 Risk Characterization

Using the human exposure and toxicity information, HBRGs for each COPC and exposure scenario were calculated. HBRGs were then compared to detected concentrations in soil and groundwater. Chemicals with detected concentrations that exceed their HBRGs are provided in Tables 6-23 through 6-27 for the maintenance worker, construction worker, average use recreational user and high use recreational user.

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Table 3-1
Occurrence of Detected Chemicals and Selection of Chemicals of Potential Concern – Soil (Recreational User Scenario)
Hamilton Sundstrand Facility, Denver, Colorado.

Chemical Name	Minimum Detected Value (mg/kg)	Maximum Detected Value (mg/kg)	Sample ID of Maximum Detected Value	Frequency of Detection	Frequency of Detection (%)	Range of SQLs (mg/kg)	Screening Level (a) (mg/kg)	Screening Level Text	Screening Level Reference	Site-Specific Background UTLs	COPC?
PCBs											
Aroclor 1242	0.22	1.8	AOC2-3-0-SO	2 / 38	5%	0.001 - 0.2	NE	–	R9 Res Soil PRG	NA	no
Aroclor 1248	0.034	35	SWMU11-7-0-SO	5 / 38	13%	0.001 - 0.019	NE	–	R9 Res Soil PRG	NA	no
Aroclor 1254	0.02	0.068	SWMU7-2-0-SO	3 / 38	8%	0.001 - 0.2	0.22	ca	R9 Res Soil PRG	NA	no
Aroclor 1260	0.021	0.52	AOC2-1-0-SO	7 / 38	18%	0.001 - 0.2	0.22	ca	R9 Res Soil PRG	NA	YES
Total PCBs	0.96	11	TC10-6	9 / 9	100%	-	0.22	ca -1260	R9 Res Soil PRG	NA	YES
Metals											
Antimony	0.57	1.5	AOC1-3-0-SO	11 / 46	24%	0.55 - 1	3.1	nc	R9 Res Soil PRG	1.4	no
Arsenic	0.88	9.2	SWMU9-3-0-SO-DUP	44 / 46	96%	1 - 1	0.39	ca	R9 Res Soil PRG	7.0	YES
Barium	42.3	1630	SWMU	46 / 46	100%	-	540	nc	R9 Res Soil PRG	732.3	YES
Beryllium	0.17	1.2	MB-4-0.5	34 / 46	74%	0.019 - 1	15	nc	R9 Res Soil PRG	1.3	no
Cadmium	0.1	1.3	SWMU9-2-0-SO	12 / 46	26%	0.057 - 1	3.7	nc	R9 Res Soil PRG	0.1	no
Chromium	3	146	AOC2-1-0-SO	46 / 46	100%	-	210	ca	R9 Res Soil PRG	28.7	no
Cobalt	1.2	11.8	MB-4-0.5	46 / 46	100%	-	900	ca	R9 Res Soil PRG	11.2	no
Copper	2.3	368	SWMU10-7-0-SO	46 / 46	100%	-	310	nc	R9 Res Soil PRG	21.6	YES
Cyanide	0.63	32.7	SWMU9-1-0-SO	5 / 20	25%	1 - 1	120	nc	R9 Res Soil PRG	NA	no
Lead	2.9	133	SWMU10-7-0-SO	46 / 46	100%	-	400	IEUBK	R9 Res Soil PRG	18.4	no
Mercury	0.017	2	AOC4-2-0-SO	11 / 29	38%	0.015 - 1	2.3	nc	R9 Res Soil PRG	0.0	no
Nickel	1.6	25.1	AOC1-3-0-SO	46 / 46	100%	-	160	nc	R9 Res Soil PRG	22.3	no
Selenium	0.27	2.1	SWMU9-3-0-SO-DUP	22 / 46	48%	0.38 - 1	39	nc	R9 Res Soil PRG	1.1	no
Silver	0.17	5.4	AOC4-5-0-SO	21 / 46	46%	0.18 - 1	39	nc	R9 Res Soil PRG	0.3	no
Thallium	0.49	0.97	SWMU10-1-0-SO	6 / 46	13%	0.7 - 1	0.52	nc	R9 Res Soil PRG	1.7	no
Tin	0.44	19.8	SWMU10-7-0-SO	39 / 46	85%	0.32 - 1	4700	nc	R9 Res Soil PRG	1.8	no
Vanadium	8.5	43	MB-2-0.5	46 / 46	100%	-	7.8	nc	R9 Res Soil PRG	60.1	no
Zinc	10.2	177	AOC2-1-0-SO	47 / 47	100%	-	2300	nc	R9 Res Soil PRG	80.6	no
Volatile Organic Compounds (VOCs)											
1,1,1-Trichloroethane	0.00068	560	TH10-E	31 / 53	58%	0.001 - 0.001	1200	sat	R9 Res Soil PRG	NA	no
1,1,2,2-Tetrachloroethane	–	1.7	TH10-1	1 / 46	2%	0.001 - 0.0042	0.41	ca	R9 Res Soil PRG	NA	YES
1,1,2-Trichloroethane	–	0.016	SWMU10-7-0-SO	1 / 45	2%	0.001 - 0.0042	0.73	ca	R9 Res Soil PRG	NA	no
1,1-Dichloroethane	0.00082	1	AOC1-2-0-SODL	18 / 47	38%	0.001 - 0.0039	51	nc	R9 Res Soil PRG	NA	no
1,1-Dichloroethene	0.00069	0.33	AOC1-2-0-SODL	7 / 45	16%	0.001 - 0.0042	12	nc	R9 Res Soil PRG	NA	no
1,2,4-Trichlorobenzene	–	0.11	SWMU11-7-0-SO	1 / 45	2%	0.001 - 0.0042	6.2	nc	R9 Res Soil PRG	NA	no
1,2,4-Trimethylbenzene	0.0012	0.0053	AOC1-4-0-SO	6 / 45	13%	0.001 - 0.0042	5.2	nc	R9 Res Soil PRG	NA	no
1,2-Dichloroethene (total)	0.00075	34	TH10-12	14 / 48	29%	0.001 - 0.0039	4.3	nc-cis	R9 Res Soil PRG	NA	YES
1,3,5-Trimethylbenzene	0.0017	0.004	AOC1-4-0-SO	3 / 45	7%	0.001 - 0.0042	2.1	nc	R9 Res Soil PRG	NA	no
1,3-Dichlorobenzene	–	0.017	AOC2-3-0-SO	1 / 45	2%	0.001 - 0.0042	53	nc	R9 Res Soil PRG	NA	no
1,4-Dichlorobenzene	–	0.095	AOC2-3-0-SO	1 / 45	2%	0.001 - 0.0042	3.4	ca	R9 Res Soil PRG	NA	no
1,4-Dioxane	0.5	0.81	SWMU10-7-0-SO	3 / 3	100%	-	44	ca	R9 Res Soil PRG	NA	no
2-Butanone (MEK)	0.0022	0.025	SWMU7-3-0-SO	31 / 45	69%	0.001 - 0.0038	2200	nc	R9 Res Soil PRG	NA	no
4-Methyl-2-pentanone	–	0.0056	SWMU13-1-0-SORE	1 / 45	2%	0.001 - 0.0042	530	nc	R9 Res Soil PRG	NA	no
Acetone	0.012	0.84	SWMU11-7-0-SO	30 / 45	67%	0.001 - 0.001	1400	nc	R9 Res Soil PRG	NA	no
Acrolein	–	0.0062	AOC2-2-0-SO-DUP	1 / 45	2%	0.001 - 0.0042	0.01	nc	R9 Res Soil PRG	NA	no
Benzene	–	68	TH10-E	1 / 46	2%	0.001 - 0.0042	0.64	ca	R9 Res Soil PRG	NA	YES
Bromomethane	0.00084	0.0024	AOC4-1-0-SO	4 / 45	9%	0.001 - 0.0042	0.39	nc	R9 Res Soil PRG	NA	no
Carbon disulfide	0.00049	0.021	AOC2-3-0-SO	10 / 45	22%	0.001 - 0.0042	36	nc	R9 Res Soil PRG	NA	no
Chloroethane	–	0.0016	AOC1-2-0-SO	1 / 45	2%	0.001 - 0.0042	3	ca	R9 Res Soil PRG	NA	no
Chloromethane	0.00085	0.0058	AOC1-3-0-SO	7 / 45	16%	0.001 - 0.0038	4.7	nc	R9 Res Soil PRG	NA	no
cis-1,2-Dichloroethene	0.00068	0.044	AOC1-4-0-SO	11 / 45	24%	0.001 - 0.0039	4.3	nc	R9 Res Soil PRG	NA	no

Note: Footnotes are on Page 3.

Table 3-1
Occurrence of Detected Chemicals and Selection of Chemicals of Potential Concern – Soil (Recreational User Scenario)
Hamilton Sundstrand Facility, Denver, Colorado.

Chemical Name	Minimum Detected Value (mg/kg)	Maximum Detected Value (mg/kg)	Sample ID of Maximum Detected Value	Frequency of Detection	Frequency of Detection (%)	Range of SQLs (mg/kg)	Screening Level (a) (mg/kg)	Screening Level Text	Screening Level Reference	Site-Specific Background UTLs	COPC?
Ethylbenzene	0.00068	58	TH10-E	6 / 49	12%	0.001 - 0.0042	400	sat	R9 Res Soil PRG	NA	no
Iodomethane	0.0013	0.003	SWMU10-6-0-SO	6 / 45	13%	0.001 - 0.0042	NE	–	R9 Res Soil PRG	NA	no
m&p-Xylene	0.0013	0.019	SWMU7-4-0-SORE	5 / 45	11%	0.001 - 0.0042	27	nc-tot	R9 Res Soil PRG	NA	no
Methylene chloride	0.001	3	TH10-1	3 / 46	7%	0.001 - 0.0042	9.1	ca	R9 Res Soil PRG	NA	no
Naphthalene	0.094	0.94	SWMU10-7-0-SODL	2 / 46	4%	0.001 - 0.0042	5.6	nc	R9 Res Soil PRG	NA	no
n-Butylbenzene	–	0.0075	AOC2-3-0-SO	1 / 45	2%	0.001 - 0.0042	240	sat	R9 Res Soil PRG	NA	no
n-Propylbenzene	–	0.00074	AOC1-4-0-SO	1 / 45	2%	0.001 - 0.0042	240	sat	R9 Res Soil PRG	NA	no
o-Xylene	0.00055	0.0075	SWMU7-4-0-SORE	3 / 45	7%	0.001 - 0.0042	27	nc-tot	R9 Res Soil PRG	NA	no
p-Isopropyltoluene	–	0.0016	AOC4-5-0-SO	1 / 45	2%	0.001 - 0.0042	NE	–	R9 Res Soil PRG	NA	no
sec-Butylbenzene	–	0.014	AOC2-3-0-SO	1 / 45	2%	0.001 - 0.0042	220	sat	R9 Res Soil PRG	NA	no
Tetrachloroethene	0.00076	160	TC10-6	29 / 51	57%	0.001 - 0.0039	0.48	ca	R9 Res Soil PRG	NA	YES
Toluene	0.00099	170	TH10-E	9 / 47	19%	0.001 - 0.0042	520	sat	R9 Res Soil PRG	NA	no
Trichloroethene	0.00051	340	TH10-7	22 / 49	45%	0.001 - 0.0039	0.053	ca	R9 Res Soil PRG	NA	YES
Vinyl chloride	–	0.0015	SWMU13-1-0-SORE	1 / 45	2%	0.001 - 0.0042	0.079	ca	R9 Res Soil PRG	NA	no
Xylenes, total	0.0014	390	TH10-E	10 / 50	20%	0.001 - 0.0042	27	nc	R9 Res Soil PRG	NA	YES
<u>Semi-volatile Organic Compounds (SVOCs)</u>											
1,2,4,5-Tetrachlorobenzene	–	0.078	AOC2-3-0-SORE	1 / 26	4%	0.001 - 0.45	1.8	nc	R9 Res Soil PRG	NA	no
1,2,4-Trichlorobenzene	–	0.058	AOC2-3-0-SORE	1 / 26	4%	0.001 - 0.45	6.2	nc	R9 Res Soil PRG	NA	no
1,3-Dichlorobenzene	–	0.048	AOC2-3-0-SORE	1 / 26	4%	0.001 - 0.45	53	nc	R9 Res Soil PRG	NA	no
1,4-Dichlorobenzene	–	0.089	AOC2-3-0-SORE	1 / 26	4%	0.001 - 0.45	3.4	ca	R9 Res Soil PRG	NA	no
2,4,6-Tribromophenol	0.43	2.6	AOC2-4-0-SO-DUP	20 / 20	100%	-	NE	–	R9 Res Soil PRG	NA	no
2-Fluorobiphenyl	1.4	3.6	AOC2-3-0-SORE	20 / 20	100%	-	NE	–	R9 Res Soil PRG	NA	no
2-Fluorophenol	1.2	3.7	AOC2-3-0-SORE	20 / 20	100%	-	NE	–	R9 Res Soil PRG	NA	no
2-Methylnaphthalene	0.03	2.4	TC10-6	4 / 28	14%	0.001 - 0.45	5.6	nc	R9 Res Soil PRG	NA	no
4-Chloro-3-Methylphenol	–	1.6	TC10-6	1 / 27	4%	0.001 - 0.45	NE	–	R9 Res Soil PRG	NA	no
4-Methylphenol	–	0.017	AOC2-2-0-SO-DUP	1 / 26	4%	0.001 - 0.45	31	nc	R9 Res Soil PRG	NA	no
Acenaphthene	0.057	0.43	AOC2-1-0-SO	4 / 26	15%	0.001 - 0.45	370	nc	R9 Res Soil PRG	NA	no
Anthracene	0.027	0.49	AOC2-1-0-SO	5 / 26	19%	0.001 - 0.45	2200	nc	R9 Res Soil PRG	NA	no
Benzo(a)Anthracene	0.019	0.77	AOC2-1-0-SO	7 / 26	27%	0.001 - 0.45	0.62	ca	R9 Res Soil PRG	NA	YES
Benzo(a)pyrene	0.022	0.55	AOC2-1-0-SO	7 / 26	27%	0.001 - 0.45	0.062	ca	R9 Res Soil PRG	NA	YES
Benzo(b)fluoranthene	0.024	0.63	AOC2-1-0-SO	7 / 26	27%	0.001 - 0.45	0.62	ca	R9 Res Soil PRG	NA	YES
Benzo(g,h,i)perylene	0.055	0.6	AOC2-1-0-SO	6 / 26	23%	0.001 - 0.45	5.6	nc-naph	R9 Res Soil PRG	NA	no
Benzo(k)fluoranthene	0.022	0.67	AOC2-1-0-SO	7 / 26	27%	0.001 - 0.45	6.2	ca	R9 Res Soil PRG	NA	no
bis(2-ethylhexyl) Phthalate	0.029	0.17	SWMU7-2-0-SORE	13 / 26	50%	0.001 - 0.001	35	ca	R9 Res Soil PRG	NA	no
Butyl benzyl phthalate	0.024	0.05	SWMU 11-11	4 / 26	15%	0.001 - 0.45	1200	nc	R9 Res Soil PRG	NA	no
Carbazole	0.027	0.3	AOC2-1-0-SO	5 / 26	19%	0.001 - 0.45	24	ca	R9 Res Soil PRG	NA	no
Chrysene	0.025	0.84	AOC2-1-0-SO	7 / 26	27%	0.001 - 0.45	62	ca	R9 Res Soil PRG	NA	no
Decachlorobiphenyl	0.0098	0.016	SWMU10-10-0-SO	30 / 32	94%	0.01 - 0.2	NE	–	R9 Res Soil PRG	NA	no
Dibenzo(a,h)anthracene	0.023	0.17	AOC2-1-0-SO	5 / 26	19%	0.001 - 0.45	0.062	ca	R9 Res Soil PRG	NA	YES
Dibenzofuran	0.05	0.17	AOC2-1-0-SO	3 / 26	12%	0.001 - 0.45	15	nc	R9 Res Soil PRG	NA	no
Di-n-octyl phthalate	–	0.16	SWMU 11-11	1 / 26	4%	0.001 - 0.45	240	nc	R9 Res Soil PRG	NA	no
Fluoranthene	0.026	1.9	AOC2-1-0-SO	8 / 26	31%	0.001 - 0.45	230	nc	R9 Res Soil PRG	NA	no
Fluorene	0.041	0.63	TC10-6	5 / 27	19%	0.001 - 0.45	270	nc	R9 Res Soil PRG	NA	no
Hexachlorobenzene	–	0.021	AOC2-2-0-SO-DUP	1 / 26	4%	0.001 - 0.45	0.3	ca	R9 Res Soil PRG	NA	no
Indeno(1,2,3-cd)pyrene	0.036	0.47	AOC2-1-0-SO	6 / 26	23%	0.001 - 0.45	0.62	ca	R9 Res Soil PRG	NA	no
Naphthalene	0.087	0.23	AOC2-1-0-SO	3 / 26	12%	0.001 - 0.45	5.6	nc	R9 Res Soil PRG	NA	no
Pentachlorobenzene		0.048	AOC2-2-0-SO-DUP	1 / 26	4%	0.001 - 0.45	4.9	nc	R9 Res Soil PRG	NA	no

Note: Footnotes are on Page 3.

Table 3-1
Occurrence of Detected Chemicals and Selection of Chemicals of Potential Concern – Soil (Recreational User Scenario)
Hamilton Sundstrand Facility, Denver, Colorado.

Chemical Name	Minimum Detected Value (mg/kg)	Maximum Detected Value (mg/kg)	Sample ID of Maximum Detected Value	Frequency of Detection	Frequency of Detection (%)	Range of SQLs (mg/kg)	Screening Level (a) (mg/kg)	Screening Level Text	Screening Level Reference	Site-Specific Background UTLs	COPC?
Phenanthrene	0.02	2.1	AOC2-1-0-SO	8 / 27	30%	0.001 - 0.45	2200	nc-anth	R9 Res Soil PRG	NA	no
Pyrene	0.032	2.2	AOC2-1-0-SO	9 / 26	35%	0.001 - 0.45	230	nc	R9 Res Soil PRG	NA	no
Tetrachlorometaxylene	0.0089	0.017	SWMU3-5-0-SO	31 / 32	97%	0.2 - 0.2	NE	–	R9 Res Soil PRG	NA	no

Note: Statistics are based on data collected from 0 to 0.5 feet below ground surface (bgs).

(a) PRGs based on non-carcinogenic effects were adjusted by a factor of 0.1 following USEPA (1993) guidance.
COPC – Chemical of Potential Concern. A chemical is selected as a COPC if the maximum detected concentration exceeds the risk-based screening level. For metals, if the maximum detected concentration is greater than the risk-based screening level, but below the site-specific background UTL then it was not selected as a COPC.
mg/kg – milligrams per kilogram
R9 Res Soil PRG – USEPA Region 9 Preliminary Remediation Goal for Soil
ca – PRG based on carcinogenic effects

nc – PRG based on noncarcinogenic effects
IEUBK- PRG based on EPA's Integrated Exposure Uptake Biokinetic Model
UTL Upper Tolerance Limit
nc-anth – PRG for anthracene was used as a surrogate
nc-naph – PRG for naphthalene was used as a surrogate
nc-tot – PRG for total xylenes was used as a surrogate
nc-cis – PRG for cis-1,2-DCE was used as a surrogate
ca -1260 – PRG for Aroclor 1260 was used as a surrogate
– One detection was observed and that is presented as the maximum detected value.

Table 3-2

Occurrence of Detected Chemicals and Selection of Chemicals of Potential Concern – Soil (Maintenance Worker Scenario)

Hamilton Sundstrand Facility, Denver, Colorado.

Chemical Name	Minimum Detected Value (mg/kg)	Maximum Detected Value (mg/kg)	Sample ID of Maximum Detected Value	Frequency of Detection	Frequency of Detection (%)	Range of SQLs (mg/kg)	Screening Level (a) (mg/kg)	Screening Level Text	Screening Level Reference	Site-Specific Background UTLs	COPC?
PCBs											
Aroclor 1242	0.027	1.8	AOC2-3-0-SO	3 / 63	5%	0.001 - 0.2	NE	–	R9 Res Soil PRG	NA	no
Aroclor 1248	0.034	310	BS-2-6 (1.8')	20 / 78	26%	0.001 - 0.021	NE	–	R9 Res Soil PRG	NA	no
Aroclor 1254	0.02	0.068	SWMU7-2-0-SO	3 / 63	5%	0.001 - 0.2	0.22	ca	R9 Res Soil PRG	NA	no
Aroclor 1260	0.021	0.52	AOC2-1-0-SO	7 / 63	11%	0.001 - 0.2	0.22	ca	R9 Res Soil PRG	NA	YES
Total PCBs	0	11	TC10-6	18 / 18	100%	-	0.22	ca - 1260	R9 Res Soil PRG	NA	YES
Metals											
Antimony	0.57	2	AOC4-14-2	19 / 75	25%	0.48 - 1	3.1	nc	R9 Res Soil PRG	1.4	no
Arsenic	0.88	9.2	SWMU9-3-0-SO-DUP	73 / 75	97%	1 - 1	0.39	ca	R9 Res Soil PRG	7.0	YES
Barium	42.3	1630	SWMU	75 / 75	100%	-	540	nc	R9 Res Soil PRG	732.3	YES
Beryllium	0.17	1.3	AOC4-16-2	61 / 75	81%	0.019 - 1	15	nc	R9 Res Soil PRG	1.3	no
Cadmium	0.084	1.3	SWMU9-2-0-SO	28 / 75	37%	0.03 - 1	3.7	nc	R9 Res Soil PRG	0.1	no
Chromium	3	146	AOC2-1-0-SO	75 / 75	100%	-	210	ca	R9 Res Soil PRG	28.7	no
Cobalt	1.2	14	AOC5-6-2'	75 / 75	100%	-	900	ca	R9 Res Soil PRG	11.2	no
Copper	2.3	368	SWMU10-7-0-SO	75 / 75	100%	-	310	nc	R9 Res Soil PRG	21.6	YES
Cyanide	0.63	32.7	SWMU9-1-0-SO	5 / 20	25%	1 - 1	120	nc	R9 Res Soil PRG	NA	no
Lead	2.9	133	SWMU10-7-0-SO	75 / 75	100%	-	400	IEUBK	R9 Res Soil PRG	18.4	no
Mercury	0.017	2	AOC4-2-0-SO	20 / 56	36%	0.014 - 1	2.3	nc	R9 Res Soil PRG	0.027	no
Nickel	1.6	25.1	AOC1-3-0-SO	75 / 75	100%	-	160	nc	R9 Res Soil PRG	22.3	no
Selenium	0.27	2.1	SWMU9-3-0-SO-DUP	36 / 75	48%	0.38 - 1	39	nc	R9 Res Soil PRG	1.1	no
Silver	0.17	5.4	AOC4-5-0-SO	25 / 75	33%	0.16 - 1	39	nc	R9 Res Soil PRG	0.26	no
Thallium	0.49	1.7	AOC	21 / 75	28%	0.39 - 1	0.52	nc	R9 Res Soil PRG	1.7	no
Tin	0.44	19.8	SWMU10-7-0-SO	52 / 75	69%	0.32 - 1	4700	nc	R9 Res Soil PRG	1.8	no
Vanadium	8.5	43	MB-2-0.5	75 / 75	100%	-	7.8	nc	R9 Res Soil PRG	60.1	no
Zinc	10.2	177	AOC2-1-0-SO	76 / 76	100%	-	2300	nc	R9 Res Soil PRG	80.6	no
Volatile Organic Compounds (VOCs)											
1,1,1-Trichloroethane	0.00068	560	TH10-E	42 / 81	52%	0.00062 - 0.15	1200	sat	R9 Res Soil PRG	NA	no
1,1,2,2-Tetrachloroethane	–	1.7	TH10-1	1 / 74	1%	0.00072 - 0.15	0.41	ca	R9 Res Soil PRG	NA	YES
1,1,2-Trichloroethane	–	0.016	SWMU10-7-0-SO	1 / 73	1%	0.001 - 0.15	0.73	ca	R9 Res Soil PRG	NA	no
1,1-Dichloroethane	0.00067	1	AOC1-2-0-SODL	25 / 75	33%	0.00064 - 0.15	51	nc	R9 Res Soil PRG	NA	no
1,1-Dichloroethene	0.00069	0.33	AOC1-2-0-SODL	8 / 73	11%	0.0007 - 0.15	12	nc	R9 Res Soil PRG	NA	no
1,2,3-Trichlorobenzene	0.00064	0.0015	AOC4-14-2	3 / 73	4%	0.00089 - 0.15	6.2	nc-124	R9 Res Soil PRG	NA	no
1,2,4-Trichlorobenzene	0.00064	0.11	SWMU11-7-0-SO	4 / 73	5%	0.00087 - 0.15	6.2	nc	R9 Res Soil PRG	NA	no
1,2,4-Trimethylbenzene	0.0007	0.16	SWMU12-1-2-SO	8 / 73	11%	0.00069 - 0.15	5.2	nc	R9 Res Soil PRG	NA	no
1,2-Dichloroethane	–	0.0016	SWMU5-7-2-SO	1 / 73	1%	0.00083 - 0.15	0.28	ca	R9 Res Soil PRG	NA	no
1,2-Dichloroethene (total)	0.0005	34	TH10-12	26 / 76	34%	0.00046 - 0.15	4.3	nc-cis	R9 Res Soil PRG	NA	YES
1,3,5-Trimethylbenzene	0.0017	0.004	AOC1-4-0-SO	3 / 73	4%	0.00068 - 0.15	2.1	nc	R9 Res Soil PRG	NA	no
1,3-Dichlorobenzene	0.00055	0.017	AOC2-3-0-SO	4 / 73	5%	0.00057 - 0.15	53	nc	R9 Res Soil PRG	NA	no
1,4-Dichlorobenzene	–	0.095	AOC2-3-0-SO	1 / 73	1%	0.00093 - 0.15	3.4	ca	R9 Res Soil PRG	NA	no
1,4-Dioxane	0.049	0.81	SWMU10-7-0-SO	4 / 17	24%	0.12 - 0.18	44	ca	R9 Res Soil PRG	NA	no
2-Butanone (MEK)	0.002	0.045	SWMU12-4-2-SO	44 / 73	60%	0.001 - 0.15	2200	nc	R9 Res Soil PRG	NA	no
2-Hexanone	0.00066	0.0023	AOC5-2-2'RE	3 / 73	4%	0.001 - 0.15	NE	–	R9 Res Soil PRG	NA	no
4-Methyl-2-pentanone	0.00092	0.0056	SWMU13-1-0-SORE	3 / 73	4%	0.001 - 0.15	530	nc	R9 Res Soil PRG	NA	no
Acetone	0.0062	2.3	SWMU12-1-2-SO	57 / 73	78%	0.001 - 0.0064	1400	nc	R9 Res Soil PRG	NA	no
Acrolein	0.0062	0.0063	SWMU12-4-2-SO	2 / 72	3%	0.001 - 0.15	0.01	nc	R9 Res Soil PRG	NA	no
Benzene	0.00081	68	TH10-E	3 / 74	4%	0.00056 - 0.15	0.64	ca	R9 Res Soil PRG	NA	YES
Bromomethane	0.00084	0.0024	AOC4-1-0-SO	4 / 73	5%	0.00059 - 0.15	0.39	nc	R9 Res Soil PRG	NA	no
Carbon disulfide	0.00049	0.021	AOC2-3-0-SO	17 / 72	24%	0.001 - 0.15	36	nc	R9 Res Soil PRG	NA	no

Note: Footnotes are on Page 3.

Table 3-2
Occurrence of Detected Chemicals and Selection of Chemicals of Potential Concern – Soil (Maintenance Worker Scenario)
Hamilton Sundstrand Facility, Denver, Colorado.

Chemical Name	Minimum Detected Value (mg/kg)	Maximum Detected Value (mg/kg)	Sample ID of Maximum Detected Value	Frequency of Detection	Frequency of Detection (%)	Range of SQLs (mg/kg)	Screening Level (a) (mg/kg)	Screening Level Text	Screening Level Reference	Site-Specific Background UTLs	COPC?
Chloroethane	–	0.0016	AOC1-2-0-SO	1 / 73	1%	0.001 - 0.15	3	ca	R9 Res Soil PRG	NA	no
Chloromethane	0.00085	0.0058	AOC1-3-0-SO	7 / 73	10%	0.00091 - 0.15	4.7	nc	R9 Res Soil PRG	NA	no
cis-1,2-Dichloroethene	0.00047	0.044	AOC1-4-0-SO	23 / 73	32%	0.00067 - 0.15	4.3	nc	R9 Res Soil PRG	NA	no
Ethylbenzene	0.00068	58	TH10-E	6 / 77	8%	0.0008 - 0.15	400	sat	R9 Res Soil PRG	NA	no
Hexachlorobutadiene	–	0.0012	AOC4-14-2	1 / 73	1%	0.00065 - 0.15	6.2	ca	R9 Res Soil PRG	NA	no
Iodomethane	0.0013	0.003	SWMU10-6-0-SO	6 / 72	8%	0.001 - 0.15	NE	–	R9 Res Soil PRG	NA	no
m&p-Xylene	0.0013	0.019	SWMU7-4-0-SORE	5 / 71	7%	0.001 - 0.15	27	nc-tot	R9 Res Soil PRG	NA	no
Methylene chloride	0.001	3	TH10-1	4 / 74	5%	0.001 - 0.15	9.1	ca	R9 Res Soil PRG	NA	no
Naphthalene	0.00064	3.8	SWMU12-1-2-SO	6 / 74	8%	0.00075 - 0.15	5.6	nc	R9 Res Soil PRG	NA	no
n-Butylbenzene	0.00077	0.0075	AOC2-3-0-SO	2 / 73	3%	0.00067 - 0.15	240	sat	R9 Res Soil PRG	NA	no
n-Propylbenzene	–	0.00074	AOC1-4-0-SO	1 / 73	1%	0.00069 - 0.15	240	sat	R9 Res Soil PRG	NA	no
o-Xylene	0.00055	0.0075	SWMU7-4-0-SORE	3 / 67	4%	0.00072 - 0.15	27	nc-tot	R9 Res Soil PRG	NA	no
p-Isopropyltoluene	–	0.0016	AOC4-5-0-SO	1 / 73	1%	0.00058 - 0.15	NE	–	R9 Res Soil PRG	NA	no
sec-Butylbenzene	–	0.014	AOC2-3-0-SO	1 / 73	1%	0.00091 - 0.15	220	sat	R9 Res Soil PRG	NA	no
Tetrachloroethene	0.00055	160	TC10-6	46 / 79	58%	0.001 - 0.15	0.48	ca	R9 Res Soil PRG	NA	YES
Toluene	0.00095	170	TH10-E	10 / 75	13%	0.00082 - 0.15	520	sat	R9 Res Soil PRG	NA	no
Trichloroethene	0.00051	340	TH10-7	34 / 77	44%	0.00058 - 0.15	0.053	ca	R9 Res Soil PRG	NA	YES
Vinyl chloride	–	0.0015	SWMU13-1-0-SORE	1 / 73	1%	0.00069 - 0.15	0.079	ca	R9 Res Soil PRG	NA	no
Xylenes, total	0.0014	390	TH10-E	10 / 78	13%	0.00072 - 0.15	27	nc	R9 Res Soil PRG	NA	YES
Semi-volatile Organic Compounds (SVOCs)											
1,2,4,5-Tetrachlorobenzene	–	0.078	AOC2-3-0-SORE	1 / 49	2%	0.001 - 1.9	1.8	nc	R9 Res Soil PRG	NA	no
1,2,4-Trichlorobenzene	–	0.058	AOC2-3-0-SORE	1 / 49	2%	0.001 - 1.9	6.2	nc	R9 Res Soil PRG	NA	no
1,3-Dichlorobenzene	–	0.048	AOC2-3-0-SORE	1 / 49	2%	0.001 - 1.9	53	nc	R9 Res Soil PRG	NA	no
1,4-Dichlorobenzene	–	0.089	AOC2-3-0-SORE	1 / 49	2%	0.001 - 1.9	3.4	ca	R9 Res Soil PRG	NA	no
2,4,6-Tribromophenol	0.43	2.6	AOC2-4-0-SO-DUP	20 / 20	100%	-	NE	–	R9 Res Soil PRG	NA	no
2,4-Dimethylphenol	–	0.18	SWMU12-5-2	1 / 49	2%	0.001 - 1.9	120	nc	R9 Res Soil PRG	NA	no
2-Fluorobiphenyl	1.4	3.6	AOC2-3-0-SORE	20 / 20	100%	-	NE	–	R9 Res Soil PRG	NA	no
2-Fluorophenol	1.2	3.7	AOC2-3-0-SORE	20 / 20	100%	-	NE	–	R9 Res Soil PRG	NA	no
2-Methylnaphthalene	0.03	2.4	TC10-6	4 / 51	8%	0.001 - 1.9	5.6	nc	R9 Res Soil PRG	NA	no
4-Chloro-3-Methylphenol	–	1.6	TC10-6	1 / 50	2%	0.001 - 1.9	NE	–	R9 Res Soil PRG	NA	no
4-Methylphenol	0.017	0.22	SWMU12-5-2	2 / 49	4%	0.001 - 1.9	31	nc	R9 Res Soil PRG	NA	no
Acenaphthene	0.057	0.43	AOC2-1-0-SO	4 / 49	8%	0.001 - 1.9	370	nc	R9 Res Soil PRG	NA	no
Acetophenone	0.02	0.052	AOC4112RE	5 / 49	10%	0.001 - 1.9	NE	–	R9 Res Soil PRG	NA	no
Anthracene	0.027	0.49	AOC2-1-0-SO	5 / 49	10%	0.001 - 1.9	2200	nc	R9 Res Soil PRG	NA	no
Benzaldehyde	0.019	0.048	SWMU12-6-2	3 / 29	10%	0.35 - 1.9	610	nc	R9 Res Soil PRG	NA	no
Benzo(a)Anthracene	0.019	0.77	AOC2-1-0-SO	8 / 49	16%	0.001 - 1.9	0.62	ca	R9 Res Soil PRG	NA	YES
Benzo(a)pyrene	0.022	0.55	AOC2-1-0-SO	8 / 49	16%	0.001 - 1.9	0.062	ca	R9 Res Soil PRG	NA	YES
Benzo(b)fluoranthene	0.024	0.63	AOC2-1-0-SO	8 / 49	16%	0.001 - 1.9	0.62	ca	R9 Res Soil PRG	NA	YES
Benzo(g,h,i)perylene	0.055	0.6	AOC2-1-0-SO	7 / 49	14%	0.001 - 1.9	5.6	nc-naph	R9 Res Soil PRG	NA	no
Benzo(k)fluoranthene	0.022	0.67	AOC2-1-0-SO	8 / 49	16%	0.001 - 1.9	6.2	ca	R9 Res Soil PRG	NA	no
Benzoic Acid	–	0.13	AOC4-15-2	1 / 29	3%	0.88 - 4.9	100000	max	R9 Res Soil PRG	NA	no
bis(2-ethylhexyl) Phthalate	0.029	0.37	AOC5-2-2'	23 / 49	47%	0.001 - 0.83	35	ca	R9 Res Soil PRG	NA	no
Butyl benzyl phthalate	0.024	0.05	SWMU 11-11	4 / 49	8%	0.001 - 1.9	1200	nc	R9 Res Soil PRG	NA	no
Carbazole	0.027	0.3	AOC2-1-0-SO	5 / 49	10%	0.001 - 1.9	24	ca	R9 Res Soil PRG	NA	no
Chrysene	0.025	0.84	AOC2-1-0-SO	8 / 49	16%	0.001 - 1.9	62	ca	R9 Res Soil PRG	NA	no
Decachlorobiphenyl	0.0098	0.016	SWMU10-10-0-SO	32 / 34	94%	0.01 - 0.2	NE	–	R9 Res Soil PRG	NA	no
Dibenzo(a,h)anthracene	0.023	0.17	AOC2-1-0-SO	5 / 49	10%	0.001 - 1.9	0.062	ca	R9 Res Soil PRG	NA	YES
Dibenzofuran	0.05	0.17	AOC2-1-0-SO	3 / 49	6%	0.001 - 1.9	15	nc	R9 Res Soil PRG	NA	no
Di-n-butyl phthalate	0.04	0.064	AOC4-15-2	8 / 49	16%	0.001 - 1.9	610	nc	R9 Res Soil PRG	NA	no

Note: Footnotes are on Page 3.

Table 3-2
Occurrence of Detected Chemicals and Selection of Chemicals of Potential Concern – Soil (Maintenance Worker Scenario)
Hamilton Sundstrand Facility, Denver, Colorado.

Chemical Name	Minimum Detected Value (mg/kg)	Maximum Detected Value (mg/kg)	Sample ID of Maximum Detected Value	Frequency of Detection	Frequency of Detection (%)	Range of SQLs (mg/kg)	Screening Level (a) (mg/kg)	Screening Level Text	Screening Level Reference	Site-Specific Background UTLs	COPC?
Di-n-octyl phthalate	–	0.16	SWMU 11-11	1 / 49	2%	0.001 - 1.9	240	nc	R9 Res Soil PRG	NA	no
Fluoranthene	0.02	1.9	AOC2-1-0-SO	10 / 49	20%	0.001 - 1.9	230	nc	R9 Res Soil PRG	NA	no
Fluorene	0.041	0.63	TC10-6	5 / 50	10%	0.001 - 1.9	270	nc	R9 Res Soil PRG	NA	no
Hexachlorobenzene	–	0.021	AOC2-2-0-SO-DUP	1 / 49	2%	0.001 - 1.9	0.3	ca	R9 Res Soil PRG	NA	no
Indeno(1,2,3-cd)pyrene	0.036	0.47	AOC2-1-0-SO	7 / 49	14%	0.001 - 1.9	0.62	ca	R9 Res Soil PRG	NA	no
Naphthalene	0.087	0.23	AOC2-1-0-SO	3 / 49	6%	0.001 - 1.9	5.6	nc	R9 Res Soil PRG	NA	no
Pentachlorobenzene	–	0.048	AOC2-2-0-SO-DUP	1 / 49	2%	0.001 - 1.9	4.9	nc	R9 Res Soil PRG	NA	no
Phenanthrene	0.02	2.1	AOC2-1-0-SO	10 / 50	20%	0.001 - 1.9	2200	nc-anth	R9 Res Soil PRG	NA	no
Pyrene	0.032	2.2	AOC2-1-0-SO	11 / 49	22%	0.001 - 1.9	230	nc	R9 Res Soil PRG	NA	no
Tetrachlorometaxylene	0.0089	0.017	SWMU3-5-0-SO	33 / 34	97%	0.2 - 0.2	NE	–	R9 Res Soil PRG	NA	no

Note: Statistics are based on data collected from 0 to 2 feet below ground surface (bgs).

(a) PRGs based on non-carcinogenic effects were adjusted by a factor of 0.1 following USEPA (1993) guidance.
COPC – Chemical of Potential Concern. A chemical is selected as a COPC if the maximum detected concentration exceeds the risk-based screening level. For metals, if the maximum detected concentration is greater than the risk-based screening level, but below the site-specific background UTL then it was not selected as a COPC.
mg/kg – milligrams per kilogram
R9 Res Soil PRG – USEPA Region 9 Preliminary Remediation Goal for Soil
ca – PRG based on carcinogenic effects
nc – PRG based on noncarcinogenic effects

IEUBK- PRG based on EPA's Integrated Exposure Uptake Biokinetic Model
UTL Upper Tolerance Limit
nc-anth – PRG for anthracene was used as a surrogate
nc-naph – PRG for naphthalene was used as a surrogate
nc-tot – PRG for total xylenes was used as a surrogate
nc-cis – PRG for cis-1,2-DCE was used as a surrogate
nc-124 – PRG for 1,2,4-trichlorobenzene was used as a surrogate
ca -1260 – PRG for Aroclor 1260 was used as a surrogate
– One detection was observed and that is presented as the maximum detected value.

Table 3-3
Occurrence of Detected Chemicals and Selection of Chemicals of Potential Concern – Soil (Construction Worker Scenario)
Hamilton Sundstrand Facility, Denver, Colorado.

Chemical Name	Minimum Detected Value (mg/kg)	Maximum Detected Value (mg/kg)	Sample ID of Maximum Detected Value	Frequency of Detection	Frequency of Detection (%)	Range of SQLs (mg/kg)	Screening Level (a) (mg/kg)	Screening Level Text	Screening Level Reference	Site-Specific Background UTLs	COPC?
PCBs											
Aroclor 1242	0.027	100	AOC2-T4-6'RE	9 / 108	8%	0.001 - 0.21	NE	–	R9 Res Soil PRG	NA	no
Aroclor 1248	0.034	310	BS-2-6 (1.8')	30 / 133	23%	0.001 - 7.7	NE	–	R9 Res Soil PRG	NA	no
Aroclor 1254	0.02	0.12	SWMU3-5-9-SO	4 / 108	4%	0.001 - 7.7	0.22	ca	R9 Res Soil PRG	NA	no
Aroclor 1260	0.021	0.52	AOC2-1-0-SO	7 / 108	6%	0.001 - 7.7	0.22	ca	R9 Res Soil PRG	NA	YES
Total PCBs	0	11	TC10-6-5	27 / 27	100%	-	0.22	ca-1260	R9 Res Soil PRG	NA	YES
Metals											
Antimony	0.56	2	AOC4-14-2	32 / 136	24%	0.48 - 6.9	3.1	nc	R9 Res Soil PRG	1.4	no
Arsenic	0.88	24.2	SWMU7-3-9-SO	134 / 136	99%	1 - 1	0.39	ca	R9 Res Soil PRG	7.0	YES
Barium	42.3	1630	SWMU	136 / 136	100%	-	540	nc	R9 Res Soil PRG	732.3	YES
Beryllium	0.17	1.3	AOC4-16-2	112 / 136	82%	0.019 - 1	15	nc	R9 Res Soil PRG	1.3	no
Cadmium	0.058	1.3	SWMU9-2-0-SO	45 / 136	33%	0.028 - 1.1	3.7	nc	R9 Res Soil PRG	0.1	no
Chromium	3	146	AOC2-1-0-SO	136 / 136	100%	-	210	ca	R9 Res Soil PRG	28.7	no
Cobalt	1.2	14	AOC5-6-2'	136 / 136	100%	-	900	ca	R9 Res Soil PRG	11.2	no
Copper	2.3	368	SWMU10-7-0-SO	136 / 136	100%	-	310	nc	R9 Res Soil PRG	21.6	YES
Cyanide	0.63	32.7	SWMU9-1-0-SO	5 / 39	13%	0.56 - 1	120	nc	R9 Res Soil PRG	NA	no
Lead	2.9	133	SWMU10-7-0-SO	136 / 136	100%	-	400	IEUBK	R9 Res Soil PRG	18.4	no
Manganese	–	224	SB-1-8	1 / 1	100%	-	180	nc	R9 Res Soil PRG	343 (d)	no
Mercury	0.017	2	AOC4-2-0-SO	28 / 98	29%	0.014 - 1	2.3	nc	R9 Res Soil PRG	0.0	no
Nickel	1.6	25.1	AOC1-3-0-SO	136 / 136	100%	-	160	nc	R9 Res Soil PRG	22.3	no
Selenium	0.27	11	AOC2-T3-6'	58 / 136	43%	0.22 - 1	39	nc	R9 Res Soil PRG	1.1	no
Silver	0.16	5.4	AOC4-5-0-SO	35 / 136	26%	0.15 - 1.1	39	nc	R9 Res Soil PRG	0.3	no
Thallium	0.4	1.7	AOC	36 / 136	26%	0.39 - 1.1	0.52	nc	R9 Res Soil PRG	1.7	no
Tin	0.44	19.8	SWMU10-7-0-SO	92 / 135	68%	0.31 - 1	4700	nc	R9 Res Soil PRG	1.8	no
Vanadium	8.5	45.8	MB-2-7	136 / 136	100%	-	7.8	nc	R9 Res Soil PRG	60.1	no
Zinc	10.2	177	AOC2-1-0-SO	137 / 137	100%	-	2300	nc	R9 Res Soil PRG	80.6	no
Volatile Organic Compounds (VOCs)											
1,1,1-Trichloroethane	0.00055	560	TH10-E	70 / 159	44%	0.00052 - 7.9	1200	sat	Reg 9 PRG Res Soil	NA	no
1,1,2,2-Tetrachloroethane	–	1.7	TH10-1	1 / 151	1%	0.00061 - 10	0.41	ca	Reg 9 PRG Res Soil	NA	YES
1,1,2-Trichloro-1,2,2-trifluoroethane	–	0.00071	SWMU12-2-7-SO	1 / 130	1%	0.001 - 10	5600	sat	Reg 9 PRG Res Soil	NA	no
1,1,2-Trichloroethane	0.0016	6.7	AOC 6-3-5'-7'	4 / 150	3%	0.00088 - 0.66	0.73	ca	Reg 9 PRG Res Soil	NA	YES
1,1-Dichloroethane	0.00051	21	AOC 6-3-5'-7'	49 / 152	32%	0.00054 - 0.83	51	nc	Reg 9 PRG Res Soil	NA	no
1,1-Dichloroethene	0.00069	61	AOC 6-3-5'-7'	23 / 150	15%	0.00059 - 0.83	12	nc	Reg 9 PRG Res Soil	NA	YES
1,2,3-Trichlorobenzene	0.00046	0.0015	AOC4-14-2	5 / 143	3%	0.00075 - 10	6.2	nc-124	Reg 9 PRG Res Soil	NA	no
1,2,4-Trichlorobenzene	0.0004	1.2	AOC2-T4-6'	8 / 143	6%	0.00073 - 10	6.2	nc	Reg 9 PRG Res Soil	NA	no
1,2,4-Trimethylbenzene	0.0007	260	SWMU5-7-8-SO	26 / 143	18%	0.00058 - 0.65	5.2	nc	Reg 9 PRG Res Soil	NA	YES
1,2-Dichlorobenzene	–	0.0017	SWMU4-1-5-SO	1 / 144	1%	0.00045 - 47	600	sat	Reg 9 PRG Res Soil	NA	no
1,2-Dichloroethane	0.0014	0.0016	SWMU5-7-2-SO	2 / 150	1%	0.0007 - 10	0.28	ca	Reg 9 PRG Res Soil	NA	no
1,2-Dichloroethene (total)	0.0005	42	AOC 6-3-5'-7'DL	41 / 153	27%	0.00039 - 0.66	4.3	nc-cis	Reg 9 PRG Res Soil	NA	no (b)
1,3,5-Trimethylbenzene	0.0017	88	SWMU5-7-8-SO	16 / 143	11%	0.00057 - 0.65	2.1	nc	Reg 9 PRG Res Soil	NA	YES
1,3-Dichlorobenzene	0.00055	0.017	AOC2-3-0-SO	5 / 143	3%	0.00048 - 10	53	nc	Reg 9 PRG Res Soil	NA	no
1,4-Dichlorobenzene	0.0021	1.4	AOC2-T2-6'	5 / 143	3%	0.00078 - 10	3.4	ca	Reg 9 PRG Res Soil	NA	no
1,4-Dioxane	0.049	0.81	SWMU10-7-0-SO	6 / 29	21%	0.12 - 16	44	ca	Reg 9 PRG Res Soil	NA	no
2-Butanone (MEK)	0.002	1.6	SWMU5-2-8-SO	75 / 150	50%	0.001 - 10	2200	nc	Reg 9 PRG Res Soil	NA	no
2-Chlorotoluene	–	0.0011	SWMU4-1-5-SO	1 / 143	1%	0.00051 - 10	16	nc	Reg 9 PRG Res Soil	NA	no
2-Hexanone	0.00066	0.068	SWMU4-1-5-SODL	4 / 150	3%	0.001 - 10	NE	–	Reg 9 PRG Res Soil	NA	no
4-Chlorotoluene	–	0.0013	SWMU4-1-5-SO	1 / 143	1%	0.00078 - 10	NE	–	Reg 9 PRG Res Soil	NA	no
4-Methyl-2-pentanone	0.00064	0.18	SB-1	6 / 150	4%	0.001 - 10	530	nc	Reg 9 PRG Res Soil	NA	no

Note: Footnotes are on Page 3.

Table 3-3
Occurrence of Detected Chemicals and Selection of Chemicals of Potential Concern – Soil (Construction Worker Scenario)
Hamilton Sundstrand Facility, Denver, Colorado.

Chemical Name	Minimum Detected Value (mg/kg)	Maximum Detected Value (mg/kg)	Sample ID of Maximum Detected Value	Frequency of Detection	Frequency of Detection (%)	Range of SQLs (mg/kg)	Screening Level (a) (mg/kg)	Screening Level Text	Screening Level Reference	Site-Specific Background UTLs	COPC?
Acetone	0.0052	8.9	SWMU5-7-8-SO	100 / 150	67%	0.001 - 10	1400	nc	Reg 9 PRG Res Soil	NA	no
Acrolein	0.00045	0.0063	SWMU12-4-2-SO	4 / 130	3%	0.001 - 10	0.01	nc	Reg 9 PRG Res Soil	NA	no
Benzene	0.00064	68	TH10-E	8 / 152	5%	0.00047 - 0.74	0.64	ca	Reg 9 PRG Res Soil	NA	YES
Bromobenzene	–	0.001	SWMU4-1-5-SO	1 / 143	1%	0.00049 - 10	2.8	nc	Reg 9 PRG Res Soil	NA	no
Bromomethane	0.00084	0.0024	AOC4-1-0-SO	4 / 150	3%	0.0005 - 10	0.39	nc	Reg 9 PRG Res Soil	NA	no
Carbon disulfide	0.00049	0.021	AOC2-3-0-SO	27 / 130	21%	0.001 - 10	36	nc	Reg 9 PRG Res Soil	NA	no
Chloroethane	0.0016	0.0075	SWMU-11-2-4.5-SORE	2 / 150	1%	0.00089 - 10	3	ca	Reg 9 PRG Res Soil	NA	no
Chloroform	–	0.00094	SWMU12-2-7-SO	1 / 150	1%	0.00058 - 10	0.22	ca	Reg 9 PRG Res Soil	NA	no
Chloromethane	0.00085	0.0058	AOC1-3-0-SO	8 / 150	5%	0.00077 - 10	4.7	nc	Reg 9 PRG Res Soil	NA	no
cis-1,2-Dichloroethene	0.00047	42	AOC 6-3-5'-7'DL	38 / 143	27%	0.00056 - 0.65	4.3	nc	Reg 9 PRG Res Soil	NA	YES
Ethylbenzene	0.00068	61	SWMU5-7-8-SO	16 / 155	10%	0.00067 - 0.66	400	sat	Reg 9 PRG Res Soil	NA	no
Hexachlorobutadiene	0.0007	0.0012	AOC4-14-2	2 / 143	1%	0.00055 - 10	6.2	ca	Reg 9 PRG Res Soil	NA	no
Iodomethane	0.00074	0.003	SWMU10-6-0-SO	11 / 130	8%	0.001 - 10	NE	–	Reg 9 PRG Res Soil	NA	no
Isobutyl alcohol	–	110	SWMU5-2-4-SODL	1 / 122	1%	0.001 - 520	1300	nc	Reg 9 PRG Res Soil	NA	no
Isopropylbenzene	0.00086	10	SWMU5-7-8-SO	8 / 143	6%	0.00059 - 0.65	57	nc	Reg 9 PRG Res Soil	NA	no
m&p-Xylene	0.00083	290	SWMU5-7-8-SO	16 / 137	12%	0.001 - 0.65	27	nc-tot	Reg 9 PRG Res Soil	NA	no (c)
Methacrylonitrile	–	0.078	SWMU13-1-8-SO	1 / 130	1%	0.001 - 10	0.21	nc	Reg 9 PRG Res Soil	NA	no
Methyl methacrylate	–	6.4	SWMU5-2-4-SODL	1 / 130	1%	0.001 - 10	220	nc	Reg 9 PRG Res Soil	NA	no
Methylene chloride	0.00081	3	TH10-1	7 / 151	5%	0.00075 - 10	9.1	ca	Reg 9 PRG Res Soil	NA	no
Naphthalene	0	56	SWMU5-7-8-SO	19 / 146	13%	0.00063 - 47	5.6	nc	Reg 9 PRG Res Soil	NA	YES
n-Butylbenzene	0.00077	35	SWMU5-7-8-SO	14 / 143	10%	0.00056 - 10	240	sat	Reg 9 PRG Res Soil	NA	no
n-Propylbenzene	0.00067	43	SWMU5-7-8-SO	12 / 143	8%	0.00058 - 0.65	240	sat	Reg 9 PRG Res Soil	NA	no
o-Xylene	0.00055	120	SWMU5-7-8-SO	13 / 132	10%	0.00061 - 0.65	27	nc-tot	Reg 9 PRG Res Soil	NA	no (c)
p-Isopropyltoluene	0.0016	13	RT-SVE-3(7.8-8.8)	12 / 143	8%	0.00049 - 0.65	NE	–	Reg 9 PRG Res Soil	NA	no
sec-Butylbenzene	0.0021	9.9	SWMU5-7-8-SO	13 / 143	9%	0.00077 - 0.65	220	sat	Reg 9 PRG Res Soil	NA	no
t-Butylbenzene	–	0.0014	SWMU4-1-5-SO	1 / 143	1%	0.0005 - 10	390	sat	Reg 9 PRG Res Soil	NA	no
Tetrachloroethene	0.00051	160	TC10-6	80 / 157	51%	0.00059 - 0.5	0.48	ca	Reg 9 PRG Res Soil	NA	YES
Toluene	0.00095	170	TH10-E	24 / 153	16%	0.00069 - 0.33	520	sat	Reg 9 PRG Res Soil	NA	no
Trichloroethene	0.00051	340	TH10-7	55 / 154	36%	0.00049 - 0.5	0.053	ca	Reg 9 PRG Res Soil	NA	YES
Vinyl chloride	–	0.0015	SWMU13-1-0-SORE	1 / 150	1%	0.00058 - 10	0.079	ca	Reg 9 PRG Res Soil	NA	no
Xylenes, total	0.00068	430	SWMU5-7-8-SO	25 / 156	16%	0.00061 - 0.65	27	nc	Reg 9 PRG Res Soil	NA	YES
<u>Semi-volatile Organic Compounds (SVOCs)</u>											
1,1-Biphenyl	–	0.037	AOC2-T2-6'	1 / 45	2%	0.35 - 7.6	300	nc	R9 Res Soil PRG	NA	no
1,2,4,5-Tetrachlorobenzene	–	0.078	AOC2-3-0-SORE	1 / 83	1%	0.001 - 7.6	1.8	nc	R9 Res Soil PRG	NA	no
1,2,4-Trichlorobenzene	0.058	2.2	AOC2-T4-6'	4 / 85	5%	0.001 - 47	6.2	nc	R9 Res Soil PRG	NA	no
1,3-Dichlorobenzene	0.048	0.14	AOC2-T2-6'RE	3 / 84	4%	0.001 - 47	53	nc	R9 Res Soil PRG	NA	no
1,4-Dichlorobenzene	0.089	1.1	AOC2-T2-6'RE	3 / 84	4%	0.001 - 47	3.4	ca	R9 Res Soil PRG	NA	no
2,4,6-Tribromophenol	0.43	3.2	SWMU9-4-5-SO	38 / 38	100%	-	NE	–	R9 Res Soil PRG	NA	no
2,4-Dimethylphenol	–	0.18	SWMU12-5-2	1 / 84	1%	0.001 - 47	120	nc	R9 Res Soil PRG	NA	no
2-Fluorobiphenyl	1.3	3.6	AOC2-3-0-SORE	38 / 38	100%	-	NE	–	R9 Res Soil PRG	NA	no
2-Fluorophenol	1.2	3.7	AOC2-3-0-SORE	38 / 38	100%	-	NE	–	R9 Res Soil PRG	NA	no
2-Methylnaphthalene	0	2.4	TC10-6	7 / 87	8%	0.001 - 47	5.6	nc	R9 Res Soil PRG	NA	no
4-Chloro-3-Methylphenol	0	1.6	TC10-6	2 / 86	2%	0.001 - 47	NE	–	R9 Res Soil PRG	NA	no
4-Methylphenol	0.017	0.22	SWMU12-5-2	2 / 84	2%	0.001 - 47	31	nc	R9 Res Soil PRG	NA	no
Acenaphthene	0.057	0.43	AOC2-1-0-SO	6 / 84	7%	0.001 - 47	370	nc	R9 Res Soil PRG	NA	no
Acetophenone	0.02	0.072	AOC4-8-78RE	8 / 83	10%	0.001 - 7.6	NE	–	R9 Res Soil PRG	NA	no
Anthracene	0.027	0.53	SWMU12-9-3.2	7 / 84	8%	0.001 - 47	2200	nc	R9 Res Soil PRG	NA	no
Benzaldehyde	0.019	0.048	SWMU12-6-2	3 / 45	7%	0.35 - 7.6	610	nc	R9 Res Soil PRG	NA	no
Benzo(a)Anthracene	0.019	0.77	AOC2-1-0-SO	10 / 84	12%	0.001 - 47	0.62	ca	R9 Res Soil PRG	NA	YES

Note: Footnotes are on Page 3.

Table 3-3

Occurrence of Detected Chemicals and Selection of Chemicals of Potential Concern – Soil (Construction Worker Scenario)

Hamilton Sundstrand Facility, Denver, Colorado.

Chemical Name	Minimum Detected Value (mg/kg)	Maximum Detected Value (mg/kg)	Sample ID of Maximum Detected Value	Frequency of Detection	Frequency of Detection (%)	Range of SQLs (mg/kg)	Screening Level (a) (mg/kg)	Screening Level Text	Screening Level Reference	Site-Specific Background UTLs	COPC?
Benzo(a)pyrene	0.022	0.55	AOC2-1-0-SO	10 / 84	12%	0.001 - 47	0.062	ca	R9 Res Soil PRG	NA	YES
Benzo(b)fluoranthene	0.024	0.63	AOC2-1-0-SO	10 / 84	12%	0.001 - 47	0.62	ca	R9 Res Soil PRG	NA	YES
Benzo(g,h,i)perylene	0.055	0.6	AOC2-1-0-SO	8 / 84	10%	0.001 - 47	5.6	nc-naph	R9 Res Soil PRG	NA	no
Benzo(k)fluoranthene	0.022	0.67	AOC2-1-0-SO	10 / 84	12%	0.001 - 47	6.2	ca	R9 Res Soil PRG	NA	no
Benzoic Acid	–	0.13	AOC4-15-2	1 / 46	2%	0.88 - 230	100000	max	R9 Res Soil PRG	NA	no
bis(2-ethylhexyl) Phthalate	0	0.93	SWMU12-9-3.2	34 / 85	40%	0.001 - 47	35	ca	R9 Res Soil PRG	NA	no
Butyl benzyl phthalate	0.024	0.05	SWMU 11-11	4 / 84	5%	0.001 - 47	1200	nc	R9 Res Soil PRG	NA	no
Carbazole	0.027	0.3	AOC2-1-0-SO	5 / 83	6%	0.001 - 7.6	24	ca	R9 Res Soil PRG	NA	no
Chrysene	0.025	0.84	AOC2-1-0-SO	10 / 84	12%	0.001 - 47	62	ca	R9 Res Soil PRG	NA	no
Decachlorobiphenyl	0.0098	0.017	SWMU-11-3-5-SO	58 / 61	95%	0.001 - 0.2	NE	–	R9 Res Soil PRG	NA	no
Dibenzo(a,h)anthracene	0.023	0.17	AOC2-1-0-SO	5 / 84	6%	0.001 - 47	0.062	ca	R9 Res Soil PRG	NA	YES
Dibenzofuran	0.05	0.41	SWMU12-9-3.2	5 / 84	6%	0.001 - 47	15	nc	R9 Res Soil PRG	NA	no
Di-n-butyl phthalate	0.022	0.064	AOC4-15-2	15 / 84	18%	0.001 - 47	610	nc	R9 Res Soil PRG	NA	no
Di-n-octyl phthalate	–	0.16	SWMU 11-11	1 / 84	1%	0.001 - 47	240	nc	R9 Res Soil PRG	NA	no
Fluoranthene	0.02	1.9	AOC2-1-0-SO	15 / 84	18%	0.001 - 47	230	nc	R9 Res Soil PRG	NA	no
Fluorene	0	0.63	TC10-6	10 / 86	12%	0.001 - 47	270	nc	R9 Res Soil PRG	NA	no
Hexachlorobenzene	–	0.021	AOC2-2-0-SO-DUP	1 / 84	1%	0.001 - 47	0.3	ca	R9 Res Soil PRG	NA	no
Indeno(1,2,3-cd)pyrene	0.036	0.47	AOC2-1-0-SO	8 / 84	10%	0.001 - 47	0.62	ca	R9 Res Soil PRG	NA	no
Naphthalene	0.087	0.24	SWMU12-9-3.2	5 / 83	6%	0.001 - 7.6	5.6	nc	R9 Res Soil PRG	NA	no
Pentachlorobenzene	–	0.048	AOC2-2-0-SO-DUP	1 / 83	1%	0.001 - 7.6	4.9	nc	R9 Res Soil PRG	NA	no
Phenanthrene	0	3.3	SWMU12-9-3.2	13 / 86	15%	0.001 - 47	2200	nc-anth	R9 Res Soil PRG	NA	no
Pyrene	0.032	2.2	AOC2-1-0-SO	16 / 84	19%	0.001 - 47	230	nc	R9 Res Soil PRG	NA	no
Tetrachlorometaxylene	0.0089	0.018	SWMU3-5-9-SO	60 / 61	98%	0.2 - 0.2	NE	–	R9 Res Soil PRG	NA	no

Note: Statistics are based on data collected from 0 to 9.5 feet below ground surface (bgs).

(a) PRGs based on non-carcinogenic effects were adjusted by a factor of 0.1 following USEPA (1993) guidance.

(b) Total 1,2 DCE was not identified as a COPC because cis 1,2 DCE was evaluated.

(c) Individual isomers were not identified as COPCs because total xylenes were retained.

(d) Mean background concentration for manganese in Colorado surface soils, as cited in USEPA, 2005b.

COPC – Chemical of Potential Concern. A chemical is selected as a COPC if the maximum detected concentration exceeds the risk-based screening level. For metals, if the maximum detected concentration is greater than the risk-based screening level, but below the site-specific background UTL then it was not selected as a COPC.

NA Not Available.

mg/kg – milligrams per kilogram

R9 Res Soil PRG – USEPA Region 9 Preliminary Remediation Goal for Soil

ca – PRG based on carcinogenic effects

nc – PRG based on noncarcinogenic effects

IEUBK- PRG based on EPA's Integrated Exposure Uptake Biokinetic Model

UTL Upper Tolerance Limit

nc-anth – PRG for anthracene was used as a surrogate

nc-naph – PRG for naphthalene was used as a surrogate

nc-tot – PRG for total xylenes was used as a surrogate

nc-cis – PRG for cis-1,2-DCE was used as a surrogate

nc-124 – PRG for 1,2,4-trichlorobenzene was used as a surrogate

ca -1260 – PRG for Aroclor 1260 was used as a surrogate

– One detection was observed and that is presented as the maximum detected value.

Table 3-4
Occurrence of Detected Chemicals and Selection of Chemicals of Potential Concern – Groundwater
Hamilton Sundstrand Facility, Denver, Colorado.

Chemical Name	Minimum Detected Value (ug/L)	Maximum Detected Value (ug/L)	Sample ID of Maximum Detected Value	Frequency of Detection	Frequency of Detection (%)	Range of SQLs (ug/L)	Screening Level (a) (ug/L)	Screening Level Text	Screening Level Reference	COPC?
Volatile Organic Compounds (VOCs)										
1,1,1-Trichloroethane	0.2	65000	AOC3-1-HIGH	559 / 824	68%	0.16 - 10	320	nc	Reg 9 PRG Tap Water	YES
1,1,2,2-Tetrachloroethane	–	510	GW-30	1 / 824	0.1%	0.2 - 800	0.055	ca	Reg 9 PRG Tap Water	YES
1,1,2-Trichloro-1,2,2-trifluoroethane	0.21	33	SWMU5-1	15 / 537	3%	0.79 - 270	5900	nc	Reg 9 PRG Tap Water	no
1,1,2-Trichloroethane	0.24	18	SWMU 5-1	19 / 824	2%	0.32 - 1300	0.2	ca	Reg 9 PRG Tap Water	YES
1,1-Dichloroethane	0.17	2700	TP-10-1-HIGH	485 / 824	59%	0.16 - 640	81	nc	Reg 9 PRG Tap Water	YES
1,1-Dichloroethene	0.2	6800	AOC3-1-HIGH	472 / 824	57%	0.14 - 5	34	nc	Reg 9 PRG Tap Water	YES
1,2,3-Trichlorobenzene	0.21	1	TP-26	5 / 824	1%	0.18 - 720	NE	–	Reg 9 PRG Tap Water	no
1,2,4-Trichlorobenzene	0.2	17	GW-33	7 / 824	1%	0.32 - 1300	0.72	nc	Reg 9 PRG Tap Water	YES
1,2,4-Trimethylbenzene	0.16	5000	SLOMU5-1	77 / 824	9%	0.14 - 560	1.2	nc	Reg 9 PRG Tap Water	YES
1,2-Dichlorobenzene	0.32	2.6	TP-5	4 / 824	0.5%	0.13 - 520	37	nc	Reg 9 PRG Tap Water	no
1,2-Dichloroethane	0.16	3.9	PW-2	22 / 824	3%	0.13 - 520	0.12	ca	Reg 9 PRG Tap Water	YES
1,2-Dichloroethene (total)	0.16	7300	SWMU5-1DL	407 / 683	60%	0.15 - 600	6.1	nc-cis	Reg 9 PRG Tap Water	no (b)
1,3,5-Trimethylbenzene	0.45	1700	SLOMU5-1	53 / 824	6%	0.14 - 560	1.2	nc	Reg 9 PRG Tap Water	YES
1,4-Dioxane	12	150	GW-4	5 / 128	4%	1 - 71000	6.1	ca	Reg 9 PRG Tap Water	YES
2-Butanone (MEK)	5.2	940	GW-62	36 / 824	4%	1 - 7300	700	nc	Reg 9 PRG Tap Water	YES
2-Hexanone	9.5	360	TP-5	2 / 824	0.2%	1 - 5600	NE	–	Reg 9 PRG Tap Water	no
4-Methyl-2-pentanone	–	8.1	GW-62	1 / 824	0.1%	0.49 - 2000	200	nc	Reg 9 PRG Tap Water	no
Acetone	1.3	320	AOC1-3-GW	114 / 824	14%	1 - 7600	550	nc	Reg 9 PRG Tap Water	no
Benzene	0.17	250	SLOMU5-1	56 / 824	7%	0.16 - 640	0.35	ca	Reg 9 PRG Tap Water	YES
Bromodichloromethane	0.24	1.6	GW-59	6 / 824	1%	0.17 - 680	0.18	ca	Reg 9 PRG Tap Water	YES
Bromomethane	–	1	GW-58	1 / 824	0.1%	0.21 - 840	0.87	nc	Reg 9 PRG Tap Water	YES
Carbon disulfide	0.23	1.8	GW-4	7 / 553	1%	0.45 - 270	100	nc	Reg 9 PRG Tap Water	no
Carbon tetrachloride	–	0.94	GW-49	1 / 824	0.1%	0.19 - 760	0.17	ca	Reg 9 PRG Tap Water	YES
Chloroethane	0.25	38	PW-2	16 / 824	2%	0.41 - 1600	4.6	ca	Reg 9 PRG Tap Water	YES
Chloroform	0.18	64	AOC1-3	98 / 824	12%	0.16 - 640	0.17	ca	Reg 9 PRG Tap Water	YES
Chloromethane	0.21	0.65	GW-63	26 / 824	3%	0.3 - 1200	16	nc	Reg 9 PRG Tap Water	no
cis-1,2-Dichloroethene	0.16	6900	SWMU5-1DL	467 / 824	57%	0.15 - 600	6.1	nc	Reg 9 PRG Tap Water	YES
Decanal	–	1.8	GW-13	1 / 1	100%	-	NE	–	Reg 9 PRG Tap Water	no
Ethyl methacrylate	–	220	GW-30	1 / 537	0.2%	0.86 - 270	55	nc	Reg 9 PRG Tap Water	YES
Ethylbenzene	0.17	1500	SLOMU5-1	59 / 824	7%	0.16 - 640	130	nc	Reg 9 PRG Tap Water	YES
Iodomethane	–	0.22	GW-58	1 / 537	0.2%	0.23 - 270	NE	–	Reg 9 PRG Tap Water	no
Isobutyl alcohol	3.4	400	TP-2	6 / 266	2%	1 - 36000	180	nc	Reg 9 PRG Tap Water	YES
Isopropylbenzene	0.22	54	SWMU5-1	43 / 824	5%	0.19 - 760	66	nc	Reg 9 PRG Tap Water	no
m&p-Xylene	0.66	5400	SLOMU5-1	46 / 824	6%	0.34 - 1400	21	nc-tot	Reg 9 PRG Tap Water	no (c)
Methyl methacrylate	8	13	TP-2	4 / 539	1%	1 - 270	140	nc	Reg 9 PRG Tap Water	no
Methyl tert-Butyl Ether	0.2	80	GW-46	27 / 824	3%	0.25 - 1000	6.2	ca	Reg 9 PRG Tap Water	YES
Methylene chloride	0.35	660	TP-3	52 / 824	6%	0.32 - 1300	4.3	ca	Reg 9 PRG Tap Water	YES
Naphthalene	0.28	1200	SLOMU5-1	64 / 824	8%	0.22 - 880	0.62	nc	Reg 9 PRG Tap Water	YES
n-Butylbenzene	0.16	560	SLOMU5-1	44 / 824	5%	0.14 - 560	24	nc	Reg 9 PRG Tap Water	YES
n-Propylbenzene	0.17	600	SLOMU5-1	51 / 824	6%	0.16 - 640	24	nc	Reg 9 PRG Tap Water	YES
o-Xylene	0.45	2900	SLOMU5-1	61 / 824	7%	0.19 - 760	21	nc-tot	Reg 9 PRG Tap Water	no (c)
p-Isopropyltoluene	0.19	110	GW-33	43 / 824	5%	0.17 - 680	NE	–	Reg 9 PRG Tap Water	no

Note: Footnotes are on Page 2.

Table 3-4
Occurrence of Detected Chemicals and Selection of Chemicals of Potential Concern – Groundwater
Hamilton Sundstrand Facility, Denver, Colorado.

Chemical Name	Minimum Detected Value (ug/L)	Maximum Detected Value (ug/L)	Sample ID of Maximum Detected Value	Frequency of Detection	Frequency of Detection (%)	Range of SQLs (ug/L)	Screening Level (a) (ug/L)	Screening Level Text	Screening Level Reference	COPC?
sec-Butylbenzene	0.22	76	SWMU 5-2	54 / 824	7%	0.17 - 680	24	nc	Reg 9 PRG Tap Water	YES
Styrene	11	380	TP-2(GW)	2 / 824	0.2%	0.17 - 680	160	nc	Reg 9 PRG Tap Water	YES
t-Butylbenzene	0.17	15	GW-33	17 / 824	2%	0.16 - 640	24	nc	Reg 9 PRG Tap Water	no
Tetrachloroethene	0.2	940	A0C4-11	612 / 830	74%	0.2 - 800	0.1	ca	Reg 9 PRG Tap Water	YES
Tetrahydrofuran	–	18	TP-15DL	1 / 537	0.2%	1 - 2700	1.6	ca	Reg 9 PRG Tap Water	YES
Toluene	0.2	390	AOC 6-9	33 / 824	4%	0.17 - 680	72	nc	Reg 9 PRG Tap Water	YES
trans-1,2-Dichloroethene	0.18	24	TP-16	49 / 824	6%	0.15 - 600	12	nc	Reg 9 PRG Tap Water	YES
Trichloroethene	0.18	770	SWMU 5-1	602 / 831	72%	0.16 - 640	0.028	ca	Reg 9 PRG Tap Water	YES
Vinyl chloride	0.23	3.8	GW-46	4 / 824	0.5%	0.17 - 680	0.02	ca	Reg 9 PRG Tap Water	YES
Xylenes, total	0.45	1900	SWMU5-1	49 / 682	7%	0.19 - 760	21	nc	Reg 9 PRG Tap Water	YES

(a) PRGs based on non-carcinogenic effects were adjusted by a factor of 0.1 following USEPA (1993) guidance.

(b) Total 1,2 DCE was not identified as a COPC because cis 1,2 DCE was evaluated.

(c) Individual isomers were not identified as COPCs because total xylenes were retained.

COPC – Chemical of Potential Concern. A chemical is selected as a COPC if the maximum detected concentration exceeds the risk-based screening level. If the maximum detected concentration is less than the risk-based screening level, then it was not selected as a COPC.

ug/L – micrograms per liter
R9 tap water PRG – USEPA Region 9 Preliminary Remediation Goal for tap water
ca – PRG based on carcinogenic effects
nc – PRG based on noncarcinogenic effects
nc-tot – PRG for total xylenes was used as a surrogate
nc-cis – PRG for cis-1,2-DCE was used as a surrogate
– One detection was observed and that is presented as the maximum detected value.

Table 4-1. Receptor-Specific Exposure Parameters, Hamilton Sundstrand Facility, Denver, Colorado.

			High-Use Recreational User						Average-Use Recreational User						Maintenance Worker		Construction Worker	
Parameter	Symbol	units	Child		Youth		Adult		Child		Youth		Adult					
General Factors																		
Averaging Time (cancer)	ATc	days	25,550	[a]	25,550	[a]	25,550	[a]	25,550	[a]	25,550	[a]	25,550	[a]	25,550	[a]	25,550	[a]
Averaging Time (noncancer)	ATnc	days	2,190	[a]	3,650	[a]	10,950	[a]	2,190	[a]	2,190	[a]	10,950	[a]	9,125	[a]	42	[a]
Body Weight	BW	kg	15	[e]	45	[e]	70	[b,c]	15	[e]	45	[e]	70	[b,c]	70	[b,c]	70	[b,c]
Exposure Frequency	EF	days/year	100	[h]	130	[g]	100	[h]	40	[j]	50	[i]	40	[j]	225	[f]	—	
Exposure Frequency (Const. Worker)	EF	days/week	—		—		—		—		—		—		—		5	[k]
Exposure Duration	ED	years	6	[b,c]	10	[g]	30	[b,c]	6	[b,c]	6	[i]	30	[b,c]	25	[b,c]	—	
Exposure Duration (Const. Worker)	ED	weeks	—		—		—		—		—		—		—		6	[k]
Groundwater - Inhalation of Volatiles																		
Breathing Rate	BRgw	m^3/day	—		—		—		—		—		—		—		20	[b,c]
Soil - Ingestion (Oral)																		
Incidental Soil Ingestion Rate	IRs	mg/day	200	[c,f]	200	[c,f]	100	[c]	200	[c,f]	100	[c,f]	50	[c]	100	[f]	330	[f]
Fraction Ingested from Souce	FI	unitless	1		1		1		1		1		1		1		1	
Soil - Dermal Contact																		
Exposed Skin Surface Area	SSAs	cm^2	2,800	[d,f]	4,800	[L]	5,700	[d,f]	2,800	[d,f]	4,800	[L]	5,700	[d]	3,300	[d]	3,300	[f]
Soil-to-Skin Adherence Rate	SAR	mg/cm^2/day	0.2	[d,f]	0.2	[d,f]	0.07	[d,f]	0.2	[d,f]	0.2	[d,f]	0.07	[d]	0.2	[d]	0.3	[f]
Soil - Inhalation of Dust and Vapor																		
Breathing Rate	BRs	m^3/day	8	[n]	14	[m]	20	[c]	8	[n]	14	[m]	20	[c]	20	[b,c]	20	[b,c]

[a] The averaging time for cancer risk is the expected lifespan of 70 years expressed in days.
The averaging time for non-cancer hazard is the total exposure duration expressed in days.

[b] USEPA (1989).

[c] USEPA (1991).

[d] USEPA (2004).

[e] USEPA (1997).

[f] USEPA (2002)

[g] High-use recreational youth assumed to be 7 to 16 year old who accesses the site an average of 4 days/week for 33 weeks/year (i.e., 8 months: March thru October) for recreational activities.

[h] High-use recreational adult and child assumed to access the site an average of 3 days/week for 33 weeks/year (i.e., 8 months: March thru October) for recreational activities.

[i] Average-use recreational youth assumed to be a 7 to 13 year old who accesses the site 1 to 2 days a week for 33 weeks/year (i.e., 8 months: March thru October) for recreational activities.

[j] Average-use recreational adult and child assumed to access the site 5 days a month for 8 months/year for recreational activities.

[k] Exposure frequency of 5 days/week for a 6 week construction project.

[L] Skin surface area averaged across gender for exposure while wearing a short-sleeved shirt, shorts and shoes (USEPA, 1997).

[m] Age-weighted average over gender from recommended inhalation rates of 9 -11 year olds (males 14 m^3/day; females 13 m^3/day), 12-14 year olds (males 15 m^3/day; females 12 m^3/day), and 15-18 year olds (males 17 m^3/day; females 12 m^3/day). (USEPA, 1997).

[n] Age-weighted average from recommended inhalation rates of 6.8 m^3/day, 8.3 m^3/day, and 10m^3/day for age groups of 1-2 years old, 3-5 years old, and 6-8 years old, respectively (USEPA, 1997). Based on negotiation with CDPHE on September 25, 2007, this age-weighted average will be used to represent the site-specific inhalation rate for the child recreational user scenario. These CDPHE negotiated breathing rates represent about 4 hours/day of heavy recreational activity or 6 hours/day of moderate activity by children and adults.

cm	Centimeter.	m	Meter.
kg	Kilogram.	mg	Milligram.

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Table 4-2
Summary of Chemical and Physical Properties
Hamilton Sundstrand Facility, Denver, Colorado.

Chemicals of Potential Concern	Molecular Weight (g/mol)	Water Solubility (mg/L)	Henry's Law Constant (unitless) (25 °C)	Diffusivity in Air (cm^2/sec)	Diffusivity in Water (cm^2/sec)	K_{oc} (L/kg)	Melting Point [a] (°C)
Volatile Organic Compounds							
1,1,1-Trichloroethane	133	1.3E+03	7.1E-01	7.8E-02	8.8E-06	110	-30.4
1,1,2,2-Tetrachloroethane	168	2.9E+03	1.4E-02	7.1E-02	7.9E-06	93	-43.8
1,1,2-Trichloroethane	133	4.4E+03	3.7E-02	7.8E-02	8.8E-06	50	-62.59
1,1-Dichloroethane	99	5.1E+03	2.3E-01	7.4E-02	1.1E-05	32	-96.44
1,1-Dichloroethene	97	2.3E+03	1.1E+00	9.0E-02	1.0E-05	59	-122.5
1,2,4-Trichlorobenzene	181	3.0E+02	5.8E-02	3.0E-02	8.2E-06	1800	17
1,2,4-Trimethylbenzene	120	5.7E+01	2.5E-01	6.4E-02	7.9E-06	718	-43.8
1,2-Dichloroethane	99	8.6E+03	4.8E-02	1.0E-01	9.9E-06	44	-35.5
1,2-Dichloroethene (Total)	97	3.5E+03	1.7E-01	7.4E-02	1.1E-05	44	-94.13
1,3,5-Trimethylbenzene	120	4.8E+01	3.6E-01	6.0E-02	8.7E-06	703	-44.7
1,4-Dioxane	88	2.1E+05	2.0E-04	2.3E-01	1.0E-05	1	11.8
2-Butanone	72	2.2E+05	2.3E-03	8.1E-02	9.8E-06	4	-86.6
Benzene	78	1.8E+03	2.3E-01	8.8E-02	9.8E-06	59	5.5
Bromodichloromethane	164	1.3E+03	8.7E-02	3.0E-02	1.1E-05	35	-57
Bromomethane	95	1.5E+04	2.6E-01	7.3E-02	1.2E-05	9	-105.39
Carbon tetrachloride	154	7.9E+02	1.1E+00	7.8E-02	8.8E-06	49	-23
Chloroethane	65	6.7E+03	4.6E-01	2.7E-01	1.2E-05	24	-138.7
Chloroform	119	8.0E+03	1.5E-01	1.0E-01	1.0E-05	35	-63.6
cis-1,2-Dichloroethene	97	3.5E+03	1.7E-01	7.4E-02	1.1E-05	36	-80
Ethyl methacrylate	114	2.0E+01	1.0E+01	9.1E-02	8.6E-06	840	-67.05
Ethylbenzene	106	1.7E+02	3.2E-01	7.5E-02	7.8E-06	518	-94.9
Isobutyl alcohol	74	8.5E+04	4.9E-04	8.6E-02	9.3E-06	62	-74.01
Methyl tert-Butyl Ether	85	1.5E+05	2.4E-02	8.0E-02	1.0E-05	6	-94.3
Methylene chloride	85	1.3E+04	9.0E-02	1.0E-01	1.2E-05	12	-95.1
Naphthalene	130	3.1E+01	1.8E-02	5.9E-02	7.5E-06	1200	80.2
n-Butylbenzene	134	1.4E+01	5.4E-01	7.5E-02	7.8E-06	2800	-87.9
n-Propylbenzene	120	1.4E+01	5.4E-01	7.5E-02	7.8E-06	2800	-34.98
sec-Butylbenzene	134	1.7E+01	7.7E-01	7.5E-02	7.8E-06	2200	-34.4
Styrene	104	3.1E+02	1.1E-01	7.1E-02	8.0E-06	780	-48.31
Tetrachloroethene	166	2.1E+02	7.5E-01	7.2E-02	8.2E-06	160	-22.3
Tetrahydrofuran	72	1.0E+06	2.9E-03	9.8E-02	1.1E-05	1	-84.89
Toluene	92	5.3E+02	2.7E-01	8.7E-02	8.6E-06	180	-94.9
trans-1,2-Dichloroethene	97	4.5E+03	3.9E-01	7.1E-02	1.2E-05	44	-49.8
Trichloroethene	131	1.1E+03	4.0E-01	7.9E-02	9.1E-06	170	-84.7
Vinyl chloride	63	8.8E+03	1.1E+00	1.1E-01	1.2E-06	24	-153.7
Xylenes (total)	106	1.6E+02	2.7E-01	7.1E-02	7.8E-06	410	-25.2

Table 4-2
Summary of Chemical and Physical Properties
Hamilton Sundstrand Facility, Denver, Colorado.

Chemicals of Potential Concern	Molecular Weight (g/mol)	Water Solubility (mg/L)	Henry's Law Constant (unitless) (25 °C)	Diffusivity in Air (cm²/sec)	Diffusivity in Water (cm²/sec)	K_{oc} (L/kg)	Melting Point [a] (°C)
Semivolatile Organic Compounds							
Benzo(a)Anthracene	228	9.4E-03	7.8E-05	5.1E-02	9.0E-06	231000	84
Benzo(a)pyrene	252	1.6E-03	1.9E-05	4.3E-02	9.0E-06	787000	176.5
Benzo(b)fluoranthene	252	1.5E-03	2.7E-05	2.3E-02	5.6E-06	803000	168
Dibenzo(a,h)anthracene	278	2.5E-03	5.0E-06	2.0E-02	5.2E-06	2620000	269.5
PCBs [b]	326	1.4E-02	1.2E-02	1.6E-02	5.0E-06	75600	134.6
Metals							
Arsenic	78	3.5E+04	3.2E+01	—	—	14	188.28
Barium	137	5.5E+04	1.0E+00	—	—	14	710
Copper	64	4.2E+05	1.0E+00	—	—	14	1083

°C – degrees Celsius
cm^2/sec – square centimeters per second
mg/L – milligrams per liter
L/kg – liters per kilogram
K_{oc} – organic carbon partition coefficient
[a] Melting points were calculated using EPI Suite Software.
[b] PCB (Aroclor 1254) chemical and physical information was taken from EPI Suite Software and the USEPA Vapor Intrusion Model lookup table (methoxychlor).

Table 4-3
Calculation of the Particulate Emission Factor for Wind-Blown Fugitive Dust
Hamilton Sundstrand Facility, Denver, Colorado

$$PEF_{wind} = Q/C_{wind} \times \left[\frac{3600}{0.036 \times (1-V) \times \left(\frac{U_m}{U_t} \right)^3 \times F(x)} \right]$$

PEF_{wind}	**=**	Chronic particulate emission factor for maintenance activities (m^3/kg) =	**8.04E+08**	
where:				
Q/C_{wind}	=	Inverse of 1-hr avg. air concentration at center of the square emission source (g/m^2-s per kg/m^3) =	34.00	USEPA 2002, default
V	=	Fraction of vegetative cover (unitless) =	5.00E-01	USEPA, 2002
U_m	=	Mean annual wind speed (meters per second) =	4.47E+00	NOAA, 1998
U_t	=	Equivalent threshold value of windspeed at 7 m =	1.13E+01	USEPA, 2002
X	=	Function of Ut/Um; x = 0.886 x (Ut/Um)	2.24E+00	USEPA, 2002
F(x)	=	Function dependent on U_m/U_t ; $F(x) = 0.18 \times (8x^3 + 12x) \times \exp(-x^2)$ (unitless) =	1.37E-01	USEPA, 2002

Table 4-4. Calculation of Volatilization Factors for Soil Exposure, Hamilton Sundstrand Facility, Denver, Colorado.

Volatilization Factors (calculated for VOCs only):

Chemical of Potential Concern	Soil Saturation Limit (mg/kg) (Csat)	Diffusivity in Air (cm^2/sec) (D_{air})	Diffusivity in Water (cm^2/sec) (D_{wat})	Henry's Law Constant ($atm\text{-}m^3/mol$) (H)	Henry's Law Constant (unitless) (H_o)	Partition Coefficient (mL/g) (Koc)	Apparent Diffusivity (cm^2/sec) (D_A)	Volatilization Factor (m^3/kg) (VF)
<u>Volatile Organic Compounds</u>								
cis-1,2-Dichloroethene	1,010	0.0736	1.13E-05	4.08E-03	1.67E-01	36	2.99E-04	3.58E+03
1,1,2,2-Tetrachloroethane	1,110	0.0710	7.90E-06	3.50E-04	1.43E-02	93	1.95E-05	1.40E+04
Tetrachloroethene	123	0.0720	8.20E-06	1.77E-02	7.23E-01	160	6.12E-04	2.50E+03
Trichloroethene	641	0.0790	9.10E-06	9.85E-03	4.03E-01	170	3.83E-04	3.16E+03
1,1,2-Trichloroethane	1,340	0.0780	8.80E-06	9.10E-04	3.72E-02	50	6.85E-05	7.48E+03
1,1-Dichloroethene	993	0.0900	1.04E-05	2.61E-02	1.07E+00	59	1.56E-03	1.57E+03
1,2,4-Trimethylbenzene	94.7	0.0644	7.92E-06	6.16E-03	2.52E-01	717.6	6.86E-05	7.47E+03
1,3,5-Trimethylbenzene	79.3	0.0602	8.67E-06	8.77E-03	3.58E-01	703	9.22E-05	6.44E+03
Benzene	613	0.0880	9.80E-06	5.55E-03	2.27E-01	59	4.10E-04	3.06E+03
Naphthalene	220	0.0590	7.50E-06	4.80E-04	1.96E-02	1,200	3.28E-06	3.42E+04
Xylenes, total	168	0.0714	7.80E-06	7.30E-03	2.98E-01	410	1.42E-04	5.19E+03

$$VF = \frac{Q/C_{vol} \times [\,3.14 \times D_A \times T\,]^{1/2}}{2 \times \rho_b \times D_A \times (10{,}000\ cm^2/m^2)}$$

$$D_A = \frac{[\,(\,\theta_{as}^{3.33} \times D_{air} \times H_o\,) + (\,\theta_{ws}^{3.33} \times D_{wat}\,)\,] / \theta_T^2}{(\,\rho_b \times Koc \times Foc\,) + \theta_{ws} + (\,\theta_{as} \times H_o)}$$

Input Parameters

Foc =	0.002	unitless	Fraction organic carbon (USEPA 2002, default)
ρ_b =	1.5	g/cm^3	Soil dry bulk density (USEPA 2002, silt soil type)
θ_{as} =	0.16	unitless	Air-filled soil porosity (θ_T - θ_{ws}), silt soil type
θ_T =	0.46	unitless	Total soil porosity (USEPA 2002, silt soil type)
θ_{ws} =	0.3	unitless	Water-filled soil porosity (USEPA 2002, silt soil type)
Q/C_{vol} =	34.0	$(g/m^2/sec)/(kg/m^3)$	Volatile emission flux per unit concentration (USEPA 2002, default for Denver, CO); based on 43 acre area.
T =	9.5E+08	sec	Exposure interval (USEPA 2002)

—	Not applicable.	kg	Kilogram.	mol	Mole.
atm	Atmosphere.	m	Meter.	*MP*	Not applicable (melting point >30 °C).

Table 4-4. Calculation of Volatilization Factors for Soil Exposure, Hamilton Sundstrand Facility, Denver, Colorado.

Volatilization Factors (calculated for VOCs only):

Chemical of Potential Concern	Soil Saturation Limit (mg/kg) (Csat)	Diffusivity in Air (cm²/sec) (D_{air})	Diffusivity in Water (cm²/sec) (D_{wat})	Henry's Law Constant (atm-m³/mol) (H)	Henry's Law Constant (unitless) (H_o)	Partition Coefficient (mL/g) (Koc)	Apparent Diffusivity (cm²/sec) (D_A)	Volatilization Factor (m³/kg) (VF)

cm	Centimeter.	mg	Milligram.	*NV*	Not applicable (not significantly volatile).
g	Gram.	mL	Milliliter.	sec	Second.

Table 6-1. Health-Based Remedial Goal Equations for Exposure to Soil, Recreational User, Maintenance Worker and Construction Worker Exposure, Hamilton Sundstrand Facility, Denver, Colorado.

ROUTE-SPECIFIC REMEDIAL GOALS:

Oral:

$$(HBRG_o)_{C\ or\ NC} = \frac{(TCR\ or\ THQ) \times BW \times (AT_C\ or\ AT_{NC}) \times (10^6\ mg/kg)}{IRs \times FI \times EF \times ED \times (CSF_o\ or\ [1/RfD_o])}$$

Dermal:

$$(HBRG_d)_{C\ or\ NC} = \frac{(TCR\ or\ THQ) \times BW \times (AT_C\ or\ AT_{NC}) \times (10^6\ mg/kg)}{SSAs \times SAR \times ABSd \times EF \times ED \times (CSF_a\ or\ [1/RfD_a])}$$

Inhalation: (VOCs)

$$(HBRG_i)_{C\ or\ NC} = \frac{(TCR\ or\ THQ) \times BW \times VF \times (AT_C\ or\ AT_{NC})}{BRs \times EF \times ED \times (CSF_i\ or\ [1/RfD_i])}$$

$$VF = \frac{Q/C_{vol} \times [3.14 \times D_A \times T]^{1/2}}{2 \times \rho_b \times D_A \times (10{,}000\ cm^2/m^2)}$$

$$D_A = \frac{[(\theta_{as}^{3.33} \times D_{air} \times H_o) + (\theta_{ws}^{3.33} \times D_{wat})] / \theta_T^2}{(\rho_b \times Koc \times Foc) + \theta_{ws} + (\theta_{as} \times H_o)}$$

Inhalation: (non-VOCs)

$$(HBRG_i)_{C\ or\ NC} = \frac{(TCR\ or\ THQ) \times BW \times PEF \times (AT_C\ or\ AT_{NC})}{BRs \times EF \times ED \times (CSF_i\ or\ [1/RfD_i])}$$

$$PEF = \frac{Q/C_{wind} \times (3{,}600\ sec/hr)}{RPF \times (1-V) \times (Um/Ut)^3 \times Fx}$$

REMEDIAL GOAL BASED ON CANCER EFFECTS: (combining all exposure routes)

$$HBRG_C = \frac{1}{[1/(HBRG_o)_C] + [1/(HBRG_d)_C] + [1/(HBRG_i)_C]}$$

REMEDIAL GOAL BASED ON NON-CANCER EFFECTS: (combining all exposure routes)

$$HBRG_{NC} = \frac{1}{[1/(HBRG_o)_{NC}] + [1/(HBRG_d)_{NC}] + [1/(HBRG_i)_{NC}]}$$

$HBRG = MINIMUM\ of\ HBRG_C\ and\ HBRG_{NC}$

HBRG for VOCs with melting point less than 30°C should not exceed the soil saturation limit (C_{sat}):

$$C_{sat} = \frac{S}{\rho_b} \times [(Koc \times Foc \times \rho_b) + \theta_{ws} + (H_o \times \theta_{as})]$$

Variable Definitions:	
θ_{as}	Air-filled porosity of the soil (unitless).
θ_T	Total soil porosity (unitless).
θ_{ws}	Water-filled porosity of the soil (unitless).
ρ_b	Dry soil bulk density (g/cm³).
ABSd	Dermal absorption efficiency (unitless) (Table 5-3 & 5-5).
AT_C	Averaging time for cancer effects (days) (Table 4-1).
AT_{NC}	Averaging time for non-cancer effects (days) (Table 4-1).

Table 6-1. Health-Based Remedial Goal Equations for Exposure to Soil, Recreational User, Maintenance Worker and Construction Worker Exposure, Hamilton Sundstrand Facility, Denver, Colorado.

BRs	Breathing rate for soil exposure scenario (m^3/day) (Table 4-1).
BW	Body weight (kg) (Table 4-1).
C_{sat}	Constituent saturation limit in soil (mg/kg).
CSF	Cancer slope factor for oral (CSF_o), dermal (adjusted to an absorbed dose, CSF_a), or inhalation (CSF_i) exposure (kg-day/mg [inverse mg/kg/day]) (Tables 5-1 and 5-2).
D_A	Apparent diffusivity in soil (cm^2/sec).
D_{air}	Constituent diffusivity in air (cm^2/sec) (Table 4-2).
D_{wat}	Constituent diffusivity in water (cm^2/sec) (Table 4-2).
ED	Exposure duration (years) (Table 4-1).
EF	Exposure frequency (days/year) (Table 4-1).
FI	Fraction ingested from area of concern (unitless) (Table 4-1).
Foc	Fraction organic carbon in the soil (unitless).
Fx	Function of Ut/Um (unitless); $Fx = 0.18 \times (8x^3 + 12x) \times \exp[-(x^2)]$, where $x = 0.886 \times (Ut/Um)$.
H	Henry's law constant (atm-m^3/mol) (Table 4-2).
H_o	Dimensionless Henry's law constant (unitless); calculated as $H_o = H / RT$.
HBRG	Health-based remedial goal for soil (mg/kg).
IRs	Ingestion rate of soil (mg/day) (Table 4-1).
Koc	Organic carbon partition coefficient (cm^3/g = mL/g = L/kg) (Table 4-2).
PEF	Particulate emission factor (m^3/kg).
Q/C_{vol}	Volatile emission flux per unit concentration [(g/m^2/sec)/(kg/m^3)].
Q/C_{wind}	Particulate emission flux per unit concentration [(g/m^2/sec)/(kg/m^3)].
RfD	Reference dose for oral (RfD_o), dermal (adjusted to an absorbed dose, RfD_a), or inhalation (RfD_i) exposure (mg/kg/day) (Tables 5-3 and 5-4).
RPF	Respirable particle fraction (0.036 g/m^2/hr).
S	Constituent solubility limit in water (mg/L).
SAR	Soil-to-skin adherence rate (mg/cm^2/day) (Table 4-1).
SSAs	Exposed skin surface area for soil contact (cm^2) (Table 4-1).
T	Exposure interval (sec).
TCR	Target cancer risk (unitless).
THQ	Target hazard quotient for non-cancer effects (unitless).
Um	Mean annual wind speed (m/sec).
Ut	Equivalent threshold value of windspeed at 7 meters (11.32 m/sec).
V	Fraction of vegetative cover (unitless).
VF	Volatilization factor (m^3/kg).
VOCs	Volatile organic compounds.
x	Intermediate value in the calculation of PEF; $x = 0.886 \times (Ut/Um)$.

Table 6-2. Health-Based Remedial Goal Equations for Groundwater Based on Vapor Migration to Outdoor Air, Recreational User and Maintenance Worker Exposure, Hamilton Sundstrand Facility, Denver, Colorado.

$$(\mathrm{HBRG})_{C\ or\ NC} = \frac{(\mathrm{HBRG_{air}})_{C\ or\ NC}}{\mathrm{VF_{wamb}}}$$

$$\mathrm{VF_{wamb}} = \frac{H_o}{1 + \left(\frac{U_{air} \times MZh \times L_T}{W \times D_{gw}}\right)} \times (1000\ \ L/m^3)$$

$$D_{gw} = L_T \times \left(\frac{h_{cap}}{D_{cap}} + \frac{h_V}{D_S}\right)^{-1}$$

$$D_S = \left[D_{air} \times \left(\frac{\theta_{as}^{3.33}}{\theta_T^{2}}\right)\right] + \left[\frac{D_{wat}}{H_o} \times \left(\frac{\theta_{ws}^{3.33}}{\theta_T^{2}}\right)\right]$$

$$D_{cap} = \left[D_{air} \times \left(\frac{\theta_{acap}^{3.33}}{\theta_T^{2}}\right)\right] + \left[\frac{D_{wat}}{H_o} \times \left(\frac{\theta_{wcap}^{3.33}}{\theta_T^{2}}\right)\right]$$

CANCER EFFECTS:

$$(\mathrm{HBRG_{air}})_C = \frac{TCR \times BW \times AT_C}{BRair \times EF \times ED \times CSF_i}$$

NON-CANCER EFFECTS:

$$(\mathrm{HBRG_{air}})_{NC} = \frac{THQ \times BW \times AT_{NC} \times RfD_i}{BRair \times EF \times ED}$$

HBRG = MINIMUM of $\mathrm{HBRG_C}$ and $\mathrm{HBRG_{NC}}$ and S

Variable Definitions:

θ_{acap}	Air-filled porosity in capillary fringe soil (unitless).
θ_{as}	Air-filled porosity in vadose zone soil (unitless).
θ_T	Total soil porosity (unitless).
θ_{wcap}	Water-filled porosity in capillary fringe soil (unitless).
θ_{ws}	Water-filled porosity in vadose zone soil (unitless).
AT_C	Averaging time for cancer effects (days) (Table 4-1).
AT_{NC}	Averaging time for non-cancer effects (days) (Table 4-1).
BRair	Breathing rate (m^3/day) (Table 4-1).
BW	Body weight (kg) (Table 4-1).
CSF_i	Cancer slope factor for inhalation exposure (kg-day/mg [inverse mg/kg/day]) (Table 5-2).
D_{air}	Constituent diffusivity in air (cm^2/sec) (Table 4-2).
D_{cap}	Effective diffusion coefficient in the capillary fringe soil (cm^2/sec).
D_{gw}	Effective diffusion coefficient between groundwater and the soil surface (cm^2/sec).

Table 6-2. Health-Based Remedial Goal Equations for Groundwater Based on Vapor Migration to Outdoor Air, Recreational User and Maintenance Worker Exposure, Hamilton Sundstrand Facility, Denver, Colorado.

D_S	Effective diffusion coefficient in vadose zone soil (cm²/sec).
D_{wat}	Constituent diffusivity in water (cm²/sec) (Table 4-2).
ED	Exposure duration (years) (Table 4-1).
EF	Exposure frequency (days/year) (Table 4-1).
H	Henry's law constant (atm-m³/mol) (Table 4-2).
HBRG	Health-based remedial goal for groundwater (mg/L).
$HBRG_{air}$	Health-based remedial goal for outdoor air (mg/m³).
h_{cap}	Thickness of capillary fringe (cm).
H_o	Dimensionless Henry's law constant (unitless); calculated as H_o = H/RT.
h_v	Thickness of vadose zone (cm).
L_T	Distance from groundwater to the ground surface (cm).
MZh	Ambient air mixing zone height (cm).
RfD_i	Reference dose for inhalation exposure (mg/kg/day) (Table 5-4).
RT	Product of the universal gas constant (R = 8.206 × 10^{-5} atm-m^3/mol/K) and the relevant Kelvin temperature (T = 298.15 K); RT = 0.02447 atm-m^3/mol.
S	Constituent solubility limit in water (mg/L).
TCR	Target cancer risk (unitless).
THQ	Target hazard quotient for non-cancer effects (unitless).
U_{air}	Wind speed in ambient mixing zone (cm/sec).
VF_{wesp}	Volatilization factor for vapor migration from groundwater to outdoor (ambient) air (m³/L).
W	Width of source area parallel to wind direction (cm).

Table 6-3. Health-Based Remedial Goal Equations for Construction Worker Exposure to Vapors from Groundwater Migrating to a Construction Trench, Hamilton Sundstrand Facility, Denver, Colorado.

$$(HBRGgw)_{C\ or\ NC} = \frac{(HBRG_{air})_{C\ or\ NC}}{VF}$$

Volatilization Factor:

$$VF = \frac{(H_i \times D_{air} \times AC_{vad}^{3.33} \times A \times F \times 10^{-3} \times 10^{4} \times 3600)}{(R \times T \times L_d \times ACH \times V \times Por_{vad}^{2})}$$

$$L_d = (L_{gw} - D_{trench})$$

CANCER EFFECTS:

$$(HBRG_{air})_C = \frac{TCR \times BW \times AT_C}{BRair \times EF \times ED \times CSF_i}$$

NONCANCER EFFECTS:

$$(HBRG_{air})_{NC} = \frac{THQ \times BW \times AT_{NC} \times RfD_i}{BRair \times EF \times ED}$$

$HBRG = MINIMUM\ of\ HBRG_C\ and\ HBRG_{NC}$

Variable Definitions:	
A	Area of trench (m^2) (length x width).
AC_{vad}	Volumetric air content in vadose zone soil (cm^3/cm^3).
ACH	Air changes per hour (h^{-1}).
AT_C	Averaging time for cancer effects (days) (Table 4-1).
AT_{NC}	Averaging time for non-cancer effects (days) (Table 4-1).
BRair	Breathing rate (m^3/day) (Table 4-1).
BW	Body weight (kg) (Table 4-1).
CSF_i	Cancer slope factor for inhalation exposure (kg-day/mg [inverse mg/kg/day]) (Table 5-2).
D_{trench}	Depth of trench (cm).
D_{air}	Diffusion coefficient for chemical in air (cm^2/sec).
ED	Exposure duration (years) (Table 4-1).
EF	Exposure frequency (days/year) (Table 4-1).
F	Fraction of trench floor through which contaminant can enter (unitless).
HBRG	Health-based remedial goal for groundwater (mg/L).
$HBRG_{air}$	Health-based remedial goal for outdoor air (mg/m^3).
H_i	Henry's law constant for chemical (atm-m^3/mol).
L_d	Distance between trench bottom and groundwater (cm).
L_{gw}	Depth to groundwater (cm).
Por_{vad}	Total soil porosity in vadose zone (cm^3/cm^3).

Table 6-3. Health-Based Remedial Goal Equations for Construction Worker Exposure to Vapors from Groundwater Migrating to a Construction Trench, Hamilton Sundstrand Facility, Denver, Colorado.

R	Ideal gas constant (atm-m^3/mole-K).
RfD_i	Reference dose for inhalation exposure (mg/kg/day) (Table 5-4).
T	Average system absolute temperature (K).
TCR	Target cancer risk (unitless).
THQ	Target hazard quotient for non-cancer effects (unitless).
V	Volume of trench (m^3) (length x width x depth).
VDEQ	Virginia Department of Environmental Quality
VF	Volatilization factor (L/m^3).
10^{-3}	Conversion factor (L/cm^3).
10^4	Conversion factor (cm^2/m^2).
3600	Conversion factor (s/hr).

Table 6-4. Summary of Soil Health Based Remedial Goals (HBRGs) for Maintenance Worker, Construction Worker and Recreational User Exposure Scenarios, Hamilton Sundstrand Facility, Denver, Colorado.

HBRGs for Soil:

			Health-Based Remedial Goals for Soil Exposure (mg/kg)[a]					
Chemical of Potential Concern	**Maintenance Worker**	**Construction Worker**	**High Use Recreational User**			**Average Use Recreation User**		
			Child	**Youth**	**Adult**	**Child**	**Youth**	**Adult**
Volatile Organic Compounds								
1,1,2,2-Tetrachloroethane	1.0E+00	1.7E+02	4.1E+00	3.6E+00	1.9E+00	1.0E+01	1.7E+01	5.0E+00
1,1,2-Trichloroethane	NA	1.4E+02	NA	NA	NA	NA	NA	NA
1,1-Dichloroethene	NA	3.8E+02	NA	NA	NA	NA	NA	NA
1,2,4-Trimethylbenzene	NA	6.2E+01	NA	NA	NA	NA	NA	NA
1,3,5-Trimethylbenzene	NA	5.4E+01	NA	NA	NA	NA	NA	NA
Benzene	1.7E+00	1.2E+02	7.7E+00	6.5E+00	3.2E+00	1.9E+01	2.9E+01	8.2E+00
cis-1,2-Dichloroethene	2.0E+02	1.7E+02	2.2E+02	3.1E+02	4.5E+02	5.6E+02	8.2E+02	1.1E+03
Naphthalene	NA	1.4E+02	NA	NA	NA	NA	NA	NA
Tetrachloroethene	1.5E+00	1.2E+02	3.7E+00	4.0E+00	2.7E+00	9.2E+00	2.3E+01	7.8E+00
Trichloroethene	1.2E-01	2.2E+01	5.8E-01	4.8E-01	2.3E-01	1.5E+00	2.1E+00	5.8E-01
Xylenes, total	8.4E+02	7.2E+02	1.0E+03	1.3E+03	1.9E+03	2.5E+03	3.5E+03	4.7E+03
Semivolatile Organic Compounds								
Benzo(a)Anthracene	2.3E+00	1.8E+02	3.2E+00	3.7E+00	5.4E+00	8.0E+00	2.3E+01	2.0E+01
Benzo(a)pyrene	2.3E-01	1.8E+01	3.2E-01	3.7E-01	5.4E-01	8.0E-01	2.3E+00	2.0E+00
Benzo(b)fluoranthene	2.3E+00	1.8E+02	3.2E+00	3.7E+00	5.4E+00	8.0E+00	2.3E+01	2.0E+01
Dibenzo(a,h)anthracene	2.3E-01	1.8E+01	3.2E-01	3.7E-01	5.4E-01	8.0E-01	2.3E+00	2.0E+00
PCBs	8.3E-01	1.0E+01	1.1E+00	1.3E+00	1.9E+00	2.9E+00	8.2E+00	7.0E+00
Metals								
Arsenic	1.8E+00	8.2E+01	2.0E+00	2.6E+00	3.5E+00	4.9E+00	2.0E+01	1.6E+01
Barium	1.7E+05	5.9E+04	5.1E+04	1.1E+05	3.8E+05	1.3E+05	5.3E+05	1.5E+06
Copper	4.5E+04	1.2E+04	1.1E+04	2.5E+04	1.0E+05	2.7E+04	1.3E+05	5.1E+05

[a] Minimum of the $HBRG_C$ for Cancer Effects and $HBRG_{NC}$ for Non-Cancer Effects.

mg/kg - Milligrams per kilogram.

PCBs - Polychlorinated Biphenyls.

NA - Not applicable because the maximum detected concentration for the soil depth of concern (i.e., 0-2 or 0-0.5 ft bgs) is less than the screening level.
Therefore, the chemical was not identified as a chemical of potential concern (COPC).

Table 6-5. Summary of Groundwater Health Based Remedial Goals (HBRGs) for Maintenance Worker, Construction Worker and Recreational User Exposure Scenarios, Hamilton Sundstrand Facility, Denver, Colorado.

HBRGs for Groundwater:

	Health-Based Remedial Goals for Groundwater Exposure (mg/L)[a] [b]							
Chemical of Potential Concern	**Maintenance Worker**	**Construction Worker**	**High Use Recreational User**			**Average Use Recreation User**		
			Child	**Youth**	**Adult**	**Child**	**Youth**	**Adult**
Volatile Organic Compounds								
1,1,1-Trichloroethane	7.0E+04	1.5E+03	8.4E+04	1.1E+05	1.6E+05	2.1E+05	2.9E+05	3.9E+05
1,1,2,2-Tetrachloroethane	2.9E+01	1.7E+02	1.5E+02	1.2E+02	5.5E+01	3.7E+02	5.0E+02	1.4E+02
1,1,2-Trichloroethane	3.9E+01	7.9E+01	1.9E+02	1.5E+02	7.3E+01	4.9E+02	6.7E+02	1.8E+02
1,1-Dichloroethane	2.0E+04	4.7E+03	2.4E+04	3.2E+04	4.6E+04	6.1E+04	8.4E+04	1.1E+05
1,1-Dichloroethene	1.6E+03	3.4E+01	2.0E+03	2.6E+03	3.6E+03	4.9E+03	6.7E+03	9.1E+03
1,2,4-Trichlorobenzene	1.2E+03	3.3E+01	1.5E+03	2.0E+03	2.8E+03	3.8E+03	5.2E+03	7.0E+03
1,2,4-Trimethylbenzene	2.7E+02	6.0E+00	3.2E+02	4.3E+02	6.0E+02	8.1E+02	1.1E+03	1.5E+03
1,2-Dichloroethane	1.4E+01	1.6E+01	7.1E+01	5.6E+01	2.6E+01	1.8E+02	2.4E+02	6.6E+01
1,3,5-Trimethylbenzene	2.0E+02	4.5E+00	2.5E+02	3.2E+02	4.6E+02	6.1E+02	8.4E+02	1.1E+03
1,4-Dioxane	4.3E+03	1.5E+04	2.2E+04	1.7E+04	8.1E+03	5.4E+04	7.4E+04	2.0E+04
2-Butanone (MEK)	2.3E+06	8.8E+04	2.8E+06	3.7E+06	5.3E+06	7.0E+06	9.7E+06	1.3E+07
Benzene	1.3E+01	2.5E+01	6.6E+01	5.2E+01	2.4E+01	1.6E+02	2.2E+02	6.1E+01
Bromodichloromethane	3.8E+01	2.2E+02	1.9E+02	1.5E+02	7.2E+01	4.8E+02	6.6E+02	1.8E+02
Bromomethane	1.9E+02	4.4E+00	2.3E+02	3.1E+02	4.3E+02	5.8E+02	7.9E+02	1.1E+03
Carbon tetrachloride	1.7E+00	7.5E+00	8.3E+00	6.6E+00	3.1E+00	2.1E+01	2.9E+01	7.8E+00
Chloroethane	2.2E+01	9.7E+01	1.1E+02	8.5E+01	4.0E+01	2.7E+02	3.7E+02	1.0E+02
Chloroform	5.5E+00	2.8E+01	2.8E+01	2.2E+01	1.0E+01	6.9E+01	9.5E+01	2.6E+01
cis-1,2-Dichloroethene	2.0E+03	4.7E+01	2.4E+03	3.1E+03	4.5E+03	6.0E+03	8.2E+03	1.1E+04
Ethyl methacrylate	2.8E+02	5.8E+00	3.4E+02	4.4E+02	6.3E+02	8.4E+02	1.2E+03	1.6E+03
Ethylbenzene	3.1E+04	6.9E+02	3.7E+04	4.9E+04	7.0E+04	9.3E+04	1.3E+05	1.7E+05
Isobutyl alcohol	5.6E+06	4.1E+05	6.7E+06	8.9E+06	1.3E+07	1.7E+07	2.3E+07	3.1E+07
Methyl tert-Butyl Ether	3.5E+03	2.0E+04	1.7E+04	1.4E+04	6.5E+03	4.4E+04	6.0E+04	1.6E+04
Methylene chloride	4.6E+02	2.4E+03	2.3E+03	1.8E+03	8.6E+02	5.7E+03	7.9E+03	2.1E+03
Naphthalene	1.7E+03	4.2E+01	2.1E+03	2.7E+03	3.8E+03	5.1E+03	7.1E+03	9.6E+03
n-Butylbenzene	2.6E+03	5.7E+01	3.2E+03	4.2E+03	6.0E+03	8.0E+03	1.1E+04	1.5E+04
n-Propylbenzene	2.6E+03	5.7E+01	3.2E+03	4.2E+03	6.0E+03	8.0E+03	1.1E+04	1.5E+04
sec-Butylbenzene	1.9E+03	3.9E+01	2.3E+03	3.0E+03	4.2E+03	5.7E+03	7.8E+03	1.1E+04
Styrene	8.7E+04	6.0E+03	1.0E+05	1.4E+05	2.0E+05	2.6E+05	3.6E+05	4.9E+05
Tetrachloroethene	6.8E+00	1.1E+01	3.4E+01	2.7E+01	1.3E+01	8.5E+01	1.2E+02	3.2E+01
Tetrahydrofuran	2.4E+03	1.8E+04	1.2E+04	9.6E+03	4.5E+03	3.0E+04	4.2E+04	1.1E+04
Toluene	1.6E+05	3.5E+03	1.9E+05	2.5E+05	3.5E+05	4.7E+05	6.5E+05	8.8E+05
trans-1,2-Dichloroethene	1.6E+03	3.6E+01	1.9E+03	2.5E+03	3.6E+03	4.8E+03	6.6E+03	9.0E+03
Trichloroethene	5.8E-01	2.7E+00	2.9E+00	2.3E+00	1.1E+00	7.3E+00	9.9E+00	2.7E+00
Vinyl chloride	2.1E+00	9.4E+00	1.1E+01	8.4E+00	4.0E+00	2.7E+01	3.7E+01	9.9E+00
Xylenes, total	3.8E+03	7.7E+01	4.6E+03	6.0E+03	8.6E+03	1.1E+04	1.6E+04	2.1E+04

[a] Minimum of the HBRG$_C$ for Cancer Effects and HBRG$_{NC}$ for Non-Cancer Effects.

[b] Calculated using volatilization factor (VF) for vapor migration from groundwater to outdoor (ambient) air for the maintenance worker and recreational user and a VF for vapor migration from groundwater to a construction trench for the construction worker.

mg/L - Milligrams per Liter.

Table 6-6. Health-Based Remedial Goal Calculations for COPCs in Soil Based on Maintenance Worker Exposure, Hamilton Sundstrand Facility, Denver, Colorado.

Chemical of Potential Concern	VF *or* PEF [a] (m³/kg)		CANCER EFFECTS				NON-CANCER EFFECTS				Minimum HBRG (mg/kg) [b]	
			Route-Specific HBRG (mg/kg)			$HBRG_C$ (mg/kg)	Route-Specific HBRG (mg/kg)			$HBRG_{NC}$ (mg/kg)		
			Oral $(HBRG_o)_C$	Dermal $(HBRG_d)_C$	Inhalation $(HBRG_i)_C$	TCR = 1E-06	Oral $(HBRG_o)_{NC}$	Dermal $(HBRG_d)_{NC}$	Inhalation $(HBRG_i)_{NC}$	THQ = 1		
Volatile Organic Compounds												
cis-1,2-Dichloroethene	3.58E+03	V	NC	—	NC	NC	1.1E+04	—	2.0E+02	2.0E+02	2.0E+02	N
1,1,2,2-Tetrachloroethane	1.40E+04	V	1.6E+01	—	1.1E+00	1.0E+00	6.8E+04	—	4.8E+03	4.5E+03	1.0E+00	C
Tetrachloroethene	2.50E+03	V	5.9E+00	—	1.9E+00	1.5E+00	1.1E+04	—	1.4E+02	1.4E+02	1.5E+00	C
Trichloroethene	3.16E+03	V	7.9E+00	—	1.3E-01	1.2E-01	3.4E+02	—	2.1E+02	1.3E+02	1.2E-01	C
Benzene	3.06E+03	V	5.8E+01	—	1.8E+00	1.7E+00	4.5E+03	—	1.5E+02	1.4E+02	1.7E+00	C
Xylenes, total	5.19E+03	V	NC	—	NC	NC	2.3E+05	—	8.4E+02	8.4E+02	8.4E+02	N
Semivolatile Organic Compounds												
Benzo(a)Anthracene	8.04E+08	P	4.4E+00	5.1E+00	NA	2.3E+00	NA	NA	NA	NA	2.3E+00	C
Benzo(a)pyrene	8.04E+08	P	4.4E-01	5.1E-01	4.2E+03	2.3E-01	NA	NA	NA	NA	2.3E-01	C
Benzo(b)fluoranthene	8.04E+08	P	4.4E+00	5.1E+00	NA	2.3E+00	NA	NA	NA	NA	2.3E+00	C
Dibenzo(a,h)anthracene	8.04E+08	P	4.4E-01	5.1E-01	NA	2.3E-01	NA	NA	NA	NA	2.3E-01	C
PCBs	8.04E+08	P	1.6E+00	1.7E+00	6.4E+03	8.3E-01	2.3E+01	2.5E+01	9.1E+04	1.2E+01	8.3E-01	C
Metals												
Arsenic	8.04E+08	P	2.1E+00	1.1E+01	8.5E+02	1.8E+00	3.4E+02	1.7E+03	3.9E+04	2.8E+02	1.8E+00	C
Barium	8.04E+08	P	NC	—	NC	NC	2.3E+05	—	6.5E+05	1.7E+05	1.7E+05	N
Copper	8.04E+08	P	NC	—	NC	NC	4.5E+04	—	NA	4.5E+04	4.5E+04	N

[a] Volatilization factor (VF) (for VOCs) (identified by "V") or particulate emission factor (PEF) (for non-VOCs) (identified by "P"), calculated on Tables 4-3 and 4-4.

[b] Minimum of the $HBRG_C$ (identified by "C") and $HBRG_{NC}$ (identified by "N").

—	Not applicable; dermal absorption is assumed to be negligible.	mg/kg	Milligrams per kilogram.
COPCs	Chemicals of potential concern.	PEF	Particulate emission factor.
HBRG	Heath-based remedial goal.	TCR	Target cancer risk.
NC	Not evaluated as a carcinogen.	THQ	Target hazard quotient for non-cancer effects.
NA	Not available.	VF	Volatilization factor.
m³/kg	Cubic meters per kilogram.	VOCs	Volatile organic compounds.

Equations: (see Table 6-1)

(HBRGo)c = (TCR × 70 × 25,550 × 1,000,000) / (100 × 1 × 225 × 25 × CSFo)

(HBGd)c = (TCR × 70 × 25,550 × 1,000,000) / (3,300 × 0.2 × ABSd × 225 × 25 × CSFa)

(HBRGi)c = (TCR × [VF or PEF] × 70 × 25,550) / (20 × 225 × 25 × CSFi)

HBRGc = 1 / [1/ (HBRGo)c] + [1/ (HBRGd)c] + [1/ (HBRGi)c])

(HBRGo)nc = (THQ × 70 × 9,125× 1,000,000) / (100 × 1 × 225 × 25 × [1/RfDo])

(HBRGd)nc = (THQ × 70 × 9,125 × 1,000,000) / (3,300 × 0.2 × ABSd × 225 × 25 × [1/RfDa])

(HBRGi)nc = (THQ × [VF or PEF] × 70 × 9,125) / (20 × 225 × 25 × [1/RfDi])

HBRGnc = 1 / [1/ (HBRGo)nc] + [1/ (HBRGd)nc] + [1/ (HBRGi)nc])

Table 6-7. **Health-Based Remedial Goal Calculations for COPCs in Soil Based on Construction Worker Exposure, Hamilton Sundstrand Facility, Denver, Colorado.**

Chemical of Potential Concern	VF *or* PEF[a] (m^3/kg)		CANCER EFFECTS				NON-CANCER EFFECTS				Minimum HBRG (mg/kg) [b]	
			Route-Specific HBRG (mg/kg)			HBRG_C (mg/kg)	Route-Specific HBRG (mg/kg)			HBRG_{NC} (mg/kg)		
			Oral $(\text{HBRG}_o)_C$	Dermal $(\text{HBRG}_d)_C$	Inhalation $(\text{HBRG}_i)_C$	TCR = 1E-06	Oral $(\text{HBRG}_o)_{NC}$	Dermal $(\text{HBRG}_d)_{NC}$	Inhalation $(\text{HBRG}_i)_{NC}$	THQ = 1		
Volatile Organic Compounds												
1,1-Dichloroethene	1.57E+03	V	NA	—	NA	NA	2.7E+03	—	4.4E+02	3.8E+02	3.8E+02	N
cis-1,2-Dichloroethene	3.58E+03	V	NC	—	NC	NC	3.0E+04	—	1.8E+02	1.7E+02	1.7E+02	N
1,1,2,2-Tetrachloroethane	1.40E+04	V	9.0E+02	—	2.1E+02	1.7E+02	1.8E+04	—	4.1E+03	3.3E+03	1.7E+02	C
Tetrachloroethene	2.50E+03	V	3.3E+02	—	3.6E+02	1.7E+02	3.0E+04	—	1.2E+02	1.2E+02	1.2E+02	N
1,1,2-Trichloroethane	7.48E+03	V	3.2E+03	—	4.0E+02	3.5E+02	1.2E+04	—	1.5E+02	1.4E+02	1.4E+02	N
Trichloroethene	3.16E+03	V	4.5E+02	—	2.4E+01	2.2E+01	8.9E+01	—	1.8E+03	8.5E+01	2.2E+01	C
1,2,4-Trimethylbenzene	7.47E+03	V	NA	—	NA	NA	1.5E+04	—	6.3E+01	6.2E+01	6.2E+01	N
1,3,5-Trimethylbenzene	6.44E+03	V	NA	—	NA	NA	1.5E+04	—	5.4E+01	5.4E+01	5.4E+01	N
Benzene	3.06E+03	V	3.3E+03	—	3.3E+02	3.0E+02	1.2E+03	—	1.3E+02	1.2E+02	1.2E+02	N
Naphthalene	3.42E+04	V	NC	NC	NC	NC	5.9E+03	1.5E+04	1.4E+02	1.4E+02	1.4E+02	N
Xylenes, total	5.19E+03	V	NC	—	NC	NC	5.9E+04	—	7.3E+02	7.2E+02	7.2E+02	N
Semivolatile Organic Compounds												
Benzo(a)Anthracene	8.04E+08	P	2.5E+02	6.3E+02	NA	1.8E+02	NA	NA	NA	NA	1.8E+02	C
Benzo(a)pyrene	8.04E+08	P	2.5E+01	6.3E+01	7.8E+05	1.8E+01	NA	NA	NA	NA	1.8E+01	C
Benzo(b)fluoranthene	8.04E+08	P	2.5E+02	6.3E+02	NA	1.8E+02	NA	NA	NA	NA	1.8E+02	C
Dibenzo(a,h)anthracene	8.04E+08	P	2.5E+01	6.3E+01	NA	1.8E+01	NA	NA	NA	NA	1.8E+01	C
PCBs	8.04E+08	P	9.0E+01	2.2E+02	1.2E+06	6.4E+01	1.5E+01	3.5E+01	7.9E+04	1.0E+01	1.0E+01	N
Metals												
Arsenic	8.04E+08	P	1.2E+02	1.3E+03	1.6E+05	1.1E+02	8.9E+01	9.9E+02	3.4E+04	8.2E+01	8.2E+01	N
Barium	8.04E+08	P	NC	—	NC	NC	5.9E+04	—	5.5E+06	5.9E+04	5.9E+04	N
Copper	8.04E+08	P	NC	—	NC	NC	1.2E+04	—	NA	1.2E+04	1.2E+04	N

[a] Volatilization factor (VF) (for VOCs) (identified by "V") or particulate emission factor (PEF) (for non-VOCs) (identified by "P"), calculated on Tables 4-3 and 4-4.

[b] Minimum of the HBRG_C (identified by "C") and HBRG_{NC} (identified by "N").

—	Not applicable; dermal absorption is assumed to be negligible.	mg/kg	Milligrams per kilogram.
COPCs	Chemicals of potential concern.	PEF	Particulate emission factor, subchronic.
HBRG	Heath-based remedial goal.	TCR	Target cancer risk.
NA	Not available.	THQ	Target hazard quotient for non-cancer effects.
NC	Not evaluated as a carcinogen.	VFsc	Volatilization factor, subchronic.
m^3/kg	Cubic meters per kilogram.	VOCs	Volatile organic compounds.

Equations: (see Table 6-2)

(HBRGo)c = (TCR × 70 × 25,550 × 1,000,000) / (330 × 1 × 5 × 6 × CSFo)

(HBRGd)c = (TCR × 70 × 25,550 × 1,000,000) / (3,300 × 0.3 × ABSd × 5 × 6 × CSFa)

(HBRGi)c = (TCR × [VF or PEF] × 70 × 25,550) / (20 × 5 × 6 × CSFi)

HBRGc = 1 / [1/ (HBRGo)c] + [1/ (HBRGd)c] + [1/ (HBRGi)c])

(HBRGo)nc = (THQ × 70 × 42× 1,000,000) / (330 × 1 × 5 × 6 × [1/RfDo])

(HBRGd)nc = (THQ × 70 × 42 × 1,000,000) / (3,300 × 0.3 × ABSd × 5 × 6 × [1/RfDa])

(HBRGi)nc = (THQ × [VF or PEF] × 70 × 42) / (20 × 5 × 6 × [1/RfDi])

HBRGnc = 1 / [1/ (HBRGo)nc] + [1/ (HBRGd)nc] + [1/ (HBRGi)nc])

Table 6-8. Health-Based Remedial Goal Calculations for COPCs in Soil Based on Average Use Child Recreational User Exposure, Hamilton Sundstrand Facility, Denver, Colorado.

Chemical of Potential Concern	VF *or* PEF [a] (m³/kg)		CANCER EFFECTS				NON-CANCER EFFECTS				Minimum HBRG (mg/kg) [b]	
			Route-Specific HBRG (mg/kg)			$HBRG_C$ (mg/kg)	Route-Specific HBRG (mg/kg)			$HBRG_{NC}$ (mg/kg)		
			Oral $(HBRG_o)_C$	Dermal $(HBRG_d)_C$	Inhalation $(HBRG_i)_C$	TCR = 1E-06	Oral $(HBRG_o)_{NC}$	Dermal $(HBRG_d)_{NC}$	Inhalation $(HBRG_i)_{NC}$	THQ = 1		
<u>Volatile Organic Compounds</u>												
cis-1,2-Dichloroethene	3.58E+03	V	NC	—	NC	NC	6.8E+03	—	6.1E+02	5.6E+02	5.6E+02	N
1,1,2,2-Tetrachloroethane	1.40E+04	V	4.0E+01	—	1.4E+01	1.0E+01	4.1E+04	—	1.4E+04	1.1E+04	1.0E+01	C
Tetrachloroethene	2.50E+03	V	1.5E+01	—	2.4E+01	9.2E+00	6.8E+03	—	4.3E+02	4.0E+02	9.2E+00	C
Trichloroethene	3.16E+03	V	2.0E+01	—	1.6E+00	1.5E+00	2.1E+02	—	6.2E+02	1.5E+02	1.5E+00	C
Benzene	3.06E+03	V	1.5E+02	—	2.2E+01	1.9E+01	2.7E+03	—	4.5E+02	3.9E+02	1.9E+01	C
Xylenes, total	5.19E+03	V	NC	—	NC	NC	1.4E+05	—	2.5E+03	2.5E+03	2.5E+03	N
<u>Semivolatile Organic Compounds</u>												
Benzo(a)Anthracene	8.04E+08	P	1.1E+01	3.0E+01	NA	8.0E+00	NA	NA	NA	NA	8.0E+00	C
Benzo(a)pyrene	8.04E+08	P	1.1E+00	3.0E+00	5.2E+04	8.0E-01	NA	NA	NA	NA	8.0E-01	C
Benzo(b)fluoranthene	8.04E+08	P	1.1E+01	3.0E+01	NA	8.0E+00	NA	NA	NA	NA	8.0E+00	C
Dibenzo(a,h)anthracene	8.04E+08	P	1.1E+00	3.0E+00	NA	8.0E-01	NA	NA	NA	NA	8.0E-01	C
<u>PCBs</u>	8.04E+08	P	4.0E+00	1.0E+01	8.0E+04	2.9E+00	1.4E+01	3.5E+01	2.8E+05	9.8E+00	2.9E+00	C
<u>Metals</u>												
Arsenic	8.04E+08	P	5.3E+00	6.3E+01	1.1E+04	4.9E+00	2.1E+02	2.4E+03	1.2E+05	1.9E+02	4.9E+00	C
Barium	8.04E+08	P	NC	—	NC	NC	1.4E+05	—	2.0E+06	1.3E+05	1.3E+05	N
Copper	8.04E+08	P	NC	—	NC	NC	2.7E+04	—	NA	2.7E+04	2.7E+04	N

[a] Volatilization factor (VF) (for VOCs) (identified by "V") or particulate emission factor (PEF) (for non-VOCs) (identified by "P"), calculated on Tables 4-3 and 4-5.

[b] Minimum of the $HBRG_C$ (identified by "C") and $HBRG_{NC}$ (identified by "N").

—	Not applicable; dermal absorption is assumed to be negligible.	mg/kg	Milligrams per kilogram.
COPCs	Chemicals of potential concern.	PEF	Particulate emission factor.
HBRG	Heath-based remedial goal.	TCR	Target cancer risk.
NA	Not available.	THQ	Target hazard quotient for non-cancer effects.
NC	Not evaluated as a carcinogen.	VF	Volatilization factor.
m³/kg	Cubic meters per kilogram.	VOCs	Volatile organic compounds.

<u>Equations:</u> (see Table 6-1)

(HBRGo)c = (TCR × 15 × 25,550 × 1,000,000) / (200 × 1 × 40 × 6 × CSFo)

(HBRGd)c = (TCR × 15 × 25,550 × 1,000,000) / (2,800 × 0.2 × ABSd × 40 × 6 × CSFa)

(HBRGi)c = (TCR × [VF or PEF] × 15 × 25,550) / (8 × 40 × 6 × CSFi)

HBRGc = 1 / [1/ (HBRGo)c] + [1/ (HBRGd)c] + [1/ (HBRGi)c])

(HBRGo)nc = (THQ × 15 × 2,190× 1,000,000) / (200 × 1 × 40 × 6 × [1/RfDo])

(HBRGd)nc = (THQ × 15 × 2,190 × 1,000,000) / (2,800 × 0.2 × ABSd × 40 × 6 × [1/RfDa])

(HBRGi)nc = (THQ × [VF or PEF] × 15 × 2,190) / (8 × 40 × 6 × [1/RfDi])

HBRGnc = 1 / [1/ (HBRGo)nc] + [1/ (HBRGd)nc] + [1/ (HBRGi)nc])

Table 6-9. Health-Based Remedial Goal Calculations for COPCs in Soil Based on High Use Child Recreational User Exposure, Hamilton Sundstrand Facility, Denver, Colorado.

Chemical of Potential Concern	VF *or* PEF [a] (m³/kg)		CANCER EFFECTS				NON-CANCER EFFECTS				Minimum HBRG (mg/kg) [b]	
			Route-Specific HBRG (mg/kg)			$HBRG_C$ (mg/kg)	Route-Specific HBRG (mg/kg)			$HBRG_{NC}$ (mg/kg)		
			Oral $(HBRG_o)_C$	Dermal $(HBRG_d)_C$	Inhalation $(HBRG_i)_C$	TCR = 1E-06	Oral $(HBRG_o)_{NC}$	Dermal $(HBRG_d)_{NC}$	Inhalation $(HBRG_i)_{NC}$	THQ = 1		
<u>Volatile Organic Compounds</u>												
cis-1,2-Dichloroethene	3.58E+03	V	NC	—	NC	NC	2.7E+03	—	2.4E+02	2.2E+02	2.2E+02	N
1,1,2,2-Tetrachloroethane	1.40E+04	V	1.6E+01	—	5.5E+00	4.1E+00	1.6E+04	—	5.8E+03	4.3E+03	4.1E+00	C
Tetrachloroethene	2.50E+03	V	5.9E+00	—	9.7E+00	3.7E+00	2.7E+03	—	1.7E+02	1.6E+02	3.7E+00	C
Trichloroethene	3.16E+03	V	8.0E+00	—	6.3E-01	5.8E-01	8.2E+01	—	2.5E+02	6.2E+01	5.8E-01	C
Benzene	3.06E+03	V	5.8E+01	—	8.9E+00	7.7E+00	1.1E+03	—	1.8E+02	1.5E+02	7.7E+00	C
Xylenes, total	5.19E+03	V	NC	—	NC	NC	5.5E+04	—	1.0E+03	1.0E+03	1.0E+03	N
<u>Semivolatile Organic Compounds</u>												
Benzo(a)Anthracene	8.04E+08	P	4.4E+00	1.2E+01	NA	3.2E+00	NA	NA	NA	NA	3.2E+00	C
Benzo(a)pyrene	8.04E+08	P	4.4E-01	1.2E+00	2.1E+04	3.2E-01	NA	NA	NA	NA	3.2E-01	C
Benzo(b)fluoranthene	8.04E+08	P	4.4E+00	1.2E+01	NA	3.2E+00	NA	NA	NA	NA	3.2E+00	C
Dibenzo(a,h)anthracene	8.04E+08	P	4.4E-01	1.2E+00	NA	3.2E-01	NA	NA	NA	NA	3.2E-01	C
<u>PCBs</u>	8.04E+08	P	1.6E+00	4.1E+00	3.2E+04	1.1E+00	5.5E+00	1.4E+01	1.1E+05	3.9E+00	1.1E+00	C
<u>Metals</u>												
Arsenic	8.04E+08	P	2.1E+00	2.5E+01	4.3E+03	2.0E+00	8.2E+01	9.8E+02	4.7E+04	7.6E+01	2.0E+00	C
Barium	8.04E+08	P	NC	—	NC	NC	5.5E+04	—	7.9E+05	5.1E+04	5.1E+04	N
Copper	8.04E+08	P	NC	—	NC	NC	1.1E+04	—	NA	1.1E+04	1.1E+04	N

[a] Volatilization factor (VF) (for VOCs) (identified by "V") or particulate emission factor (PEF) (for non-VOCs) (identified by "P"), calculated on Tables 4-3 and 4-5.

[b] Minimum of the $HBRG_C$ (identified by "C") and $HBRG_{NC}$ (identified by "N").

—	Not applicable; dermal absorption is assumed to be negligible.	mg/kg	Milligrams per kilogram.
COPCs	Chemicals of potential concern.	PEF	Particulate emission factor.
HBRG	Heath-based remedial goal.	TCR	Target cancer risk.
NC	Not evaluated as a carcinogen.	THQ	Target hazard quotient for non-cancer effects.
NA	Not available.	VF	Volatilization factor.
m³/kg	Cubic meters per kilogram.	VOCs	Volatile organic compounds.

<u>Equations:</u> (see Table 6-1)

(HBRGo)c = (TCR × 15 × 25,550 × 1,000,000) / (200 × 1 × 100 × 6 × CSFo)

(HBRGd)c = (TCR × 15 × 25,550 × 1,000,000) / (2,800 × 0.2 × ABSd × 100 × 6 × CSFa)

(HBRGi)c = (TCR × [VF or PEF] × 15 × 25,550) / (8 × 100 × 6 × CSFi)

HBRGc = 1 / [1/ (HBRGo)c] + [1/ (HBRGd)c] + [1/ (HBRGi)c])

(HBRGo)nc = (THQ × 15 × 2,190× 1,000,000) / (200 × 1 × 100 × 6 × [1/RfDo])

(HBRGd)nc = (THQ × 15 × 2,190 × 1,000,000) / (2,800 × 0.2 × ABSd × 100 × 6 × [1/RfDa])

(HBRGi)nc = (THQ × [VF or PEF] × 15 × 2,190) / (8 × 100 × 6 × [1/RfDi])

HBRGnc = 1 / [1/ (HBRGo)nc] + [1/ (HBRGd)nc] + [1/ (HBRGi)nc])

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Table 6-10. Health-Based Remedial Goal Calculations for COPCs in Soil Based on Average Use Youth Recreational User Exposure, Hamilton Sundstrand Facility, Denver, Colorado.

Chemical of Potential Concern	VF *or* PEF [a] (m³/kg)		CANCER EFFECTS				NON-CANCER EFFECTS				Minimum HBRG (mg/kg) [b]	
			Route-Specific HBRG (mg/kg)			$HBRG_C$ (mg/kg)	Route-Specific HBRG (mg/kg)			$HBRG_{NC}$ (mg/kg)		
			Oral $(HBRG_o)_C$	Dermal $(HBRG_d)_C$	Inhalation $(HBRG_i)_C$	TCR = 1E-06	Oral $(HBRG_o)_{NC}$	Dermal $(HBRG_d)_{NC}$	Inhalation $(HBRG_i)_{NC}$	THQ = 1		
Volatile Organic Compounds												
cis-1,2-Dichloroethene	3.58E+03	V	NC	—	NC	NC	3.3E+04	—	8.4E+02	8.2E+02	8.2E+02	N
1,1,2,2-Tetrachloroethane	1.40E+04	V	1.9E+02	—	1.9E+01	1.7E+01	2.0E+05	—	2.0E+04	1.8E+04	1.7E+01	C
Tetrachloroethene	2.50E+03	V	7.1E+01	—	3.3E+01	2.3E+01	3.3E+04	—	5.9E+02	5.8E+02	2.3E+01	C
Trichloroethene	3.16E+03	V	9.6E+01	—	2.2E+00	2.1E+00	9.9E+02	—	8.5E+02	4.6E+02	2.1E+00	C
Benzene	3.06E+03	V	7.0E+02	—	3.1E+01	2.9E+01	1.3E+04	—	6.2E+02	5.9E+02	2.9E+01	C
Xylenes, total	5.19E+03	V	NC	—	NC	NC	6.6E+05	—	3.5E+03	3.5E+03	3.5E+03	N
Semivolatile Organic Compounds												
Benzo(a)Anthracene	8.04E+08	P	5.3E+01	4.2E+01	NA	2.3E+01	NA	NA	NA	NA	2.3E+01	C
Benzo(a)pyrene	8.04E+08	P	5.3E+00	4.2E+00	7.1E+04	2.3E+00	NA	NA	NA	NA	2.3E+00	C
Benzo(b)fluoranthene	8.04E+08	P	5.3E+01	4.2E+01	NA	2.3E+01	NA	NA	NA	NA	2.3E+01	C
Dibenzo(a,h)anthracene	8.04E+08	P	5.3E+00	4.2E+00	NA	2.3E+00	NA	NA	NA	NA	2.3E+00	C
PCBs	8.04E+08	P	1.9E+01	1.4E+01	1.1E+05	8.2E+00	6.6E+01	4.9E+01	3.8E+05	2.8E+01	8.2E+00	C
Metals												
Arsenic	8.04E+08	P	2.6E+01	8.9E+01	1.5E+04	2.0E+01	9.9E+02	3.4E+03	1.6E+05	7.6E+02	2.0E+01	C
Barium	8.04E+08	P	NC	—	NC	NC	6.6E+05	—	2.7E+06	5.3E+05	5.3E+05	N
Copper	8.04E+08	P	NC	—	NC	NC	1.3E+05	—	NA	1.3E+05	1.3E+05	N

[a] Volatilization factor (VF) (for VOCs) (identified by "V") or particulate emission factor (PEF) (for non-VOCs) (identified by "P"), calculated on Tables 4-3 and 4-5.

[b] Minimum of the $HBRG_C$ (identified by "C") and $HBRG_{NC}$ (identified by "N").

—	Not applicable; dermal absorption is assumed to be negligible.	mg/kg	Milligrams per kilogram.
COPCs	Chemicals of potential concern.	PEF	Particulate emission factor.
HBRG	Heath-based remedial goal.	TCR	Target cancer risk.
NA	Not available.	THQ	Target hazard quotient for non-cancer effects.
NC	Not evaluated as a carcinogen.	VF	Volatilization factor.
m³/kg	Cubic meters per kilogram.	VOCs	Volatile organic compounds.

Equations: (see Table 6-1)

(HBRGo)c = (TCR × 45 × 25,550 × 1,000,000) / (100 × 1 × 50 × 6 × CSFo)

(HBRGd)c = (TCR × 45 × 25,550 × 1,000,000) / (4,800 × 0.2 × ABSd × 50 × 6 × CSFa)

(HBRGi)c = (TCR × [VF or PEF] × 45 × 25,550) / (14 × 50 × 6 × CSFi)

HBRGc = 1 / [1/ (HBRGo)c] + [1/ (HBRGd)c] + [1/ (HBRGi)c])

(HBRGo)nc = (THQ × 45 × 2,190× 1,000,000) / (100 × 1 × 50 × 6 × [1/RfDo])

(HBRGd)nc = (THQ × 45 × 2,190 × 1,000,000) / (4,800 × 0.2 × ABSd × 50 × 6 × [1/RfDa])

(HBGi)nc = (THQ × [VF or PEF] × 45 × 2,190) / (14 × 50 × 6 × [1/RfDi])

HBRGnc = 1 / [1/ (HBRGo)nc] + [1/ (HBRGd)nc] + [1/ (HBRGi)nc])

Table 6-11. Health-Based Remedial Goal Calculations for COPCs in Soil Based on High Use Youth Recreational User Exposure, Hamilton Sundstrand Facility, Denver, Colorado.

			CANCER EFFECTS				NON-CANCER EFFECTS				Minimum	
Chemical of Potential Concern	VF *or* PEF [a] (m³/kg)		Route-Specific HBRG (mg/kg)			$HBRG_C$ (mg/kg)	Route-Specific HBRG (mg/kg)			$HBRG_{NC}$ (mg/kg)	HBRG (mg/kg) [b]	
			Oral $(HBRG_o)_C$	Dermal $(HBRG_d)_C$	Inhalation $(HBRG_i)_C$	TCR = 1E-06	Oral $(HBRG_o)_{NC}$	Dermal $(HBRG_d)_{NC}$	Inhalation $(HBRG_i)_{NC}$	THQ = 1		
Volatile Organic Compounds												
cis-1,2-Dichloroethene	3.58E+03	V	NC	—	NC	NC	6.3E+03	—	3.2E+02	3.1E+02	3.1E+02	N
1,1,2,2-Tetrachloroethane	1.40E+04	V	2.2E+01	—	4.4E+00	3.6E+00	3.8E+04	—	7.6E+03	6.3E+03	3.6E+00	C
Tetrachloroethene	2.50E+03	V	8.2E+00	—	7.7E+00	4.0E+00	6.3E+03	—	2.3E+02	2.2E+02	4.0E+00	C
Trichloroethene	3.16E+03	V	1.1E+01	—	5.0E-01	4.8E-01	1.9E+02	—	3.3E+02	1.2E+02	4.8E-01	C
Benzene	3.06E+03	V	8.0E+01	—	7.1E+00	6.5E+00	2.5E+03	—	2.4E+02	2.2E+02	6.5E+00	C
Xylenes, total	5.19E+03	V	NC	NC	NC	NC	1.3E+05	2.6E+05	1.3E+03	1.3E+03	1.3E+03	N
Semivolatile Organic Compounds												
Benzo(a)Anthracene	8.04E+08	P	6.1E+00	9.7E+00	NA	3.7E+00	NA	NA	NA	NA	3.7E+00	C
Benzo(a)pyrene	8.04E+08	P	6.1E-01	9.7E-01	1.6E+04	3.7E-01	NA	NA	NA	NA	3.7E-01	C
Benzo(b)fluoranthene	8.04E+08	P	6.1E+00	9.7E+00	NA	3.7E+00	NA	NA	NA	NA	3.7E+00	C
Dibenzo(a,h)anthracene	8.04E+08	P	6.1E-01	9.7E-01	NA	3.7E-01	NA	NA	NA	NA	3.7E-01	C
PCBs	8.04E+08	P	2.2E+00	3.3E+00	2.5E+04	1.3E+00	1.3E+01	1.9E+01	1.5E+05	7.6E+00	1.3E+00	C
Metals												
Arsenic	8.04E+08	P	2.9E+00	2.0E+01	3.4E+03	2.6E+00	1.9E+02	1.3E+03	6.2E+04	1.7E+02	2.6E+00	C
Barium	8.04E+08	P	NC	—	NC	NC	1.3E+05	—	1.0E+06	1.1E+05	1.1E+05	N
Copper	8.04E+08	P	NC	—	NC	NC	2.5E+04	—	NA	2.5E+04	2.5E+04	N

[a] Volatilization factor (VF) (for VOCs) (identified by "V") or particulate emission factor (PEF) (for non-VOCs) (identified by "P"), calculated on Tables 4-3 and 4-5.

[b] Minimum of the $HBRG_C$ (identified by "C") and $HBRG_{NC}$ (identified by "N").

—	Not applicable; dermal absorption is assumed to be negligible.	mg/kg	Milligrams per kilogram.
COPCs	Chemicals of potential concern.	PEF	Particulate emission factor.
HBRG	Heath-based remedial goal.	TCR	Target cancer risk.
NA	Not available.	THQ	Target hazard quotient for non-cancer effects.
NC	Not evaluated as a carcinogen.	VF	Volatilization factor.
m³/kg	Cubic meters per kilogram.	VOCs	Volatile organic compounds.

Equations: (see Table 6-1)

(HBRGo)c = (TCR × 45 × 25,550 × 1,000,000) / (200 × 1 × 130 × 10 × CSFo)

(HBRGd)c = (TCR × 45 × 25,550 × 1,000,000) / (4,800 × 0.2 × ABSd × 130 × 10 × CSFa)

(HBRGi)c = (TCR × [VF or PEF] × 45 × 25,550) / (14 × 130 × 10 × CSFi)

HBRGc = 1 / [1/ (HBRGo)c] + [1/ (HBRGd)c] + [1/ (HBRGi)c])

(HBRGo)nc = (THQ × 45 × 3,650× 1,000,000) / (200 × 1 × 130 × 10 × [1/RfDo])

(HBRGd)nc = (THQ × 45 × 3,650 × 1,000,000) / (4,800 × 0.2 × ABSd × 130 × 10 × [1/RfDa])

(HBRGi)nc = (THQ × [VF or PEF] × 45 × 3,650) / (14 × 130 × 10 × [1/RfDi])

HBRGnc = 1 / [1/ (HBRGo)nc] + [1/ (HBRGd)nc] + [1/ (HBRGi)nc])

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Table 6-12. Health-Based Remedial Goal Calculations for COPCs in Soil Based on Average Use Adult Recreational User Exposure, Hamilton Sundstrand Facility, Denver, Colorado.

Chemical of Potential Concern	VF *or* PEF [a] (m³/kg)		CANCER EFFECTS				NON-CANCER EFFECTS				Minimum HBRG (mg/kg) [b]	
			Route-Specific HBRG (mg/kg)			$HBRG_C$ (mg/kg)	Route-Specific HBRG (mg/kg)			$HBRG_{NC}$ (mg/kg)		
			Oral $(HBRG_o)_C$	Dermal $(HBRG_d)_C$	Inhalation $(HBRG_i)_C$	TCR = 1E-06	Oral $(HBRG_o)_{NC}$	Dermal $(HBRG_d)_{NC}$	Inhalation $(HBRG_i)_{NC}$	THQ = 1		
<u>Volatile Organic Compounds</u>												
cis-1,2-Dichloroethene	3.58E+03	V	NC	—	NC	NC	1.3E+05	—	1.1E+03	1.1E+03	1.1E+03	N
1,1,2,2-Tetrachloroethane	1.40E+04	V	1.5E+02	—	5.1E+00	5.0E+00	7.7E+05	—	2.7E+04	2.6E+04	5.0E+00	C
Tetrachloroethene	2.50E+03	V	5.5E+01	—	9.0E+00	7.8E+00	1.3E+05	—	8.0E+02	7.9E+02	7.8E+00	C
Trichloroethene	3.16E+03	V	7.5E+01	—	5.9E-01	5.8E-01	3.8E+03	—	1.2E+03	8.9E+02	5.8E-01	C
Benzene	3.06E+03	V	5.4E+02	—	8.3E+00	8.2E+00	5.1E+04	—	8.4E+02	8.3E+02	8.2E+00	C
Xylenes, total	5.19E+03	V	NC	—	NC	NC	2.6E+06	—	4.7E+03	4.7E+03	4.7E+03	N
<u>Semivolatile Organic Compounds</u>												
Benzo(a)Anthracene	8.04E+08	P	4.1E+01	3.9E+01	NA	2.0E+01	NA	NA	NA	NA	2.0E+01	C
Benzo(a)pyrene	8.04E+08	P	4.1E+00	3.9E+00	1.9E+04	2.0E+00	NA	NA	NA	NA	2.0E+00	C
Benzo(b)fluoranthene	8.04E+08	P	4.1E+01	3.9E+01	NA	2.0E+01	NA	NA	NA	NA	2.0E+01	C
Dibenzo(a,h)anthracene	8.04E+08	P	4.1E+00	3.9E+00	NA	2.0E+00	NA	NA	NA	NA	2.0E+00	C
<u>PCBs</u>	8.04E+08	P	1.5E+01	1.3E+01	3.0E+04	7.0E+00	2.6E+02	2.3E+02	5.1E+05	1.2E+02	7.0E+00	C
<u>Metals</u>												
Arsenic	8.04E+08	P	2.0E+01	8.3E+01	4.0E+03	1.6E+01	3.8E+03	1.6E+04	2.2E+05	3.0E+03	1.6E+01	C
Barium	8.04E+08	P	NC	—	NC	NC	2.6E+06	—	3.7E+06	1.5E+06	1.5E+06	N
Copper	8.04E+08	P	NC	—	NC	NC	5.1E+05	—	NA	5.1E+05	5.1E+05	N

[a] Volatilization factor (VF) (for VOCs) (identified by "V") or particulate emission factor (PEF) (for non-VOCs) (identified by "P"), calculated on Tables 4-3 and 4-5.

[b] Minimum of the $HBRG_C$ (identified by "C") and $HBRG_{NC}$ (identified by "N").

—	Not applicable; dermal absorption is assumed to be negligible.	mg/kg	Milligrams per kilogram.
COPCs	Chemicals of potential concern.	PEF	Particulate emission factor.
HBRG	Heath-based remedial goal.	TCR	Target cancer risk.
NA	Not available.	THQ	Target hazard quotient for non-cancer effects.
NC	Not evaluated as a carcinogen.	VF	Volatilization factor.
m³/kg	Cubic meters per kilogram.	VOCs	Volatile organic compounds.

<u>Equations:</u> (see Table 6-1)

(HBRGo)c = (TCR × 70 × 25,550 × 1,000,000) / (50 × 1 × 40 × 30 × CSFo)

(HBRGd)c = (TCR × 70 × 25,550 × 1,000,000) / (5,700 × 0.1 × ABSd × 40 × 30 × CSFa)

(HBRGi)c = (TCR × [VF or PEF] × 70 × 25,550) / (20 × 40 × 30 × CSFi)

HBRGc = 1 / [1/ (HBRGo)c] + [1/ (HBRGd)c] + [1/ (HBRGi)c])

(HBRGo)nc = (THQ × 70 × 10,950× 1,000,000) / (50 × 1 × 40 × 30 × [1/RfDo])

(HBRGd)nc = (THQ × 70 × 10,950 × 1,000,000) / (5,700 × 0.1 × ABSd × 40 × 30 × [1/RfDa])

(HBRGi)nc = (THQ × [VF or PEF] × 70 × 10,950) / (20 × 40 × 30 × [1/RfDi])

HBRGnc = 1 / [1/ (HBRGo)nc] + [1/ (HBRGd)nc] + [1/ (HBRGi)nc])

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Table 6-13. Health-Based Remedial Goal Calculations for COPCs in Soil Based on High Use Adult Recreational User Exposure, Hamilton Sundstrand Facility, Denver, Colorado.

Chemical of Potential Concern	VF *or* PEF [a] (m³/kg)		CANCER EFFECTS				NON-CANCER EFFECTS				Minimum HBRG (mg/kg) [b]	
			Route-Specific HBRG (mg/kg)			$HBRG_C$ (mg/kg)	Route-Specific HBRG (mg/kg)			$HBRG_{NC}$ (mg/kg)		
			Oral $(HBRG_o)_C$	Dermal $(HBRG_d)_C$	Inhalation $(HBRG_i)_C$	TCR = 1E-06	Oral $(HBRG_o)_{NC}$	Dermal $(HBRG_d)_{NC}$	Inhalation $(HBRG_i)_{NC}$	THQ = 1		
<u>Volatile Organic Compounds</u>												
cis-1,2-Dichloroethene	3.58E+03	V	NC	—	NC	NC	2.6E+04	—	4.6E+02	4.5E+02	4.5E+02	N
1,1,2,2-Tetrachloroethane	1.40E+04	V	3.0E+01	—	2.1E+00	1.9E+00	1.5E+05	—	1.1E+04	1.0E+04	1.9E+00	C
Tetrachloroethene	2.50E+03	V	1.1E+01	—	3.6E+00	2.7E+00	2.6E+04	—	3.2E+02	3.2E+02	2.7E+00	C
Trichloroethene	3.16E+03	V	1.5E+01	—	2.4E-01	2.3E-01	7.7E+02	—	4.6E+02	2.9E+02	2.3E-01	C
Benzene	3.06E+03	V	1.1E+02	—	3.3E+00	3.2E+00	1.0E+04	—	3.4E+02	3.3E+02	3.2E+00	C
Xylenes, total	5.19E+03	V	NC	—	NC	NC	5.1E+05	—	1.9E+03	1.9E+03	1.9E+03	N
<u>Semivolatile Organic Compounds</u>												
Benzo(a)Anthracene	8.04E+08	P	8.2E+00	1.6E+01	NA	5.4E+00	NA	NA	NA	NA	5.4E+00	C
Benzo(a)pyrene	8.04E+08	P	8.2E-01	1.6E+00	7.8E+03	5.4E-01	NA	NA	NA	NA	5.4E-01	C
Benzo(b)fluoranthene	8.04E+08	P	8.2E+00	1.6E+01	NA	5.4E+00	NA	NA	NA	NA	5.4E+00	C
Dibenzo(a,h)anthracene	8.04E+08	P	8.2E-01	1.6E+00	NA	5.4E-01	NA	NA	NA	NA	5.4E-01	C
<u>PCBs</u>	8.04E+08	P	3.0E+00	5.3E+00	1.2E+04	1.9E+00	5.1E+01	9.1E+01	2.1E+05	3.3E+01	1.9E+00	C
<u>Metals</u>												
Arsenic	8.04E+08	P	4.0E+00	3.3E+01	1.6E+03	3.5E+00	7.7E+02	6.4E+03	8.8E+04	6.8E+02	3.5E+00	C
Barium	8.04E+08	P	NC	—	NC	NC	5.1E+05	—	1.5E+06	3.8E+05	3.8E+05	N
Copper	8.04E+08	P	NC	—	NC	NC	1.0E+05	—	NA	1.0E+05	1.0E+05	N

[a] Volatilization factor (VF) (for VOCs) (identified by "V") or particulate emission factor (PEF) (for non-VOCs) (identified by "P"), calculated on Tables 4-3 and 4-5.

[b] Minimum of the $HBRG_C$ (identified by "C") and $HBRG_{NC}$ (identified by "N").

—	Not applicable; dermal absorption is assumed to be negligible.
COPCs	Chemicals of potential concern.
HBRG	Heath-based remedial goal.
NA	Not available.
NC	Not evaluated as a carcinogen.
m³/kg	Cubic meters per kilogram.
mg/kg	Milligrams per kilogram.
PEF	Particulate emission factor.
TCR	Target cancer risk.
THQ	Target hazard quotient for non-cancer effects.
VF	Volatilization factor.
VOCs	Volatile organic compounds.

<u>Equations:</u> (see Table 6-1)

(HBRGo)c = (TCR × 70 × 25,550 × 1,000,000) / (100 × 1 × 100 × 30 × CSFo)

(HBRGd)c = (TCR × 70 × 25,550 × 1,000,000) / (5,700 × 0.1 × ABSd × 100 × 30 × CSFa)

(HBRGi)c = (TCR × [VF or PEF] × 70 × 25,550) / (20 × 100 × 30 × CSFi)

HBRGc = 1 / [1/ (HBRGo)c] + [1/ (HBRGd)c] + [1/ (HBRGi)c])

(HBRGo)nc = (THQ × 70 × 10,950× 1,000,000) / (100 × 1 × 100 × 30 × [1/RfDo])

(HBRGd)nc = (THQ × 70 × 10,950 × 1,000,000) / (5,700 × 0.1 × ABSd × 100 × 30 × [1/RfDa])

(HBRGi)nc = (THQ × [VF or PEF] × 70 × 10,950) / (20 × 100 × 30 × [1/RfDi])

HBRGnc = 1 / [1/ (HBRGo)nc] + [1/ (HBRGd)nc] + [1/ (HBRGi)nc])

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Table 6-14. Health-Based Remedial Goal Calculations for COPCs in Groundwater Based on Vapor Migration to Outdoor Air, Maintenance Worker Exposure, Hamilton Sundstrand Facility, Denver, Colorado.

Chemical of Potential Concern	VF [a] (m³/L)	CANCER EFFECTS		NON-CANCER EFFECTS		Minimum HBRG (mg/L) [b]	
		Route-Specific HBRG (mg/L) Inhalation $(HBRG_i)_C$	$HBRG_C$ (mg/L) TCR = 1E-06	Route-Specific HBRG (mg/L) Inhalation $(HBRG_i)_{NC}$	$HBRG_{NC}$ (mg/L) THQ = 1		
Volatile Organic Compounds							
1,1-Dichloroethane	3.93E-05	NA	—	2.0E+04	2.0E+04	2.0E+04	N
1,1-Dichloroethene	2.00E-04	NA	—	1.6E+03	1.6E+03	1.6E+03	N
cis-1,2-Dichloroethene	2.87E-05	NC	—	2.0E+03	2.0E+03	2.0E+03	N
Tetrachloroethene	1.13E-04	6.8E+00	6.8E+00	5.0E+02	5.0E+02	6.8E+00	C
1,1,1-Trichloroethane	1.16E-04	NC	—	7.0E+04	7.0E+04	7.0E+04	N
1,1,2-Trichloroethane	7.31E-06	3.9E+01	3.9E+01	3.1E+03	3.1E+03	3.9E+01	C
Trichloroethene	6.88E-05	5.8E-01	5.8E-01	9.4E+02	9.4E+02	5.8E-01	C
1,1,2,2-Tetrachloroethane	2.69E-06	2.9E+01	2.9E+01	1.3E+05	1.3E+05	2.9E+01	C
1,2,4-Trichlorobenzene	4.55E-06	NC	—	1.2E+03	1.2E+03	1.2E+03	N
1,2,4-Trimethylbenzene	3.62E-05	NA	—	2.7E+02	2.7E+02	2.7E+02	N
1,2-Dichloroethane	1.24E-05	1.4E+01	1.4E+01	6.4E+02	6.4E+02	1.4E+01	C
1,3,5-Trimethylbenzene	4.76E-05	NA	—	2.0E+02	2.0E+02	2.0E+02	N
1,4-Dioxane	3.34E-07	4.3E+03	4.3E+03	—	—	4.3E+03	C
2-Butanone (MEK)	6.95E-07	NC	—	2.3E+06	2.3E+06	2.3E+06	N
Benzene	4.46E-05	1.3E+01	1.3E+01	1.1E+03	1.1E+03	1.3E+01	C
Bromodichloromethane	6.68E-06	3.8E+01	3.8E+01	1.7E+04	1.7E+04	3.8E+01	C
Bromomethane	4.23E-05	NC	—	1.9E+02	1.9E+02	1.9E+02	N
Carbon tetrachloride	1.83E-04	1.7E+00	1.7E+00	1.7E+03	1.7E+03	1.7E+00	C
Chloroethane	2.55E-04	2.2E+01	2.2E+01	6.4E+04	6.4E+04	2.2E+01	C
Chloroform	3.57E-05	5.5E+00	5.5E+00	4.5E+03	4.5E+03	5.5E+00	C
Ethyl methacrylate	1.83E-03	NA	—	2.8E+02	2.8E+02	2.8E+02	N
Ethylbenzene	5.26E-05	NC	—	3.1E+04	3.1E+04	3.1E+04	N
Isobutyl alcohol	3.06E-07	NA	—	5.6E+06	5.6E+06	5.6E+06	N
Methyl tert-Butyl Ether	5.04E-06	3.5E+03	3.5E+03	9.7E+05	9.7E+05	3.5E+03	C
Methylene chloride	2.17E-05	4.6E+02	4.6E+02	2.2E+05	2.2E+05	4.6E+02	C
Naphthalene	2.85E-06	NC	—	1.7E+03	1.7E+03	1.7E+03	N
n-Butylbenzene	8.59E-05	NA	—	2.6E+03	2.6E+03	2.6E+03	N
n-Propylbenzene	8.59E-05	NA	—	2.6E+03	2.6E+03	2.6E+03	N
sec-Butylbenzene	1.21E-04	NA	—	1.9E+03	1.9E+03	1.9E+03	N
Styrene	1.87E-05	NA	—	8.7E+04	8.7E+04	8.7E+04	N
Tetrahydrofuran	9.68E-07	2.4E+03	2.4E+03	5.0E+05	5.0E+05	2.4E+03	C
Toluene	5.17E-05	NC	—	1.6E+05	1.6E+05	1.6E+05	N
trans-1,2-Dichloroethene	6.03E-05	NA	—	1.6E+03	1.6E+03	1.6E+03	N
Vinyl chloride	2.44E-04	2.1E+00	2.1E+00	6.7E+02	6.7E+02	2.1E+00	C
Xylenes, total	4.27E-05	NC	—	3.8E+03	3.8E+03	3.8E+03	N

[a] Volatilization factor (VF) (for VOCs) for vapor migration from groundwater to outdoor (ambient) air, calculated on Table 6-3.

[b] Minimum of the $HBRG_C$ (identified by "C") and $HBRG_{NC}$ (identified by "N").

—	Not applicable.	mg/L	Milligrams per liter.
COPCs	Chemicals of potential concern.	TCR	Target cancer risk.
HBRG	Heath-based remedial goal.	THQ	Target hazard quotient for non-cancer effects.
NA	Not available.	VF	Volatilization factor.
NC	Not evaluated as a carcinogen.	VOCs	Volatile organic compounds.
m³/L	Cubic meters per Liter.		

Equations: (see Table 6-3)

$(HBRGi)c = (TCR \times 70 \times 25{,}550) / (20 \times 225 \times 25 \times CSFi) / VF$

$(HBRGi)nc = (THQ \times 70 \times 9{,}125) / (20 \times 225 \times 25 \times [1/RfDi]) / VF$

Table 6-15. Health-Based Remedial Goal Calculations for COPCs in Groundwater Based on Vapor Migration to a Construction Trench, Construction Worker Exposure, Hamilton Sundstrand Facility, Denver, Colorado.

Chemical of Potential Concern	VF [a] (L/m³)	CANCER EFFECTS: Route-Specific HBRG (mg/L) Inhalation $(HBRG_i)_C$	CANCER EFFECTS: $HBRG_C$ (mg/L) TCR = 1E-06	NON-CANCER EFFECTS: Route-Specific HBG (mg/L) Inhalation $(HBRG_i)_{NC}$	NON-CANCER EFFECTS: $HBRG_{NC}$ (mg/L) THQ = 1	Minimum HBRG (mg/L) [b]	
<u>Volatile Organic Compounds</u>							
1,1-Dichloroethane	1.46E-03	NA	—	4.7E+03	4.7E+03	4.7E+03	N
1,1-Dichloroethene	8.23E-03	NA	—	3.4E+01	3.4E+01	3.4E+01	N
cis-1,2-Dichloroethene	1.05E-03	NC	—	4.7E+01	4.7E+01	4.7E+01	N
Tetrachloroethene	4.47E-03	3.2E+01	3.2E+01	1.1E+01	1.1E+01	1.1E+01	N
1,1,1-Trichloroethane	4.70E-03	NC	—	1.5E+03	1.5E+03	1.5E+03	N
1,1,2-Trichloroethane	2.49E-04	2.1E+02	2.1E+02	7.9E+01	7.9E+01	7.9E+01	N
Trichloroethene	2.73E-03	2.7E+00	2.7E+00	2.1E+02	2.1E+02	2.7E+00	C
1,1,2,2-Tetrachloroethane	8.71E-05	1.7E+02	1.7E+02	3.4E+03	3.4E+03	1.7E+02	C
1,2,4-Trichlorobenzene	1.47E-04	NC	—	3.3E+01	3.3E+01	3.3E+01	N
1,2,4-Trimethylbenzene	1.39E-03	NA	—	6.0E+00	6.0E+00	6.0E+00	N
1,2-Dichloroethane	4.30E-04	7.6E+01	7.6E+01	1.6E+01	1.6E+01	1.6E+01	N
1,3,5-Trimethylbenzene	1.85E-03	NA	—	4.5E+00	4.5E+00	4.5E+00	N
1,4-Dioxane	1.77E-05	1.5E+04	1.5E+04	—	—	1.5E+04	C
2-Butanone (MEK)	1.61E-05	NC	—	8.8E+04	8.8E+04	8.8E+04	N
Benzene	1.71E-03	6.4E+01	6.4E+01	2.5E+01	2.5E+01	2.5E+01	N
Bromodichloromethane	2.21E-04	2.2E+02	2.2E+02	4.4E+02	4.4E+02	2.2E+02	C
Bromomethane	1.58E-03	NC	—	4.4E+00	4.4E+00	4.4E+00	N
Carbon tetrachloride	7.55E-03	7.5E+00	7.5E+00	3.5E+01	3.5E+01	7.5E+00	C
Chloroethane	1.05E-02	9.7E+01	9.7E+01	1.3E+03	1.3E+03	9.7E+01	C
Chloroform	1.34E-03	2.8E+01	2.8E+01	2.5E+02	2.5E+02	2.8E+01	C
Ethyl methacrylate	7.65E-02	NA	—	5.8E+00	5.8E+00	5.8E+00	N
Ethylbenzene	2.07E-03	NC	—	6.9E+02	6.9E+02	6.9E+02	N
Isobutyl alcohol	3.62E-06	NA	—	4.1E+05	4.1E+05	4.1E+05	N
Methyl tert-Butyl Ether	1.65E-04	2.0E+04	2.0E+04	2.5E+04	2.5E+04	2.0E+04	C
Methylene chloride	7.79E-04	2.4E+03	2.4E+03	5.4E+03	5.4E+03	2.4E+03	C
Naphthalene	9.93E-05	NC	—	4.2E+01	4.2E+01	4.2E+01	N
n-Butylbenzene	3.42E-03	NA	—	5.7E+01	5.7E+01	5.7E+01	N
n-Propylbenzene	3.42E-03	NA	—	5.7E+01	5.7E+01	5.7E+01	N
sec-Butylbenzene	4.99E-03	NA	—	3.9E+01	3.9E+01	3.9E+01	N
Styrene	6.97E-04	NA	—	6.0E+03	6.0E+03	6.0E+03	N
Tetrahydrofuran	2.40E-05	1.8E+04	1.8E+04	1.8E+04	1.8E+04	1.8E+04	N
Toluene	2.01E-03	NC	—	3.5E+03	3.5E+03	3.5E+03	N
trans-1,2-Dichloroethene	2.32E-03	NA	—	3.6E+01	3.6E+01	3.6E+01	N
Vinyl chloride	1.03E-02	9.4E+00	9.4E+00	1.4E+01	1.4E+01	9.4E+00	C
Xylenes, total	1.83E-03	NC	—	7.7E+01	7.7E+01	7.7E+01	N

[a] Volatilization factor (VF) (for VOCs) for vapor migration from groundwater to a construction trench, calculated on Table 6-4.

[b] Minimum of the $HBRG_C$ (identified by "C") and $HBRG_{NC}$ (identified by "N").

—	Not applicable.	mg/L	Milligrams per liter.
COPCs	Chemicals of potential concern.	TCR	Target cancer risk.
HBRG	Heath-based remedial goal.	THQ	Target hazard quotient for non-cancer effects.
NA	Not available.	VF	Volatilization factor.
NC	Not evaluated as a carcinogen.	VOCs	Volatile organic compounds.
m³/L	Cubic meters per Liter.		

<u>Equations:</u> (see Table 6-4)

(HBRGi)c = (TCR × 70 × 25,550) / (20 × 5 × 6 × CSFi) / VF

(HBRGi)nc = (THQ × 70 × 42) / (20 × 5 × 6 × [1/RfDi]) / VF

Table 6-16. Health-Based Remedial Goal Calculations for COPCs in Groundwater Based on Vapor Migration to Outdoor Air, Average Use Child Recreational User Exposure, Hamilton Sundstrand Facility, Denver, Colorado.

		CANCER EFFECTS		NON-CANCER EFFECTS		Minimum HBRG (mg/L) [b]	
Chemical of Potential Concern	VF [a] (m³/L)	Route-Specific HBRG (mg/L) Inhalation $(HBRG_i)_C$	$HBRG_C$ (mg/L) TCR = 1E-06	Route-Specific HBRG (mg/L) Inhalation $(HBRG_i)_{NC}$	$HBRG_{NC}$ (mg/L) THQ = 1		
Volatile Organic Compounds							
1,1-Dichloroethane	3.93E-05	NA	—	6.1E+04	6.1E+04	6.1E+04	N
1,1-Dichloroethene	2.00E-04	NA	—	4.9E+03	4.9E+03	4.9E+03	N
cis-1,2-Dichloroethene	2.87E-05	NC	—	6.0E+03	6.0E+03	6.0E+03	N
Tetrachloroethene	1.13E-04	8.5E+01	8.5E+01	1.5E+03	1.5E+03	8.5E+01	C
1,1,1-Trichloroethane	1.16E-04	NC	—	2.1E+05	2.1E+05	2.1E+05	N
1,1,2-Trichloroethane	7.31E-06	4.9E+02	4.9E+02	9.4E+03	9.4E+03	4.9E+02	C
Trichloroethene	6.88E-05	7.3E+00	7.3E+00	2.8E+03	2.8E+03	7.3E+00	C
1,1,2,2-Tetrachloroethane	2.69E-06	3.7E+02	3.7E+02	3.8E+05	3.8E+05	3.7E+02	C
1,2,4-Trichlorobenzene	4.55E-06	NC	—	3.8E+03	3.8E+03	3.8E+03	N
1,2,4-Trimethylbenzene	3.62E-05	NA	—	8.1E+02	8.1E+02	8.1E+02	N
1,2-Dichloroethane	1.24E-05	1.8E+02	1.8E+02	1.9E+03	1.9E+03	1.8E+02	C
1,3,5-Trimethylbenzene	4.76E-05	NA	—	6.1E+02	6.1E+02	6.1E+02	N
1,4-Dioxane	3.34E-07	5.4E+04	5.4E+04	—	—	5.4E+04	C
2-Butanone (MEK)	6.95E-07	NC	—	7.0E+06	7.0E+06	7.0E+06	N
Benzene	4.46E-05	1.6E+02	1.6E+02	3.3E+03	3.3E+03	1.6E+02	C
Bromodichloromethane	6.68E-06	4.8E+02	4.8E+02	5.1E+04	5.1E+04	4.8E+02	C
Bromomethane	4.23E-05	NC	—	5.8E+02	5.8E+02	5.8E+02	N
Carbon tetrachloride	1.83E-04	2.1E+01	2.1E+01	5.1E+03	5.1E+03	2.1E+01	C
Chloroethane	2.55E-04	2.7E+02	2.7E+02	1.9E+05	1.9E+05	2.7E+02	C
Chloroform	3.57E-05	6.9E+01	6.9E+01	1.3E+04	1.3E+04	6.9E+01	C
Ethyl methacrylate	1.83E-03	NA	—	8.4E+02	8.4E+02	8.4E+02	N
Ethylbenzene	5.26E-05	NC	—	9.3E+04	9.3E+04	9.3E+04	N
Isobutyl alcohol	3.06E-07	NA	—	1.7E+07	1.7E+07	1.7E+07	N
Methyl tert-Butyl Ether	5.04E-06	4.4E+04	4.4E+04	2.9E+06	2.9E+06	4.4E+04	C
Methylene chloride	2.17E-05	5.7E+03	5.7E+03	6.8E+05	6.8E+05	5.7E+03	C
Naphthalene	2.85E-06	NC	—	5.1E+03	5.1E+03	5.1E+03	N
n-Butylbenzene	8.59E-05	NA	—	8.0E+03	8.0E+03	8.0E+03	N
n-Propylbenzene	8.59E-05	NA	—	8.0E+03	8.0E+03	8.0E+03	N
sec-Butylbenzene	1.21E-04	NA	—	5.7E+03	5.7E+03	5.7E+03	N
Styrene	1.87E-05	NA	—	2.6E+05	2.6E+05	2.6E+05	N
Tetrahydrofuran	9.68E-07	3.0E+04	3.0E+04	1.5E+06	1.5E+06	3.0E+04	C
Toluene	5.17E-05	NC	—	4.7E+05	4.7E+05	4.7E+05	N
trans-1,2-Dichloroethene	6.03E-05	NA	—	4.8E+03	4.8E+03	4.8E+03	N
Vinyl chloride	2.44E-04	2.7E+01	2.7E+01	2.0E+03	2.0E+03	2.7E+01	C
Xylenes, total	4.27E-05	NC	—	1.1E+04	1.1E+04	1.1E+04	N

[a] Volatilization factor (VF) (for VOCs) for vapor migration from groundwater to outdoor (ambient) air, calculated on Table 6-3.

[b] Minimum of the $HBRG_C$ (identified by "C") and $HBRG_{NC}$ (identified by "N").

—	Not applicable.	mg/L	Milligrams per liter.
COPCs	Chemicals of potential concern.	TCR	Target cancer risk.
HBRG	Heath-based remedial goal.	THQ	Target hazard quotient for non-cancer effects.
NA	Not available.	VF	Volatilization factor.
NC	Not evaluated as a carcinogen.	VOCs	Volatile organic compounds.
m³/L	Cubic meters per Liter.		

Equations: (see Table 6-3)

(HBRGi)c = (TCR × 15 × 25,550) / (8 × 40 × 6 × CSFi) / VF

(HBRGi)nc = (THQ × 15 × 2,190) / (8 × 40 × 6 × [1/RfDi]) / VF

Table 6-17. Health-Based Remedial Goal Calculations for COPCs in Groundwater Based on Vapor Migration to Outdoor Air, High Use Child Recreational User Exposure, Hamilton Sundstrand Facility, Denver, Colorado.

Chemical of Potential Concern	VF [a] (m³/L)	CANCER EFFECTS		NON-CANCER EFFECTS		Minimum HBRG (mg/L) [b]	
		Route-Specific HBRG(mg/L) Inhalation $(HBRG_i)_C$	$HBRG_C$ (mg/L) TCR = 1E-06	Route-Specific HBRG (mg/L) Inhalation $(HBRG_i)_{NC}$	$HBRG_{NC}$ (mg/L) THQ = 1		
Volatile Organic Compounds							
1,1-Dichloroethane	3.93E-05	NA	—	2.4E+04	2.4E+04	2.4E+04	N
1,1-Dichloroethene	2.00E-04	NA	—	2.0E+03	2.0E+03	2.0E+03	N
cis-1,2-Dichloroethene	2.87E-05	NC	—	2.4E+03	2.4E+03	2.4E+03	N
Tetrachloroethene	1.13E-04	3.4E+01	3.4E+01	6.0E+02	6.0E+02	3.4E+01	C
1,1,1-Trichloroethane	1.16E-04	NC	—	8.4E+04	8.4E+04	8.4E+04	N
1,1,2-Trichloroethane	7.31E-06	1.9E+02	1.9E+02	3.7E+03	3.7E+03	1.9E+02	C
Trichloroethene	6.88E-05	2.9E+00	2.9E+00	1.1E+03	1.1E+03	2.9E+00	C
1,1,2,2-Tetrachloroethane	2.69E-06	1.5E+02	1.5E+02	1.5E+05	1.5E+05	1.5E+02	C
1,2,4-Trichlorobenzene	4.55E-06	NC	—	1.5E+03	1.5E+03	1.5E+03	N
1,2,4-Trimethylbenzene	3.62E-05	NA	—	3.2E+02	3.2E+02	3.2E+02	N
1,2-Dichloroethane	1.24E-05	7.1E+01	7.1E+01	7.7E+02	7.7E+02	7.1E+01	C
1,3,5-Trimethylbenzene	4.76E-05	NA	—	2.5E+02	2.5E+02	2.5E+02	N
1,4-Dioxane	3.34E-07	2.2E+04	2.2E+04	—	—	2.2E+04	C
2-Butanone (MEK)	6.95E-07	NC	—	2.8E+06	2.8E+06	2.8E+06	N
Benzene	4.46E-05	6.6E+01	6.6E+01	1.3E+03	1.3E+03	6.6E+01	C
Bromodichloromethane	6.68E-06	1.9E+02	1.9E+02	2.1E+04	2.1E+04	1.9E+02	C
Bromomethane	4.23E-05	NC	—	2.3E+02	2.3E+02	2.3E+02	N
Carbon tetrachloride	1.83E-04	8.3E+00	8.3E+00	2.0E+03	2.0E+03	8.3E+00	C
Chloroethane	2.55E-04	1.1E+02	1.1E+02	7.7E+04	7.7E+04	1.1E+02	C
Chloroform	3.57E-05	2.8E+01	2.8E+01	5.4E+03	5.4E+03	2.8E+01	C
Ethyl methacrylate	1.83E-03	NA	—	3.4E+02	3.4E+02	3.4E+02	N
Ethylbenzene	5.26E-05	NC	—	3.7E+04	3.7E+04	3.7E+04	N
Isobutyl alcohol	3.06E-07	NA	—	6.7E+06	6.7E+06	6.7E+06	N
Methyl tert-Butyl Ether	5.04E-06	1.7E+04	1.7E+04	1.2E+06	1.2E+06	1.7E+04	C
Methylene chloride	2.17E-05	2.3E+03	2.3E+03	2.7E+05	2.7E+05	2.3E+03	C
Naphthalene	2.85E-06	NC	—	2.1E+03	2.1E+03	2.1E+03	N
n-Butylbenzene	8.59E-05	NA	—	3.2E+03	3.2E+03	3.2E+03	N
n-Propylbenzene	8.59E-05	NA	—	3.2E+03	3.2E+03	3.2E+03	N
sec-Butylbenzene	1.21E-04	NA	—	2.3E+03	2.3E+03	2.3E+03	N
Styrene	1.87E-05	NA	—	1.0E+05	1.0E+05	1.0E+05	N
Tetrahydrofuran	9.68E-07	1.2E+04	1.2E+04	6.1E+05	6.1E+05	1.2E+04	C
Toluene	5.17E-05	NC	—	1.9E+05	1.9E+05	1.9E+05	N
trans-1,2-Dichloroethene	6.03E-05	NA	—	1.9E+03	1.9E+03	1.9E+03	N
Vinyl chloride	2.44E-04	1.1E+01	1.1E+01	8.0E+02	8.0E+02	1.1E+01	C
Xylenes, total	4.27E-05	NC	—	4.6E+03	4.6E+03	4.6E+03	N

[a] Volatilization factor (VF) (for VOCs) for vapor migration from groundwater to outdoor (ambient) air, calculated on Table 6-3.

[b] Minimum of the $HBRG_C$ (identified by "C") and $HBRG_{NC}$ (identified by "N").

—	Not applicable.	mg/L	Milligrams per liter.
COPCs	Chemicals of potential concern.	TCR	Target cancer risk.
HBRG	Heath-based remedial goal.	THQ	Target hazard quotient for non-cancer effects.
NA	Not available.	VF	Volatilization factor.
NC	Not evaluated as a carcinogen.	VOCs	Volatile organic compounds.
m³/L	Cubic meters per Liter.		

Equations: (see Table 6-3)

(HBRGi)c = (TCR × 15 × 25,550) / (8 × 100 × 6 × CSFi) / VF

(HBRGi)nc = (THQ × 15 × 2,190) / (8 × 100 × 6 × [1/RfDi]) / VF

Table 6-18. Health-Based Remedial Goal Calculations for COPCs in Groundwater Based on Vapor Migration to Outdoor Air, Average Use Youth Recreational User Exposure, Hamilton Sundstrand Facility, Denver, Colorado.

Chemical of Potential Concern	VF [a] (m³/L)	CANCER EFFECTS		NON-CANCER EFFECTS		Minimum HBRG (mg/L) [b]	
		Route-Specific HBRG (mg/L) Inhalation $(HBRG_i)_C$	$HBRG_C$ (mg/L) TCR = 1E-06	Route-Specific HBRG (mg/L) Inhalation $(HBRG_i)_{NC}$	$HBRG_{NC}$ (mg/L) THQ = 1		
<u>Volatile Organic Compounds</u>							
1,1-Dichloroethane	3.93E-05	NA	—	8.4E+04	8.4E+04	8.4E+04	N
1,1-Dichloroethene	2.00E-04	NA	—	6.7E+03	6.7E+03	6.7E+03	N
cis-1,2-Dichloroethene	2.87E-05	NC	—	8.2E+03	8.2E+03	8.2E+03	N
Tetrachloroethene	1.13E-04	1.2E+02	1.2E+02	2.1E+03	2.1E+03	1.2E+02	C
1,1,1-Trichloroethane	1.16E-04	NC	—	2.9E+05	2.9E+05	2.9E+05	N
1,1,2-Trichloroethane	7.31E-06	6.7E+02	6.7E+02	1.3E+04	1.3E+04	6.7E+02	C
Trichloroethene	6.88E-05	9.9E+00	9.9E+00	3.9E+03	3.9E+03	9.9E+00	C
1,1,2,2-Tetrachloroethane	2.69E-06	5.0E+02	5.0E+02	5.2E+05	5.2E+05	5.0E+02	C
1,2,4-Trichlorobenzene	4.55E-06	NC	—	5.2E+03	5.2E+03	5.2E+03	N
1,2,4-Trimethylbenzene	3.62E-05	NA	—	1.1E+03	1.1E+03	1.1E+03	N
1,2-Dichloroethane	1.24E-05	2.4E+02	2.4E+02	2.7E+03	2.7E+03	2.4E+02	C
1,3,5-Trimethylbenzene	4.76E-05	NA	—	8.4E+02	8.4E+02	8.4E+02	N
1,4-Dioxane	3.34E-07	7.4E+04	7.4E+04	—	—	7.4E+04	C
2-Butanone (MEK)	6.95E-07	NC	—	9.7E+06	9.7E+06	9.7E+06	N
Benzene	4.46E-05	2.2E+02	2.2E+02	4.5E+03	4.5E+03	2.2E+02	C
Bromodichloromethane	6.68E-06	6.6E+02	6.6E+02	7.0E+04	7.0E+04	6.6E+02	C
Bromomethane	4.23E-05	NC	—	7.9E+02	7.9E+02	7.9E+02	N
Carbon tetrachloride	1.83E-04	2.9E+01	2.9E+01	6.9E+03	6.9E+03	2.9E+01	C
Chloroethane	2.55E-04	3.7E+02	3.7E+02	2.6E+05	2.6E+05	3.7E+02	C
Chloroform	3.57E-05	9.5E+01	9.5E+01	1.8E+04	1.8E+04	9.5E+01	C
Ethyl methacrylate	1.83E-03	NA	—	1.2E+03	1.2E+03	1.2E+03	N
Ethylbenzene	5.26E-05	NC	—	1.3E+05	1.3E+05	1.3E+05	N
Isobutyl alcohol	3.06E-07	NA	—	2.3E+07	2.3E+07	2.3E+07	N
Methyl tert-Butyl Ether	5.04E-06	6.0E+04	6.0E+04	4.0E+06	4.0E+06	6.0E+04	C
Methylene chloride	2.17E-05	7.9E+03	7.9E+03	9.3E+05	9.3E+05	7.9E+03	C
Naphthalene	2.85E-06	NC	—	7.1E+03	7.1E+03	7.1E+03	N
n-Butylbenzene	8.59E-05	NA	—	1.1E+04	1.1E+04	1.1E+04	N
n-Propylbenzene	8.59E-05	NA	—	1.1E+04	1.1E+04	1.1E+04	N
sec-Butylbenzene	1.21E-04	NA	—	7.8E+03	7.8E+03	7.8E+03	N
Styrene	1.87E-05	NA	—	3.6E+05	3.6E+05	3.6E+05	N
Tetrahydrofuran	9.68E-07	4.2E+04	4.2E+04	2.1E+06	2.1E+06	4.2E+04	C
Toluene	5.17E-05	NC	—	6.5E+05	6.5E+05	6.5E+05	N
trans-1,2-Dichloroethene	6.03E-05	NA	—	6.6E+03	6.6E+03	6.6E+03	N
Vinyl chloride	2.44E-04	3.7E+01	3.7E+01	2.8E+03	2.8E+03	3.7E+01	C
Xylenes, total	4.27E-05	NC	—	1.6E+04	1.6E+04	1.6E+04	N

[a] Volatilization factor (VF) (for VOCs) for vapor migration from groundwater to outdoor (ambient) air, calculated on Table 6-3.

[b] Minimum of the $HBRG_C$ (identified by "C") and $HBRG_{NC}$ (identified by "N").

—	Not applicable.	mg/L	Milligrams per liter.
COPCs	Chemicals of potential concern.	TCR	Target cancer risk.
HBRG	Heath-based remedial goal.	THQ	Target hazard quotient for non-cancer effects.
NA	Not available.	VF	Volatilization factor.
NC	Not evaluated as a carcinogen.	VOCs	Volatile organic compounds.
m³/L	Cubic meters per Liter.		

<u>Equations:</u> (see Table 6-3)

(HBRGi)c = (TCR × 45 × 25,550) / (14 × 50 × 6 × CSFi) / VF

(HBRGi)nc = (THQ × 45 × 2,190) / (14 × 50 × 6 × [1/RfDi]) / VF

Table 6-19. Health-Based Remedial Goal Calculations for COPCs in Groundwater Based on Vapor Migration to Outdoor Air, High Use Youth Recreational User Exposure, Hamilton Sundstrand Facility, Denver, Colorado.

Chemical of Potential Concern	VF [a] (m³/L)	CANCER EFFECTS		NON-CANCER EFFECTS		Minimum HBRG (mg/L) [b]	
		Route-Specific HBRG (mg/L) Inhalation $(HBRG_i)_C$	$HBRG_C$ (mg/L) TCR = 1E-06	Route-Specific HBRG (mg/L) Inhalation $(HBRG_i)_{NC}$	$HBRG_{NC}$ (mg/L) THQ = 1		
Volatile Organic Compounds							
1,1-Dichloroethane	3.93E-05	NA	—	3.2E+04	3.2E+04	3.2E+04	N
1,1-Dichloroethene	2.00E-04	NA	—	2.6E+03	2.6E+03	2.6E+03	N
cis-1,2-Dichloroethene	2.87E-05	NC	—	3.1E+03	3.1E+03	3.1E+03	N
Tetrachloroethene	1.13E-04	2.7E+01	2.7E+01	8.0E+02	8.0E+02	2.7E+01	C
1,1,1-Trichloroethane	1.16E-04	NC	—	1.1E+05	1.1E+05	1.1E+05	N
1,1,2-Trichloroethane	7.31E-06	1.5E+02	1.5E+02	4.9E+03	4.9E+03	1.5E+02	C
Trichloroethene	6.88E-05	2.3E+00	2.3E+00	1.5E+03	1.5E+03	2.3E+00	C
1,1,2,2-Tetrachloroethane	2.69E-06	1.2E+02	1.2E+02	2.0E+05	2.0E+05	1.2E+02	C
1,2,4-Trichlorobenzene	4.55E-06	NC	—	2.0E+03	2.0E+03	2.0E+03	N
1,2,4-Trimethylbenzene	3.62E-05	NA	—	4.3E+02	4.3E+02	4.3E+02	N
1,2-Dichloroethane	1.24E-05	5.6E+01	5.6E+01	1.0E+03	1.0E+03	5.6E+01	C
1,3,5-Trimethylbenzene	4.76E-05	NA	—	3.2E+02	3.2E+02	3.2E+02	N
1,4-Dioxane	3.34E-07	1.7E+04	1.7E+04	—	—	1.7E+04	C
2-Butanone (MEK)	6.95E-07	NC	—	3.7E+06	3.7E+06	3.7E+06	N
Benzene	4.46E-05	5.2E+01	5.2E+01	1.7E+03	1.7E+03	5.2E+01	C
Bromodichloromethane	6.68E-06	1.5E+02	1.5E+02	2.7E+04	2.7E+04	1.5E+02	C
Bromomethane	4.23E-05	NC	—	3.1E+02	3.1E+02	3.1E+02	N
Carbon tetrachloride	1.83E-04	6.6E+00	6.6E+00	2.7E+03	2.7E+03	6.6E+00	C
Chloroethane	2.55E-04	8.5E+01	8.5E+01	1.0E+05	1.0E+05	8.5E+01	C
Chloroform	3.57E-05	2.2E+01	2.2E+01	7.1E+03	7.1E+03	2.2E+01	C
Ethyl methacrylate	1.83E-03	NA	—	4.4E+02	4.4E+02	4.4E+02	N
Ethylbenzene	5.26E-05	NC	—	4.9E+04	4.9E+04	4.9E+04	N
Isobutyl alcohol	3.06E-07	NA	—	8.9E+06	8.9E+06	8.9E+06	N
Methyl tert-Butyl Ether	5.04E-06	1.4E+04	1.4E+04	1.5E+06	1.5E+06	1.4E+04	C
Methylene chloride	2.17E-05	1.8E+03	1.8E+03	3.6E+05	3.6E+05	1.8E+03	C
Naphthalene	2.85E-06	NC	—	2.7E+03	2.7E+03	2.7E+03	N
n-Butylbenzene	8.59E-05	NA	—	4.2E+03	4.2E+03	4.2E+03	N
n-Propylbenzene	8.59E-05	NA	—	4.2E+03	4.2E+03	4.2E+03	N
sec-Butylbenzene	1.21E-04	NA	—	3.0E+03	3.0E+03	3.0E+03	N
Styrene	1.87E-05	NA	—	1.4E+05	1.4E+05	1.4E+05	N
Tetrahydrofuran	9.68E-07	9.6E+03	9.6E+03	8.0E+05	8.0E+05	9.6E+03	C
Toluene	5.17E-05	NC	—	2.5E+05	2.5E+05	2.5E+05	N
trans-1,2-Dichloroethene	6.03E-05	NA	—	2.5E+03	2.5E+03	2.5E+03	N
Vinyl chloride	2.44E-04	8.4E+00	8.4E+00	1.1E+03	1.1E+03	8.4E+00	C
Xylenes, total	4.27E-05	NC	—	6.0E+03	6.0E+03	6.0E+03	N

[a] Volatilization factor (VF) (for VOCs) for vapor migration from groundwater to outdoor (ambient) air, calculated on Table 6-3.

[b] Minimum of the $HBRG_C$ (identified by "C") and $HBRG_{NC}$ (identified by "N").

—	Not applicable.	mg/L	Milligrams per liter.
COPCs	Chemicals of potential concern.	TCR	Target cancer risk.
HBRG	Heath-based remedial goal.	THQ	Target hazard quotient for non-cancer effects.
NA	Not available.	VF	Volatilization factor.
NC	Not evaluated as a carcinogen.	VOCs	Volatile organic compounds.
m³/L	Cubic meters per Liter.		

Equations: (see Table 6-3)

(HBRGi)c = (TCR × 45 × 25,550) / (14 × 130 × 10 × CSFi) / VF

(HBRGi)nc = (THQ × 45 × 3,650) / (14 × 130 × 10 × [1/RfDi]) / VF

Table 6-20. Health-Based Remedial Goal Calculations for COPCs in Groundwater Based on Vapor Migration to Outdoor Air, Average Use Adult Recreational User Exposure, Hamilton Sundstrand Facility, Denver, Colorado.

		CANCER EFFECTS		NON-CANCER EFFECTS		Minimum	
Chemical of Potential Concern	VF [a] (m³/L)	Route-Specific HBRG (mg/L) Inhalation $(HBRG_i)_C$	$HBRG_C$ (mg/L) TCR = 1E-06	Route-Specific HBRG (mg/L) Inhalation $(HBRG_i)_{NC}$	$HBRG_{NC}$ (mg/L) THQ = 1	HBRG (mg/L) [b]	
Volatile Organic Compounds							
1,1-Dichloroethane	3.93E-05	NA	—	1.1E+05	1.1E+05	1.1E+05	N
1,1-Dichloroethene	2.00E-04	NA	—	9.1E+03	9.1E+03	9.1E+03	N
cis-1,2-Dichloroethene	2.87E-05	NC	—	1.1E+04	1.1E+04	1.1E+04	N
Tetrachloroethene	1.13E-04	3.2E+01	3.2E+01	2.8E+03	2.8E+03	3.2E+01	C
1,1,1-Trichloroethane	1.16E-04	NC	—	3.9E+05	3.9E+05	3.9E+05	N
1,1,2-Trichloroethane	7.31E-06	1.8E+02	1.8E+02	1.7E+04	1.7E+04	1.8E+02	C
Trichloroethene	6.88E-05	2.7E+00	2.7E+00	5.3E+03	5.3E+03	2.7E+00	C
1,1,2,2-Tetrachloroethane	2.69E-06	1.4E+02	1.4E+02	7.1E+05	7.1E+05	1.4E+02	C
1,2,4-Trichlorobenzene	4.55E-06	NC	—	7.0E+03	7.0E+03	7.0E+03	N
1,2,4-Trimethylbenzene	3.62E-05	NA	—	1.5E+03	1.5E+03	1.5E+03	N
1,2-Dichloroethane	1.24E-05	6.6E+01	6.6E+01	3.6E+03	3.6E+03	6.6E+01	C
1,3,5-Trimethylbenzene	4.76E-05	NA	—	1.1E+03	1.1E+03	1.1E+03	N
1,4-Dioxane	3.34E-07	2.0E+04	2.0E+04	—	—	2.0E+04	C
2-Butanone (MEK)	6.95E-07	NC	—	1.3E+07	1.3E+07	1.3E+07	N
Benzene	4.46E-05	6.1E+01	6.1E+01	6.2E+03	6.2E+03	6.1E+01	C
Bromodichloromethane	6.68E-06	1.8E+02	1.8E+02	9.6E+04	9.6E+04	1.8E+02	C
Bromomethane	4.23E-05	NC	—	1.1E+03	1.1E+03	1.1E+03	N
Carbon tetrachloride	1.83E-04	7.8E+00	7.8E+00	9.4E+03	9.4E+03	7.8E+00	C
Chloroethane	2.55E-04	1.0E+02	1.0E+02	3.6E+05	3.6E+05	1.0E+02	C
Chloroform	3.57E-05	2.6E+01	2.6E+01	2.5E+04	2.5E+04	2.6E+01	C
Ethyl methacrylate	1.83E-03	NA	—	1.6E+03	1.6E+03	1.6E+03	N
Ethylbenzene	5.26E-05	NC	—	1.7E+05	1.7E+05	1.7E+05	N
Isobutyl alcohol	3.06E-07	NA	—	3.1E+07	3.1E+07	3.1E+07	N
Methyl tert-Butyl Ether	5.04E-06	1.6E+04	1.6E+04	5.4E+06	5.4E+06	1.6E+04	C
Methylene chloride	2.17E-05	2.1E+03	2.1E+03	1.3E+06	1.3E+06	2.1E+03	C
Naphthalene	2.85E-06	NC	—	9.6E+03	9.6E+03	9.6E+03	N
n-Butylbenzene	8.59E-05	NA	—	1.5E+04	1.5E+04	1.5E+04	N
n-Propylbenzene	8.59E-05	NA	—	1.5E+04	1.5E+04	1.5E+04	N
sec-Butylbenzene	1.21E-04	NA	—	1.1E+04	1.1E+04	1.1E+04	N
Styrene	1.87E-05	NA	—	4.9E+05	4.9E+05	4.9E+05	N
Tetrahydrofuran	9.68E-07	1.1E+04	1.1E+04	2.8E+06	2.8E+06	1.1E+04	C
Toluene	5.17E-05	NC	—	8.8E+05	8.8E+05	8.8E+05	N
trans-1,2-Dichloroethene	6.03E-05	NA	—	9.0E+03	9.0E+03	9.0E+03	N
Vinyl chloride	2.44E-04	9.9E+00	9.9E+00	3.8E+03	3.8E+03	9.9E+00	C
Xylenes, total	4.27E-05	NC	—	2.1E+04	2.1E+04	2.1E+04	N

[a] Volatilization factor (VF) (for VOCs) for vapor migration from groundwater to outdoor (ambient) air, calculated on Table 6-3.

[b] Minimum of the $HBRG_C$ (identified by "C") and $HBRG_{NC}$ (identified by "N").

—	Not applicable.	mg/L	Milligrams per liter.
COPCs	Chemicals of potential concern.	TCR	Target cancer risk.
HBRG	Heath-based remedial goal.	THQ	Target hazard quotient for non-cancer effects.
NA	Not available.	VF	Volatilization factor.
NC	Not evaluated as a carcinogen.	VOCs	Volatile organic compounds.
m³/L	Cubic meters per Liter.		

Equations: (see Table 6-3)

$(HBRGi)c = (TCR \times 70 \times 25{,}550) / (20 \times 40 \times 30 \times CSFi) / VF$

$(HBRGi)nc = (THQ \times 70 \times 10{,}950) / (20 \times 40 \times 30 \times [1/RfDi]) / VF$

Table 6-21. Health-Based Remedial Goal Calculations for COPCs in Groundwater Based on Vapor Migration to Outdoor Air, High Use Adult Recreational User Exposure, Hamilton Sundstrand Facility, Denver, Colorado.

		CANCER EFFECTS		NON-CANCER EFFECTS		Minimum
Chemical of Potential Concern	VF [a] (m³/L)	Route-Specific HBRG (mg/L) Inhalation $(HBRG_i)_C$	$HBRG_C$ (mg/L) TCR = 1E-06	Route-Specific HBRG (mg/L) Inhalation $(HBRG_i)_{NC}$	$HBRG_{NC}$ (mg/L) THQ = 1	HBRG (mg/L) [b]
Volatile Organic Compounds						
1,1-Dichloroethane	3.93E-05	NA	—	4.6E+04	4.6E+04	4.6E+04 N
1,1-Dichloroethene	2.00E-04	NA	—	3.6E+03	3.6E+03	3.6E+03 N
cis-1,2-Dichloroethene	2.87E-05	NC	—	4.5E+03	4.5E+03	4.5E+03 N
Tetrachloroethene	1.13E-04	1.3E+01	1.3E+01	1.1E+03	1.1E+03	1.3E+01 C
1,1,1-Trichloroethane	1.16E-04	NC	—	1.6E+05	1.6E+05	1.6E+05 N
1,1,2-Trichloroethane	7.31E-06	7.3E+01	7.3E+01	7.0E+03	7.0E+03	7.3E+01 C
Trichloroethene	6.88E-05	1.1E+00	1.1E+00	2.1E+03	2.1E+03	1.1E+00 C
1,1,2,2-Tetrachloroethane	2.69E-06	5.5E+01	5.5E+01	2.8E+05	2.8E+05	5.5E+01 C
1,2,4-Trichlorobenzene	4.55E-06	NC	—	2.8E+03	2.8E+03	2.8E+03 N
1,2,4-Trimethylbenzene	3.62E-05	NA	—	6.0E+02	6.0E+02	6.0E+02 N
1,2-Dichloroethane	1.24E-05	2.6E+01	2.6E+01	1.4E+03	1.4E+03	2.6E+01 C
1,3,5-Trimethylbenzene	4.76E-05	NA	—	4.6E+02	4.6E+02	4.6E+02 N
1,4-Dioxane	3.34E-07	8.1E+03	8.1E+03	—	—	8.1E+03 C
2-Butanone (MEK)	6.95E-07	NC	—	5.3E+06	5.3E+06	5.3E+06 N
Benzene	4.46E-05	2.4E+01	2.4E+01	2.5E+03	2.5E+03	2.4E+01 C
Bromodichloromethane	6.68E-06	7.2E+01	7.2E+01	3.8E+04	3.8E+04	7.2E+01 C
Bromomethane	4.23E-05	NC	—	4.3E+02	4.3E+02	4.3E+02 N
Carbon tetrachloride	1.83E-04	3.1E+00	3.1E+00	3.8E+03	3.8E+03	3.1E+00 C
Chloroethane	2.55E-04	4.0E+01	4.0E+01	1.4E+05	1.4E+05	4.0E+01 C
Chloroform	3.57E-05	1.0E+01	1.0E+01	1.0E+04	1.0E+04	1.0E+01 C
Ethyl methacrylate	1.83E-03	NA	—	6.3E+02	6.3E+02	6.3E+02 N
Ethylbenzene	5.26E-05	NC	—	7.0E+04	7.0E+04	7.0E+04 N
Isobutyl alcohol	3.06E-07	NA	—	1.3E+07	1.3E+07	1.3E+07 N
Methyl tert-Butyl Ether	5.04E-06	6.5E+03	6.5E+03	2.2E+06	2.2E+06	6.5E+03 C
Methylene chloride	2.17E-05	8.6E+02	8.6E+02	5.1E+05	5.1E+05	8.6E+02 C
Naphthalene	2.85E-06	NC	—	3.8E+03	3.8E+03	3.8E+03 N
n-Butylbenzene	8.59E-05	NA	—	6.0E+03	6.0E+03	6.0E+03 N
n-Propylbenzene	8.59E-05	NA	—	6.0E+03	6.0E+03	6.0E+03 N
sec-Butylbenzene	1.21E-04	NA	—	4.2E+03	4.2E+03	4.2E+03 N
Styrene	1.87E-05	NA	—	2.0E+05	2.0E+05	2.0E+05 N
Tetrahydrofuran	9.68E-07	4.5E+03	4.5E+03	1.1E+06	1.1E+06	4.5E+03 C
Toluene	5.17E-05	NC	—	3.5E+05	3.5E+05	3.5E+05 N
trans-1,2-Dichloroethene	6.03E-05	NA	—	3.6E+03	3.6E+03	3.6E+03 N
Vinyl chloride	2.44E-04	4.0E+00	4.0E+00	1.5E+03	1.5E+03	4.0E+00 C
Xylenes, total	4.27E-05	NC	—	8.6E+03	8.6E+03	8.6E+03 N

[a] Volatilization factor (VF) (for VOCs) for vapor migration from groundwater to outdoor (ambient) air, calculated on Table 6-3.

[b] Minimum of the $HBRG_C$ (identified by "C") and $HBRG_{NC}$ (identified by "N").

—	Not applicable.	mg/L	Milligrams per liter.
COPCs	Chemicals of potential concern.	TCR	Target cancer risk.
HBRG	Heath-based remedial goal.	THQ	Target hazard quotient for non-cancer effects.
NA	Not available.	VF	Volatilization factor.
NC	Not evaluated as a carcinogen.	VOCs	Volatile organic compounds.
m³/L	Cubic meters per Liter.		

Equations: (see Table 6-3)

(HBRGi)c = (TCR × 70 × 25,550) / (20 × 100 × 30 × CSFi) / VF

(HBRGi)nc = (THQ × 70 × 10,950) / (20 × 100 × 30 × [1/RfDi]) / VF

Table 6-22. Summary of Detected Concentrations in Soil Exceeding Calculated Health-Based Remedial Goals
Hamilton Sundstrand Facility, Denver, Colorado.

Sample Location	Sample Elevation (AMSL)	Assumed Final Grade Elevation (AMSL)	Sample Depth Below Final Grade (Feet)	Compound Detected	Detected Concentration (mg/kg)	Applicable HBRG (mg/kg) [a]
SWMU 5						
SWMU5-2	5245	5249	4	1,2,4-Trimethylbenzene	130	62
	5241	5249	8	1,2,4-Trimethylbenzene	120	62
SWMU5-7	5241	5249	8	1,2,4-Trimethylbenzene	260	62
				1,3,5-Trimethylbenzene	88	54
SWMU 12/AOC 5						
SWMU12-1	5248	5250	2	TCE	1.5	0.12
				PCE	8.6	1.5
SWMU 9						
SWMU9-2	5224	5224	0	Benzo(a)pyrene	0.23	0.23
RT-SVE-3						
RT-SVE-3	5230	5238	8	1,2,4-Trimethylbenzene	120	62
				1,3,5-Trimethylbenzene	61	54
AOC 2						
AOC2-1	5221	5221	0	Benzo(a)pyrene	0.55	0.23
AOC2-2	5220	5220	0	Aroclor 1248	23	0.83
AOC2-3	5219	5219	0	Aroclor 1242	1.8	0.83
BS-2-3	5218	5220	2	Aroclor 1248	61	0.83
BS-2-35	5217	5219	2	Aroclor 1248	46	0.83
BS-2-6	5218	5220	2	Aroclor 1248	310	0.83
BS-2-8	5218	5220	2	Aroclor 1248	121	0.83
BS-2-1	5218	5220	2	Aroclor 1248	35	0.83
BS-2-11	5218	5220	2	Aroclor 1248	130	0.83
BS-2-18	5218	5220	2	Aroclor 1248	8.8	0.83
BS-2-2	5218	5220	2	Aroclor 1248	51	0.83
BS-2-20	5218	5220	2	Aroclor 1248	1.7	0.83
BS-2-4	5218	5220	2	Aroclor 1248	4.4	0.83
BS-2-9	5218	5220	2	Aroclor 1248	60	0.83
BS-2-10	5218	5220	2	Aroclor 1248	22.3	0.83
BS-2-21	5218	5220	2	Aroclor 1248	109	0.83
BS-2-23	5219	5221	2	Aroclor 1248	20.5	0.83
BS-2-7	5218	5220	2	Aroclor 1248	32	0.83
BS-2-12	5218	5220	2	Aroclor 1248	148	0.83
AOC2-T2	5214	5220	6	Aroclor 1242	20	10
AOC2-T2	5214	5220	6	Aroclor 1242	58	10
AOC2-T4	5214	5220	6	Aroclor 1242	120	10
AOC 1						
AOC1-3	5247	5247	0	Arsenic	9.1	7[b]
AOC 4						
AOC4-6	5239	5239	0	Arsenic	7.8	7[b]
AOC4-15	5240	5242	2	Arsenic	7.8	7[b]
AOC4-19	5240	5242	2	Arsenic	7.1	7[b]
AOC4-25	5222	5224	2	Arsenic	8.7	7[b]

Notes:

[a] For concentrations detected in soil depths from 0 to 2 feet bgs, the lowest HBRG for the recreational user and maintenance worker scenario is applied; for concentrations detected in soil depths greater than 2 feet bgs, the HBRG for the construction worker scenario is applied.

[b] Site-specific background Upper Tolerance Limit (UTL) for arsenic is 7.0.

AMSL	Elevation in feet above mean sea level	PCE	Tetrachloroethene
AOC	Area of Concern	SWMU	Solid Waste Management Unit
HBRG	Health-Based Remedial Goal	TCE	Trichloroethene
mg/kg	Milligram per kilogram		

Table 6-23
Comparison Maximum Detected Concentrations for COPCs in Groundwater to Calculated Health-Based Remedial Goals
Maintenance Worker Scenario
Hamilton Sundstrand Facility, Denver, Colorado.

Chemicals of Potential Concern	Maximum Detected Value (ug/L)	Sample ID of Maximum Detected Value	Frequency of Detection	Range of SQLs (ug/L)	Calculated HBRG (ug/L)	Does Maximum Exceed HBRG?
Volatile Organic Compounds (VOCs)						
1,1-Dichloroethane	2700	TP-10-1-HIGH	485 / 824	0.16 - 640	3.9E+01	YES
1,1-Dichloroethene	6800	AOC3-1-HIGH	472 / 824	0.14 - 5	2.0E+04	no
cis-1,2-Dichloroethene	6900	SWMU5-1DL	467 / 824	0.15 - 600	5.5E+00	YES
Tetrachloroethene	940	A0C4-11	612 / 830	0.2 - 800	8.7E+04	no
1,1,1-Trichloroethane	65000	AOC3-1-HIGH	559 / 824	0.16 - 10	0.0E+00	YES
1,1,2-Trichloroethane	18	SWMU 5-1	19 / 824	0.32 - 1300	2.9E+01	no
Trichloroethene	770	SWMU 5-1	602 / 831	0.16 - 640	1.6E+03	no
1,1,2,2-Tetrachloroethane	510	GW-30	1 / 824	0.2 - 800	7.0E+04	no
1,2,4-Trichlorobenzene	17	GW-33	7 / 824	0.32 - 1300	1.6E+03	no
1,2,4-Trimethylbenzene	5000	SLOMU5-1	77 / 824	0.14 - 560	1.2E+03	YES
1,2-Dichloroethane	3.9	PW-2	22 / 824	0.13 - 520	2.7E+02	no
1,3,5-Trimethylbenzene	1700	SLOMU5-1	53 / 824	0.14 - 560	1.4E+01	YES
1,4-Dioxane	150	GW-4	5 / 128	1 - 71000	2.0E+02	no
2-Butanone (MEK)	940	GW-62	36 / 824	1 - 7300	4.3E+03	no
Benzene	250	SLOMU5-1	56 / 824	0.16 - 640	2.3E+06	no
Bromodichloromethane	1.6	GW-59	6 / 824	0.17 - 680	1.3E+01	no
Bromomethane	1	GW-58	1 / 824	0.21 - 840	3.8E+01	no
Carbon tetrachloride	0.94	GW-49	1 / 824	0.19 - 760	1.9E+02	no
Chloroethane	38	PW-2	16 / 824	0.41 - 1600	1.7E+00	YES
Chloroform	64	AOC1-3	98 / 824	0.16 - 640	2.2E+01	YES
Ethyl methacrylate	220	GW-30	1 / 537	0.86 - 270	2.0E+03	no
Ethylbenzene	1500	SLOMU5-1	59 / 824	0.16 - 640	2.8E+02	YES
Isobutyl alcohol	400	TP-2	6 / 266	1 - 36000	3.1E+04	no
Methyl tert-Butyl Ether	80	GW-46	27 / 824	0.25 - 1000	5.6E+06	no
Methylene chloride	660	TP-3	52 / 824	0.32 - 1300	3.5E+03	no
Naphthalene	1200	SLOMU5-1	64 / 824	0.22 - 880	4.6E+02	YES
n-Butylbenzene	560	SLOMU5-1	44 / 824	0.14 - 560	1.7E+03	no
n-Propylbenzene	600	SLOMU5-1	51 / 824	0.16 - 640	2.6E+03	no
sec-Butylbenzene	76	SWMU 5-2	54 / 824	0.17 - 680	2.6E+03	no
Styrene	380	TP-2(GW)	2 / 824	0.17 - 680	1.9E+03	no
Tetrahydrofuran	18	TP-15DL	1 / 537	1 - 2700	6.8E+00	YES
Toluene	390	AOC 6-9	33 / 824	0.17 - 680	2.4E+03	no
trans-1,2-Dichloroethene	24	TP-16	49 / 824	0.15 - 600	1.6E+05	no
Vinyl chloride	3.8	GW-46	4 / 824	0.17 - 680	5.8E-01	YES
Xylenes, total	1900	SWMU5-1	49 / 682	0.19 - 760	2.1E+00	YES

ug/L – micrograms per liter
COPC – Chemical of Potential Concern.
HBRG – Heath-based remedial goal.

Table 6-24

Comparison Maximum Detected Concentrations for COPCs in Groundwater to Calculated Health-Based Remedial Goals

Construction Worker Scenario

Hamilton Sundstrand Facility, Denver, Colorado.

Chemicals of Potential Concern	Maximum Detected Value (ug/L)	Sample ID of Maximum Detected Value	Frequency of Detection	Range of SQLs (ug/L)	Calculated HBRG (ug/L)	Does Maximum Exceed HBRG?
Volatile Organic Compounds (VOCs)						
1,1-Dichloroethane	2700	TP-10-1-HIGH	485 / 824	0.16 - 640	7.9E+01	YES
1,1-Dichloroethene	6800	AOC3-1-HIGH	472 / 824	0.14 - 5	4.7E+03	YES
cis-1,2-Dichloroethene	6900	SWMU5-1DL	467 / 824	0.15 - 600	2.8E+01	YES
Tetrachloroethene	940	A0C4-11	612 / 830	0.2 - 800	6.0E+03	no
1,1,1-Trichloroethane	65000	AOC3-1-HIGH	559 / 824	0.16 - 10	0.0E+00	YES
1,1,2-Trichloroethane	18	SWMU 5-1	19 / 824	0.32 - 1300	1.7E+02	no
Trichloroethene	770	SWMU 5-1	602 / 831	0.16 - 640	3.6E+01	YES
1,1,2,2-Tetrachloroethane	510	GW-30	1 / 824	0.2 - 800	1.5E+03	no
1,2,4-Trichlorobenzene	17	GW-33	7 / 824	0.32 - 1300	3.4E+01	no
1,2,4-Trimethylbenzene	5000	SLOMU5-1	77 / 824	0.14 - 560	3.3E+01	YES
1,2-Dichloroethane	3.9	PW-2	22 / 824	0.13 - 520	6.0E+00	no
1,3,5-Trimethylbenzene	1700	SLOMU5-1	53 / 824	0.14 - 560	1.6E+01	YES
1,4-Dioxane	150	GW-4	5 / 128	1 - 71000	4.5E+00	YES
2-Butanone (MEK)	940	GW-62	36 / 824	1 - 7300	1.5E+04	no
Benzene	250	SLOMU5-1	56 / 824	0.16 - 640	8.8E+04	no
Bromodichloromethane	1.6	GW-59	6 / 824	0.17 - 680	2.5E+01	no
Bromomethane	1	GW-58	1 / 824	0.21 - 840	2.2E+02	no
Carbon tetrachloride	0.94	GW-49	1 / 824	0.19 - 760	4.4E+00	no
Chloroethane	38	PW-2	16 / 824	0.41 - 1600	7.5E+00	YES
Chloroform	64	AOC1-3	98 / 824	0.16 - 640	9.7E+01	no
Ethyl methacrylate	220	GW-30	1 / 537	0.86 - 270	4.7E+01	YES
Ethylbenzene	1500	SLOMU5-1	59 / 824	0.16 - 640	5.8E+00	YES
Isobutyl alcohol	400	TP-2	6 / 266	1 - 36000	6.9E+02	no
Methyl tert-Butyl Ether	80	GW-46	27 / 824	0.25 - 1000	4.1E+05	no
Methylene chloride	660	TP-3	52 / 824	0.32 - 1300	2.0E+04	no
Naphthalene	1200	SLOMU5-1	64 / 824	0.22 - 880	2.4E+03	no
n-Butylbenzene	560	SLOMU5-1	44 / 824	0.14 - 560	4.2E+01	YES
n-Propylbenzene	600	SLOMU5-1	51 / 824	0.16 - 640	5.7E+01	YES
sec-Butylbenzene	76	SWMU 5-2	54 / 824	0.17 - 680	5.7E+01	YES
Styrene	380	TP-2(GW)	2 / 824	0.17 - 680	3.9E+01	YES
Tetrahydrofuran	18	TP-15DL	1 / 537	1 - 2700	1.1E+01	YES
Toluene	390	AOC 6-9	33 / 824	0.17 - 680	1.8E+04	no
trans-1,2-Dichloroethene	24	TP-16	49 / 824	0.15 - 600	3.5E+03	no
Vinyl chloride	3.8	GW-46	4 / 824	0.17 - 680	2.7E+00	YES
Xylenes, total	1900	SWMU5-1	49 / 682	0.19 - 760	9.4E+00	YES

ug/L – micrograms per liter

COPC – Chemical of Potential Concern.

HBRG – Heath-based remedial goal.

Table 6-25

Comparison Maximum Detected Concentrations for COPCs in Groundwater to Calculated Health-Based Remedial Goals

Average Use Recreational User Scenario

Hamilton Sundstrand Facility, Denver, Colorado.

Chemicals of Potential Concern	Maximum Detected Value (ug/L)	Sample ID of Maximum Detected Value	Frequency of Detection	Range of SQLs (ug/L)	Calculated HBRG [a] (ug/L)		Does Maximum Exceed HBRG?
Volatile Organic Compounds (VOCs)							
1,1-Dichloroethane	2700	TP-10-1-HIGH	485 / 824	0.16 - 640	6.1E+04	c	no
1,1-Dichloroethene	6800	AOC3-1-HIGH	472 / 824	0.14 - 5	4.9E+03	c	YES
cis-1,2-Dichloroethene	6900	SWMU5-1DL	467 / 824	0.15 - 600	6.0E+03	c	YES
Tetrachloroethene	940	A0C4-11	612 / 830	0.2 - 800	3.2E+01	a	YES
1,1,1-Trichloroethane	65000	AOC3-1-HIGH	559 / 824	0.16 - 10	2.1E+05	c	no
1,1,2-Trichloroethane	18	SWMU 5-1	19 / 824	0.32 - 1300	1.8E+02	a	no
Trichloroethene	770	SWMU 5-1	602 / 831	0.16 - 640	2.7E+00	a	YES
1,1,2,2-Tetrachloroethane	510	GW-30	1 / 824	0.2 - 800	1.4E+02	a	YES
1,2,4-Trichlorobenzene	17	GW-33	7 / 824	0.32 - 1300	3.8E+03	c	no
1,2,4-Trimethylbenzene	5000	SLOMU5-1	77 / 824	0.14 - 560	8.1E+02	c	YES
1,2-Dichloroethane	3.9	PW-2	22 / 824	0.13 - 520	6.6E+01	a	no
1,3,5-Trimethylbenzene	1700	SLOMU5-1	53 / 824	0.14 - 560	6.1E+02	c	YES
1,4-Dioxane	150	GW-4	5 / 128	1 - 71000	2.0E+04	a	no
2-Butanone (MEK)	940	GW-62	36 / 824	1 - 7300	7.0E+06	c	no
Benzene	250	SLOMU5-1	56 / 824	0.16 - 640	6.1E+01	a	YES
Bromodichloromethane	1.6	GW-59	6 / 824	0.17 - 680	1.8E+02	a	no
Bromomethane	1	GW-58	1 / 824	0.21 - 840	5.8E+02	c	no
Carbon tetrachloride	0.94	GW-49	1 / 824	0.19 - 760	7.8E+00	a	no
Chloroethane	38	PW-2	16 / 824	0.41 - 1600	1.0E+02	a	no
Chloroform	64	AOC1-3	98 / 824	0.16 - 640	2.6E+01	a	YES
Ethyl methacrylate	220	GW-30	1 / 537	0.86 - 270	8.4E+02	c	no
Ethylbenzene	1500	SLOMU5-1	59 / 824	0.16 - 640	9.3E+04	c	no
Isobutyl alcohol	400	TP-2	6 / 266	1 - 36000	1.7E+07	c	no
Methyl tert-Butyl Ether	80	GW-46	27 / 824	0.25 - 1000	1.6E+04	a	no
Methylene chloride	660	TP-3	52 / 824	0.32 - 1300	2.1E+03	a	no
Naphthalene	1200	SLOMU5-1	64 / 824	0.22 - 880	5.1E+03	c	no
n-Butylbenzene	560	SLOMU5-1	44 / 824	0.14 - 560	8.0E+03	c	no
n-Propylbenzene	600	SLOMU5-1	51 / 824	0.16 - 640	8.0E+03	c	no
sec-Butylbenzene	76	SWMU 5-2	54 / 824	0.17 - 680	5.7E+03	c	no
Styrene	380	TP-2(GW)	2 / 824	0.17 - 680	2.6E+05	c	no
Tetrahydrofuran	18	TP-15DL	1 / 537	1 - 2700	1.1E+04	a	no
Toluene	390	AOC 6-9	33 / 824	0.17 - 680	4.7E+05	c	no
trans-1,2-Dichloroethene	24	TP-16	49 / 824	0.15 - 600	4.8E+03	c	no
Vinyl chloride	3.8	GW-46	4 / 824	0.17 - 680	9.9E+00	a	no
Xylenes, total	1900	SWMU5-1	49 / 682	0.19 - 760	1.1E+04	c	no

[a] HBRG presented is the lowest HBRG calculated for the evaluated receptors, child (c), youth (y), or adult (a).

ug/L – micrograms per liter

COPC – Chemical of Potential Concern.

HBRG – Heath-based remedial goal.

Table 6-26
Comparison Maximum Detected Concentrations for COPCs in Groundwater to Calculated Health-Based Remedial Goals
High Use Recreational User Scenario
Hamilton Sundstrand Facility, Denver, Colorado.

Chemicals of Potential Concern	Maximum Detected Value (ug/L)	Sample ID of Maximum Detected Value	Frequency of Detection	Range of SQLs (ug/L)	Calculated HBRG [a] (ug/L)		Does Maximum Exceed HBRG?
Volatile Organic Compounds (VOCs)							
1,1-Dichloroethane	2700	TP-10-1-HIGH	485 / 824	0.16 - 640	2.4E+04	c	no
1,1-Dichloroethene	6800	AOC3-1-HIGH	472 / 824	0.14 - 5	2.0E+03	c	YES
cis-1,2-Dichloroethene	6900	SWMU5-1DL	467 / 824	0.15 - 600	2.4E+03	c	YES
Tetrachloroethene	940	A0C4-11	612 / 830	0.2 - 800	1.3E+01	a	YES
1,1,1-Trichloroethane	65000	AOC3-1-HIGH	559 / 824	0.16 - 10	8.4E+04	c	no
1,1,2-Trichloroethane	18	SWMU 5-1	19 / 824	0.32 - 1300	7.3E+01	a	no
Trichloroethene	770	SWMU 5-1	602 / 831	0.16 - 640	1.1E+00	a	YES
1,1,2,2-Tetrachloroethane	510	GW-30	1 / 824	0.2 - 800	5.5E+01	a	YES
1,2,4-Trichlorobenzene	17	GW-33	7 / 824	0.32 - 1300	1.5E+03	c	no
1,2,4-Trimethylbenzene	5000	SLOMU5-1	77 / 824	0.14 - 560	3.2E+02	c	YES
1,2-Dichloroethane	3.9	PW-2	22 / 824	0.13 - 520	2.6E+01	a	no
1,3,5-Trimethylbenzene	1700	SLOMU5-1	53 / 824	0.14 - 560	2.5E+02	c	YES
1,4-Dioxane	150	GW-4	5 / 128	1 - 71000	8.1E+03	a	no
2-Butanone (MEK)	940	GW-62	36 / 824	1 - 7300	2.8E+06	c	no
Benzene	250	SLOMU5-1	56 / 824	0.16 - 640	2.4E+01	a	YES
Bromodichloromethane	1.6	GW-59	6 / 824	0.17 - 680	7.2E+01	a	no
Bromomethane	1	GW-58	1 / 824	0.21 - 840	2.3E+02	c	no
Carbon tetrachloride	0.94	GW-49	1 / 824	0.19 - 760	3.1E+00	a	no
Chloroethane	38	PW-2	16 / 824	0.41 - 1600	4.0E+01	a	no
Chloroform	64	AOC1-3	98 / 824	0.16 - 640	1.0E+01	a	YES
Ethyl methacrylate	220	GW-30	1 / 537	0.86 - 270	3.4E+02	c	no
Ethylbenzene	1500	SLOMU5-1	59 / 824	0.16 - 640	3.7E+04	c	no
Isobutyl alcohol	400	TP-2	6 / 266	1 - 36000	6.7E+06	c	no
Methyl tert-Butyl Ether	80	GW-46	27 / 824	0.25 - 1000	6.5E+03	a	no
Methylene chloride	660	TP-3	52 / 824	0.32 - 1300	8.6E+02	a	no
Naphthalene	1200	SLOMU5-1	64 / 824	0.22 - 880	2.1E+03	c	no
n-Butylbenzene	560	SLOMU5-1	44 / 824	0.14 - 560	3.2E+03	c	no
n-Propylbenzene	600	SLOMU5-1	51 / 824	0.16 - 640	3.2E+03	c	no
sec-Butylbenzene	76	SWMU 5-2	54 / 824	0.17 - 680	2.3E+03	c	no
Styrene	380	TP-2(GW)	2 / 824	0.17 - 680	1.0E+05	c	no
Tetrahydrofuran	18	TP-15DL	1 / 537	1 - 2700	4.5E+03	a	no
Toluene	390	AOC 6-9	33 / 824	0.17 - 680	1.9E+05	c	no
trans-1,2-Dichloroethene	24	TP-16	49 / 824	0.15 - 600	1.9E+03	c	no
Vinyl chloride	3.8	GW-46	4 / 824	0.17 - 680	4.0E+00	a	no
Xylenes, total	1900	SWMU5-1	49 / 682	0.19 - 760	4.6E+03	c	no

[a] HBRG presented is the lowest HBRG calculated for the evaluated receptors, child (c), youth (y), or adult (a).
ug/L – micrograms per liter
COPC – Chemical of Potential Concern.
HBRG – Heath-based remedial goal.

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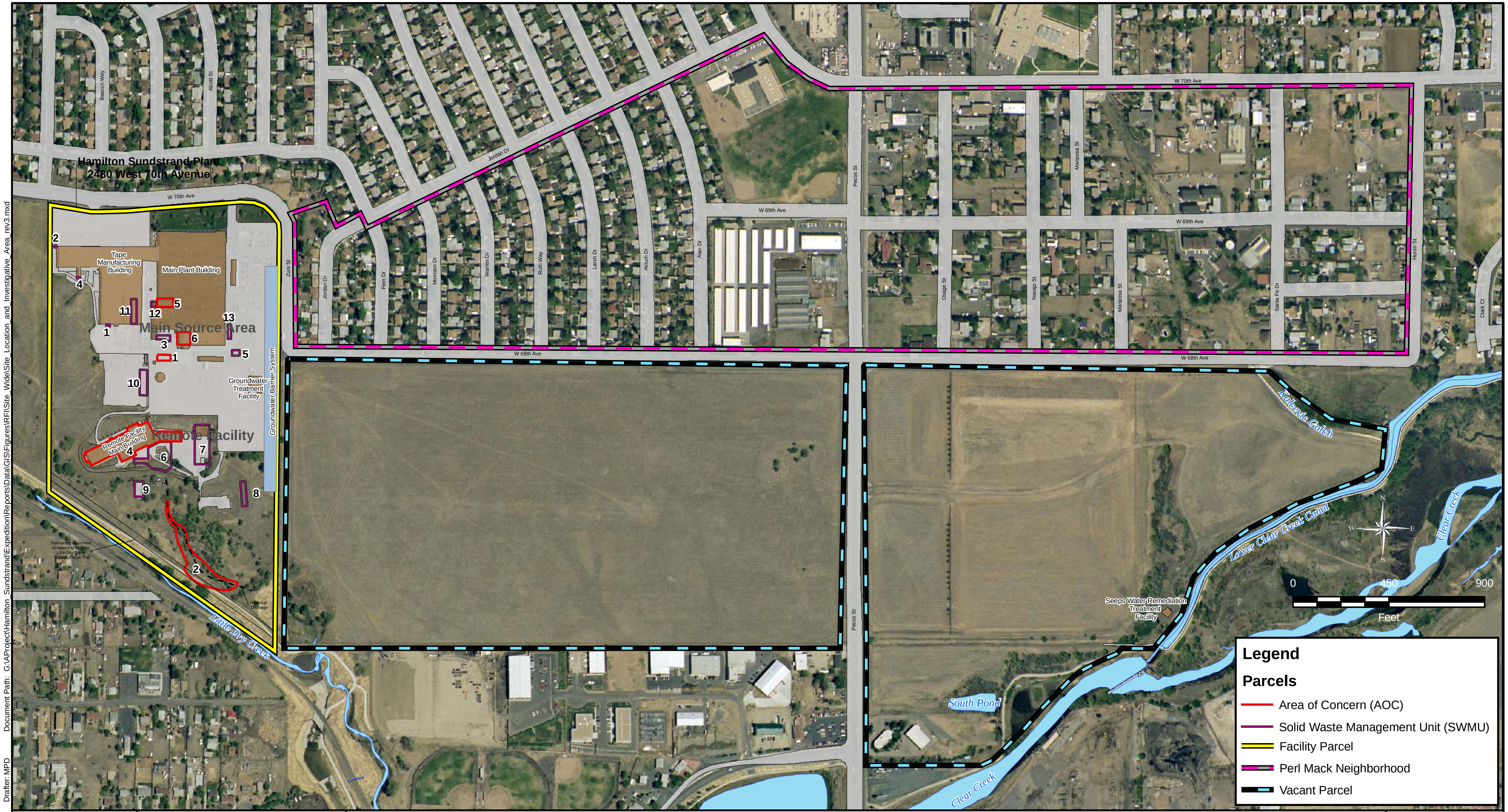

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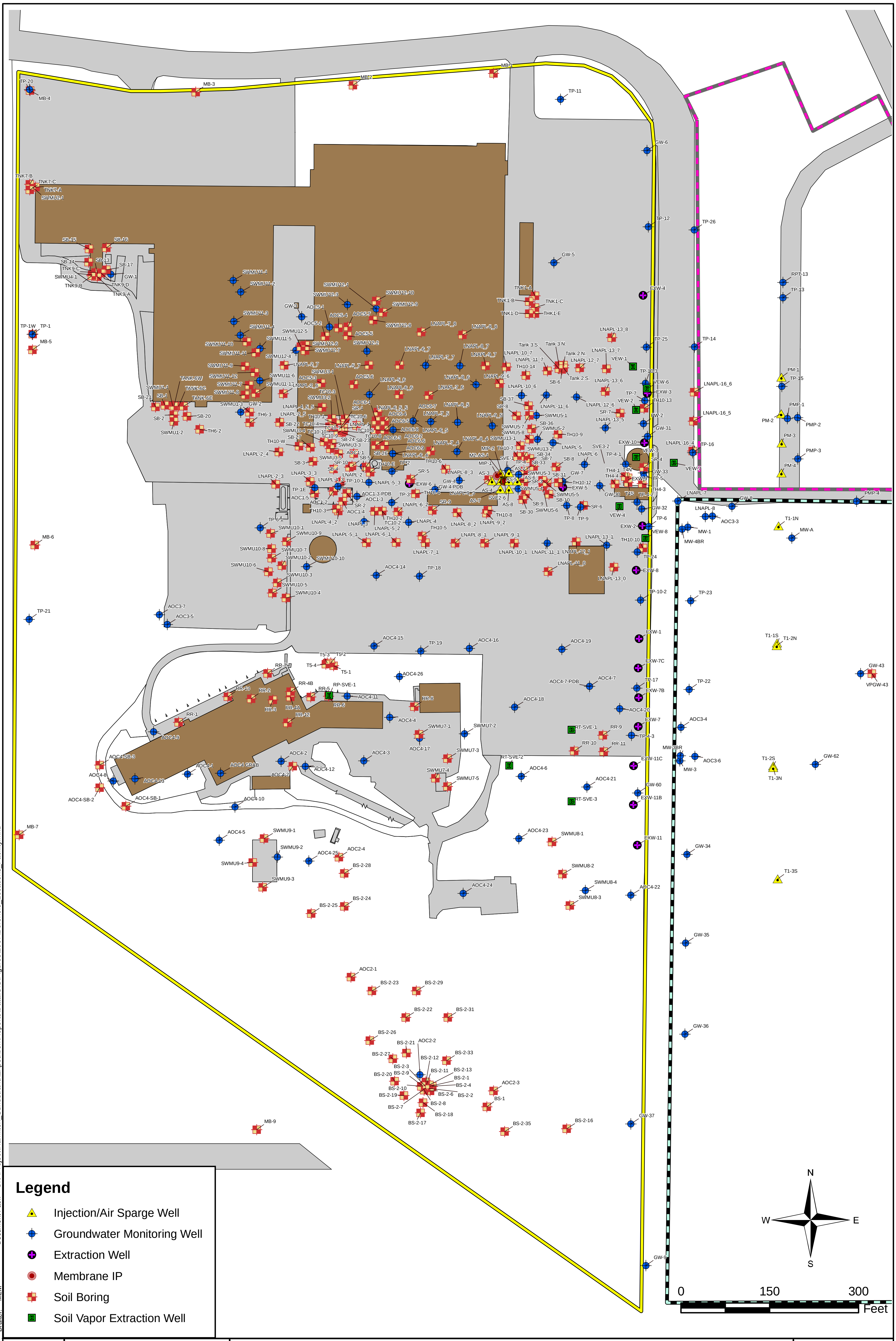
Hamilton Sundstrand
Denver, Colorado

Project Number
GP000UTC.C000

Drawing Date
09/20/2007

Figure
2-1



Legend

- ▲ Injection/Air Sparge Well
- ⊕ Groundwater Monitoring Well
- ✚ Extraction Well
- ◉ Membrane IP
- ▣ Soil Boring
- ▣ Soil Vapor Extraction Well

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Drafter: MLM

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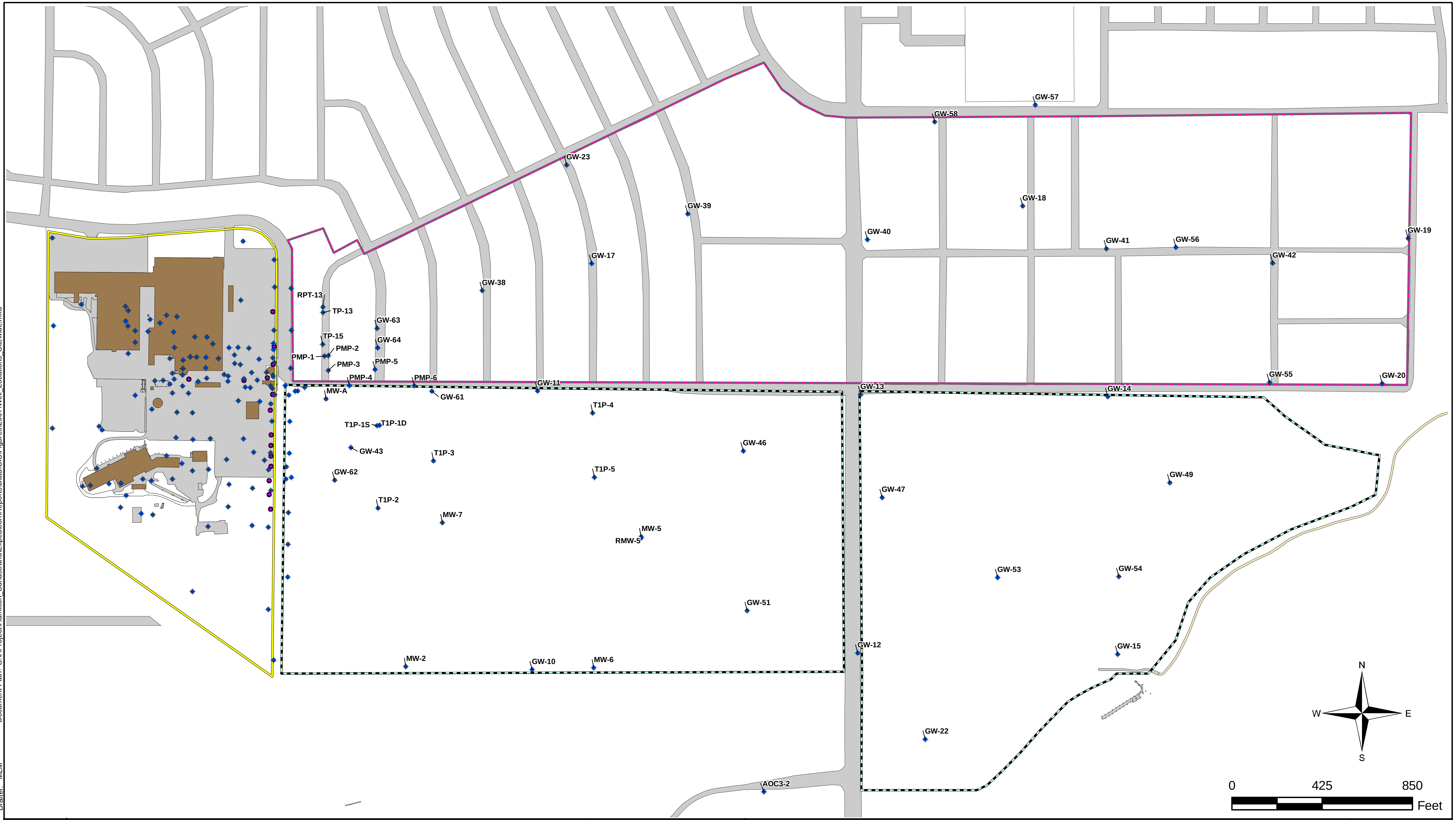
Facility Borehole and Well Locations

Hamilton Sundstrand
Denver, Colorado

Project Number
GP000UTC.E000

Drawing Date
07/26/2007

Figure
3-1



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Legend

- 🔵 Monitoring Well
- ⊕ Extraction Well

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Offsite Groundwater Monitoring Wells

Hamilton Sundstrand
Denver, Colorado

Project Number
GP000UTC.C000

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Figure
3-2

Appendix B

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MEMO

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From:
Mark J. Lupo, Ph.D., P.G.
Changyong Zhang, Ph.D.

Date:
26 February 2007

ARCADIS Project No.:
GP000UTC.K000.KG215

Subject:
Impacted Clay and Silt as a Groundwater Contaminant Source

Introduction

Air sparging and soil vapor extraction (SVE) are being evaluated as a potential remediation technology for the former Hamilton Sundstrand facility in Denver, Colorado. The facility is located at 2480 West 70th Avenue in Denver, Colorado, and is presently owned by the United Technologies Corporation (UTC). Data were collected in support of an upcoming pilot test. The data show that chlorinated hydrocarbons and other organic contaminants are present in fine-grained soil above the coarse sand and gravel that comprise the lower part of the vadose zone and the saturated zone. The project team raised two questions concerning this layer. The first question was whether chlorinated hydrocarbons in this layer would recontaminate the sand layer after the air sparging and SVE remediations are complete and maintain concentrations in the groundwater that would impede the efforts of ARCADIS to meet its remediation goals for groundwater. The second question was to evaluate the distribution and characteristics of NAPL and residual NAPL/soil as a part of the determination of the ability of air sparging and SVE to remediate the sand and gravel layer. This memo concerns the first question. The second will be addressed in a separate communication.

The six main constituents of concern (COCs) in the northern part of the former plant are 1,1,1-trichloroethane (TCA), 1,1-dichloroethane (DCA), 1,1-dichloroethene (DCE), cis-1,2-dichloroethene (cis-1,2-DCE), tetrachloroethene (PCE), and trichloroethene (TCE). Most of the calculations below involve the mass of these six COCs.

In considering the question of leachability, several factors were taken into account. First, boring logs were made available of ten new borings, SR-1 to SR-10, together with analytical results from soil samples and fluorescence data. The analyses included both total concentrations and leachate analysis using the Synthetic Precipitate Leaching Procedure (SPLP). Second, geotechnical data were available. Third, fluid property data were collected. A map was provided showing the locations of the borings. Finally, analyses of groundwater from previous sampling events and the groundwater modeling results entered into the interpretation.

General Observations from the Soil Data

Of the ten borings, four were located in the source areas at release points, SR-1, SR-2, SR-3, and SR-10. The other borings were not located at SWMUs, but were in the general source area. Every boring was matched with a nearby groundwater monitoring point (Table 1). It can be seen the groundwater exceeds MCLs for at least one COC at every location, as one would expect in the source area. However, the leachate does not exceed the MCLs above the saturated zone for the borings that were not at release points, except for a minor PCE exceedance at SR-8 in the smear zone.

In the logs in of the borings not at release points, the highest photoionization detector (PID) readings occur several feet above the water table, in the smear zone. Concentrations are often highest just below the boundary between sand and finer soils, confirming that the contamination in these areas came from a lateral direction and not from above. Only one sample was collected from fine soils from these borings, a sample at 24 to25 feet below ground surface (bgs) from SR-4. This sample is relatively uncontaminated. Five of the six COCs were not detected in the soil or leachate in spite of low detection limits. Only TCA was detected, but at a low level, with a 7.7 µg/kg total concentration and 0.21 µg/L in the leachate.

The borings from release points in the source areas had a different profile. SR-1 was advanced at SWMU 3. The sandy clay above the coarse material was definitely impacted: All of the COCs except PCE were detected in both the soil and the leachate. TCA and TCE exceeded the MCL in the leachate. SR-2 was advanced at Area of Concern (AOC) 1, where TCA had been stored. At this location, TCA and its daughters were detected in the leachate above MCLs (as well as a lower concentration detection of TCE) in a sample collected in the finer soil. This soil was classified as silty sand. The concentrations in the well-graded sand below this silty sand were lower. SR-3 was located at SWMU 5. PCE was detected above its MCL in the leachate in the silty sand sample collected at this location. SR-10 was advanced between AOC-1 and SWMU 3 where releases from buried pipes connecting the two areas were suspected. All of the COCs were detected in the soil, and four of them were in the leachate; PCE exceeded its MCL in the leachate.

At eight of the ten locations, the highest COC concentrations and PID readings occurred in the coarse soil rather than in the finer soil. In six of these locations, this was expected because the sand was contaminated laterally. Impacts were introduced above the water table by the smearing of LNAPL with the rise and fall of the water table. At SR-1 and SR-10, higher concentrations occur in sand than in overlying clay. This can be explained by the presence of petroleum at these locations and because the sand is within the smear zone. At SR-2 and SR-3, concentrations in overlying finer soil (silty sand) are greater than the concentrations in the coarser sand, as one would intuitively expect in locations at which contaminants were released from above.

Obviously, there is no danger of COCs contaminating the coarse material after SVE is complete at locations where the material above is not impacted. The main potential for recontamination is at the locations of releases. The remainder of this memorandum will focus on those areas.

Chlorinated Contaminants in the Fine Soils

The recontamination question has several important components, and all of them involve the material in the fine soils. The first is how much mass remains suspended in fine soils above the smear zone that is targeted for remediation. The second question is the ability of any nonaqueous phase in the finer soils to release COCs into the pore water to form leachate, and the third question is downward flux of leachate. A corollary to the third question is the lateral flux of the groundwater. The ratio of the two fluxes is a dilution factor that can be applied to the leachable concentrations of the COCs in the fine soils to predict the post-SVE concentrations in the groundwater.

Adsorbed Mass Estimate

The first question, the estimate of the mass of COCs in the fine soils, is difficult to answer based upon the four SR data points that were collected in the silt or clay soil. These points are SR-1 at 14 to 15 feet below the top of the boring (which was approximately 10 feet below original grade), SR-2 at 19 feet bgs, SR-3 at 24 to 25 feet bgs, and SR-10 at 19 to 20 feet bgs. The RFI contains a larger body of data. The estimation process would be a time consuming effort. For reasons that will be more clear below, a simple estimate will be sufficient. This estimate can initially be made by taking the highest concentration of each COC from the four data points listed above. This will afford a conservative upper bound. TCA had a concentration of 1,900 mg/kg in SR-2, and DCE had 34 mg/kg in the same sample. The other four COCs were nondetections with a detection limit of 56 mg/kg in SR-2, with concentrations lower than that in some of the other samples. Therefore, they were assumed to be present at 28 mg/kg. It should be noted that the highest detection of any of these four COCs was 27 mg/kg for cis-1,2-DCE in SR-1. The combined area of SWMU 5, SWMU 3, and AOC 1 was estimated by the project team to be 25,728 square feet. The impacted area was assumed to be 10 feet thick, with a grain density of 2.65 g/cc and a porosity of 35%. Thus the fine soil has a mass of 12.5 million kg, and the total mass of COCs in these soils is 25,675 kg or 56,678 pounds (Table 2). In a previous memorandum dated November 3, 2006, it was estimated that the mass of COCs in the coarse soil was approximately 17,000 pounds, with the majority being found in the smear zone. Using a similar averaging technique, the ten SR borings suggest a total mass of 22, 466 pounds (Table 3), a number of the same order of magnitude. In either case, this conservative estimation method leads to the conclusion that the mass of COCs suspended in finer soil above the intervals likely to benefit from air sparging and SVE is nearly three times that of the coarser material.

A less conservative estimate is made if averages are used instead of maximum values for the concentrations of the COCs in the fine soils. This method is more realistic, because the comparison is made between averages, rather than comparing a mass derived from maximum concentrations to one derived from average concentrations. In this case, the total is approximately 16,000 pounds (Table 4), a value approximately equal to the amount already in the coarse soil.

A second important point concerning the mass of COCs is its lateral distribution. As stated above, the release points have an area that is approximately 26,000 square feet. The total size of the source area is approximately 161,000 square feet. Therefore, one sixth that of the area of the coarse soil that contributes COCs to groundwater is overlain by fine soil laden with COCs.

The mass estimates in this section only account for adsorbed chlorinated hydrocarbons and do not include the leachate. This exclusion is not important. The leachate data in Table 5 are expressed in µg/L, as opposed to the soil data which are in mg/kg. An estimate of the mass represented by the leachate can be made by estimating the volume of the leachate in liters and multiplying by the COC concentrations. This is done in Table 6. The release zone was assumed to be 25,728 square feet as in earlier computation. The leachate was assumed to be in a layer 10 feet thick. Boring logs indicate that the actual thickness may vary from 3 to 20 feet. The porosity of the fines is taken to be 39.2%, the average of the two cores for which this was measured in clay. The saturation was 84%, the average value for the same two cores. The resulting leachate volume is 2.4 million liters. When the concentrations in Table 5 are averaged and applied to this volume, it can be seen the total contaminant mass in the leachate is only about 15 pounds.

In summary, the quantity of COCs in fine soil above the coarse sand is approximately equal to the mass of the present smear zone. It should be noted that these estimates only include the adsorbed mass and not the leachate. The mass of COCs in the leachate is considerably less than that adsorbed to the soil.

Potential for Nonaqueous Liquids in the Fine Soil to Release COCs

Computing the potential for COCs to partition from the soil organic matter in the fine soil to the soil pore water is traditionally done by partition coefficients. There are other methods such as the dual equilibrium desorption model (DED) of Chen, et al. (2004). In addition to the question of desorption, there is the matter of petroleum NAPL suspended in the silt and clay from which chlorinated hydrocarbons can migrate into soil pore water by diffusion. No fluorescence measurements were made in the finer soil. The only way to estimate the potential mass of LNAPL in the fine soil would be to measure the irreducible oil saturation of the soil. This was not done, as the van Genuchten parameters were not part of the data request made of PTS laboratories on the SR soils. For the purposes of this memorandum, it is sufficient to note the present concentrations in the leachate which were measured by SPLP in four of the SR borings into the release zones. From Table 5, it can be seen that the soil contamination in the fine soil is capable of generating concentrations of the COCs in leachate that exceed MCLs. It should be noted that SR-2 was advanced near a former storage tank in which TCA product had been stored. The three dichloroethylene isomers that represent daughter constituents were not observed in the SPLP leachate in the fine soil in excess of their MCLs, except at SR-2, where DCA and DCE, daughters of TCA, were detected above their respective MCLs.

In summary, any NAPL or contamination adsorbed to the fine soil in the shallower part of the vadose zone is capable of generating leachate with concentrations in excess of the MCLs for at least one of the COCs.

Downward Flux of Leachate

The downward flux of leachate can be estimated by the following reasoning. The deep percolation rate in this part of Denver has been estimated by the groundwater model to be 1.9 inches per year in the irrigated areas, such as the residential neighborhoods within the model domain, and 0.39 inches per year in non-irrigated areas, such as the Acquired Properties. Since the former facility's closure in 2004, the lawn has not been watered, but one would expect that the site will be well irrigated after its conversion to recreational use. Thus, 1.9 inches per year was chosen as the deep percolation rate. The intrinsic permeability of the soil cores were measured by PTS Laboratories in 14 samples. Two of them were in the fine soils, SR-10 at 19 to 20 feet bgs and SR-1 at 14'4" to 15 feet bgs. The boring logs identify both samples as sandy or silty clay. The intrinsic permeabilities of these samples were measured at 0.442 millidarcy and 2.12 millidarcy. One millidarcy is equivalent to a hydraulic conductivity of 10^{-6} cm/sec, or 1.0 ft/yr. Such conductivity is sufficient to sustain a water percolation of 1.9 inches per year. This is equal to 0.158 ft/yr. The release zones are 26,000 square feet in area. Thus, if the effective porosity is 25%, the volume of leachate crossing the boundary of the fine soil and the coarse soil is 1,029 cubic feet per year, or 2.82 cubic feet per day.

The lateral flux of groundwater can be computed by multiplying the groundwater velocity (7 ft/day) by the thickness of the saturated zone (10 feet) and the width of the impacted zone (240 feet), as well as the effective porosity. One obtains a flux of 4,200 cubic feet per day. Dividing 4,200 by 2.82 indicates a dilution factor greater than 1,000 for any leachate moving into the saturated zone.

Discussion

Dividing any of the values in Table 5 by 1,000 would lead to a concentration that is less than the MCL for the respective COC. This would suggest that dilution is sufficient to prevent the recontamination of the groundwater after SVE and air sparging are complete. One may wonder how the groundwater was contaminated initially, given such low fluxes of COCs. One has to remember that the release took place for 30 years, from 1956 to 1986. During that time, oil could overcome capillary forces in the clay and silt, and LNAPL could reach the groundwater. At present, LNAPL may no longer be able to overcome capillary forces. Thus, the contamination of the groundwater is maintained at the present concentrations by the smear zone LNAPL. If this material could be stripped of COCs by SVE, and if the coarse sands could be remediated of the COCs, the downward flux of leachate would be overcome by the lateral flux of groundwater.

One very important assumption is that the LNAPL is not able to migrate from the fine soil to the coarse sand. Any LNAPL present in the shallow finer soils is expected to be held in place by capillary forces. If NAPL is still moving downward, it would be at very specific macrofeatures within the source areas. The addition of fresh NAPL to the present plume cannot be a large quantity, because the plume has been stable, and groundwater concentrations have dropped somewhat in the past 20 years. It is likely that the downward flow of LNAPL from the clay to the sand slowed down or stopped shortly after the excavations where leaking tanks were formerly located. LNAPL in the finer soils is expected to be bound. This not known as a fact, but it is highly unlikely that the LNAPL is migrating downward at quantities great enough to confound the SVE effort given the age of the release and the behavior of the plume.

Conclusion

Using data from soil cores in the source area and analyses for COCs in soil and leachate, as well as petrophysical data, the mass of the COCs in finer soils was estimated. Although the estimate suggests that the mass present in this area is at least as great as the COC mass in the smear zone, the potential for recontamination of the lower vadose zone and saturated zone is limited. COC concentrations in the leachate determined by SPLP are insufficient to overcome dilution by the 7 ft/day groundwater flow in the area. If the removal of the COCs from the existing smear zone would reduce COC concentrations in groundwater below MCLs, material suspended above the remediation zone should not be able to recontaminate the groundwater to levels in excess of MCLs. This conclusion is predicated on the flow of COCs from fine soils being in the dissolved phase (leachate) and not the nonaqueous phase. It is expected that the LNAPL is no longer able to flow downward, as it has reached irreducible saturation in the fine soils and is held in place by capillary forces.

Table 1. Location of Contamination in Leachate and Groundwater at the Locations of Ten Soil Borings
Former Hamilton Sundstrand Facility, Denver, Colorado

			Leachate						**Nearby Groundwater**						
Boring	**Fine Soil**	**Source**	**TCA**	**PCE**	**TCE**	**1,1-DCA**	**1,1-DCE**	**cis-1,2-DCE**	**Well**	**TCA**	**PCE**	**TCE**	**1,1-DCA**	**1,1-DCE**	**cis-1,2-DCE**
SR-1	14-15	SWMU 3	MCLE	MCLE	MCLE	MCLE	MCLE	MCLE	LNAPL-1	2,500	48	580	180	90	1,100
SR-2	19	AOC 1	MCLE	MCLE	MCLE	MCLE	MCLE	None?	AOC1-3	37,000	<100	<100	450	930	<100
SR-3	24-25	SWMU 5	present	MCLE	present	None	None	low	SWMU5-4	280	1.3	4.2	7.3	8.1	44
SR-4	24-25	Gate	low	None	None	None	None	None	GW-33	270	2.9J	2.3J	460	43J	440
SR-5	None	EXW-6	None	None	None	None	None	None	EXW-6	1,100	<5	8.7	17	34	21
SR-6	None	Yellow	None	low	None	None	None	None	TP-9	150	14J	23J	12J	3.9J	140J
SR-7	None	Yellow	low	low	None	None	None	None	TP-7	1,200	190	150	47J	45J	150*
SR-8	None	SWMU 5	present	MCLE	present	None	None	None	GW-5	78	2.4	3.3	9.8	13	<1
SR-9	None	None	low	None	None	None	None	None	GW-4	410	<4	4.1	12	9.5	<4
SR-10	19-20	AOC 1	present	MCLE	MCLE	low	None	present	LNAPL-2	3,000	<20	240	72	140	710

Notes:

Groundwater concentrations in µg/L.

Fine Soil locations are in feet below ground surface.

*Used data from EXW-3

MCLE: Concentration exceeds drinking water Maximum Concentration Levels (MCLs) promulgated by the USEPA.

Present: COC is present the sample in at least one sample.

Low: COC is present in at least one sample, but its concentration is less than 1 µg/L.

None: COC not detected in sample.

Yellow: Within yellow boundary in soil contamination map.

Soil Color code:

None	No fine soil sampled in this core.
■	Clay or silt present; sample collected at listed depth.

Leachate and groundwater color code:

🟩	COC not detected.
🟨	COC detected below MCL.
🟧	COC concentration exceeds MCL.
🟪	High dectection limit makes it difficult to determine if the MCL was exceeded, or if the COC is present.

Table 2. A Conservative Estimate of COC Mass in the Shallow Fine Soils Using Maximum Concentrations
Former Hamilton Sundstrand Facility, Denver, Colorado

Mass of fine soils:

SWMU3, Aoc1	4188	ft2		
SWMU5	21540	ft2		
Area	25,728	ft2		
Thickness	10	ft		
Volume	257280	ft3		
Porosity	0.35	(dim.)		
Solid volume	167,232	ft3	4,735,482,889	cc
Density	2.65	g/cc		
Mass	**12,549,030**	**kg**	12,549,029,657	g

COC mass in fine soils:

TCA	1900	mg/kg	23,843	kg total mass	52,634	pounds
PCE	28	mg/kg	351	kg total mass	776	pounds
TCE	28	mg/kg	351	kg total mass	776	pounds
DCA	28	mg/kg	351	kg total mass	776	pounds
DCE	34	mg/kg	427	kg total mass	942	pounds
cis-1,2-DCE	28	mg/kg	351	kg total mass	776	pounds
Total	2,046	mg/kg	25,675	kg total mass	56,678	pounds

Mass of COCs in Coarse Soils:

Notes:

kg: Kilograms.
mg/kg: Milligrams per kilogram.
ft: Feet.
ft2: Square feet.
ft3: Cubic feet.
(dim): Dimensionless.
cc: Cubic centimeters.
g: Grams.
g/cc: Grams per cubic centimeter.

Table 3. Estimate of the Mass of COCs in the Coarse Soils
Former Hamilton Sundstrand Facility, Denver, Colorado

Mass of coarse soils:

Length	570	ft2		
Width	240	ft2		
Area	136,800	ft2		
Thickness	10	ft		
Volume	1,368,000	ft3		
Porosity	0.35	(dim.)		
Solid volun	889,200	ft3	25,179,339,990	cc
Density	2.65	g/cc		
Mass	**66,725,251**	**kg**	66,725,250,972	g

Average Concentraction in mg/kg

	TCA	PCE	TCE	DCA	DCE	cis-1,2-DCE
Average:	109	5	21	4	4	9
SR-1	650	10	170	4.8	4.8	52
	99	15	38	3.9	3.9	1.7
	230	5.2	35	2.8	2.2	21
SR-2	500	30	30	30	30	30
	0.59	0.25	0.25	0.25	0.25	0.25
SR-3	6.9	2.1	13	13	13	13
	1.7	2.6	2.3	2.3	2.3	2.3
SR-5	0.014	0.0016	0.0053	0.0053	0.0053	0.0053
SR-6	0.41	2.5	2.5	2.5	2.5	2.5
SR-7	2.3	0.33	0.22	0.6	0.16	0.33
SR-8	13	1.2	1.3	1.2	1.2	0.33
SR-9	0.037	0.059	0.059	0.059	0.021	0.059
SR-10	0.14	0.26	0.033	0.26	0.26	0.26
	19	0.16	1.7	1.3	0.22	0.64
Mass						
kg	7,259	332	1,403	300	290	593
pounds	16,025	733	3,097	663	640	1,309

Total mass in pounds: 22,466

Notes:
- kg: Kilograms.
- mg/kg: Milligrams per kilogram.
- ft: Feet.
- ft2: Square feet.
- ft3: Cubic feet.
- (dim): Dimensionless.
- cc: Cubic centimeters.
- g: Grams.
- g/cc: Grams per cubic centimeter.

Table 4. Estimate of COC Mass in Fine Soils Using by Averaging
Former Hamilton Sundstrand Facility, Denver, Colorado

Mass of fine soils from Table 2:

12,549,030 kg

	Average Concentraction in mg/kg					
	TCA	PCE	TCE	DCA	DCE	cis-1,2-DCE
Average:	519	10	9	8	9	15
SR-1	170	6	3.4	1.5	1.3	27
SR-2	1900	28	28	28	34	28
SR-3	2.2	6.8	2.35	2.35	2.35	2.35
SR-10	3.2	0.27	0.49	0.12	0.085	1.9
Mass						
kg	6,511	129	107	100	118	186
pounds	14,373	284	237	221	261	410

Total mass in pounds: 15,788

Notes:
- kg: Kilograms.
- mg/kg: Milligrams per kilogram.

Table 5. Concentrations of COCs in Leachate in the Shallow Fine Soil Samples
Former Hamilton Sundstrand Facility, Denver, Colorado

Leachate

Boring	Depth (ft. bgs)	TCA μg/L	PCE μg/L	TCE μg/L	DCA μg/L	DCE μg/L	cis-1,2-DCE μg/L
MCL	-	200	5	5	10	7	70
SR-1	14 - 15	510	<10	9.5	5.9	2.2	56
SR-2	19	10000	<100	21	37	110	<100
SR-3	24 - 25	0.99	18	<1.0	<1.0	<1.0	<1.0
SR-10	19 - 20	15	19	5.3	<1.0	<1.0	1.3

Notes:

μg/L: Micrograms per liter.

ft. bgs: Feet below ground surface.

▨ Shading indicates that the leachate exceeds the MCL for the given COC.

Table 6. Estimating the Total Mass of Six Chlorinated Constituents in Leachate
Former Hamilton Sundstrand Facility, Denver, Colorado

Leachate volume:

Area	25,728	ft2				
Thickness	10	ft		Average	SR-1	SR-10
Porosity	0.392	(dim)	<==	39.15	41.6	36.7
Saturation	0.840	(dim)	<==	0.840295	0.800481	0.880109
Volume	84,639	ft3				
Volume	**2,396,706**	**liters**				

	Average Concentraction in µg/L					
	TCA	PCE	TCE	DCA	DCE	cis-1,2-DCE
Average:	2,631	37	9	11	29	40
SR-1	510	10	9.5	5.9	2.2	56
SR-2	10000	100	21	37	110	100
SR-3	0.99	18	1	1	1	1
SR-10	15	19	5.3	1	1	1.3
Mass						
kg	6.31	0.09	0.02	0.03	0.07	0.09
pounds	14	0	0	0	0	0
Total mass in pounds:		**15**				

Nondetections were treated as if the analyte were present at its detection limits.

Notes:
- ft: Feet.
- ft2: Square feet.
- ft3: Cubic feet.
- (dim): Dimensionless.
- µg/L: Micrograms per liter.