Final Supplemental RCRA Facility Investigation Report

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ACRONYMS

AES	Advanced Energy System
AOC	Area of Concern
AOI	Area of Investigation
AST	aboveground storage tank
AWPI	Ayerst Wyeth Pharmaceuticals, Inc.
BCME	British Columbia Ministry of the Environment
bgs	below ground surface
BTEX	benzene, ethylbenzene, toluene, and xylenes
CD	compact disc
CDI	chemical daily intake
CMI	Corrective Measures Implementation
CMS	Corrective Measures Study
COC	chemical of concern
COPC	chemical of potential concern
CPCPRC	Chevron Phillips Chemical Puerto Rico Core, LLC
CSM	Conceptual Site Model
CTE	central tendency exposure
DL	detection limit
DNA	deoxyribonucleic acid
DPE	dual-phase extraction
DQO	data quality objective
EFR	Enhanced Fluid Recovery
EI	Environmental Indicator
EPA	U.S. Environmental Protection Agency
EPC	exposure point concentration
ESL	ecological screening level
ft	feet or foot
gpm	gallons per minute
HHRA	Human Health Risk Assessment
HI	hazard index
HWMU	hazardous water management unit
ILCR	incremental lifetime cancer risk
IRIS	Integrated Risk Information System
LNAPL	light non-aqueous phase liquid
MPS	media protection standard
msl	mean sea level
NCP	National Contingency Plan

NPDES	National Pollutant Discharge Elimination System
OU	operable unit
PAH	polynuclear aromatic hydrocarbon
PC	permeability constant
PID	photoionization detector
PPE	personal protective equipment
ppm	parts per million
PRASA	Puerto Rico Aqueduct and Sewer Authority
PREQB	Puerto Rico Environmental Quality Board
RBC	risk-based concentration
RBSL	risk-based screening level
RCRA	Resource Conservation and Recovery Act
RfC	reference concentration
RfD	reference dose
RFI	RCRA Facility Investigation
RME	reasonable maximum exposure
SLERA	Screening Level Ecological Risk Assessment
SRFI	Supplemental RCRA Facility Investigation
SVOC	semi-volatile organic compound
UCL	upper confidence level
USCS	Unified Soil Classification System
VISM	Voluntary Interim Stabilization Measure (System)
VOC	volatile organic compound
WWTP	Wastewater Treatment Plant

1. INTRODUCTION

In September 1995, the U.S. Environmental Protection Agency (EPA) and Chevron Phillips Chemical Puerto Rico Core, LLC's (CPCPRC) predecessor, Phillips Puerto Rico Core Inc., entered into an Administrative Order on Consent (the "Order"), Docket No. II Resource Conservation and Recovery Act (RCRA)-95-3008(h)-0307 for its facility in Guayama, Puerto Rico (the "Facility"). In general, that Order required the following:

- Development of work planning documents;
- Laboratory, field and bench-scale studies;
- Field investigations and associated Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI) Report of groundwater, soil, sediment, air, and surface water impacts;
- Investigation analyses, analyzing the RFI data with respect to the adequacy of data (i.e., any data gaps);
- Risk assessment, human health, and the environment;
- Corrective Measures Study (CMS); and
- Corrective Measures Implementation (CMI).

CPCPRC has completed the majority of the work identified in the 1995 Order. The following presents a brief summary of that work (documentation is on file in the project records):

1995 to 1999	Work planning, laboratory and bench-scale studies, and field investigations of groundwater, soil, sediment, air, and surface water impacts.
July 1999	CPCPRC completed the RFI and submitted the Final RFI Report to the EPA.
January 2000	EPA issued a letter (dated January 4, 2000) wherein EPA approved the RFI on the condition that the CMS address the EPA's noted concerns.
October 2003	EPA determined that the benzene, ethylbenzene, toluene, and xylenes (BTEX) plumes are stable and posted the determination (the Groundwater Environmental Indicator [EI]) on the EPA web site.
November 2004	CPCPRC submitted the Final Risk Characterization Report (CPCPRC, 2004), which addressed EPA's concerns and presented the media-specific media protection standards (MPSs).
February 2005	The Final Risk Characterization Report (CPCPRC, 2004) was approved in an email dated February 1, 2005.
March 2006	EPA and CPCPRC agreed that the RFI phase of the work had been completed at the facility and that work planning for the CMS phase of work could begin.
October 2006	CPCPRC submitted the Final CMS Work Plan.
April 2007	CPCPRC submitted the Draft Site-Wide CMS Report.

September 2007	The Puerto Rico Environmental Quality Board (PREQB) provided comments on the Draft Site-Wide CMS Report.
August 2008	CPCPRC announced the permanent cessation of operations at the Facility and its intent to decommission and dismantle the process units, tanks, and related equipment.
2009-2011	The dismantling activities were implemented and involved the physical dismantlement of equipment, tanks, and piping for sale, reuse, or recycling. During this time, CPCPRC performed initial characterization sampling of soil in areas exposed by demolition.
October 2011	CPCPRC, EPA, and PREQB met to discuss the scope and schedule for the CMS Report considering the initial characterization sampling of soil exposed by demolition.
4th Quarter 2011	Decommissioning and dismantlement was completed and 19 Areas of Concern (AOCs) were identified based on initial sampling efforts.
August 2011 and January 2012	AOC field investigation conducted in two phases in August/September 2011 and January 2012.
July 2012	CPCPRC submitted the Draft AOC Investigation Report.
January 2013	EPA and the PREQB provide review comments on the Draft AOC Investigation Report.
April 2013	CPCPRC submitted the Final AOC Investigation Report revised to address EPA comments on the Draft report.

Current activities at the Facility include routine groundwater monitoring related to the Order, and ongoing interim measures conducted through implementation of the Enhanced Fluid Recovery (EFR) system and the Voluntary Interim Stabilization Measure (VISM) system. The location of the CPCPRC Facility is presented in Figure 1-1.

The EFR is a mobile variation of what is commonly referred to as dual-phase extraction, vacuum enhanced recovery, multi-phase extraction, or “bioslurping.” The performance of the EFR system is reported in quarterly progress reports and in an annual summary report submitted to the EPA and the PREQB.

The VISM system is composed of an air-sparging trench along a portion of the eastern Facility boundary, vapor recovery system, and vapor treatment units. The performance of the VISM system is reported in semi-annual progress reports submitted to the EPA and PREQB.

1.1 Purpose

The purpose of the Supplemental RCRA Facility Investigation (SRFI) work was to conduct investigations focused on finalizing the nature and extent of sulfolane. In a teleconference with the EPA on February 27, 2013, it was acknowledged that the nature and extent of the primary Facility-related contaminants, BTEX, had been completed. However, the nature and extent of sulfolane contamination was identified as a data gap. In response, CPCPRC submitted the Draft SRFI Work Plan (North Wind, 2013a). The EPA and PREQB provided comments on the Draft work plan, CPCPRC addressed those comments, and the

Final SRFI Work Plan (North Wind, 2013b) was approved in September 2013 (hereafter referred to as the approved Work Plan).

The purpose of this SRFI Report is the following:

- To document the field activities and findings of the SRFI completed October through December 2013 in onsite areas and in March 2014 and December 2014 along the Puerto Rico Aqueduct and Sewer Authority (PRASA) pipeline offsite to the east of the Facility.

- To present the analytical results for sulfolane from a complete round of groundwater sampling performed in June/July 2013 at 78 site monitoring wells, and 3 Effluent Channel surface water and sediment sample locations. The June/July 2013 sampling event was performed as part of routine semi-annual monitoring.

- To present the analytical results for sulfolane from 10 sediment samples collected from the Effluent Channel in November 2013 as part of a voluntary sampling effort.

- To present the analytical results for sulfolane from a round of groundwater sampling performed in December 2013 at 116 monitoring wells, one well newly installed as part of the SRFI (MW-167), and 3 Effluent Channel surface water and sediment sample locations. The December 2013 event was performed in accordance with the approved Work Plan.

The description of the nature and extent of sulfolane contamination and the risk assessment results herein, together with the results of the AOC investigation and AOC risk assessment, are intended to finalize the investigation phase of the RCRA process and support the scope of the CMS phase of work at the Facility. It is noted that the investigation areas identified in the approved Work Plan were designated as Areas of Interest (AOIs) and this term is used in this report to describe the SRFI areas. The locations of the AOIs along with the locations of the site monitoring wells sampled during the SRFI are presented in Figure 1-2.

1.1.1 SRFI Investigation Objectives and Approach

The SRFI work addressed the Data Quality Objectives (DQOs) presented in the approved Work Plan to finalize the nature and extent of sulfolane contamination at 15 AOIs, and use these data to determine the potential risk posed by sulfolane contamination. The DQOs for this work were the following:

OUs	DQO – Investigate Operable Units (OUs) where sulfolane was possibly used, stored or conveyed as a result of historical operations or inadvertent releases.
Tank Storage	DQO – Investigate former tank locations where sulfolane may have possibly been inadvertently released to the environment. As a note, the tank storage areas examined as part of this Supplemental RFI work included re-examination of the sulfolane data at the 19 AOCs already investigated as part of the AOC Investigation efforts plus all other former storage tanks.
Process Units	DQO – Investigate former process units where sulfolane may have possibly been inadvertently released to the environment.
Groundwater	DQO 1 – Investigate areas where sulfolane is observed to be migrating across facility boundaries.

> DQO 2 – Collect one round of groundwater samples from all 116 Facility monitoring wells to verify/refine the mapped extent of sulfolane in groundwater.

Each of the 15 AOIs was treated as an individual area in terms of sample collection, regardless of size or proximity to other AOIs. Characterization of each AOI was detailed in the SRFI Work Plan (North Wind, 2013b) and included a specified number of surface soil samples, subsurface soil samples, and groundwater samples. In addition to the planned work, CPCPRC performed additional sampling, as necessary, based on field and analytical data, to complete the delineation of contamination.

Regarding soil characterization, CPCPRC used direct push drilling methods with a 4-foot (ft) core barrel to obtain soil core from the ground surface to the top of groundwater at the time of drilling. Consistent with the AOC investigation work, one soil sample was to be collected from the 0- to 2-ft depth interval (surface soil) for laboratory analysis. For each 4-ft soil core below the surface soil sample (i.e., subsurface soil), a portion of each 4-ft section of core was placed in a sealable plastic bag and a photoionization detector (PID) was used to measure the headspace in the bag after the sample equilibrated. One soil sample was collected from the interval exhibiting the highest PID headspace reading relative to ambient background. If no samples exhibited elevated headspace readings relative to ambient background, the sample from the interval directly above the water table at the time of drilling was selected for laboratory analysis. It is noted that although sulfolane, a semivolatile organic compound (SVOC), does not illicit a response on a PID, sulfolane is observed to occur with volatile organic compounds (VOCs) found in Facility samples. Therefore, the PID readings were expected to provide a reasonable screening approach for identifying intervals with sulfolane contamination.

Regarding groundwater characterization at the AOIs, CPCPRC collected one groundwater sample from a direct push boring located upgradient of the AOI and one groundwater sample from a direct push boring located downgradient of the AOI. Groundwater from the site monitoring wells was collected using dedicated sampling equipment and low-flow sampling methods consistent with the methods used to collect the routine groundwater samples (i.e., samples collected during the semi-annual and VISM sampling programs).

The SRFI work addressed the DQOs as follows:

DQO	Feature(s) Investigated	DQO Met?
OUs	With the exception of the Tank Storage Areas in OU 1, sulfolane was not used or present in the other 7 OUs. In addition, the other 7 OUs (OU 2 through OU 8) were either decommissioned and demolished, clean closed under RCRA, or were found to not be contaminated based on previous RFI work. It is noted that OU 1 also included groundwater and all monitoring wells were sampled as part of this SRFI investigation.	Yes. Tank storage areas where sulfolane was used, stored or conveyed as a result of historical operations or inadvertent releases were investigated. All monitoring wells were sampled as part of this investigation.
Tank Storage	The 13 former storage tank areas identified in the Work Plan were investigated. With the exception of the minor deviations listed in Section 2.4 of this report, all samples were collected as planned.	Yes. The data collected is adequate to define the nature and extent of sulfolane contamination from historical releases during tank storage operations.

Process Units	Tank 540 was located immediately adjacent to the sulfolane process unit. This tank was used for sulfolane storage and sulfolane was detected in the soil during the AOC investigation. Monitoring well MW-113 is located directly downgradient of former Tank 540. Samples were collected from the Tank 540 AOI and from MW-113 as planned.	Yes. The data collected is adequate to define the nature and extent of sulfolane in the vicinity of the former sulfolane process unit.
Groundwater	All groundwater monitoring wells were sampled as planned. In addition, the areas where sulfolane was suspected to be migrating offsite were investigated by installing and sampling a new monitoring well (MW-167) along the Western boundary and the investigating the six planned locations along the PRASA pipeline offsite to the east.	Yes. The data collected is adequate to define the nature and extent of sulfolane in groundwater.

The analytical data obtained from the sampling was validated by an independent, Puerto Rico certified data validator. The specific methods and procedures used during the completion of the SRFI are presented in the following sections of this report.

1.2 Site Background

The Facility is 211 acres in size and is located on the southeast coast of Puerto Rico centered at approximately 17°56'45" north latitude and 66°08'30" west longitude. CPCPRC is located about 0.25 miles north of the Caribbean Sea (Figure 1-1). The Facility was constructed in 1966 on land previously used for sugar cane cultivation. The Facility operated as a specialty chemicals production facility that operated from 1966 to 2004. The CPCPRC facility was constructed to primarily process naphtha into a variety of refined hydrocarbon products including, but not limited to benzene, toluene, xylenes, cyclohexanes, liquid petroleum gas, gasoline, and diesel fuels. Sulfolane was used as part of the chemical process, and through inadvertent releases, it was introduced into the environment.

1.2.1 Site Setting and Use

Prior to demolition, the Facility consisted of a Process Area with structures, piping, and other appurtenances on a concrete slab and product storage in Tank Basins A through N. Some other smaller areas of product storage were located in the northern portion of the Facility. The administrative offices and other support services were also located in the northern portion of the Facility. Near the southern portion of the Facility, there was a Wastewater Treatment Plant (WWTP) and associated ponds and structures.

The Facility is completely demolished and the activity at the Facility is limited to work related to periodic mowing and groundskeeping, work to operate and maintain the VISM and EFR systems, and routine groundwater monitoring.

Based on current surrounding land use and likely expectations of future land use, the Facility will remain industrial.

1.2.2 Topography and Physiography

The Facility area was previously graded to accommodate sugar cane cultivation. Elevations range from 45 ft above mean sea level (msl) at the northern portion of CPCPRC, to less than 5 ft msl at the southern boundary. During construction of the Facility in 1966, the area was re-graded to construct containment berms around the aboveground storage tank (AST) basins and the former ASTs were constructed on raised soil platforms. The soil platforms range in height from about 1 ft to approximately 10 ft above the surrounding grade.

A manmade harbor, Las Mareas Harbor, was built about a half-mile southwest of the main operation area to receive and ship products for CPCPRC. As part of the Facility decommissioning, the harbor area, including two ponds for the storage of ship ballast water (the Ballast Water Basins), underwent clean closure activities under RCRA with the supervision of EPA and PREQB. The Ballast Water Basins were clean closed in compliance with RCRA and other applicable legal requirements in 2010. CPCPRC's lease to the harbor area has been terminated and the land is no longer part of the Facility.

In addition to the Ballast Water Basins, two Hazardous Waste Management Units (HWMUs) and three Lime ponds were located onsite. The Lime ponds have been backfilled and graded to match surrounding topography. The two HWMUs, the Oxidation Pond and Off-Specification Pond, were clean closed in 2013 under RCRA with the supervision of EPA and PREQB. The Lime Ponds were not RCRA regulated however, the ponds were decommissioned consistent with clean closure methods and procedures in 2013.

1.2.3 Surface Water Features

During its operational period, surface water drainage across the CPCPRC facility entered one of five stormwater runoff collection or diversion systems (Phillips, 1999). Runoff was then either contained in the Storm Water Pond and/or the Final Holding Pond or entered one of several permitted National Pollutant Discharge Elimination System (NPDES) outfalls as described in the RFI Report (Phillips, 1999). Water that entered the Storm Water Pond and/or the Final Holding Pond was treated in the onsite WWTP.

Recently, the WWTP was completely removed and the NPDES permit was terminated by agreement with EPA. Also, by agreement with the EPA, CPCPRC terminated the Facility's Multi-sector General Permit for storm water. All stormwater from the Facility is considered clean storm water and this water drains generally from north to south where it enters the manmade earthen Effluent Channel located along the southern border of the Facility. All storm water modifications were performed in cooperation with, and under the supervision of, the EPA and PREQB.

West of the CPCPRC property, CPCPRC's storm water in the Effluent Channel commingles with discharges from Ayerst Wyeth Pharmaceuticals, Inc. (AWPI) and storm water runoff from the surrounding area, and then ultimately discharges to the Caribbean Sea at Las Mareas Harbor.

1.2.4 Climate and Precipitation

The Facility is set in a tropical area, with mean monthly temperatures above 64.4 degrees Fahrenheit, and a dry winter season. The mean annual precipitation in Guayama, located east of the facility, is 60 inches. Jobos, located west of the facility, receives an average of 45 inches of rain fall annually. The rainy season generally extends from May through November, with the dry season from December through April. On average, approximately 75% of the annual precipitation occurs during the rainy season.

1.2.5 Demographics and Land Use

In the past, the land surrounding the Facility was used mainly for sugar cane production. Currently, PRASA operates a WWTP east of the Facility and Advanced Energy System's (AES) coal-fired power plant operates directly to the west in the area previously referenced as the "West Cane field" in earlier reports. Several industrial facilities are located north of Highway 3 (approximately a half-mile north of the Facility). These include AWPI, Baxter and IPR Pharmaceutical Company, and the former Fibers facility (a listed Superfund site). A Puerto Rico Department of Corrections facility is located directly northwest of the AWPI Plant and houses a population of approximately 600 inmates.

AP Industries, Inc. (formerly the location of SmithKline & Beecham Laboratories, as well as ChemSource, Inc.) is located near the northwest corner of the AES power plant property approximately a half-mile northwest of the facility.

Similar to the CPCPRC site, the pre-construction topography of the AES area sloped to the south with elevations at approximately 24 ft above msl in the north and about 5 ft above msl at the southern property boundary. Construction of the AES coal-fired power plant began in November 1999 and included complete removal of all vegetation in the field to the west of CPCPRC (termed the West Cane Field in historical Facility reports). Following this site preparation work, AES transported, placed, and compacted fill material. The fill was placed to raise and level the area and, therefore, more fill was placed in the southern portions of the facility than in the northern portions. Based on discussion with AES during January-February 2001, about 8 ft of fill was placed at the southern edge and little to no fill was placed along the northern edge of the property. Construction of the power facility was then started on the compacted and graded fill. Only a small portion of the AES property has remained undeveloped. This area runs along AES's southern fence line. The AES property is fenced and guarded 24-hours a day, 7 days a week.

The town of Guayama, located northeast of the Facility, is the largest population center in the area. The population of the Guayama Municipio is approximately 42,000. The permanent population within a 2-mile radius of the facility is small and generally is employed by the industrial facilities surrounding CPCPRC, the government, or the fishing industry.

In the mid-1960s, all the inhabitants of Las Mareas were relocated to the village of Barrancas, approximately 2 miles northeast. The population of Barrancas is approximately 4,500. Las Mareas subsequently was re-inhabited and approximately 30 to 35 small dwellings are currently occupied. To the north, is Colonia Reunion, a small community of approximately 4 to 5 small dwellings.

Based on current surrounding land use and likely expectations of future land use, the Facility will remain industrial.

1.3 Previous Investigations

The following describes the scope of previous investigations performed at the Facility. The investigations were conducted in accordance with the requirements of the Order. The results of these previous investigations are summarized in Section 2.

1.3.1 RFI Investigations

The RFI was initiated in 1995 and a large data set was compiled through the multiple phases of investigations that were performed. The investigations focused on determining the nature and extent of contamination in OUs defined in the Order. Figure 1-3 presents the locations for the OUs along with some other site features that were present at the time (i.e., before complete demolition of the Facility). Each phase of investigation was designed to address data gaps from previous phases.

CPCPRC completed the RFI and submitted the Final RFI Report to the EPA in July 1999. Between 1999 and 2006, CPCPRC performed risk assessment work and performed numerous voluntary investigations primarily to refine the understanding of the lithology and physical structure of the groundwater system beneath the Facility and in the offsite areas where contamination was identified. In 2006, EPA and CPCPRC agreed that the RFI phase of the work had been completed at the Facility and that work planning for the CMS phase of work could begin.

In between October 2006 and September 2007, CPCPRC worked with the EPA and EQB on the CMS phase of work including submitting a CMS Work Plan and a Draft Site-Wide CMS Report. When cessation of operations was announced in 2008 and decommissioning and demolition of the Facility commenced, it was agreed the CMS phase of work would be re-initiated after post demolition investigation was completed.

1.3.2 AOC Investigation

In August 2008, CPCPRC announced the permanent cessation of operations at the Facility and began complete demolition of the Facility. During the deconstruction and dismantlement of the Facility, areas of potential contamination were identified and sampled. If the analytical results indicated contamination was present above the risk-based screening levels (RBSLs), the area was retained as an AOC for further investigation and characterization. Sampling efforts completed during the deconstruction and dismantlement of the Facility identified 19 AOCs (Figure 1-4).

The investigation of the 19 AOCs was performed after complete demolition of the Facility and was conducted in two phases: the first in August/September 2011 and the second in January 2012. During the AOC investigation, a total of 259 surface soil samples and 259 subsurface soil samples were collected. Two groundwater samples were collected at each of the 19 AOCs for a total of 38 samples. In addition, groundwater samples were collected in May/June 2012 and in December 2012. The May/June 2012 sampling event included sampling total of 78 wells. The December 2012 sampling event included the 54 regularly monitored CA and VISM wells. These AOC investigation samples were analyzed for the Facility's Modified Skinner List of chemicals.

1.4 Semi-Annual Sampling

Since 1999, CPCPRC has been sampling a subset (54) of the 117 existing site monitoring wells on a semi-annual basis. The monitoring wells primarily include wells located offsite and along the boundaries of the Facility. The objective of this semi-annual sampling is to track groundwater contamination and verify that the migration of contaminated groundwater is controlled until the CMS remedy for groundwater is implemented. The analytical suite used to track groundwater contamination consists of a subset of the Modified Skinner List of chemicals.

Since the submission of the AOC Investigation Report in April 2013, CPCPRC has performed two rounds of groundwater sampling. One sampling event was performed in late June/early July and consisted of an expanded list of groundwater monitoring wells to include the 54 wells that are routinely sampled plus 25 additional monitoring wells. In December 2013, the 54 routinely sampled wells plus 63 wells samples as part of the AOI investigation resulted in all 117 site monitoring wells being sampled to provide a site wide view of the nature and extent of groundwater contamination.

In addition to the groundwater sampling, the surface water and sediment in the Effluent Channel are sampled on a semi-annual basis. Data from the sampling conducted in June/July 2013 and December 2013 are evaluated in the risk assessment presented herein. The results of previous sampling events have been presented in other site reports over the years.

1.5 Ongoing Interim Actions

The following describes the interim actions that are ongoing at the Facility to address groundwater contamination.

1.5.1 Enhanced Fluid Recovery

CPCPRC has been implementing EFR in focused areas of the Facility since September 1996. EFR is a mobile variation of what is commonly referred to as dual-phase extraction (DPE), vacuum enhanced recovery, multi-phase extraction or "bioslurping." Extracted fluids are temporarily contained in the tank of a specially equipped vacuum truck for subsequent treatment at the Facility's Air Stripper. This treated water is then discharged to the PRASA. Over the last several years, the absence of releases, natural attenuation, and the application of EFR has resulted in significant improvement in groundwater quality. The observed changes include the absence of light non-aqueous phase liquid (LNAPL) in the wells and significant declines in dissolved phase benzene concentrations in several wells.

CPCPRC's EFR program includes revisiting the EFR application approach on the quarterly basis to tailor the extraction regime based on the most current benzene data. As an interim measure, the application of EFR has been effective at reducing the mass of benzene in groundwater. The effectiveness of EFR as the final remedy or part of the final remedy will be evaluated in the CMS. Until the final remedy is determined and in place, CPCPRC continues to implement an aggressive EFR program to further reduce benzene mass in groundwater.

1.5.2 Voluntary Interim Stabilization Measure

The VISM system was constructed in 1996 as a voluntary interim measure to reduce benzene levels in the Upper Alluvial aquifer near the southeastern boundary of the Facility. The VISM system consists of an air sparging trench, vapor recovery system, and vapor treatment units. In addition, a 12-inch diameter well was installed at the south end of the trench to facilitate removal of any free-phase petroleum hydrocarbon that may collect in the trench and/or the recovery well. The VISM system has been operating since 1996.

BTEX concentrations have been tracked over the last 18 years. It is observed that BTEX levels in groundwater have been below the performance standard established for the VISM of 200 parts per million (ppm) at all of the VISM wells and piezometers since June 2009.

The effectiveness of VISM as the final remedy, or part of the final remedy, will be evaluated in the CMS. Until the final remedy is determined and in place, CPCPRC continues to operate the VISM system to further reduce BTEX levels in groundwater.

2. INVESTIGATION DATA

The following sections summarize the investigation work completed at the Facility.

2.1 RFI Data Summary

2.1.1 Analytical Data

As discussed above, the RFI work conducted between 1995 and 1999 investigated the nature and extent of contamination at OUs defined in the Order. Analyses were performed on 370 chemicals from 450 samples of media, including groundwater, soil, sediment, surface water, and air. It should be noted that, although a broad range of chemicals were analyzed, sulfolane was not part of any target compound list at the time. Sulfolane was added to the analytical list after sulfolane was discovered beneath a demolished structure (Tank 540). Tank 540 was used for sulfolane storage and sulfolane was detected in the soil during the tank dismantling.

The results of the RFI work and subsequent risk assessment demonstrated that of the 370 chemicals analyzed, only 12 were identified as chemicals of concern (COCs); with the primary facility-related contamination being the BTEX constituents, benzene in particular.

2.1.2 Physical Data

In addition to analytical data, extensive geologic data were collected during the RFI. Much of this work consisted of voluntary investigations using direct-push drilling techniques to refine the understanding of the subsurface hydrogeology. The following is a brief overview of the hydrogeological site conceptual model developed from these efforts:

- The base of the aquifer system in the vicinity of the site is identified as andesite bedrock and is typically found at about 80 ft below ground surface (bgs).

- Above the bedrock is the Lower Alluvial aquifer. The Lower Alluvial aquifer is present beneath the entire facility and the top of the unit is typically observed at about 25 ft bgs. The aquifer materials consist primarily of fine-to-medium sand with some gravel. Groundwater flow in this aquifer is generally to the south.

- Above the Lower Alluvial aquifer, a clay layer is typically found. This layer forms a discontinuous aquitard between the lower and Upper Alluvial aquifers.

- The Upper Alluvial aquifer was deposited in an alluvial fan/transitional marine environment. The aquifer materials consist of widely varying combinations of silt, sand, and gravel. Groundwater flow in this aquifer is to the east, south, and west with the orientation of the sand deposits exerting the primary control on groundwater flow.

2.2 AOC INVESTIGATION SULFOLANE DATA SUMMARY

The AOC investigation approach was based on the Conceptual Site Model (CSM) of chemical release and transport. Facility-related chemical contaminants could have been released (source) onto surface soil, could then have infiltrated through the subsurface soil, and could then be transported away from the source via groundwater. The following sections summarize the results of the soil, groundwater, surface water, and sediment sampling including AOC risk assessment findings. The results for all detected chemicals are discussed; however, the sulfolane data are the focus of this SRFI.

2.2.1 Surface Soil

Surface soil is considered soil from the ground surface to 2 ft bgs. The results of the AOC surface soil sampling indicated that the BTEX constituents and four other VOCs, four polynuclear aromatic hydrocarbons (PAHs), the SVOCs sulfolane, bis(2-ethylhexyl)phthalate, and naphthalene, and 16 metals were found above the RBSLs. These constituents were carried forward to the Human Health Risk Assessment (HHRA). In the HHRA, the receptor groups that could be at potential risk during contact with surface soil included the construction worker, the industrial worker, and the trespasser.

The results of the HHRA indicated that the construction worker could be at risk from sulfolane in the soil during the course of construction. The industrial worker would not be at risk working at the site now or in the future. Similarly, the trespasser would not be at risk from exposure to soil. The extent of sulfolane in surface soil is presented in Figure 3-14 along with the SRFI surface soil data. This figure depicts all locations sampled and the sample locations where sulfolane was above the most conservative RBSL of 3.2 µg/Kg (shown by red symbol).

2.2.2 Subsurface Soil

Subsurface soil is considered soil below 2 ft to the top of the water table at the time of drilling. The results of the AOC subsurface soil sampling indicated that the BTEX constituents and seven other VOCs, four PAHs, the SVOCs sulfolane, bis(2-ethylhexyl)phthalate, and naphthalene, and 15 metals were found above RBSLs. These constituents were carried forward to the HHRA. In the HHRA, the receptor group that could be at potential risk during contact with subsurface soil included the construction worker.

The results of the HHRA indicated that the construction worker could be at risk from sulfolane in the soil during the course of construction. The extent of sulfolane in subsurface soil is presented in Figure 3-15 along with the SRFI subsurface soil data. This figure depicts all locations sampled and the sample locations where sulfolane was above the most conservative RBSL of 3.2 µg/Kg (shown by red symbol).

2.2.3 Groundwater

Groundwater samples were collected from open boreholes and Upper Alluvial and Lower Alluvial monitoring wells. The results of the AOC groundwater sampling indicated that the BTEX constituents and two other VOCs, four PAHs, the SVOCs sulfolane, bis(2-ethylhexyl)phthalate, and naphthalene, and 10 metals (monitoring well samples) were found above RBSLs. These constituents were carried forward to the HHRA. In the HHRA, a hypothetical resident and the construction worker could be at potential risk during contact with groundwater.

The results of the HHRA indicated that for the resident would be at risk from exposure to sulfolane in the groundwater; although, benzene was by far the largest risk contributor. For the construction worker, the risk from exposure to sulfolane in the groundwater was acceptable. The extent of sulfolane in groundwater is presented in Figures 2-1 through 2-4.

Figure 2-1 presents the extent of sulfolane in the Upper Alluvial aquifer and includes the groundwater samples collected from the open boreholes during the AOC Investigation and the monitoring wells sampled during the May/June 2012 comprehensive sampling event. As shown in Figure 2-1, sulfolane contamination is present in three distinct plumes coincident with the presence of sand channels in the Upper Alluvial aquifer.

The December 2012 sulfolane data in the Upper Alluvial aquifer (Figure 2-3) shows a similar distribution of sulfolane to the May/June 2012 data. It is noted that the December 2012 sampling included fewer wells than the May/June 2012 sampling. Overall, it is observed that the sulfolane in the Upper Alluvial aquifer in May/June 2012 and December 2012 are similar in concentration and distribution, although some slight increases and decreases occurred.

Figure 2-2 and Figure 2-4 present the sulfolane data in the Lower Alluvial aquifer based on the May/June 2012 and December 2012 expanded semi-annual monitoring events, respectively. As shown in Figure 2-2 for the May/June 2012 samples, sulfolane is above the RBSL of 16 µg/L in seven of the 11 onsite Lower Alluvial aquifer monitoring wells and in six of the 12 offsite Lower Alluvial aquifer monitoring wells. For the December 2012 samples (Figure 2-4), sulfolane is above the RBSL in 3 of the 4 onsite Lower Alluvial aquifer monitoring wells and seven of the 12 offsite Lower Alluvial aquifer monitoring wells.

2.2.4 Surface Water and Sediment

In the Effluent Channel surface water, sulfolane was detected in one sample (Ditch-1) at a concentration of 0.94 µg/L during the December 2012 sampling event (Figure 2-3). The detection did not exceed the RBSL. Sulfolane was not detected at this location during the May/June 2012 sampling event Figure 2-1).

In Effluent Channel sediment, sulfolane was detected at on location (Channel-2) at a level of 130 J µg/Kg in May/June 2012 (Figure 2-1). The detection did not exceed the RBSL. Sulfolane was not detected in sediment in the December 2012 samples (Figure 2-3).

The results of the HHRA indicated the surface water and sediment did not pose any potential excess risk.

2.3 SRFI Data Collection Program

The SRFI was performed from October through December 2013 in onsite areas and in March 2014 and December 2014 along the PRASA pipeline offsite to the east of the Facility. Table 2-1 lists the 15 AOIs identified in the approved Work Plan and each of the 15 AOIs were characterized as individual areas. The sample design for each AOI was based on the grid developed for that individual AOI. The sizes of the AOIs ranged from 20 ft in diameter to 150 ft in diameter and the number of grid nodes was dependent upon the size of the AOI and the DQOs of the investigation. The specific number and the location of the samples are presented in the AOI-specific discussions in Section 3.

All borings drilled during the SRFI work used a direct push drilling system and soil sampling was completed by obtaining core material from the selected depth and immediately filling the sample jar(s) for sulfolane analysis. The soil core was described using the Unified Soil Classification System (USCS) system and the boring logs for the SRFI locations are provided in Appendix A. The laboratory data packages were submitted to CPCPRC and an independent, Puerto Rico certified data validator completed the validation of all the analytical data.

Upon completion of sampling the borings were backfilled using native materials (unused core) and any remaining void space was filled with grout.

In addition, this report presents the analytical results for the following events:

- The analytical results for sulfolane from a complete round of groundwater sampling performed in June/July 2013 at 78 site monitoring wells, and 3 Effluent Channel surface water and sediment sample locations. The June/July 2013 sampling event was performed as part of routine semi-annual monitoring.

- The analytical results for sulfolane from 10 sediment samples collected from the Effluent Channel in November 2013 as part of a voluntary sampling effort.
- The analytical results for sulfolane from a round of groundwater sampling performed in December 2013 at 116 monitoring wells, one well newly installed as part of the SRFI (MW-167), and 3 Effluent Channel surface water and sediment sample locations. The December 2013 event was performed in accordance with the approved Work Plan.

2.3.1 Surface Soil

Direct push drilling methods to obtain soil core from the ground surface to the top of groundwater. Consistent with previous characterization work, one soil sample was collected from the 0- to 2-ft depth interval (surface soil). During the SRFI, a total of 63 surface soil samples were collected and analyzed for sulfolane.

2.3.2 Subsurface Soil

For soil intervals below the surface soil sample (i.e., subsurface soil), a portion of each 4-ft section of core was placed in a sealable plastic bag and a PID was used to measure the headspace in the bag after the sample equilibrated. One soil sample was collected from the interval exhibiting the highest PID headspace reading relative to ambient background. If no 4-ft section of core exhibited elevated headspace readings relative to ambient background, the sample from the interval directly above the water table at the time of drilling was selected for laboratory analysis. During the SRFI, a total of 63 subsurface soil samples were collected and analyzed for sulfolane.

2.3.3 Groundwater

The groundwater samples were collected at each AOI from the open borehole using a peristaltic pump with dedicated tubing. Groundwater was typically found between 4 and 16 ft bgs. If groundwater was not encountered, the borehole was advanced to a maximum depth of 20 ft bgs. Water was not encountered at Tank 40 and Tank 50 AOIs and at Tank 250 AOI. At Tank 40 AOI, locations 0040-06 and 0040-07 were dry at the time of drilling. At Tank 50 AOI, location 0050-06 was dry at the time of drilling. At Tank 250 AOI, locations 0250-06 and 0250-07 were dry at the time of drilling.

At these locations, the borings were dry at 20 ft and groundwater samples could not be collected. During the SRFI, a total of 17 groundwater samples were collected from the open boreholes and analyzed for sulfolane. The locations for the borings at each AOI are presented in Figure 3-1 through Figure 3-12. The boring logs are included in Appendix A and depict where water was encountered during drilling and the total depth drilled at each location.

Groundwater samples collected at the monitoring wells were collected using the same low-flow sampling techniques used during routine groundwater sampling events.

2.3.4 Effluent Channel Surface Water

The water in the Effluent Channel is regularly sampled for a target list of chemicals as part of the ongoing semi-annual monitoring program. In June 2013 and again in December 2013, three surface water samples were collected and analyzed for the target list, including sulfolane.

2.3.5 Effluent Channel Sediment

The sediment in the Effluent Channel is sampled semi-annually along with the surface water at three locations for a target list of chemicals. In June 2013 and again in December 2013, three sediment samples were collected and analyzed for the target list, including sulfolane.

It is noted here that, CPCPRC elected to collect 10 sediment samples from the Effluent Channel to better characterize the sediment quality in the channel. These 10 samples were collected in November 2013 and are included in the data presentation herein.

2.4 DEVIATIONS FROM THE WORK PLAN

Two of the sample locations at Tank 540 could not be drilled at the planned locations because subsurface structures including the concrete footings of the former cooling towers and other foundation structures prevented drilling. As a result, the two locations were adjusted to locations where borings could be successfully advanced. Specifically, location 0540-016 was moved 8 ft north of the planned location and 0540-017 was moved 6 ft south of the planned location.

As previously noted, five of the planned groundwater samples were not collected at Tank 40 and Tank 50 AOIs and at Tank 250 AOI. At Tank 40 AOI, locations 0040-06 and 0040-07 were dry at the time of drilling. At Tank 50 AOI, location 0050-06 was dry at the time of drilling. At Tank 250 AOI, locations 0250-06 and 0250-07 were dry at the time of drilling. Although groundwater samples could not be collected at these 5 boreholes, groundwater samples were collected from all Facility monitoring wells, including wells located near these AOIs. The comprehensive groundwater data set from the monitoring wells is adequate to define the nature and extent of sulfolane in groundwater.

2.5 SECONDARY FIELD ACTIVITIES

2.5.1 Field Equipment Calibration Procedures

Field instruments were calibrated and maintained in accordance with the manufactures specifications. The PID was calibrated daily prior to use and as necessary. The groundwater quality meter was calibrated daily prior to use.

2.5.2 Field Decontamination Procedures

All Direct Push tooling (drill rods, bits, caps) that contacted soil were decontaminated between each use. Sampling equipment such as spoons, were decontaminated between each use. Direct Push tooling and sampling equipment were decontaminated using a non-phosphate soap wash followed by a potable water rinse and a deionized/distilled water rinse.

2.5.3 Field Health and Safety

The SRFI was performed in accordance to the project Safety and Health Plan. Site control consisted of measures to prevent human exposure to hazardous materials at the site. No safety incidents or issues occurred during the field investigation.

2.5.4 Investigation Derived Waste Management

Field activities included the generation of investigation derived waste, including decontamination water, unused core, personal protective equipment (PPE), and disposable sampling equipment. With the exception of the unused core from the borings along the PRASA pipeline, unused core was containerized and properly disposed offsite as non-hazardous waste. For the six PRASA borings, the unused core was used to backfill the boring from which they were derived. Decontamination water was disposed of at the Facility WWTP. Disposable sampling equipment and PPE received a gross decontamination, if necessary, and was disposed of with the Facility waste.

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3. NATURE AND EXTENT OF CONTAMINATION

3.1 Summary of Analytical Data Evaluated

The nature and extent evaluation is intended to present a complete picture of sulfolane contamination in soil, groundwater, surface water, and sediment. The data evaluation presents the results of the SRFI soil sampling followed by a site-wide overview of sulfolane contamination in soil based on the SRFI and AOC soil sampling results. Sulfolane in groundwater includes a presentation of the groundwater data collected from monitoring wells during the June/July 2013 sampling event, from the open boreholes in October 2013 and March 2014, and the December 2013 groundwater sampling event. These data are then compared to the groundwater data presented in the AOC Investigation Report. Sulfolane data for surface water and sediment in the Effluent Channel includes a presentation of the data collected during the June/July 2013 sampling event and the December 2013 sampling event. In addition, sediment data collected from 10 locations CPCPRC elected to sample voluntarily in November 2013 are included in the Effluent Channel sediment discussion. These data also comprise the dataset used in the HHRA in Section 5 of this report.

The analytical data are discussed in the sections below and are provided in Appendix B on compact disk (CD).

3.1.1 Data Evaluation and Screening

In the nature and extent evaluation below, the analytical data are presented relative to the most conservative sulfolane RBSL. The RBSLs were calculated based on the CSM of potential exposure for the four plausible receptor groups (resident, industrial worker, construction worker, and trespasser). The media (surface soil, subsurface soil, groundwater, surface water, and sediment) and pathways (ingestion, inhalation, and dermal contact) were included in the calculations. In addition, the protection of groundwater from leaching of sulfolane through the soil was considered. The lowest RBSL that would be protective of any receptor for each media was used for the data screening. The RBSL calculation methods are the same as those used in quantitative risk calculations and result in a conservative screening of the chemical data.

The calculated RBSLs for the plausible exposure pathways are 16 µg/L for residential groundwater, 615,600 µg/Kg for industrial worker soil, 346,000 µg/L and 237,400 µg/Kg for construction worker groundwater and soil, respectively, 1,825,000 µg/Kg for trespasser sediment, and 3.2 µg/L for the protection of groundwater. The detailed RBSL calculations for receptor group by media are provided in Appendix B on CD.

3.2 Surface and Subsurface Soil Results

3.2.1 SRFI Soil Results

The following subsections present and discuss the analytical results for the surface soil and subsurface soil samples collected during the SRFI investigation. The results are presented individually for each of the 15 AOIs. Tables 3-1 through 3-15 present the analytical results for soils at the 15 AOIs. These tables also present the groundwater results for completeness. The groundwater data are discussed later in this section. Figures 3-1 through 3-12 present the boring locations for each AOI.

3.2.1.1 Tank 40

Tank 40 was an 80-ft diameter tank that was used to store sulfolane. The Tank 40 sampling design is displayed in Figure 3-1. The borings were equally spaced within the footprint of the tank. The borings for water samples were placed outside of the tank footprint at locations upgradient and downgradient of the tank. A total of 7 borings were drilled at Tank 40 including 5 for soil sampling and 2 for borings for groundwater sampling. As mentioned previously, groundwater was not present at the time of drilling.

The analytical results for the soil samples are presented in Table 3-1. As shown in Table 3-1, sulfolane was not detected in any of the five surface soil or subsurface soil samples.

3.2.1.2 Tank 50

Tank 50 was a 119-ft diameter tank that was used to store sulfolane. The Tank 50 sampling design is displayed in Figure 3-1. The borings were equally spaced within the footprint of the tank. The borings for water samples were placed outside of the tank footprint at locations upgradient and downgradient of the tank. A total of 7 borings were drilled at Tank 50 including 5 for soil sampling and 2 for borings for groundwater sampling. As mentioned previously, groundwater was not present at one of the borings at the time of drilling.

The analytical results for the collected samples are presented in Table 3-2. As shown in Table 3-2, sulfolane was detected once at a level of 490 micrograms per Kilogram (µg/Kg). This exceedance was from the sample in the middle of the former tank footprint. This detection exceeded the conservative RBSL for sulfolane in soil of 3.2 µg/Kg. Sulfolane was not detected in any of the 5 subsurface soil samples.

3.2.1.3 Tank 130

Tank 130 was a 150-ft diameter tank that was used to store sulfolane. The Tank 130 sampling design is displayed in Figure 3-2. The borings were equally spaced within the footprint of the tank. The borings for water samples were placed outside of the tank footprint at locations upgradient and downgradient of the tank. A total of 7 borings were drilled at Tank 130 including 5 for soil sampling and 2 for borings for groundwater sampling.

The analytical results for the collected samples are presented in Table 3-3. As shown in Table 3-3, sulfolane was not detected in any of the 5 surface soil or subsurface soil samples.

3.2.1.4 Tank 250

Tank 250 was a 36-ft diameter tank that was used to store sulfolane. The Tank 250 sampling design is displayed in Figure 3-3. The borings were equally spaced within the footprint of the tank. The borings for water samples were placed outside of the tank footprint at locations upgradient and downgradient of the tank. A total of 7 borings were drilled at Tank 250 including 5 for soil sampling and 2 for borings for groundwater sampling. As mentioned previously, groundwater was not present at the time of drilling.

The analytical results for the soil samples are presented in Table 3-4. As shown in Table 3-4, sulfolane was not detected in any of the five surface soil samples. In subsurface soil samples, sulfolane was detected once at a level of 60 µg/Kg, above its conservative RBSL of 3.2 µg/Kg. This detection was at sample location 0250-04 in the southwest portion of the sampling grid.

3.2.1.5 Tank 270

Tank 270 was a 67-ft diameter tank that was used to store sulfolane. The Tank 270 sampling design is displayed in Figure 3-4. The borings were equally spaced within the footprint of the tank. The borings for water samples were placed outside of the tank footprint at locations upgradient and downgradient of the tank. A total of 7 borings were drilled at Tank 270 including 5 for soil sampling and 2 for borings for groundwater sampling.

The analytical results for the collected samples are presented in Table 3-5. As shown in Table 3-5, sulfolane was not detected in any of the 5 surface soil or subsurface soil samples.

3.2.1.6 Tank 320

Tank 320 was a 25-ft diameter tank that was used to store sulfolane. The Tank 320 sampling design is displayed in Figure 3-5. The borings were equally spaced within the footprint of the tank. The borings for water samples were placed outside of the tank footprint at locations upgradient and downgradient of the tank. A total of 5 borings were drilled at Tank 320 including 3 for soil sampling and 2 for borings for groundwater sampling.

The analytical results for the collected samples are presented in Table 3-6. As shown in Table 3-6, sulfolane was not detected in any of the three surface soil or subsurface soil samples.

3.2.1.7 Tank 400

Tank 400 was a 20-ft diameter tank that was used to store sulfolane. The Tank 400 sampling design is displayed in Figure 3-6. A total of three borings were drilled for soil sampling at Tank 400. The borings were approximately equally spaced within the footprint of the tank. Four borings were drilled for groundwater sampling to characterize groundwater around former Tanks, 400, 410, 420, 430, 440, and 520, as shown in Figure 3-6.

The analytical results for the soil samples are presented in Table 3-7. As shown in Table 3-7, sulfolane was not detected in any of the three surface soil or subsurface soil samples.

3.2.1.8 Tank 410

Tank 410 was a 20-ft diameter tank that was used to store sulfolane. The Tank 400 sampling design is displayed in Figure 3-6. A total of three borings were drilled for soil sampling at Tank 410. The borings were approximately equally spaced within the footprint of the tank. Four borings were drilled for groundwater sampling to characterize groundwater around former Tanks, 400, 410, 420, 430, 440, and 520 as shown in Figure 3-6.

The analytical results for the collected samples are presented in Table 3-8. As shown in Table 3-8, sulfolane was not detected in any of the five surface soil or subsurface soil samples.

3.2.1.9 Tank 420

Tank 420 was a 20-ft diameter tank that was used to store sulfolane. The Tank 400 sampling design is displayed in Figure 3-6. A total of three borings were drilled for soil sampling at Tank 420. The borings were approximately equally spaced within the footprint of the tank. Four borings were drilled for groundwater sampling to characterize groundwater around former Tanks, 400, 410, 420, 430, 440, and 520, as shown in Figure 3-6.

The analytical results for the soil samples are presented in Table 3-9. As shown in Table 3-9, sulfolane was not detected in any of the three surface soil or subsurface soil samples.

3.2.1.10 Tank 430

Tank 430 was a 20-ft diameter tank that was used to store sulfolane. The Tank 430 sampling design is displayed in Figure 3-7. A total of 5 borings were drilled for soil sampling at Tank 430. The borings were approximately equally spaced within the footprint of the tank. Four borings were drilled for groundwater sampling to characterize groundwater around former Tanks, 400, 410, 420, 430, 440, and 520, as shown in Figure 3-6.

The analytical results for the soil samples are presented in Table 3-10. As shown in Table 3-10, sulfolane was not detected in any of the five surface soil or subsurface soil samples.

3.2.1.11 Tank 440

Tank 440 was a 55-ft diameter tank that was used to store sulfolane. The Tank 440 sampling design is displayed in Figure 3-8. A total of 5 borings were drilled for soil sampling at Tank 440. The borings were approximately equally spaced within the footprint of the tank. Four borings were drilled for groundwater sampling to characterize groundwater around former Tanks 400, 410, 420, 430, 440, and 520 as shown in Figure 3-6.

The analytical results for the soil samples are presented in Table 3-11. As shown in Table 3-11, sulfolane was not detected in any of the 5 surface soil or subsurface soil samples.

3.2.1.12 Tank 520

Tank 520 was a 55-ft diameter tank that was used to store sulfolane. The Tank 520 sampling design is displayed in Figure 3-9. A total of five borings were drilled for soil sampling at Tank 520. The borings were approximately equally spaced within the footprint of the tank. Four borings were drilled for groundwater sampling to characterize groundwater around former Tanks 400, 410, 420, 430, 440, and 520 as shown in Figure 3-6.

The analytical results for the soil samples are presented in Table 3-12. As shown in Table 3-12, sulfolane was not detected in any of the 5 surface soil or subsurface soil samples.

3.2.1.13 Tank 540

Tank 540 was a 20-ft diameter tank that was used to store sulfolane. The Tank 540 sampling design is displayed in Figure 3-10. The sampling design for Tank was 540 was to step out 100 ft in all four directions from the center of the former tank footprint. A total of 4 borings were drilled at Tank 540 and these 4 were for soil sampling only. Groundwater in this area is well characterized through routine groundwater sampling. As previously noted, the boring locations identified in the approved Work Plan could not be drilled because of subsurface obstructions. The borings were relocated to the nearest possible point that could be successfully drilled and sampled. The actual boring locations are shown in Figure 3-10.

The analytical results for the soil samples are presented in Table 3-13. As shown in Table 3-13, sulfolane was detected in 3 of the 4 samples. The highest detection was in the boring to the south of Tank 540. All 3 detections were above the conservative sulfolane RBSL of 3.2 µg/Kg. Sulfolane was not detected in the sample to the north. In subsurface soil, sulfolane was detected in the same 3 borings where sulfolane was found in surface soil. Similar to surface soil, sulfolane was not found in subsurface soil to the north of Tank 540.

3.2.1.14 Western Boundary

Monitoring well MW-167 was installed along the western boundary of the site as shown in Figure 3-11. At MW-167, 1 surface soil sample and 1 subsurface soil sample were collected. Groundwater was collected from this well during the December 2103 sampling event and after the well had been properly developed. The soil boring log and monitoring well diagram for MW-167 are provided in Appendix A.

The analytical results for the collected samples are presented in Table 3-14. As shown in Table 3-14, sulfolane was not detected in either of the 2 samples.

3.2.1.15 PRASA Pipeline

Investigation along the PRASA pipeline included drilling borings along the pipeline at the 6 locations presented in Figure 3-12. During the March 2014 sampling work, one subsurface soil sample was collected at each of the six locations in accordance with the approved Work Plan. The surface soil was not sampled at these locations because the DQO for this sampling was to characterize the subsurface conditions immediately adjacent to the pipeline envelope. To address EPA comments on the Draft SRFI Report (Appendix D), surface soil samples were collected at the six locations in December 2014. One groundwater sample was collected from the open borehole at each location in March 2014.

The analytical results for the collected samples are presented in Table 3-15. As shown in Table 3-15, sulfolane was not detected in any of the six surface soil samples. Sulfolane was detected in one of the six subsurface soil samples. This detection was at location PRASA-04 at a level of 85 μg/Kg, above the conservative sulfolane RBSL of 3.2 μg/Kg.

3.2.2 Site-Wide Overview of Soil Results

Figure 3-13 presents the spatial distribution of soil samples collected during the SRFI. The sitewide overview of the surface soil and subsurface soil sampling for both the AOC and SRFI sampling events are depicted in Figures 3-14 and 3-15, respectively. The locations where sulfolane levels were above the conservative RBSL of 3.2 μg/Kg are shown with a red symbol. As shown in Figure 3-14 and Figure 3-15, at most sampling locations sulfolane levels were below the conservative RBSL. Where sulfolane did exceed the RBSL, the majority of those exceedances were at 4 AOCs; Tank 170, Tank 360, Tank 540, and Tank 700.

3.3 Groundwater Sampling Results

As previously discussed, groundwater samples were collected from site monitoring wells in June/July 2013, prior to the SRFI field investigation. This sampling event was a semi-annual sampling event expanded from the 54 wells that are routinely sampled to include 25 additional monitoring wells. In October 2013 and March 2014, the SRFI drilling work was performed and 17 grab samples were collected from open boreholes. In December 2013, as part of the AOI investigation, all 117 site monitoring wells were sampled in accordance with the approved Work Plan. The groundwater sample data is presented in Appendix B and is also presented graphically in Figures 3-17 through 3-19.

Figure 3-17 presents the sulfolane results from the December 2013 sampling of all site monitoring wells completed in the Upper Alluvial aquifer plus the groundwater grab samples collected from the open boreholes during SRFI drilling. As shown in Figure 3-17, red isoconcentration lines have been developed based on these data. For comparison, green isoconcentration lines have been included on Figure 3-17 to represent contours developed during the AOC investigation and previously presented in Figure 2-3 of this report.

Examination of the isoconcentration lines in Figure 3-17 shows that the extent of sulfolane determined from the June 2012 data and the extent determined from the December 2013 data are essentially the same. Both data sets indicate sulfolane is present beneath the Facility and extends offsite to the east, south, and west. Sulfolane was not found in groundwater north of the former Process Area.

Figure 3-18 presents the sulfolane results from the June/July 2013 expanded semi-annual monitoring event for the Lower Alluvial aquifer. As shown in Figure 3-18, sulfolane was detected at 20 locations ranging between 0.58 µg/L at MW-133D and 4,700 µg/L at MW-46D. Seventeen of the detections were above the sulfolane RBSL of 16 µg/L.

Figure 3-19 presents the sulfolane results from the December 2013 sampling of all site monitoring wells completed in the Lower Alluvial aquifer. As shown in Figure 3-19 sulfolane was detected at 16 locations ranging between 9 µg/L at MW-136D and 3,500 µg/L at MW-46D. Twelve of the detections were above the sulfolane RBSL of 16 µg/L.

3.4 Effluent Channel Surface Water Results

The Effluent Channel surface water was sampled in June/July 2013 and again in December 2013. Three surface water samples were collected each time. The locations of the Effluent Channel surface water sample locations (Ditch-1 through Ditch-3) are presented in Figure 3-15 and Figure 3-17.

As shown on Figure 3-16, sulfolane was detected at all three locations in June/July 2013. Sulfolane ranged between 0.9 µg/L at Ditch-3 and 19 µg/L at Ditch-2. The detection at Ditch-2 was above the sulfolane RBSL of 16 µg/L.

As shown on Figure 3-17, sulfolane was detected at two locations in December 2013. Sulfolane ranged was detected at a level of 240 µg/L at Ditch-2 and at a level of 2.9 µg/L. The detection at Ditch-2 was above the sulfolane drinking water RBSL of 16 µg/L. Sulfolane was not detected at location Ditch-1.

3.5 Effluent Channel Sediment Results

The Effluent Channel sediment was sampled July 2013, November 2013, and December 2013. The Effluent Channel sediment sample locations are presented in Figure 3-20. The results of the sediment sampling are presented in Table 3-16.

As shown in Table 3-16, sulfolane was not detected in the July 2013 sediment samples. Sulfolane was detected at one location in the December 2013 sampling event. In December 2013, sulfolane was detected at one location, Channel-2, at a level of 190 µg/Kg above the conservative sulfolane RBSL for soil of 3.2 µg/Kg.

At the 10 locations sampled on a voluntary basis in November 2013, sulfolane was detected at three locations. Sulfolane was detected at Channel-11 at a level of 68 µg/Kg, at Channel-15 at a level of 49 µg/Kg, and at Channel-17 at a level of 150 µg/Kg. These three detections are above the conservative sulfolane RBSL for soil of 3.2 µg/Kg.

4. FATE AND TRANSPORT

The following section presents an analysis of the fate and transport of sulfolane in soil and groundwater. The physical properties of sulfolane are discussed followed by an analysis of its expected fate and transport in the natural environment.

4.1 Sulfolane Chemical Properties

Sulfolane in pure form is a clear, colorless liquid, but in industry it often takes on a light yellow color due to interaction with air. The physical and chemical properties of sulfolane are summarized below.

Chemical formula – $C^4H^8O^2S$
Molecular weight – 120.17 g/mol
Color – Clear, colorless liquid; light yellow
Boiling point – 285 °C
Density at 15 °C, g/cm^3 – 1.276
Log K_{OW} – - 0.77
Log K_{OC} – 0.07
Vapor pressure at 20 °C – 0.00409 mm Hg
Henry's law constant at 25 °C – 4.83×10^{-6} atm-m^3 /mol

Sulfolane is soluble in water due to the highly polar sulfur–oxygen double bonds. Sulfolane does not volatilize from water or soil as evidenced by its low vapor pressure and Henry's Law Constant.

In soil, sulfolane does not adsorb, as shown by the log octanol/water partition coefficient (log Kow). The organic carbon partition coefficient (Koc), estimated at 0.07, shows that the compound is mobile in soil.

In water, the primary attenuation mechanism appears to be biodegradation in an aerobic environment. However, some evidence of biodegradation under specific anoxic conditions has been documented.

4.2 Lithology and Other Physical Considerations

CPCPRC has expended significant effort to understand the subsurface conditions at the Facility. These efforts have included the initial RFI work, voluntary installation of 431 Geoprobe™ borings, installation and sampling of 92 Upper Alluvial monitoring wells and 25 Lower Alluvial monitoring wells, AOC investigation, and this SRFI work. This section brings together the relevant information and findings developed from these extensive efforts.

4.2.1 Hydrogeology

The site conceptual model of hydrogeology is summarized below. More detailed information on site geology and hydrogeology is presented in the RFI Report (Phillips, 1999).

At the base of the system, andesite bedrock is found. The bedrock is typically found at about 80 ft bgs. The andesite bedrock is not considered to act as an aquifer in the vicinity of the site. Above the bedrock is the Lower Alluvial aquifer. The Lower Alluvial aquifer is present beneath the entire Facility and the top of the unit is typically observed at about 25 ft bgs. The aquifer materials consist primarily of fine to medium sand with some gravel. Groundwater flow in this aquifer is generally to the south. Ultimately, groundwater in this aquifer discharges to the Caribbean Sea.

Above the lower Alluvial Aquifer, a clay layer is typically found. This clay layer forms a discontinuous aquitard between the Lower and Upper Alluvial aquifers. The Upper Alluvial aquifer was deposited in an alluvial fan/transitional marine environment. The aquifer materials consist of varying combinations of silt, sand, and gravel. The extent of sulfolane contamination in the Upper Alluvial aquifer (Figure 2-3 and Figure 3-17) generally coincides with the presence of the more permeable sand and gravel materials deposited in paleo-stream channels. Groundwater flow directions in this aquifer are to the southeast, south, and southwest also coincident with the orientation of the sand deposits. These paleo-channel deposits exert the primary control on groundwater flow in this aquifer. Ultimately, groundwater in this aquifer discharges to the Caribbean Sea.

4.2.2 Surficial Deposits

As mentioned previously, it was observed that the former ASTs were constructed on elevated soil platforms some as high as approximately 8 ft. The composition of the soil platforms was observed to be primarily silts and clays with minor sand content.

Below the natural grade of the site, the soil profile of the vadose zone (the unsaturated zone above the water table) was observed to be relatively thin with depth to water ranging from approximately 2.5 to 18 ft bgs. The lithology of the vadose zone soils is observed to be primarily fine grained silts and clays with some sands.

Based on the lithology and seasonal observation of water level variations, most water during light rainfall events either evaporates or is surface runoff. During the rainy season, heavier rainfall events result in infiltration into the vadose zone. When in contact with contaminants present in the soil, this water can mobilize contaminants through the soil profile to the underlying groundwater.

4.3 Natural Attenuation

Natural attenuation is the processes by which contaminants in soil and groundwater are decreased or degraded through natural processes. The processes involved in natural attenuation include: adsorption, biodegradation, volatilization, dispersion and diffusion. The following subsections provide a brief summary of the processes as they relate to benzene and sulfolane.

If discharged to the environment, sulfolane's fate and transport characteristics are governed according to its chemical-specific properties including:

- Water solubility,
- Organic carbon partition coefficient (Koc),
- Octanol-water partition coefficient (Kow),
- Vapor pressure,
- Henry's Law constant, and
- Biodegradation rate.

The water solubility of a chemical partly determines the extent to which a substance can partition between soil and groundwater. Both K_{oc} and K_{ow} are be used to predict the degree of chemical sorption to organics in soil. The higher the K_{ow}, the greater the affinity for partitioning to organic carbon in the soil and aquifer. Vapor pressure and the Henry's Law constant indicate how readily a compound will volatilize from water into the atmosphere. The properties of sulfolane are presented and discussed in the following sections.

4.3.1 Adsorption

Unlike a water particle or conservative solute, an organic solute particle may partition (or adsorb) from the groundwater to the aquifer matrix. As a result of this adsorption process, the movement of the solute particle is slowed down (retarded) relative to the movement of groundwater. The degree to which contaminants are adsorbed on soils is dependent on the fraction of organic carbon (f_{oc}) and the chemical-specific water/carbon-partitioning coefficient (K_{oc}). Adsorption of sulfolane is examined below.

To estimate the amount of soil partitioning, and hence retardation, the ratio of hydrocarbons in the soil and water phase (the soil-water distribution coefficient - K_d) are calculated using the following equation:

$$K_d = f_{oc} K_{oc}$$

From information provided in the literature (Wiedemeier et. al, 1998) values for these parameters are:

f_{oc} of 0.1% (f_{oc} = 0.001 for a medium fluvial/deltaic sand).

K_{oc} = 83 Liters/kilogram (benzene)

K_{oc} = 1.17 Liters/kilogram (sulfolane).

The value for f_{oc} of 0.1% is equivalent to 1 gram of organic carbon per 1,000 grams of sample, or 1,000 mg/Kg.

As a result of adsorption, contaminant transport velocity in the aquifer would be less than the seepage velocity of the groundwater. The ratio of the velocities is expressed as:

$$V_s/V_c = R$$

Where:

V_s = average groundwater seepage velocity
V_c = average velocity of contaminants
R = coefficient of retardation.

The coefficient of retardation can be defined by the following linear relationship:

$$R = 1 + (K_d \theta_b / n)$$

Where:

R= coefficient of retardation
K_d = distribution coefficient for sulfolane (0.00117 Liters/kilogram)
n = effective porosity (20% Upper Alluvial and 30% Lower Alluvial)
θ_b = soil bulk density (value of 1.7 Kg/L from Wiedemeier et. al, September 1998).

Using these values, the following coefficients of retardation for sulfolane were calculated:

Sulfolane Upper Alluvial aquifer – 1.0

Sulfolane Lower Alluvial aquifer – 1.0.

Based on the calculations above, sulfolane is expected to travel at the same rate as a water particle and would not be expected to adsorb onto the aquifer matrix.

4.3.2 Biodegradation

As mentioned previously, sulfolane is a non-target list compound and only recently has been considered in the analysis of groundwater quality impacts. As such, research on sulfolane biodegradation is advancing and the processes for degradation are not yet well understood. The majority of the published information regarding the environmental fate of sulfolane suggests that oxidation by aerobic microorganisms is the primary degradation pathway for sulfolane. This view appears to be related to the fact that aerobic sulfolane degradation has been observed by all researchers who studied it, while anaerobic sulfolane degradation has been sporadically observed.

Biodegradation of sulfolane Saint-Fort (2006) observed aerobic sulfolane degradation in aquifer microcosms, but no anaerobic degradation.

Kim et al. (1999) observed anaerobic sulfolane degradation in aquifer microcosms, but did not speculate regarding the mechanism.

Greene et al. (1998) observed anaerobic sulfolane degradation associated with nitrate reduction and manganese reduction in some of their replicates. Notably, manganese oxide was added to some of these replicates to stimulate manganese reduction. Additionally, anaerobic sulfolane degradation was observed in the replicates incubated at 8 degrees C, but not in replicates incubated at 28 degrees C. A significant lag period was observed prior to the onset of manganese reduction and sulfolane degradation. Finally, Greene et al. noted that the amount of reduced manganese observed in the microcosms was insufficient to account for complete mineralization of the sulfolane that disappeared from the microcosms.

The rate of observed sulfolane degradation was reported to have zero-order kinetics in both aerobic and anaerobic sediment microcosms (Greene et al., 1998; Greene and Fedorak, 2001, Saint-Fort, 2006). Additionally, amendment of sediment microcosms with phosphorus, while stimulating the growth of purported sulfolane-degrading organisms, was actually associated with longer lag times and, ultimately, slower sulfolane degradation rates relative to the unamended control (Greene and Fedorak, 2001).

Anaerobic sulfolane degradation resulting in the production of thiolane has been described by some researchers (Kim, 1999), but the general consensus of the literature is that the rates of anaerobic biodegradation of sulfolane are negligible compared to aerobic processes.

Finally, while much of the existing literature regarding environmental fate of sulfolane documents the lack of appearance of stoichiometric amounts of the hypothesized aerobic daughter products (carbon dioxide, sulfuric acid, hydroxybutene sulfonic acid), no other sulfolane degradation metabolites have been documented either.

4.3.3 Volatilization to the Atmosphere

Migration of volatile constituents is dependent on the depth of the contamination and the characteristics of the specific chemical. The partitioning of a compound between the water and air matrices depends on the vapor pressure and the water solubility of that compound. Compounds, which have a high vapor pressure and a low water solubility, readily evaporate from the liquid phase and enter the atmosphere or soil vapor. Henry's Law constant is the ratio of vapor pressure to water solubility and describes the volatilization of dissolved organic solutes from water.

In the subsurface, transport of volatile organics in the gas phase occurs when the chemical partitions from the liquid phase to the gas phase. The primary mechanism affecting gas-phase transport is diffusion. The transport of chemicals through the soil-gas phase also will be affected by adsorption to soil, dissolution into water and biodegradation. Based on the Henry's Law constant for sulfolane of $4.83x10^{-6}$ $atm\text{-}m^3$ /mol, volatilization from groundwater is not expected to occur.

4.3.4 Dispersion and Diffusion

Dispersion is present as either hydrodynamic or mechanical. Hydrodynamic dispersion is the process whereby a contaminant plume spreads out in directions that are longitudinal and transverse to the direction of plume migration. Mechanical dispersion is the mixing that occurs as a result of local variations in velocity around some mean velocity of flow. With time, a given volume of solute will gradually become more dispersed as different portions of the mass are transported at differing velocities. Molecular diffusion occurs when concentration gradients cause solutes to migrate from zones of higher concentration to ones of lower concentrations, even in the absence of groundwater flow. Molecular diffusion only plays a role at low groundwater velocities.

Hydraulic conductivity values are relatively high and the orientation of sand deposits in the Upper Alluvial aquifer play the dominant role in governing the migration of contaminants. Therefore, diffusion and dispersion likely exert only minor effects on contaminant migration.

4.4 Summary of Analysis

The following observations are made regarding contaminant fate and transport at the Facility:

- Sulfolane released to soil through inadvertent leaks and spills can be mobilized to underlying groundwater when precipitation events large enough to result in infiltration occur and that infiltrating water comes in contact with sulfolane present in the soil.

- In the upper alluvial aquifer, the presence and orientation of more permeable materials present in paleo-stream channels exert the primary control on groundwater flow and contaminant transport. Lithologic information indicates these paleo-channels are discontinuous and typically terminate in fine-grained deposits of silt and clay.

- In the lower alluvial aquifer, groundwater flow and contaminant transport is generally to the south in the direction of regional flow and groundwater in this aquifer ultimately discharges to the Caribbean Sea.

- Sulfolane is not expected to be adsorbed to the aquifer matrix. Although sulfolane's biodegradation behavior in the natural environment is not completely understood, it is unlikely sulfolane would actively degrade through biological processes.

It should be noted that migration and fate of sulfolane, as well as other contaminants in groundwater, are influenced by the active application of interim measures. As mentioned previously, CPCPRC has been implementing EFR and VISM since 1996. Through extraction and treatment, these measures work to reduce contaminant mass and influence contaminant extent, fate, and transport.

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5. BASELINE RISK ASSESSMENT

As mentioned previously, CPCPRC performed extensive risk assessment as part of the AOC investigation activities and this HHRA represents an update of potential risk posed by sulfolane contamination. In accordance with risk assessment guidelines, this HHRA considers conservative but reasonable exposure scenarios. The receptor groups evaluated are based on current and potential future site-specific uses. The HHRA focuses on the 15 AOIs and 19 AOCs as potential contaminant sources and the potential receptors that are likely to be exposed to any of the AOIs and AOCs. The sulfolane data from the SRFI and AOC investigation were considered collectively to formulate a site-wide, comprehensive assessment of potential risk.

In accordance with the approved Work Plan, evaluation of the sulfolane data relative to potential ecological impacts is limited to a brief synopsis of the state of the practice.

5.1 Human Health Risk Assessment

The objective of a baseline HHRA is to analyze the potential “baseline risk” (i.e., the risk that could occur if no action were taken to remediate sulfolane at the site) under current and potential future land use conditions. The methodology and technical approach for performing the HHRA was based on applicable EPA guidance documents (EPA, 1989, 1991, 1992, 2001 and b, 2002, and 2004).

5.1.1 Data Quality

The analytical data were validated by a Puerto Rico certified chemist, using the EPA Region 2 data validation guidelines. The data validation reports are presented in Appendix C (included on CD). No sulfolane data were rejected during data validation.

The analyses were performed using the analytical method developed for sulfolane. The field duplicate and blank data indicated that the sampling and laboratory cleaning procedures were implemented consistently and properly.

5.1.2 Exposure Assessment and Site-Specific Exposure Model

The conceptual exposure model for the site describes the potential sources of sulfolane contamination, potential receptor populations, and exposure pathways for the current and potential future receptors. The components of the conceptual exposure model are discussed below and presented graphically in Figure 5-1.

5.1.2.1 Contaminant Sources

During the period that the Facility was active, CPCPRC processed naphtha into light hydrocarbon products, including BTEX. The feedstocks, intermediates, process chemicals such as sulfolane, and end-products were stored in ASTs. Inadvertent releases of sulfolane into the surrounding soil occurred intermittently during the operational period of the Facility.

5.1.2.2 Contaminant Types

The focus of this SRFI report is sulfolane and the potential risk posed by this chemical is evaluated in this HHRA.

5.1.2.3 Potential Receptors and Exposure Pathways

The CSM of receptors and exposure pathways are presented graphically in Figure 5-1, and summarized in the following subsections. It is noted that the CSM shows that exposure to contaminants in groundwater via inhalation is complete. This is true for VOCs and mercury; however, because sulfolane is an SVOC, this pathway is incomplete for this specific chemical.

Resident

Currently, there are residents south of the Facility in the community of Las Mareas and north of the Facility in the community of Reunion Ward. This condition is expected to remain in the future. There are currently no residents on the site and no residents are expected to live on site in the future.

The offsite resident is assumed to be exposed to groundwater via a drinking water well. It is likely for a hypothetical drinking water well to intercept both the Upper and Lower Alluvial aquifers; therefore, the data for the two aquifers were combined for risk assessment. No dilution or attenuation of the sulfolane concentrations was assumed for offsite migration of groundwater.

The groundwater contact would include direct ingestion and dermal contact during household usage of the groundwater. These exposure routes were quantitatively evaluated for assessing the potential risk to the resident.

Sulfolane is a noncarcinogenic compound and the noncarcinogenic risks were conservatively evaluated for a resident child. The resident child was used because based on the intake, body weight, and exposure duration factors the child is more susceptible to the noncarcinogenic risks than an adult resident.

Industrial Workers

Currently, a small number of workers remain on the site and future industrial work activity at the site is plausible. Therefore, an industrial worker was evaluated in the risk assessment.

The industrial worker does not typically perform intrusive work; therefore, the exposure was limited to surface soil. Exposure to subsurface soil, groundwater, surface water, and sediment were considered to be incomplete exposure pathways.

The incidental ingestion of soil, dermal contact with soil, and inhalation of particles were evaluated as the exposure routes.

Construction Workers

Construction is plausible and during the course of construction activities, the construction worker would be potentially exposed to both surface and subsurface soil. Additionally, the construction worker could be exposed to groundwater if groundwater were encountered within the excavation depths.

Exposure to surface soil as well as the subsurface soil is considered and the data for these media were combined. The groundwater exposure is only plausible for the Upper Alluvial aquifer groundwater. This is because the Lower Alluvial aquifer is at a depth of 25 ft or more bgs and excavation to these depths is not likely.

Incidental ingestion of and dermal contact with soil, and inhalation of particulates pathways were evaluated for exposure to soil. The dermal contact pathway was evaluated for exposure to groundwater.

Trespassers

The Facility is gated and guarded 24/7 and will remain so in the future. However, current and future trespassing on the site was conservatively considered plausible. As a conservative measure, a child age 6 to 18 years was assumed to trespass the site for recreational purposes. Exposure to surface soil, surface water, and sediment were considered plausible. Ingestion, dermal contact, and inhalation of particulates pathways were evaluated quantitatively.

5.1.3 Calculation of Exposure Point Concentrations

In accordance with risk assessment guidance, the exposure point concentration (EPC) represents the concentration of a chemical in the exposure media. The representative concentration is statistically calculated from the data points, based on the range of values, variability, distribution pattern, etc.

There are two types of exposure estimates currently identified for use in risk assessments: a reasonable maximum exposure (RME) and a central tendency exposure (CTE). The RME is the maximum exposure that is reasonably expected to occur for a given exposure pathway at a site, and is intended to account for both uncertainty in the contaminant concentration and variability in the exposure parameters. As a conservative measure, the RME scenario was evaluated in this HHRA. This approach is conservative because the RME is based on the upper bound estimates of the input parameters.

Because of variations in the concentrations from location to location, the upper confidence limit (UCL) on the arithmetic mean chemical concentration is usually determined for each chemical of potential concern (COPC) and each medium. This is defined as the 95% UCL or 95UCL.

The EPA ProUCL version 5.0 statistical software was used to determine the 95UCLs for sulfolane. The software performs several statistical tests on data and calculates one or more 95UCLs. The software takes into account all detected and non-detected values in the 95UCL calculations. Unlike the previous versions of ProUCL in which the non-detected values were considered detected at one-half the reported result, in ProUCL version 5.0 the detects and non-detects are assigned "1" and "0" flags without changing the reported values.

The 95UCLs for sulfolane were calculated for the individual and combined media, as appropriate for the specific receptors. The EPCs and basis for EPC are presented in Table 5-1. The detailed outputs from the ProUCL software are presented in Appendix C.

5.1.4 Toxicity Assessment

Sulfolane is classified as a noncarcinogen and potential health risks are calculated noncarcinogenic effects. Data from toxicity studies with laboratory animals or from epidemiological studies of human populations were used to develop the toxicity values. In the risk characterization step, toxicity values are combined with exposure intakes to develop numerical estimates of hazard indices (HIs) for noncarcinogenic chemicals.

Estimates of noncarcinogenic effects are evaluated using RfDs (oral and dermal exposures) and RfCs (inhalation exposures). The RfD and RfC are threshold values based on specific toxic effects. In general, the RfD or RfC is an estimate (with uncertainty of an order of magnitude or more) of a daily exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime of exposure.

The oral toxicity values (reference dose [RfD]) and reference concentration (RfC) used in the risk assessment were obtained from the *Provisional Peer-reviewed Toxicity Values (PPRTV) for Sulfolane,* dated, January 30, 2012.

The dermal toxicity values were calculated using EPA's Final Risk Assessment Guidance for Superfund, Volume I – Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment (EPA, 2004).

5.1.5 Quantifying Chemical Intake

The chemical intake considers the specific receptors, exposure route and the EPC to derive the dosage term of chemical daily intake (CDI). The CDI is expressed as the daily intake per unit of body weight. The most common unit for CDI is mg/Kg-day; i.e., milligrams per day per Kilogram of body weight.

The CDI equations take the following general form. There may be nuances to the equations depending on the scenario; the specific equations are shown on the detailed pathway risk calculations presented on the quantitative risk calculation tables.

Ingestion CDI = EPC*IR*EF*ED*0.000001/BW/AT/365

Dermal CDI = EPC*SA*AF*ABS*EF*ED*0.000001/BW/AT/365/GI Factor

Inhalation IC = EPC*(1/PEF+1/VF)

Inhalation CDI = IC*IR*ET*EF*ED/AT/365

Where:

CDI = chronic daily intake (mg/Kg-day)
EPC = exposure point concentrations (mg/Kg or mg/L)
IR = Intake rate (mg/day or L/day or M^3/day)
EF = exposure frequency (days/year)
ED = exposure duration (years)
ET = exposure time (hrs/24 hours)
BW = body weight (Kg)
AT = attenuation time (years)
SA = skin area (cm^2)
AF = skin adherence factor (mg/cm^2)
ABS = absorption factor (unitless)
GI_Factor = gastro-intestinal absorption factor (unitless)
IC = inhaled concentration (mg/M^3)
PEF = particulate emission factor (mg/M^3)
VF = volatilization factor (mg/M^3)

The risks are then quantified using the following equations:

HI = CDI/RfD

Where:

HI = hazard index

CDI = chronic daily intake (mg/Kg-day)

RfD = noncarcinogenic reference dose (mg/Kg-day).

5.1.6 Risk Characterization

Risk characterization involved estimating the magnitude of potential adverse health effects from exposure to sulfolane. This estimation is accomplished by combining the estimated intakes (exposure levels) and toxicity factors to provide numerical estimates of HIs for the noncarcinogenic health risks. Risk characterization also considers the nature and weight of evidence supporting these estimates, as well as the magnitude of uncertainty surrounding the estimates.

For this HHRA, risks from sulfolane were calculated for each receptor and for each applicable media exposure. The risks for these scenarios are summarized below. The risk quantification included calculating the noncarcinogenic risks for each exposure route applicable to an exposure media and then adding the risks from all exposure media applicable to a receptor. As a result, cumulative risks for a receptor exposed to the plausible exposure media and pathways were calculated.

The discussion below is organized by the receptor type and for each receptor the cumulative risks are presented and discussed followed by pathway media-specific potential risks. The common EPA National Contingency Plan (NCP) barometer of noncarcinogenic risk, HI, not exceeding 1 is used to describe potential excess risk (if any).

5.1.6.1 Resident

As discussed earlier, the resident was assumed to be exposed to the combined Upper Alluvial and Lower Alluvial aquifer groundwater.

The cumulative risk summary for the resident is provided in Table 5-2. The detailed pathway risk calculations are presented in Table 5-3.

Cumulative Risk. The cumulative risks for the resident are presented in Table 5-2. Note that it is customary to present the potential risk with zero decimals. The % contributions as shown are actual percentages; they may not be exactly calculable using the truncated risk numbers on the table.

The total noncarcinogenic HI is 40, which is significantly above the acceptable NCP departure point of HI =1. Ingestion of groundwater accounts for the excess noncarcinogenic risk.

The groundwater noncarcinogenic risks calculations by pathway are presented in Table 5-3.

Risk Summary for Resident. In summary, for the residential scenario, sulfolane levels in the combined groundwater poses a potential noncarcinogenic risk.

5.1.6.2 Industrial Worker

As discussed earlier the industrial worker was assumed to be exposed to the surface soil. The worker is not exposed to subsurface media such as the soil and groundwater below a 2 ft depth.

The cumulative risk summary for the industrial worker is provided in Table 5-4. The detailed pathway risk calculations are presented in Table 5-5.

Cumulative Risk. The cumulative risks for the industrial worker are presented in Table 5-4. The total noncarcinogenic HI is 0.9, which is within the NCP departure point of HI =1.

The soil noncarcinogenic risks calculations by pathway are presented in Table 5-5.

Risk Summary for Industrial Worker. In summary, for the industrial worker scenario, there are no unacceptable risks from sulfolane in the surface soil.

5.1.6.3 Construction Worker

As discussed earlier the construction worker was assumed to be exposed to the combined surface soil and subsurface soil and to Upper Alluvial aquifer groundwater.

The cumulative risk summary for the construction worker is provided in Table 5-6. The detailed pathway risk calculations for combined soil are presented in Table 5-7. The detailed pathway risk calculations for Upper Alluvial groundwater are presented in Table 5-8.

Cumulative Risk. The cumulative risks for the construction worker are presented in Table 5-6. The total noncarcinogenic HI is 1, which is equal to the acceptable NCP departure point of HI =1. The table shows that the HI is driven by the combined soil; however, the cumulative HI is within NCP acceptance.

The soil noncarcinogenic risks calculations by pathway are presented in Table 5-7 and the noncarcinogenic risks calculations by pathway for groundwater are presented in Table 5-8.

Risk Summary for Construction Worker. In summary, for the construction worker scenario, there are no unacceptable risks from sulfolane in combined soil or Upper Alluvial groundwater.

5.1.6.4 Trespasser

As discussed earlier the trespasser was assumed to be exposed to the surface soil, and surface water and sediment in the Effluent Channel.

The cumulative risk summary for the trespasser is provided in Table 5-9. The detailed pathway risk calculations are presented in Table 5-10 (surface soil), Table 5-11 (Effluent Channel sediment), and Table 5-12 (Effluent Channel surface water).

Cumulative Risk. The cumulative risks for the trespasser are presented in Table 5-9. The total noncarcinogenic HI is 1, which is equal to the acceptable NCP departure point of HI =1. The table shows that the HI is driven by the surface soil; however, the cumulative HI is within NCP acceptance.

Risk Summary for Trespasser. In summary, for the trespasser scenario, there are no unacceptable risks from sulfolane in surface soil, sediment, or surface water.

5.2 Sulfolane Ecological Risk Assessment

The following discussion regarding the state of the practice for evaluating the potential ecological risks posed by sulfolane draws primarily from the British Columbia Ministry of the Environment (hereafter referred to as the BCME). In 2001, the BCME provided an update to Principles for Preparing Water Quality Objectives in British Columbia (updated August 7, 2001), which outlines the role of water quality criteria in risk management decisions and discusses factors to be considered when developing those criteria. In summary, the BCME recognized that to reliably understand the impacts of a chemical on aquatic biota, water quality criteria should be derived from long-term tests on many sensitive species. In the current state of practice, the data are only for short-term tests for a few species.

In 2003, the Canadian Association of Petroleum Producers commissioned work to apply the principles outlined in 2001 to an examination of the toxicolological effects of sulfolane on four plant species, one cold water fish species, and one fresh water invertebrate. In addition, the study reviewed mammalian toxicology studies for sulfolane and reviewed a subchronic study of the oral toxicity of sulfolane on rats (*Water Quality Guidelines for Sulfolane; Komex International Ltd, August 6, 2003*).

The results of work were used by the BCME to establish ambient water quality guidelines for British Columbia. The guidelines are considered safe levels for the protection of freshwater aquatic life and agricultural water uses such as irrigation water and livestock watering (*Ambient Water Quality Guidelines for Sulfolane, September 13, 2003*). The BCME's established guidelines for sulfolane for the protection of freshwater aquatic life is 50,000 µg/L. The maximum detection of sulfolane in the Effluent Channel surface water was 240 µg/L, well below the BCME's water quality guideline. Although surface water in the Effluent Channel is not currently used for irrigation or stock water, and is not expected to be in the future, it is noted that the maximum detection is also well below those protection levels (8,400 µg/L for irrigation and 14,000 µg/L for livestock).

It is noted that the 2003 study did not examine the potential effects of sulfolane in sediments on aquatic life and no studies regarding sediment criteria could be found in the literature. As a result, no sediment quality criteria for sulfolane are presented herein.

5.3 Uncertainty Analysis

This section presents a discussion of the uncertainties associated with the estimates of potential health risk provided in this baseline HHRA. The following subsections discuss uncertainty with respect to the four steps of the HHRA process.

5.3.1 Uncertainties Related to Hazard Identification

The purpose of data evaluation is to determine which chemicals, if any, are present at the site at concentrations warranting quantification of risk. Uncertainty with respect to data evaluation is associated with many sources, such as the quality of data used to characterize the site and the process to select the data for evaluation in the HHRA.

The screening process used to select COCs for evaluation in the HHRA was intended to include all chemicals with concentrations high enough to be of concern for the protection of public health. Because the COC screening procedure used the lowest of scenario-specific RBSLs to compare even a single detection out of hundreds of samples, the COC selection process was conservative so that potential sources of public health threats were not overlooked.

The COC selection process also includes an evaluation of analytical detection limits (DLs) to ensure that chemicals could be detected at concentrations of concern. With respect to sulfolane, the laboratory detection limits were low enough to satisfy the RBSLs for the considered media and receptors.

5.3.2 Uncertainties Related to Exposure Assessment

In identifying potentially complete exposure pathways for the HHRA, assumptions were made about current and future activities that occur in on site. These assumptions may result in an over- or under-estimation of risk depending on what actual activities occur in this area.

The quantification of exposure consists of two basic steps: estimation of potential EPCs and estimation of potential human intake. Potential sources of uncertainty associated with these two steps are discussed below.

5.3.3 Estimation of Exposure Point Concentrations

The objective of a risk assessment is to estimate risks associated with average exposure over an area that is contacted on a daily basis (i.e., exposure area). The EPC is used to represent the average concentration for sulfolane in an exposure area. Uncertainties associated with these EPCs may be due to uncertainties in the data set or the statistical protocols followed to calculate the EPCs.

The EPA's ProUCL software was used to calculate the EPCs. The ProUCL software considers the range and distribution of non-detected data (i.e., the detection limits) in the calculation of the 95UCL. Generally higher detection limits would tend to yield higher estimates of the 95UCL and higher risks. The ProUCL software accounts for both detects and non-detects resulting in representative EPCs. However, if the majority of the data are based on higher non-detects, the EPCs may biased higher than actual field conditions.

Also a simplifying assumption was made that EPCs remain constant for the duration of exposure. Physical, chemical, or biological processes that could reduce chemical concentrations over time were not factored into the estimates of the EPCs. Use of this conservative assumption likely contributes to an overestimation of exposure.

5.3.4 Estimation of Potential Intake

When estimating potential human intakes (i.e., doses) from theoretical exposures through various pathways, several assumptions are made. Uncertainty is associated with assumptions concerning rates of ingestion, frequency and duration of exposure, and bioavailability of the chemicals in the medium. Whenever possible, site-specific information was used in the HHRA to establish the exposure assumptions used in the risk calculations.

However, for some scenarios, site-specific information is not considered and standard default assumptions of intake are used. Typically, when site-specific information is not available to establish these assumptions, conservative (i.e., health protective) estimates of potential exposure are used (e.g., EPA default values) that may result in overestimates of risk.

For the exposure pathway involving potential exposure of construction workers to groundwater through the dermal contact route, the current EPA methodology (EPA, 2004) was used to calculate a dermal absorbed dose per exposure event (DA_{event}). This value is estimated to be the total dose dissolved in the skin at the end of the exposure time. For highly lipophilic compounds or for chemicals that exhibit a long lag time, some of the chemical dissolved in the skin may be lost due to desquamation of skin cells during that absorption period and consequently, the calculated DA_{event} value may overestimate the amount of chemical actually absorbed. A fraction absorbed term (FA) was included in the calculation of the permeability constant (PC) and DA_{event} to account for this loss of chemical through desquamation.

5.3.5 Uncertainties Related to Toxicity Information

The concentration of COCs to which people are potentially exposed in an environmental setting is usually much less than the concentrations used in the studies from which dose-response relationships are developed. Estimating potential health effects from environmental exposures, therefore, requires the use of models that allow extrapolation of health effects from high experimental doses (where effects can be measured) to low environmentally relevant doses. These models contain conservative assumptions that have uncertainties associated with them.

Uncertainties are associated with estimated noncarcinogenic toxicity values. For many noncarcinogenic effects, protective mechanisms are believed to exist in the human body that must be overcome before an adverse effect is manifested. As a result, there is a range of exposures (from zero to some finite value) that can be tolerated by the human body with essentially no expression of adverse effects. In developing a noncarcinogenic toxicity value, the approach is to identify the upper bound of this tolerance range (e.g., the maximum subthreshold level). Because there is variability within the human population, attempts are made to identify a subthreshold level that is protective of sensitive individuals in the population. For most chemicals, this level can only be estimated. Noncarcinogenic toxicity values (RfDs and RfCs) incorporate uncertainty factors that indicate the degree of extrapolation used to derive the estimated value. RfD and RfC summaries in the Integrated Risk Information System (IRIS) also contain a statement expressing the overall confidence that the evaluators have in the RfD or RfC (high, medium, or low). RfDs and RfCs are considered to have uncertainty spanning an order of magnitude or more, and, therefore, RfDs and RfCs should not be viewed as a strict scientific demarcation between toxic and nontoxic levels.

The development of the toxicity information for sulfolane is very recent and still evolving. The toxicity factors are still uncertain and may change periodically as new data become available.

Dermal toxicity values are not available in IRIS or HEAST. However, they are calculable using the dermal guidance from EPA (2004). The guidance provides methodology for adjusting oral toxicity values to be used in calculating risks for dermal exposure. Gastro-intestinal factors that modify the oral toxicity for the dermal pathway were included. The risk calculations in this document are based on the use of the gastro-intestinal factors for the soil pathways, and the PC and DA_{event} calculations for the water pathway as described above.

5.3.6 Uncertainties Related to Risk Characterization

The potential risk of adverse human health effects is characterized based on estimated potential exposures and estimated dose-response relationships. Two important additional sources of uncertainty are introduced in this phase of the HHRA: the evaluation of potential simultaneous exposure to multiple COCs and the combination of upper-bound exposure estimates with upper-bound toxicity estimates.

Only the sulfolane risks are the focus of this SRFI report. The noncarcinogenic hazards from other chemicals could impact the same organs impacted by sulfolane and, as a result, the hazard impacts could be synergistic. The synergy could be additive or subtractive depending on the chemical combination. Therefore, the noncarcinogenic hazards could be underestimated, or overestimated.

5.4 Summary of Sources of Uncertainty

There is uncertainty associated with the assumptions used to estimate potential risks from the site. While it is theoretically possible that this uncertainty leads to underestimates of potential risk, the use of numerous upper-bound and other health-protective assumptions more likely results in overestimates of potential risks. Any one individual's potential exposure and subsequent potential risk are influenced by all the exposure and toxicity parameters mentioned in this section and will vary on a case-by-case basis. Despite inevitable uncertainties associated with the steps used to estimate potential health risks, the use of numerous health-protective assumptions most likely leads to an overestimate of potential risks from exposure to environmental media at the site.

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6. SUMMARY AND CONCLUSIONS

Since the Order's inception, CPCPRC has implemented the requirements of the Order, and the AOC and SRFI investigation work specifically address the requirement in Section VI of the Order for identifying newly discovered contamination, controlling exposure to that contamination, and for notifying EPA and PREQB of that discovery.

The purpose of the SRFI work was to finalize the nature and extent of sulfolane contamination in soil, surface water, sediment, and groundwater acknowledging that the nature and extent of the primary Facility-related contaminants, BTEX, had been completed. The SRFI work focused on areas of the site that had not been previously investigated and that were suspected source areas for sulfolane based on operational knowledge. In addition, all site monitoring wells were sampled and a comprehensive sulfoalne data set was developed for groundwater.

The SRFI findings are summarized as follows:

- In surface soil, sulfolane was only detected in 4 of the 63 surface soil samples. One of these detections was at Tank 50 (sample location 0050-03) and the other three detections were at Tank 540 (sample locations 0540-14, 0540-16, and 0540-17). The results of the risk assessment indicate there are no unacceptable risks from sulfolane in surface soil.

- In subsurface soil, sulfolane was only detected in 4 of the 63 subsurface soil samples. One of these detections was at Tank 250 at 20 ft bgs (sample location 0250-04), one detection was along the PRASA pipeline at 10 ft bgs (sample location PRASA-04), and two detections were at Tank 540 at 6 ft bgs (sample location 0540-14) and 20 ft bgs (sample location (0540-17). The results of the risk assessment indicate there are no unacceptable risks from sulfolane in subsurface soil.

- In Effluent Channel surface water, sulfolane was detected in five of the six samples. The detections ranged between 0.9 µg/L and 240 µg/L. The results of the risk assessment indicate there are no unacceptable risks from sulfolane in surface water.

- In Effluent Channel sediment, sulfolane was detected in 4 of the 16 sediment samples. The detections ranged between 49 µg/Kg and 190 µg/Kg. The results of the risk assessment indicate there are no unacceptable risks from sulfolane in sediment.

- In groundwater, sulfolane was detected frequently and the groundwater data indicate sulfolane is present beneath the Facility and extends offsite to the east, south, and west. Sulfolane was not found in groundwater north of the former Process Area. The results of the risk assessment indicate that sulfolane in groundwater could pose a potential noncarcinogenic risk to the hypothetical resident.

Considering the limited number of detections in SRFI soil samples and the comprehensive groundwater data set, it is concluded that the nature and extent of sulfolane has been determined. Additionally, the results of the risk assessment show that only the hypothetical resident exposed to sulfolane in groundwater could be at potential risk. The description of the nature and extent of sulfolane contamination and the risk assessment results herein, together with the results of the AOC investigation and AOC risk assessment finalize the investigation phase of the RCRA process and support the scope of the CMS phase of work at the Facility.

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Tables

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Table 2-1. Identified areas of interest.

Area	Tank Number/Feature	Former Tank Contents/Feature	Diameter (ft)	Height (ft)	Capacity (barrels)
Basin G	0040	MF Reformate	80	39.17	34,000
Basin G	0050	Sulfolane Charge	119	35.5	65,000
Basin B	0130	Blend Stock	150	47.66	142,000
Basin H	0250	Sulfolane	36	42	7,000
Basin C	0270	Sulfolane	67	40	23,000
Basin H	0320	Cyclohexane	25	41.5	3,000
Basin F	0400	Sulfolane Charge	20	18	900
Basin F	0410	Mixed Solvent	20	18	900
Basin F	0420	Process Water	20	18	900
Basin F	0430	Process Water	20	18	900
Basin F	0440	Equipment Washings	55	30	11,000
Basin F	0520	Mixed Solvent	35	24	4,000
Former Process Area	0540	Sulfolane	20	16	NA
Western Boundary	MW-167	New monitoring well to track groundwater quality at Western boundary	NA	NA	NA
PRASA Pipeline	PRASA pipeline	Six borings to characterize sulfolane in soil and groundwater offsite to the east.	NA	NA	NA
Groundwater	Site groundwater	Sampling all site monitoring wells	NA	NA	NA

Table 3-1. Tank 40 sample results.

Sample ID	Analyte	Result	Qualifier	Unit
0040-01-SO-02	Sulfolane	37	U	µg/Kg
0040-01-SO-19	Sulfolane	39	U	µg/Kg
0040-02-SO-02	Sulfolane	38	U	µg/Kg
0040-02-SO-20	Sulfolane	40	U	µg/Kg
0040-03-SO-02	Sulfolane	38	U	µg/Kg
0040-03-SO-19	Sulfolane	39	U	µg/Kg
0040-04-SO-02	Sulfolane	37	U	µg/Kg
0040-04-SO-20	Sulfolane	41	U	µg/Kg
0040-05-SO-02	Sulfolane	39	U	µg/Kg
0040-05-SO-20	Sulfolane	40	U	µg/Kg
0040-06-GW		No water present		
0040-07-GW		No water present		

µg/Kg = milligrams per Kilogram
U = constituent not detected above the associated result.

Table 3-2. Tank 50 sample results.

Sample ID	Analyte	Result	Qualifier	Unit
0050-01-SO-02	Sulfolane	37	U	µg/Kg
0050-01-SO-19	Sulfolane	34	U	µg/Kg
0050-02-SO-02	Sulfolane	37	U	µg/Kg
0050-02-SO-20	Sulfolane	34	U	µg/Kg
0050-03-SO-02	Sulfolane	490		µg/Kg
0050-03-SO-19	Sulfolane	39	U	µg/Kg
0050-04-SO-02	Sulfolane	39	U	µg/Kg
0050-04-SO-20	Sulfolane	35	U	µg/Kg
0050-05-SO-02	Sulfolane	39	U	µg/Kg
0050-05-SO-20	Sulfolane	39	U	µg/Kg
0050-06-GW		No water present		
0050-07-GW	Sulfolane	80		µg/L

µg/Kg = micrograms per Kilogram
µg/L = micrograms per Liter
U = constituent not detected above the associated result.

Table 3-3. Tank 130 sample results.

Sample ID	Analyte	Result	Qualifier	Unit
0130-01-SO-02	Sulfolane	38	U	µg/Kg
0130-01-SO-06	Sulfolane	38	U	µg/Kg
0130-02-SO-02	Sulfolane	37	U	µg/Kg
0130-02-SO-06	Sulfolane	39	U	µg/Kg
0130-03-SO-02	Sulfolane	38	U	µg/Kg
0130-03-SO-10	Sulfolane	41	U	µg/Kg
0130-04-SO-02	Sulfolane	37	U	µg/Kg
0130-04-SO-06	Sulfolane	38	U	µg/Kg
0130-05-SO-02	Sulfolane	38	U	µg/Kg
0130-05-SO-06	Sulfolane	38	U	µg/Kg
0130-06-GW	Sulfolane	9.3	J	µg/L
0130-07-GW	Sulfolane	17		µg/L
µg/Kg = micrograms per Kilogram µg/L = micrograms per Liter U = constituent not detected above the associated result; J = constituent present at estimated value.				

Table 3-4. Tank 250 sample results.

Sample ID	Analyte	Result	Qualifier	Unit
0250-01-SO-02	Sulfolane	39	U	µg/Kg
0250-01-SO-18	Sulfolane	40	U	µg/Kg
0250-02-SO-02	Sulfolane	38	U	µg/Kg
0250-02-SO-19	Sulfolane	40	U	µg/Kg
0250-03-SO-02	Sulfolane	39	U	µg/Kg
0250-03-SO-18	Sulfolane	41	U	µg/Kg
0250-04-SO-02	Sulfolane	38	U	µg/Kg
0250-04-SO-19	Sulfolane	40	U	µg/Kg
0250-04-SO-20	Sulfolane	60	J	µg/Kg
0250-05-SO-02	Sulfolane	37	U	µg/Kg
0250-05-SO-17	Sulfolane	39	U	µg/Kg
0250-06-GW		No water present		
0250-07-GW		No water present		
µg/Kg = micrograms per Kilogram U = constituent not detected above the associated result; J = constituent present at estimated value.				

Table 3-5. Tank 270 sample results.

Sample ID	Analyte	Result	Qualifier	Unit
0270-01-SO-02	Sulfolane	39	U	µg/Kg
0270-01-SO-16	Sulfolane	40	U	µg/Kg
0270-02-SO-02	Sulfolane	39	U	µg/Kg
0270-02-SO-10	Sulfolane	35	U	µg/Kg
0270-03-SO-02	Sulfolane	40	U	µg/Kg
0270-03-SO-06	Sulfolane	39	U	µg/Kg
0270-04-SO-02	Sulfolane	39	U	µg/Kg
0270-04-SO-16	Sulfolane	42	U	µg/Kg
0270-05-SO-02	Sulfolane	38	U	µg/Kg
0270-05-SO-16	Sulfolane	40	U	µg/Kg
0270-06-GW	Sulfolane	9	J	µg/L
0270-07-GW	Sulfolane	12		µg/L

µg/Kg = micrograms per Kilogram
µg/L = micrograms per Liter
U = constituent not detected above the associated result; J = constituent present at estimated value.

Table 3-6. Tank 320 sample results.

Sample ID	Analyte	Result	Qualifier	Unit
0320-01-SO-02	Sulfolane	38	U	µg/Kg
0320-01-SO-15	Sulfolane	33	U	µg/Kg
0320-02-SO-02	Sulfolane	37	U	µg/Kg
0320-02-SO-15	Sulfolane	34	U	µg/Kg
0320-03-SO-02	Sulfolane	37	U	µg/Kg
0320-03-SO-15	Sulfolane	37	U	µg/Kg
0320-04-GW	Sulfolane	20		µg/L
0320-05-GW	Sulfolane	0.58	U	µg/L

µg/Kg = micrograms per Kilogram
µg/L = micrograms per Liter
U = constituent not detected above the associated result.

Table 3-7. Tank 400 sample results.

Sample ID	Analyte	Result	Qualifier	Unit
0400-01-SO-02	Sulfolane	37	U	µg/Kg
0400-01-SO-15	Sulfolane	39	U	µg/Kg
0400-02-SO-02	Sulfolane	35	U	µg/Kg
0400-02-SO-16	Sulfolane	39	U	µg/Kg
0400-03-SO-02	Sulfolane	38	U	µg/Kg
0400-03-SO-16	Sulfolane	42	U	µg/Kg

µg/Kg = micrograms per Kilogram

U = constituent not detected above the associated result.

Table 3-8. Tank 410 sample results.

Sample ID	Analyte	Result	Qualifier	Unit
0410-01-SO-02	Sulfolane	37	U	µg/Kg
0410-01-SO-16	Sulfolane	35	U	µg/Kg
0410-02-SO-02	Sulfolane	38	U	µg/Kg
0410-02-SO-16	Sulfolane	35	U	µg/Kg
0410-03-SO-02	Sulfolane	38	U	µg/Kg
0410-03-SO-15	Sulfolane	42	U	µg/Kg
0410-04-GW	Sulfolane	22		µg/L
0410-05-GW	Sulfolane	2.3	J	µg/L
0410-06-GW	Sulfolane	4.4	J	µg/L
0410-07-GW	Sulfolane	0.58	U	µg/L

µg/Kg = micrograms per Kilogram
µg/L = micrograms per Liter
U = constituent not detected above the associated result; J = constituent present at estimated value.

Table 3-9. Tank 420 sample results.

Sample ID	Analyte	Result	Qualifier	Unit
0420-01-SO-02	Sulfolane	37	U	µg/Kg
0420-01-SO-16	Sulfolane	41	U	µg/Kg
0420-02-SO-02	Sulfolane	38	U	µg/Kg
0420-02-SO-16	Sulfolane	38	U	µg/Kg
0420-03-SO-02	Sulfolane	38	U	µg/Kg
0420-03-SO-06	Sulfolane	36	U	µg/Kg
µg/Kg = micrograms per Kilogram U = constituent not detected above the associated result.				

Table 3-10. Tank 430 sample results.

Sample ID	Analyte	Result	Qualifier	Unit
0430-01-SO-02	Sulfolane	39	U	µg/Kg
0430-01-SO-15	Sulfolane	34	U	µg/Kg
0430-02-SO-02	Sulfolane	37	U	µg/Kg
0430-02-SO-15	Sulfolane	34	U	µg/Kg
0430-03-SO-02	Sulfolane	39	U	µg/Kg
0430-03-SO-15	Sulfolane	35	U	µg/Kg
0430-04-SO-02	Sulfolane	38	U	µg/Kg
0430-04-SO-15	Sulfolane	36	U	µg/Kg
0430-05-SO-02	Sulfolane	37	U	µg/Kg
0430-05-SO-15	Sulfolane	34	U	µg/Kg
µg/Kg = micrograms per Kilogram U = constituent not detected above the associated result.				

Table 3-11. Tank 440 sample results.

Sample ID	Analyte	Result	Qualifier	Unit
0440-01-SO-02	Sulfolane	38	U	µg/Kg
0440-01-SO-06	Sulfolane	37	U	µg/Kg
0440-02-SO-02	Sulfolane	36	U	µg/Kg
0440-02-SO-15	Sulfolane	35	U	µg/Kg
0440-03-SO-02	Sulfolane	39	U	µg/Kg
0440-03-SO-10	Sulfolane	38	U	µg/Kg
0440-04-SO-02	Sulfolane	38	U	µg/Kg
0440-04-SO-06	Sulfolane	37	U	µg/Kg
0440-05-SO-02	Sulfolane	38	U	µg/Kg
0440-05-SO-06	Sulfolane	38	U	µg/Kg

µg/Kg = micrograms per Kilogram
U = constituent not detected above the associated result.

Table 3-12. Tank 520 sample results.

Sample ID	Analyte	Result	Qualifier	Unit
0520-01-SO-02	Sulfolane	39	U	µg/Kg
0520-01-SO-10	Sulfolane	35	U	µg/Kg
0520-02-SO-02	Sulfolane	39	U	µg/Kg
0520-02-SO-10	Sulfolane	35	U	µg/Kg
0520-03-SO-02	Sulfolane	38	U	µg/Kg
0520-03-SO-10	Sulfolane	37	U	µg/Kg
0520-04-SO-02	Sulfolane	39	U	µg/Kg
0520-04-SO-13	Sulfolane	37	U	µg/Kg
0520-05-SO-02	Sulfolane	38	U	µg/Kg
0520-05-SO-12	Sulfolane	37	U	µg/Kg

µg/Kg = micrograms per Kilogram
U = constituent not detected above the associated result.

Table 3-13. Tank 540 sample results.

Sample ID	Analyte	Result	Qualifier	Unit
0540-14-SO-02	Sulfolane	160	J	µg/Kg
0540-14-SO-06	Sulfolane	79	J	µg/Kg
0540-15-SO-02	Sulfolane	37	U	µg/Kg
0540-15-SO-18	Sulfolane	40	U	µg/Kg
0540-16-SO-02	Sulfolane	170	J	µg/Kg
0540-16-SO-20	Sulfolane	39	U	µg/Kg
0540-17-SO-02	Sulfolane	1200		µg/Kg
0540-17-SO-20	Sulfolane	62	J	µg/Kg

µg/Kg = micrograms per Kilogram
U = constituent not detected above the associated result; J = constituent present at estimated value.

Table 3-14. Tank MW-167 sample results.

Sample ID	Analyte	Result	Qualifier	Unit
MW-167-01-SO-02	Sulfolane	40	U	µg/Kg
MW-167-01-SO-12	Sulfolane	35	U	µg/Kg
MW-167	Sulfolane	3.8	J	µg/L

µg/Kg = micrograms per Kilogram
µg/L = micrograms per Liter
U = constituent not detected above the associated result; J = constituent present at estimated value.

Table 3-15. PRASA pipeline area sample results.

Sample ID	Analyte	Result	Qualifier	Unit
PRASA-01-SS	Sulfolane	39	U	µg/Kg
PRASA-01-SO-10	Sulfolane	39	U	µg/Kg
PRASA-01-GW	Sulfolane	2.4	J	µg/L
PRASA-02-SS	Sulfolane	38	U	µg/Kg
PRASA-02-SO-10	Sulfolane	40	U	µg/Kg
PRASA-02-GW	Sulfolane	0.98	J	µg/L
PRASA-03-SS	Sulfolane	38	U	µg/Kg
PRASA-03-SO-10	Sulfolane	41	U	µg/Kg
PRASA-03-GW	Sulfolane	37		µg/L
PRASA-04-SS	Sulfolane	38	U	µg/Kg
PRASA-04-SO-10	Sulfolane	85	J	µg/Kg
PRASA-04-GW	Sulfolane	250		µg/L
PRASA-05-SS	Sulfolane	40	U	µg/Kg
PRASA-05-SO-08	Sulfolane	43	U	µg/Kg

Sample ID	Analyte	Result	Qualifier	Unit
PRASA-05-GW	Sulfolane	64		µg/L
PRASA-06-SS	Sulfolane	38	U	µg/Kg
PRASA-06-SO-06	Sulfolane	40	U	µg/Kg
PRASA-06-GW	Sulfolane	85		µg/L

µg/Kg = micrograms per Kilogram
µg/L = micrograms per Liter
U = constituent not detected above the associated result; J = constituent present at estimated value.

Table 3-16. Effluent Channel sediment sample results.

Sample ID	Sampling Date	Analyte	Result	Qualifier	Unit
CHANNEL-1	7/11/2013	Sulfolane	83	U	µg/Kg
CHANNEL-2	7/11/2013	Sulfolane	190	U	µg/Kg
CHANNEL-3	7/11/2013	Sulfolane	47	U	µg/Kg
CHANNEL-1	12/10/2013	Sulfolane	48	U	µg/Kg
CHANNEL-2	12/10/2013	Sulfolane	190	J	µg/Kg
CHANNEL-3	12/10/2013	Sulfolane	57	U	µg/Kg
CHANNEL-11	11/12/2013	Sulfolane	68	J	µg/Kg
CHANNEL-12	11/12/2013	Sulfolane	46	UJ	µg/Kg
CHANNEL-13	11/12/2013	Sulfolane	48	UJ	µg/Kg
CHANNEL-14	11/12/2013	Sulfolane	45	UJ	µg/Kg
CHANNEL-15	11/12/2013	Sulfolane	49	J	µg/Kg
CHANNEL-16	11/11/2013	Sulfolane	45	U	µg/Kg
CHANNEL-17	11/11/2013	Sulfolane	150	J	µg/Kg
CHANNEL-18	11/11/2013	Sulfolane	48	U	µg/Kg
CHANNEL-19	11/11/2013	Sulfolane	46	U	µg/Kg
CHANNEL-20	11/11/2013	Sulfolane	54	U	µg/Kg

µg/Kg = micrograms per Kilogram
U = constituent not detected above the associated result; J = constituent present at estimated value.

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Table 5-1. Exposure point concentrations.

Matrix	Analyte	Total Samples	Total Detects	Maximum Detected	Unit	95UCL	95UCL Basis
MW	Sulfolane	231	165	14,000	µg/L	569.9	95UCL
MW_MWD	Sulfolane	316	223	14,000	µg/L	574.6	95UCL
MWD	Sulfolane	85	58	4,700	µg/L	991.8	95UCL
SB	Sulfolane	317	43	370,000	µg/Kg	12,357	95UCL
SD	Sulfolane	16	4	190	µg/Kg	74.37	95UCL
SS	Sulfolane	322	40	17,000,000	µg/Kg	396,338	95UCL
SS_SB	Sulfolane	639	83	17,000,000	µg/Kg	198,389	95UCL
SW	Sulfolane	6	5	240	µg/L	60.14	95UCL
MW = Upper Alluvial groundwater MWD = Lower Alluvial groundwater MW_MWD = combined groundwater SB = subsurface soil				SD = sediment SS = surface soil SS_SB = combined soil SW = surface water			

Table 5-2. Residential cumulative risk.

Media	Pathway	HI	% HI
Combined Groundwater	**Ingestion**	**4.E+01**	99.9%
	Dermal	5.E-02	0.1%
	Inhalation	-	-
	Subtotal	**4.E+01**	100%
	TOTAL	**4.E+01**	100%

Table. 5-3. Resident scenario – child, combined Upper and Lower Aquifer groundwater, potential noncarcinogenic risk.

						Ingestion		Dermal			Inhalation				Total
Chemical	**Cas No.**	**Analysis**	**RfDo**	**RfCi (mg/M^3)**	**EPC (mg/L)**	**CDI (mg/Kg-day)**	**HI**	**GI Factor**	**CDI (mg/Kg-day)**	**HI**	**K_Res**	**IC (mg/m^3)**	**EC (mg/m^3)**	**HI**	**HI**
Sulfolane	126-33-0	SVOC	1.00E-03	2.00E-03	5.75E-01	3.67E-02	4.E+01	5.00E-01	4.69E-05	5.E-02	-	-	-	-	**4.E+01**

General Intake Parameters	**Units**		**Value**
Target Excess Lifetime Cancer Risk (TR_Res)	--	TR_Res	1.00E-06
Target Hazard Index (THI_Res)	--	THI_Res	1
Body Weight Adult (BW_Res)	Kg	BW_Res	70
Body Weight Child (BW_C)	Kg	BW_C	15
Averaging Time, Cancer (ATc_Res)	Yr	ATc_Res	70
Averaging Time, Non-Cancer (ATn_Res)	Yr	ATn_Res	24
Averaging Time, Non-Cancer (ATn_C)	Yr	ATn_C	6
Exposure Frequency (EF_Res)	Days/yr	EF_Res	350
Exposure Time - Showering Child (ET_C)	Hrs	ET_C	1
Exposure Time - Showering (ET_Res)	Hrs	ET_Res	0.58
Exposure Duration (ED_Res)	Yr	ED_Res	30
Exposure Duration Child (ED_C)	Yr	ED_C	6
Water Ingestion Rate - Adult (IRw_Res)	L/day	IRw_Res	2
Water Ingestion Rate - Adult (IRw_C)	L/day	IRw_C	1
Water Ingestion Factor - Age adjusted (IRw_aa)	L-year/Kg-day	IRw_aa	1.09
Air Inhalation Exposure Time (ETRes	days/day	ET_Res_MW	1.00
Air Inhalation Rate - Adult (IRa_Res)	M^3/day	IRa_Res	20
Air Inhalation Rate - Child (IRa_C)	M^3/day	IRa_C	10
Air Inhalation Factor - Age adjusted (IRa_aa)	M^3-yr/Kg-day	IRa_aa	10.9
Volatilization Factor, Water (K_Res)	L/m3	K_Res	-
Skin Surface Area - Adult (SA_Res)	cm^2/day	SA_Res	18000
Skin Surface Area - Child (SA_C)	cm^2/day	SA_C	6600
Skin Factor - Age adjusted (SA_aa)	cm^2-yr/Kg-day	SA_aa	6240
Dermal Permeability (PC)	cm/hr	PC	chem-spec

Ingestion CDI = EPC*IRw_C*EF_C*ED_C/BW_C/ATn_C/365

Dermal CDI = EPC*SA_WC*PC*ET_WC*EF_WC*ED_WC*0.001/BW_WC/AT/365

Inhalation IC = EPC*K_Res

Inhalation EC = IC*EF_Res*ED_C/ATn_C/365

ELCR = CDI * SF

Dermal HI = CDI/RfDo/GI Factor

HI = CDI/RfD

Table 5-4. Industrial worker cumulative risk.

Media	Pathway	HI	% HI
Surface Soil	**Ingestion**	4.E-01	43%
	Dermal	5.E-01	57%
	Inhalation	4.E-05	0%
	Subtotal	9.E-01	100%
	TOTAL	9.E-01	100%

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Table 5-5. Industrial worker scenario, onsite soil, potential noncarcinogenic risk.

						Ingestion		Dermal				Inhalation				Total
Chemical	**Cas No.**	**Analysis**	**RfDo**	**RfCi (mg/M^3)**	**EPC (mg/Kg)**	**CDI (mg/Kg-day)**	**HI**	**ABS**	**GI Factor**	**CDI (mg/Kg-day)**	**HI**	**VFi**	**IC (mg/m^3)**	**EC (mg/m^3)**	**HI**	**HI**
Sulfolane	126-33-0	SVOC	1.00E-03	2.00E-03	3.96E+02	3.88E-04	4.E-01	1.00E-01	5.00E-01	5.12E-04	5.E-01	-	3.66E-07	8.36E-08	4.E-05	9.E-01

General Intake Parameters	**Units**		**Value**
Target Excess Lifetime Cancer Risk (TR_SI)	--	TR_SI	1.00E-06
Target Hazard Index (THI_SI)	--	THI_SI	1
Body Weight Adult (BW_SI)	Kg	BW_SI	70
Averaging Time, Cancer (ATc_SI)	Yr	ATc_SI	70
Averaging Time, Non-Cancer (ATn_SI)	Yr	ATn_SI	25
Exposure Frequency (EF_SI)	Days/yr	EF_SI	250
Exposure Duration (ED_SI)	Yr	ED_SI	25
Soil Ingestion Rate - Adult (IRs_SI)	mg/day	IRs_SI	100
Air Inhalation Exposure Time (ET_IW)	days/day	ET_IW	0.33
Air Inhalation Rate - Adult (IRa_SI)	M^3/day	IRa_SI	20
Particulate Emission Factor (PEF_SI)	M^3/Kg	PEF_SI	1.08E+09
Volatilization Factor, Soil (VFc)	M^3/Kg		chem-spec
Skin Surface Area - Adult (SA_SI)	cm^2/day	SA_SI	3300
Adherence Factor Adult (AF_SI)	mg/cm^2	AF_SI	0.2
Absorption Factor (ABS)	--		chem-spec
Gastro-intestinal Factor (GI Factor)	--		chem-spec

Ingestion CDI = EPC*IRs_SI*EF_SI*ED_SI*0.000001/BW_SI/AT/365

Dermal CDI = EPC*SA_SI*AF_SI*ABS*EF_SI*ED_SI*0.000001/BW_SI/AT/365/GI Factor

Inhalation IC = EPC*(1/PEF_SI+1/VFi), Inhalation EC = IC*EF_SI*ED_SI/ATc_SI/365

ELCR = CDI * SF

HI = CDI/RfD

						Ingestion		Dermal				Inhalation				Total
Chemical	**Cas No.**	**Analysis**	**RfDo**	**RfCi (mg/M3)**	**EPC (mg/Kg)**	**CDI (mg/Kg-day)**	**HI**	**ABS**	**GI Factor**	**CDI (mg/Kg-day)**	**HI**	**VFi**	**IC (mg/m3)**	**EC (mg/m3)**	**HI**	**HI**
Sulfolane	126-33-0	SVOC	1.00E-03	2.00E-03	4.04E+02	3.95E-04	4.E-01	1.00E-01	5.00E-01	5.22E-04	5.E-01	-	3.73E-07	8.52E-08	4.E-05	9.E-01

General Intake Parameters	**Units**		**Value**
Target Excess Lifetime Cancer Risk (TR_SI)	--	TR_SI	1.00E-06
Target Hazard Index (THI_SI)	--	THI_SI	1
Body Weight Adult (BW_SI)	Kg	BW_SI	70
Averaging Time, Cancer (ATc_SI)	Yr	ATc_SI	70

Ingestion CDI = EPC*IRs_SI*EF_SI*ED_SI*0.000001/BW_SI/AT/365

Averaging Time, Non-Cancer (ATn_SI)	Yr	ATn_SI	25
Exposure Frequency (EF_SI)	Days/yr	EF_SI	250
Exposure Duration (ED_SI)	Yr	ED_SI	25
Soil Ingestion Rate - Adult (IRs_SI)	mg/day	IRs_SI	100
Air Inhalation Exposure Time (ET_IW)	days/day	ET_IW	0.33
Air Inhalation Rate - Adult (IRa_SI)	M3/day	IRa_SI	20
Particulate Emission Factor (PEF_SI)	M3/Kg	PEF_SI	1.08E+09
Volatilization Factor, Soil (VFc)	M3/Kg		chem-spec
Skin Surface Area - Adult (SA_SI)	cm2/day	SA_SI	3300
Adherence Factor Adult (AF_SI)	mg/cm2	AF_SI	0.2
Absorption Factor (ABS)	--		chem-spec
Gastro-intestinal Factor (GI Factor)	--		chem-spec

Dermal CDI = EPC*SA_SI*AF_SI*ABS*EF_SI*ED_SI*0.000001/BW_SI/AT/365/GI Factor

Inhalation IC = EPC*(1/PEF_SI+1/VFi), Inhalation EC = IC*EF_SI*ED_SI/ATc_SI/365

ELCR = CDI * SF

HI = CDI/RfD

Table 5-6. Construction worker cumulative risk.

Media	Pathway	HI	% HI
Combined Soil	**Ingestion**	6.E-01	62.2%
	Dermal	4.E-01	37.3%
	Inhalation	3.E-03	0.3%
	Subtotal	**1.E+00**	99.8%
Groundwater	**Ingestion**	-	-
	Dermal	2.E-03	0.2%
	Inhalation	-	-
	Subtotal	2.E-03	0.2%
	TOTAL	**1.E+00**	100%

Media	Pathway	HI	% HI	ILCR	% ILCR
Combined Soil	**Ingestion**	6.E-01	62%	-	-
	Dermal	4.E-01	37%	-	-
	Inhalation	3.E-03	0%	-	-
	Subtotal	**1.E+00**	100%	-	-
Groundwater	**Ingestion**	-	0%	-	-
	Dermal	2.E-03	0%	-	-
	Inhalation	-	0%	-	-
	Subtotal	2.E-03	0%	-	-
	TOTAL	**1.E+00**	100%		

Table 5-7. Construction worker scenario, onsite combined soil, potential noncarcinogenic risk.

						Ingestion		Dermal				Inhalation				Total
Chemical	**Cas No.**	**Analysis**	**RfDo**	**RfCi (mg/M^3)**	**EPC (mg/Kg)**	**CDI (mg/Kg-day)**	**HI**	**ABS**	**GI Factor**	**CDI (mg/Kg-day)**	**HI**	**VFc**	**IC (mg/m^3)**	**EC (mg/m^3)**	**HI**	**HI**
Sulfolane	126-33-0	SVOC	1.00E-03	2.00E-03	1.98E+02	6.41E-04	6.E-01	1.00E-01	5.00E-01	3.84E-04	4.E-01	-	2.44E-05	5.56E-06	3.E-03	**1.E+00**

General Intake Parameters	**Units**		**Value**
Target Excess Lifetime Cancer Risk (TR_SC)	--	TR_SC	1.00E-06
Target Hazard Index (THI_SC)	--	THI_SC	1
Body Weight Adult (BW_SC)	Kg	BW_SC	70
Averaging Time, Cancer (ATc_SC)	Yr	ATc_SC	70
Averaging Time, Non-Cancer (ATn_SC)	Yr	ATn_SC	1
Exposure Frequency (EF_SC)	Days/yr	EF_SC	250
Exposure Duration (ED_SC)	Yr	ED_SC	1
Soil Ingestion Rate - Adult (IRs_SC)	mg/day	IRs_SC	330
Air Inhalation Exposure Time (ET_CW)	days/day	ET_CW	0.33
Air Inhalation Rate - Adult (IRa_SC)	M^3/day	IRa_SC	20
Particulate Emission Factor (PEF_SC)	M^3/Kg	PEF_SC	8.14E+06
Volatilization Factor, Soil (VFc)	M^3/Kg		chem-spec
Skin Surface Area - Adult (SA_SC)	cm^2/day	SA_SC	3300
Adherence Factor Adult (AF_SC)	mg/cm^2	AF_SC	0.3
Absorption Factor (ABS_SC)	--	ABS_SC	chem-spec
Gastro-intestinal Factor (GI Factor)	--	GI	chem-spec

Ingestion CDI = EPC*IRs_SC*EF_SC*ED_SC*0.000001/BW_SC/AT/365

Dermal CDI = EPC*SA_SC*AF_SC*ABS*EF_SC*ED_SC*0.000001/BW_SC/AT/365/GI Factor

Inhalation IC = EPC*(1/PEF_SC+1/VFc), Inhalation EC = IC*EF_SC*ED_SC/ATn_SC/365

ELCR = CDI * SF
HI = CDI/RfD

						Ingestion		Dermal				Inhalation				Total
Chemical	**Cas No.**	**Analysis**	**RfDo**	**RfCi (mg/M3)**	**EPC (mg/Kg)**	**CDI (mg/Kg-day)**	**HI**	**ABS**	**GI Factor**	**CDI (mg/Kg-day)**	**HI**	**VFc**	**IC (mg/m3)**	**EC (mg/m3)**	**HI**	**HI**
Sulfolane	126-33-0	SVOC	1.00E-03	2.00E-03	2.00E+02	6.47E-04	6.E-01	1.00E-01	5.00E-01	3.88E-04	4.E-01	-	2.46E-05	5.62E-06	3.E-03	1.E+00
							6.E-01				4.E-01				3.E-03	**1.E+00**

General Intake Parameters	**Units**		**Value**
Target Excess Lifetime Cancer Risk (TR_SC)	--	TR_SC	1.00E-06
Target Hazard Index (THI_SC)	--	THI_SC	1
Body Weight Adult (BW_SC)	Kg	BW_SC	70
Averaging Time, Cancer (ATc_SC)	Yr	ATc_SC	70
Averaging Time, Non-Cancer (ATn_SC)	Yr	ATn_SC	1

Ingestion CDI = EPC*IRs_SC*EF_SC*ED_SC*0.000001/BW_SC/AT/365

Dermal CDI = EPC*SA_SC*AF_SC*ABS*EF_SC*ED_SC*0.000001/BW_SC/AT/365/GI Factor

Exposure Frequency (EF_SC)	Days/yr	EF_SC	250
Exposure Duration (ED_SC)	Yr	ED_SC	1
Soil Ingestion Rate - Adult (IRs_SC)	mg/day	IRs_SC	330
Air Inhalation Exposure Time (ET_CW)	days/day	ET_CW	0.33
Air Inhalation Rate - Adult (IRa_SC)	M3/day	IRa_SC	20
Particulate Emission Factor (PEF_SC)	M3/Kg	PEF_SC	8.14E+06
Volatilization Factor, Soil (VFc)	M3/Kg		chem-spec
Skin Surface Area - Adult (SA_SC)	cm2/day	SA_SC	3300
Adherence Factor Adult (AF_SC)	mg/cm2	AF_SC	0.3
Absorption Factor (ABS_SC)	--		chem-spec
Gastro-intestinal Factor (GI Factor)	--		chem-spec

Inhalation IC = EPC*(1/PEF_SC+1/VFc), Inhalation EC = IC*EF_SC*ED_SC/ATn_SC/365

ELCR = CDI * SF

HI = CDI/RfD

Table 5-8. Construction worker scenario, combined groundwater, potential noncarcinogenic risk.

						Ingestion		Dermal			Inhalation				Total
Chemical	**Cas No.**	**Analysis**	**RfDo**	**RfCi (mg/M^3)**	**EPC (mg/L)**	**CDI (mg/Kg-day)**	**HI**	**GI Factor**	**CDI (mg/Kg-day)**	**HI**	**K_WC**	**IC (mg/m^3)**	**EC (mg/m^3)**	**HI**	**HI**
Sulfolane	126-33-0	SVOC	1.00E-03	2.00E-03	5.70E-01	-	-	5.00E-01	1.65E-06	2.E-03	-	-	-	-	2.E-03

General Intake Parameters	**Units**		**Value**
Target Excess Lifetime Cancer Risk (TR_WC)	--	TR_WC	1.00E-06
Target Hazard Index (THI_WC)	--	THI_WC	1
Body Weight Adult (BW_WC)	Kg	BW_WC	70
Averaging Time, Cancer (ATc_WC)	Yr	ATc_WC	70
Averaging Time, Non-Cancer (ATn_WC)	Yr	ATn_WC	1
Exposure Frequency (EF_WC)	Days/yr	EF_WC	25
Exposure Time (ET_WC)	Hrs	ET_WC	8
Exposure Duration (ED_WC)	Yr	ED_WC	1
Water Ingestion Rate - Adult (Irw_WC)	L/day	IRw_WC	
Air Inhalation Exposure Time (ET_CW)	days/day	ET_CW	0.33
Air Inhalation Rate - Adult (IRa_WC)	M^3/day	IRa_WC	20
Volatilization Factor, Water (K_WC)	L/m3	K_WC	-
Skin Surface Area - Adult (SA_WC)	cm^2/day	SA_WC	3300
Dermal Permeability (Kp)	cm/hr	Kp	chem-spec

Ingestion CDI = EPC*IRw_WC*EF_WC*ED_WC/BW_WC/AT/365

Dermal CDI = See Constructionworker_DAD GW.xls spreadsheet

Inhalation IC = EPC*K_WC

Inhalation EC = IC*EF_WC*ED_WC/ATn_WC/365

ELCR = CDI * SF

HI = CDI/RfD

Table 5-9. Trespasser cumulative risk.

Media	Pathway	HI	% HI
Surface Soil	**Ingestion**	9.E-02	25.6%
	Dermal	3.E-01	71.7%
	Inhalation	4.E-06	0.0%
	Subtotal	4.E-01	97.3%
Sediment	**Ingestion**	6.E-06	0.0%
	Dermal	5.E-05	0.0%
	Inhalation	8.E-10	0.0%
	Subtotal	5.E-05	0.0%
Surface Water	**Ingestion**	9.E-03	2.6%
	Dermal	2.E-04	0.1%
	Inhalation	-	-
	Subtotal	9.E-03	2.6%
	TOTAL	**1.E+00**	100%

Table 5-10. Trespasser scenario, surface soil, potential noncarcinogenic risk.

						Ingestion		**Dermal**				**Inhalation**				**Total**
Chemical	**Cas No.**	**Analysis**	**RfDo**	**RfCi (mg/M^3)**	**EPC (mg/Kg)**	**CDI (mg/Kg-day)**	**HI**	**ABS**	**GI Factor**	**CDI (mg/Kg-day)**	**HI**	**VFc**	**IC (mg/m^3)**	**EC (mg/m^3)**	**HI**	**HI**
Sulfolane	126-33-0	SVOC	1.00E-03	2.00E-03	3.98E+02	9.22E-05	9.E-02	1.00E-01	5.00E-01	2.58E-04	3.E-01	-	3.73E-07	8.52E-09	4.E-06	4.E-01

General Intake Parameters	**Units**		**Value**
Target Excess Lifetime Cancer Risk (TR_TRES)	--	TR_TRES	1.00E-06
Target Hazard Index (THI_TRES)	--	THI_TRES	1
Body Weight Adult (BW_TRES)	Kg	BW_TRES	45
Averaging Time, Cancer (ATc_TRES)	Yr	ATc_TRES	70
Averaging Time, Non-Cancer (ATn_TRES)	Yr	ATn_TRES	12
Exposure Frequency (EF_TRES)	Days/yr	EF_TRES	50
Exposure Duration (ED_TRES)	Yr	ED_TRES	12
Water Ingestion Rate (IRw_TRES)	L/day	IRw_TRES	0.05
Sediment Ingestion Rate - Adult (IRs_TRES)	mg/day	IRsed_TRES	25
Soil Ingestion Rate - Adult (IRs_TRES)	mg/day	IRs_TRES	75
Air Inhalation Exposure Time (ET_Tres)	days/day	ET_Tres	0.17
Air Inhalation Rate - Adult (IRa_TRES)	M^3/day	IRa_TRES	2.25
Particulate Emission Factor (PEF_TRES)	M^3/Kg	PEF_TRES	1.08E+09
Volatilization Factor, Soil (VFc)	M^3/Kg		chem-spec
Skin Surface Area - Adult (SA_TRES)	cm^2/day	SA_TRES	3500
Adherence Factor Adult (AF_TRES)	mg/cm^2	AF_TRES	0.3
Absorption Factor (ABS_TRES)	--	ABS_TRES	chem-spec
Gastro-intestinal Factor (GI Factor)	--	GI	chem-spec

Ingestion CDI = EPC*IRs_TRES*EF_TRES*ED_TRES*0.000001/BW_TRES/ATn_TRES/365

Dermal CDI = EPC*SA_TRES*AF_TRES*ABS*EF_TRES*ED_TRES*0.000001/BW_TRES/ATn_TRES/365/GI Factor

Inhalation IC = EPC*(1/PEF_TRES+1/VFc), Inhalation EC = IC*EF_TRES*ED_TRES/BW_TRES/ATn_TRES/365

ELCR = CDI * SF

HI = CDI/RfD

Table 5-11. Trespasser scenario, surface water, potential noncarcinogenic risk.

						Ingestion		Dermal			Inhalation				Total
Chemical	**Cas No.**	**Analysis**	**RfDo**	**RfCi (mg/M^3)**	**EPC (mg/L)**	**CDI (mg/Kg-day)**	**HI**	**GI Factor**	**CDI (mg/Kg-day)**	**HI**	**K_Tres**	**IC (mg/m^3)**	**EC (mg/m^3)**	**HI**	**HI**
Sulfolane	126-33-0	SVOC	1.00E-03	2.00E-03	6.01E-02	9.15E-06	9.E-03	5.00E-01	1.91E-07	2.E-04	-	-	-	-	9.E-03

General Intake Parameters	**Units**		**Value**
Target Excess Lifetime Cancer Risk (TR_TRES)	--	TR_TRES	1.00E-06
Target Hazard Index (THI_TRES)	--	THI_TRES	1
Body Weight Adult (BW_TRES)	Kg	BW_TRES	45
Averaging Time, Cancer (ATc_TRES)	Yr	ATc_TRES	70
Averaging Time, Non-Cancer (ATn_TRES)	Yr	ATn_TRES	12
Exposure Frequency (EF_TRES)	Days/yr	EF_TRES	50
Exposure Duration (ED_TRES)	Yr	ED_TRES	12
Water Ingestion Rate (IRw_TRES)	L/day	IRw_TRES	0.05
Soil Ingestion Rate - Adult (IRs_TRES)	mg/day	IRs_TRES	100
Air Inhalation Expsoure Time (ET_Tres)	days/day	ET_Tres	0.17
Air Inhalation Rate - Adult (IRa_TRES)	M^3/day	IRa_TRES	2.25
Particulate Emission Factor (PEF_TRES)	M^3/Kg	PEF_TRES	8.47E+08
Volatilization Factor, Soil (VFc)	M^3/Kg	VFc	chem-spec
Volatilization Factor, Water (K_Tres)	L/m3	K_Tres	-
Skin Surface Area - Adult (SA_TRES)	cm^2/day	SA_TRES	3500
Dermal contact time (t_Event)	hr/event	t_Event	2
Adherence Factor Adult (AF_TRES)	mg/cm^2	AF_TRES	0.3
Absorption Factor (ABS_TRES)	--	ABS_TRES	chem-spec
Gastro-intestinal Factor (GI Factor)	--	GI	chem-spec

Ingestion CDI = EPC*IRw_WC*EF_WC*ED_WC/BW_WC/AT/365

Dermal CDI = See Constructionworker_DAD GW.xls spreadsheet

Inhalation IC = EPC*K_Tres

Inhalation EC = IC*EF_Tres*ED_Tres/ATn_Tres/365

ELCR = CDI * SF

HI = CDI/RfD

						Ingestion		Dermal			Inhalation				Total
Chemical	**Cas No.**	**Analysis**	**RfDo**	**RfCi (mg/M^3)**	**EPC (mg/L)**	**CDI (mg/Kg-day)**	**HI**	**GI Factor**	**CDI (mg/Kg-day)**	**HI**	**K_Tres**	**IC (mg/m^3)**	**EC (mg/m^3)**	**HI**	**HI**
Sulfolane	126-33-0	SVOC	1.00E-03	2.00E-03	6.01E-02	9.15E-06	9.E-03	5.00E-01	1.91E-07	2.E-04	-	-	-	-	9.E-03

General Intake Parameters	**Units**		**Value**
Target Excess Lifetime Cancer Risk (TR_TRES)	--	TR_TRES	1.00E-06
Target Hazard Index (THI_TRES)	--	THI_TRES	1

Body Weight Adult (BW_TRES)	Kg	BW_TRES	45
Averaging Time, Cancer (ATc_TRES)	Yr	ATc_TRES	70
Averaging Time, Non-Cancer (ATn_TRES)	Yr	ATn_TRES	12
Exposure Frequency (EF_TRES)	Days/yr	EF_TRES	50
Exposure Duration (ED_TRES)	Yr	ED_TRES	12
Water Ingestion Rate (IRw_TRES)	L/day	IRw_TRES	0.05
Soil Ingestion Rate - Adult (IRs_TRES)	mg/day	IRs_TRES	100
Air Inhalation Expsoure Time (ET_Tres)	days/day	ET_Tres	0.17
Air Inhalation Rate - Adult (IRa_TRES)	M^3/day	IRa_TRES	2.25
Particulate Emission Factor (PEF_TRES)	M^3/Kg	PEF_TRES	8.47E+08
Volatilization Factor, Soil (VFc)	M^3/Kg	VFc	chem-spec
Volatilization Factor, Water (K_Tres)	L/m3	K_Tres	0.5
Skin Surface Area - Adult (SA_TRES)	cm^2/day	SA_TRES	3500
Dermal contact time (t_Event)	hr/event	t_Event	2
Adherence Factor Adult (AF_TRES)	mg/cm^2	AF_TRES	0.3
Absorption Factor (ABS_TRES)	--		chem-spec
Gastro-intestinal Factor (GI Factor)	--		chem-spec

Ingestion CDI = EPC*IRw_WC*EF_WC*ED_WC/BW_WC/AT/365

Dermal CDI = See Constructionworker_DAD GW.xls spreadsheet

Inhalation IC = EPC*K_Tres

Inhalation EC = IC*EF_Tres*ED_Tres/ATn_Tres/365

ELCR = CDI * SF

HI = CDI/RfD

Table 5-12. Trespasser scenario, sediment, potential noncarcinogenic risk.

						Ingestion		Dermal				Inhalation				Total
Chemical	**Cas No.**	**Analysis**	**RfDo**	**RfCi (mg/M^3)**	**EPC (mg/Kg)**	**CDI (mg/Kg-day)**	**HI**	**ABS**	**GI Factor**	**CDI (mg/Kg-day)**	**HI**	**VFc**	**IC (mg/m^3)**	**EC (mg/m^3)**	**HI**	**HI**
Sulfolane	126-33-0	SVOC	1.00E-03	2.00E-03	7.44E-02	5.66E-09	6.E-06	1.00E-01	5.00E-01	4.75E-08	5.E-05	-	6.87E-11	1.57E-12	8.E-10	5.E-05

General Intake Parameters	**Units**		**Value**
Target Excess Lifetime Cancer Risk (TR_TRES)	--	TR_TRES	1.00E-06
Target Hazard Index (THI_TRES)	--	THI_TRES	1
Body Weight Adult (BW_TRES)	Kg	BW_TRES	45
Averaging Time, Cancer (ATc_TRES)	Yr	ATc_TRES	70
Averaging Time, Non-Cancer (ATn_TRES)	Yr	ATn_TRES	12
Exposure Frequency (EF_TRES)	Days/yr	EF_TRES	50
Exposure Duration (ED_TRES)	Yr	ED_TRES	12
Water Ingestion Rate (IRw_TRES)	L/day	IRw_TRES	0.05
Sediment Ingestion Rate - Adult (IRs_TRES)	mg/day	IRsed_TRES	25
Soil Ingestion Rate - Adult (IRs_TRES)	mg/day	IRs_TRES	75
Air Inhalation Exposure Time (ET_Tres)	days/day	ET_Tres	0.17
Air Inhalation Rate - Adult (IRa_TRES)	M^3/day	IRa_TRES	2.25
Particulate Emission Factor (PEF_TRES)	M^3/Kg	PEF_TRES	1.08E+09
Volatilization Factor, Soil (VFc)	M^3/Kg		chem-spec
Skin Surface Area - Adult (SA_TRES)	cm^2/day	SA_TRES	3500
Adherence Factor Adult (AF_TRES)	mg/cm^2	AF_TRES	0.3
Absorption Factor (ABS_TRES)	--	ABS_TRES	chem-spec
Gastro-intestinal Factor (GI Factor)	--	GI	chem-spec

Ingestion CDI = EPC*IRs_TRES*EF_TRES*ED_TRES*0.000001/BW_TRES/ATn_TRES/365

Dermal CDI = EPC*SA_TRES*AF_TRES*ABS*EF_TRES*ED_TRES*0.000001/BW_TRES/ATn_TRES/365/GI Factor

Inhalation IC = EPC*(1/PEF_TRES+1/VFc), Inhalation EC = IC*EF_TRES*ED_TRES/ATn_TRES/365

ELCR = CDI * SF

HI = CDI/RfD

APPENDIX A

Supplemental RCRA Facility Investigation Boring Logs (on CD)

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APPENDIX B

Human Health Risk Assessment Supporting Materials (Included on CD)

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APPENDIX C

Data Validation Reports
(Included on CD)

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APPENDIX D

CPCPRC Responses to EPA Comments on the Draft SRFI Report

CPCPRC RESPONSE to
EPA COMMENTS on the Supplemental RFI Report – June 2014
Chevron Phillips Chemical Puerto Rico Core, Inc.
EPA ID No PRD991291972
Guayama, Puerto Rico

November 20, 2014

The following comments have been developed based on the evaluation of the Supplemental RCRA Facility Investigation Report (SRFI Report) dated, June 2014, submitted by PEI on behalf of Chevron Phillips Chemical Puerto Rico Core, Inc. (CPCPRC), Guayama, PR.

General Comment

The Report should serve as a standalone document that describes the activities related to the investigation and the assessments on the nature and extent of sulfolane contamination in soil, groundwater, surface water, and sediment at the CPCPRC Facility at Guayama, PR. Therefore, the Report should include, emphasis and describe if the Data Quality Objectives (DQO), approved in the Supplemental RCRA Facility Investigation Work Plan, were attained.

Specific Comments

Comment 1: Section 1.1.1, *SRFI Investigation Objectives and Approach…should include the DQO as mentioned in the Supplemental RCRA Facility Investigation Work Plan and describe how these relate to the accomplished tasks and the analytical results.*

Response:

Text was added to Section 1.1.1 to include the DQOs presented in the SRFI Work Plan and to describe how the investigation work was accomplished to meet the DQOs.

Comment 2: Section 2.3, *SRFI Data Collection Program, mentions that Table 2-1 lists the 15 Areas of Interests (AOI's). However, such table only include the tanks that were identified as AOI's. Please, review and ensure that identification names or codes given to the areas under investigation or of interest are consistent throughout the investigation/remedial phases of the project. Modify as necessary.*

Response:

Table 2-1 was revised to include all 15 areas of interest and site groundwater.

Comment 3: Section 2.3.3. *Groundwater, indicates that water was not encountered at the certain boring locations (i.e. 0040-06, 0040-07, 0050-06). Please, include the AOI's denoted under these borings. In addition, explain the effects of these deviations, if any.*

Response:

The text in Section 2.3.3 and in Section 2.4, where these sample locations are also discussed, was revised to clarify the specific AOIs denoted under these borings. The text in Section 2.4 (Deviations from the Work Plan) explains that although groundwater samples could not be collected at these 5 boreholes, groundwater samples were collected from all Facility monitoring wells, including wells located near these AOIs. The comprehensive groundwater data set from the monitoring wells is adequate to define the nature and extent of sulfolane in groundwater.

Comment 4: Section 3.1.1, *Data Evaluation and Screening mentions that the RBSL's were calculated based on the CSM of potential exposure for the four plausible receptor groups.* ***Recommendation:*** *Although, RBSL's calculation are provided in Appendix B on CD, the RBSL (i.e. sulfolane for soil 3.2 µg/kg) should be mentioned in this section prior to the discussion on subsequent sections.*

Response:

The text in Section 3.1.1 has been revised to present the numeric values of the RBSLs calculated for the plausible receptors.

Comment 5: Section 3.2.1.14, *MW-167, describes the sampling event and analytical results for the samples derived from MW-167. However, the AOI's referencing name is not consistent with the Work Plan. Please, explain and modify as necessary.*

Response:

The title for Section 3.2.1.14 has been revised to read as "Western Boundary" to be consistent with the AOI referencing name in the Work Plan.

Comment 6: Section 3.2.1.15, *PRASA Pipeline, indicates that surface soil was not sampled at these locations because the DQO for this sampling was to characterize the subsurface conditions immediately adjacent to the pipeline envelope. However, the analytical results reflect detections above the conservative sulfolane RBSL. Consequently, sampling efforts to evaluate surface soil should be coordinated and performed to evaluate this AOI. Once surface soil data is obtained, it must be considered in the conceptual exposure model for the site.*

Response:

Considering this comment, CPCPRC mobilized back to these six locations and collected surface soil samples. The data from the surface soil samples are now included in the revised report. Inclusion of these data results in the update to relevant portions of the report text, tables and figures and update to the Exposure Point Concentrations (EPCs) and associated risk assessment calculations for the surface soil and combined soil.

Baseline Risk Assessment

General Comments

Section 5.1.2.3, Potential Receptors and exposure Pathways, states that exposure to contaminants in groundwater via inhalation is incomplete "... because sulfolane is an SVOC ...." According to the current (May 2014) Regional Screening Levels (RSL) table, sulfolane has a reference concentration as well as residential and industrial air screening levels. Potential inhalation of sulfolane via groundwater should be quantitatively evaluated for both the resident and construction worker exposure scenario.

Response:

CPCPRC consulted the RSL tables referenced in this comment and it is noted that for sulfolane in water (Residential Tapwater and Residential Soil to Groundwater), the inhalation risk component is not calculated. This is because research has shown that the contribution to risk from inhalation of non-volatile chemicals is negligible relative to volatile chemicals. For this reason, the volatilization factor is not assigned a value for non-volatile chemicals. This examination shows that the risk calculation approach used in the SRFI Report is the same approach used to develop the values in the RSL tables.

To address this comment, CPCPRC used the Johnson & Ettinger model to quantify indoor air sulfolane concentrations for the resident and the construction worker. The model input parameters were the same used for the hypothetical building constructed onsite (AOC Investigation Report, Appendix D dated April 2013). The chemical properties for sulfolane were added to this model as well as the sulfolane groundwater EPC. Attachment 1 presents the information relative to this modeling. As shown in the Attachment, the sulfolane groundwater concentration would have to be 49,000 µg/L to be of a concern to the resident and 207,000 µg/L to be a concern to the construction worker. Both these values are well above the groundwater EPC of 575 µg/L. These findings support the EPA RBSL calculation approach that assumes based on empirical evidence, that the contribution to risk from inhalation of non-volatile chemicals (sulfolane in this case) is negligible.

Specific Comments

Page 5-6, Section 5.1.6.4, 3rd paragraph, last sentence should indicate that the HI value is driven by surface soil not surface water.

Response:

The text has been revised based on this comment.

Attachment 1

Sulfolane Properties and References for Johnson & Ettinger Model.

Property	Value	Source
Organic Carbon Partition Coefficient, Koc, cm^3/g	9.08	ORNL
Diffusivity in Air, Da, cm^2/s	0.0716	ORNL
Diffusivity in Water, Dw, cm^2/s	0.00000991	ORNL
Pure Component Solubility, S, mg/L	293,000	ORNL
Henry's Law Constant, H', atm-m^3 /mol	8.94.83x10^{-6}	ORNL
Normal Boiling Point, Tb, ^0K	558	ORNL
Critical Temperature, Tc, ^0K	855	DDBST
Enthalpy of Vaporization, ΔHv,b, cal/mole	14,800	DDBST
Reference Concentration, RfC, mg/M^3	0.002	ORNL
Vapor Pressure at 303 ^0K, mm of Hg	0.00409	ORNL
Exposure Point Concentration in Groundwater	575 μg/L	sRFI Report

TRRP = http://www.tceq.state.tx.us/remediation/trrp/trrppcls.html

DDBST = http://www.ddbst.com/en/EED/PCP/PCPindex.php#Sulfolane

ORNL = http://rais.ornl.gov/cgi-bin/tools/TOX_search?select=chem_spef

Results from Johnson & Ettinger Model

Parameter	Value
Groundwater threshold concentration - Construction Worker	207,000 μg/L
Indoor air concentration based on 575 μg/L Groundwater - Construction Worker	2.44×10^{-2} $\mu g/M^3$
Hazard Index based on 575 μg/L in groundwater – Construction Worker	0.0028
Groundwater threshold concentration - Resident	49,000 μg/L
Indoor air concentration based on 632 μg/L Groundwater - Construction Worker	2.44×10^{-2} $\mu g/M^3$
Hazard Index based on 575 μg/L in groundwater – Resident	0.0117
EPA RSL for Air - Resident	2.1 $\mu g/M^3$ (for Hazard Index of 1)

From the Internet

http://www.ddbst.com/en/EED/PCP/PCPindex.php#Sulfolane

Critical Temperature and Pressure

Data Table

T [K]	P [kPa]	State	Reference
855.00	7290.000	Critical Point	1

List of References

Number	Source
1	Nguyen A.: Vapor pressure, heat capacity, and density along the saturation line, measurements for cyclohexanol, 2-cyclohexen-1-one, 1,2-dichloropropane, 1,4-di-tert-butylbenzene,(+-)-2-ethylhexanoic acid, 2-(methylamino)ethanol. perfluoro-n-heptane, and sulfolane. J.Chem.Eng.Data 42 (1997) 1021-1036

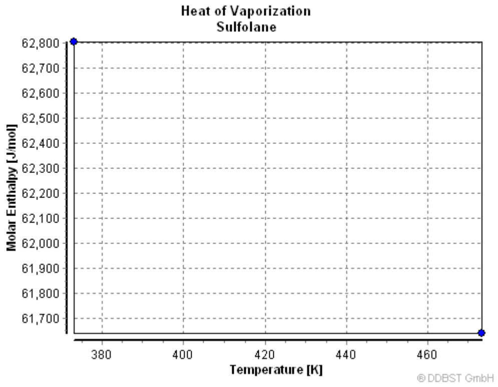
Heat of Vaporization of Sulfolane

The experimental data shown in these pages are freely available and have been published already in the DDB Explorer Edition. The data represent a **small sub list** of all available data in the Dortmund Data Bank. For more data or any further information please search the DDB or contact DDBST.

Component

Formula	Molar Mass	CAS Registry Number	Name
$C_4H_8O_2S$	120.172	126-33-0	Sulfolane

Diagrams



See larger image

Data Table

T [K]	Molar Enthalpy [J/mol]	State	Reference
373.15	62802.00	Vapor-Liquid	1
473.15	61639.00	Vapor-Liquid	1

List of References

Number	Source
1	Papadopoulos M.N.: A better way to extract aromatics.. Petrol.Refiner (1959) 185-192

Conversion Factor Joules to Calorie = 4.2 Joules per Calorie

62000 Joules/Mole = 14,800 calories/mole.

Vapor Pressure of Sulfolane

The experimental data shown in these pages are freely available and have been published already in the DDB Explorer Edition. The data represent a **small sub list** of all available data in the Dortmund Data Bank. For more data or any further information please search the DDB or contact DDBST.

Component

Formula	Molar Mass	CAS Registry Number	Name
$C_4H_8O_2S$	120.172	126-33-0	Sulfolane

Data Table

T [K]	P [kPa]	State	Reference
303.15	0.002666	Vapor-Liquid	6
303.15	0.00906	Vapor-Liquid	3
303.15	0.0091	Vapor-Liquid	2
307.71	0.0031773399096	Vapor-Liquid	4
307.71	0.003192	Vapor-Liquid	4
308.15	0.0099	Vapor-Liquid	2
312.64	0.004539	Vapor-Liquid	4
313.15	0.005333	Vapor-Liquid	6
313.15	0.0105	Vapor-Liquid	2
318.15	0.0119	Vapor-Liquid	2
323.15	0.005	Vapor-Liquid	5
323.15	0.01067	Vapor-Liquid	6
323.15	0.0156	Vapor-Liquid	2
328.15	0.0213	Vapor-Liquid	2
332.63	0.01745	Vapor-Liquid	4
333.15	0.0324	Vapor-Liquid	3

T [K]	P [kPa]	State	Reference
342.68	0.032674	Vapor-Liquid	4
348.15	0.020	Vapor-Liquid	5
354.53	0.0676	Vapor-Liquid	4
354.54	0.0676	Vapor-Liquid	4
362.25	0.10544	Vapor-Liquid	4
362.28	0.10544	Vapor-Liquid	4
362.29	0.10544	Vapor-Liquid	4
370.95	0.5333	Vapor-Liquid	1
374.85	0.600	Vapor-Liquid	1
385.35	0.6666	Vapor-Liquid	1
391.45	0.8666	Vapor-Liquid	1
406.45	1.200	Vapor-Liquid	1
412.05	1.4665	Vapor-Liquid	1
429.85	2.933	Vapor-Liquid	1

List of References

Number	Source
1	Coombs D.M.: Two-Liquid-Phase Extractive Distillation for Aromatics Recovery. Ind.Eng.Chem.Res. 26 (1987) 564-573
2	Shearn R.B.: Isothermal Vapor-Liquid Equilibria for the Systems Toluene-n-Heptane, Toluene-Propan-2-ol, Toluene-Sulfolane and Propan-2-ol-Sulfolane. J.Chem.Eng.Data 24 (1979) 195-199

3	Karvo M.: VI. Vapour-liquid equilibria for (benzene + sulfolane) and (toluene + sulfolane). J.Chem.Thermodyn. 12 (1980) 1175-1181
4	Jose J.: Static measurements of the total vapor pressure of binary mixtures of sulfolane (thiolane 1,1-dioxide) with hex-1-yne, benzene, and isopropylbenzene at temperatures between 283 and 363 K. Eldata Int.Electron.J.Phys.-Chem.Data 1 (1995) 313-320
5	Lynn S.: Vapor-Liquid Equilibria of Sulfur Dioxide in Polar Organic Solvents. Ind.Eng.Chem.Res. 26 (1987) 548-555
6	Choux G.: III. Etude des interactions eau-sulfolane. Can.J.Chem. 46 (1968) 3215-3219

Kilopascal to mm(hg) conversion

1 Kilopascal = 7.5 mm of mercury

0.002666 Kpa = 0.02 mm of mercury at 30^0 Celsius