Prepared for
Nevada Environmental Response Trust

Prepared by
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Date
July 23, 2021

BASELINE HEALTH RISK ASSESSMENT FOR OU-2 SOIL GAS AND GROUNDWATER

NEVADA ENVIRONMENTAL RESPONSE TRUST SITE HENDERSON, NEVADA

Baseline Health Risk Assessment for OU-2 Soil Gas and Groundwater

Nevada Environmental Response Trust
(Former Tronox LLC Site)
Henderson, Nevada

Nevada Environmental Response Trust (NERT) Representative Certification
I certify that this document and all attachments submitted to the Division were prepared at the request of, or under the direction or supervision of NERT. Based on my own involvement and/or my inquiry of the person or persons who manage the system(s) or those directly responsible for gathering the information or preparing the document, or the immediate supervisor of such person(s), the information submitted and provided herein is, to the best of my knowledge and belief, true, accurate, and complete in all material respects.

Office of the Nevada Environmental Response Trust

Le Petomane XXVII, Inc., not individually, but solely in its representative capacity as the Nevada Environmental Response Trust Trustee

Signature: Jay A Steinberg — Not Individually, but Solely as President of the Trustee

Name: Jay A. Steinberg, not individually, but solely in his representative capacity as President of the Nevada Environmental Response Trust Trustee

Title: Solely as President and not individually

Company: Le Petomane XXVII, Inc., not individually, but solely in its representative capacity as the Nevada Environmental Response Trust Trustee

Date: 7/23/21

Baseline Health Risk Assessment Report for OU-2 Soil Gas and Groundwater

Nevada Environmental Response Trust Site
(Former Tronox LLC Site)
Henderson, Nevada

Responsible Certified Environmental Manager (CEM) for this project

I hereby certify that I am responsible for the services described in this document and for the preparation of this document. The services described in this document have been provided in a manner consistent with the current standards of the profession and, to the best of my knowledge, comply with all applicable federal, state and local statutes, regulations and ordinances.

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John M. Pekala, PG **Date**
Principal

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Baseline Health Risk Assessment
for OU-2 Soil Gas and Groundwater
Nevada Environmental Response Trust
Henderson, Nevada

Date	**July 23, 2021**
Prepared by	**Ramboll US Consulting, Inc**
Description	**Baseline Health Risk Assessment for OU-2 Soil Gas and Groundwater**

Project No. **1690020169-007**

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ACRONYMS AND ABBREVIATIONS

API	American Petroleum Institute
ATSDR	Agency for Toxic Substances & Disease Registry
BCL	Basic Comparison Level
bgs	below ground surface
BMI	Black Mountain Industrial
BRC	Basic Remediation Company
Cal/EPA	California Environmental Protection Agency
CAS	Chemical Abstract Service
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
COH	City of Henderson
CSM	conceptual site model
DNAPL	dense non-aqueous phase liquid
DQI	data quality indicator
DUE	data usability evaluation
DVSR	data validation summary report
EDA	exploratory data analysis
EDD	electronic data deliverable
ENSR	ENSR Corporation
ENVIRON	ENVIRON International Corporation
EPC	exposure point concentration
Exponent	Exponent, Inc.
fg1	first fine-grained facies
GC/MS	gas chromatography/mass spectroscopy
HEAST	Health Effects Assessment Summary Tables
HI	hazard index
HQ	hazard quotient
HRA	health risk assessment
IQR	interquartile range
IRIS	Integrated Risk Information System
ITRC	Interstate Technology Regulatory Council

IUR	inhalation unit risk
IWF	interceptor well field
L	Liter
LOAEL	lowest-observed-adverse-effect level
LOU	Letter of Understanding
mm Hg	millimeter of mercury
mol	mole
mph	mile per hour
MRL	Minimal Risk Level
NCP	National Contingency Plan
NDEP	Nevada Division of Environmental Protection
NERT	Nevada Environmental Response Trust
NFA	no further action
Northgate	Northgate Environmental Management, Inc.
NRC	National Research Council
OSSM	Olin Chlor-Alkali/Stauffer/Syngenta/Montrose
OSWER	Office of Solid Waste and Emergency Response
PPRTV	Provisional Peer Reviewed Toxicity Values
PQL	practical quantitation limit
Qal	quaternary alluvial deposit
QAPP	Quality Assurance Project Plan
Ramboll	Ramboll US Consulting, Inc. (formerly Ramboll US Corporation)
Ramboll Environ	Ramboll Environ US Corporation
RAO	Remedial Action Objectives
RBTC	risk-based target concentration
RfC	reference concentration
RfD	reference dose
RI/FS	remedial investigation/feasibility study
RME	reasonable maximum exposure
RPD	relative percent difference
RSL	regional screening level
SIM	selective ion monitoring
Site	Nevada Environmental Response Trust Site

SOP	standard operating procedure
SQL	sample quantitation limit
TDS	Total Dissolved Solids
TIMET	Titanium Metals Corporation
Tronox	Tronox, LLC
Trust	Nevada Environmental Response Trust
UCL	upper confidence limit
µg	Microgram
UMCf	Upper Muddy Creek Formation
USEPA	United States Environmental Protection Agency
VDEQ	Virginia Department of Environmental Quality
VOC	volatile organic compound
WBZ	Water Bearing Zone

EXECUTIVE SUMMARY

This report was prepared by Ramboll US Consulting, Inc. (Ramboll) on behalf of the Nevada Environmental Response Trust (NERT or the Trust) and presents the Baseline Health Risk Assessment (BHRA) for soil gas and groundwater in Operable Unit 2 (OU-2) of the NERT RI Study Area in Henderson, Nevada. The BHRA was conducted to evaluate potential health risks to current and future residents and workers from exposures to residual levels of volatile organic compounds (VOCs) released from soil gas and groundwater to indoor, outdoor, and trench air. This BHRA report has been prepared according to the methodology described in the BHRA Work Plan for OU-1[1] and OU-2 Soil Gas and Groundwater, Revision 1 (Ramboll 2018a), submitted to the Nevada Division of Environmental Protection (NDEP) on December 18, 2018 and approved by NDEP on January 24, 2019. OU-2 is approximately 2,645 acres, is located immediately north of Operable Unit 1 (OU-1) of the NERT RI Study Area, and extends to the east. It is generally divided into two areas: 1) the NERT Off-Site Study Area component of OU-2 located west of Pabco Road; and 2) the Eastside Sub-Area component of OU-2 located east of Pabco Road, as shown on Figure ES-1. Pabco Road serves as a boundary demarcating differing historical land use within OU-2 and is also used to identify NERT's obligations related to the remedial investigation and feasibility study (RI/FS). NERT's obligations in OU-2 are different than in OU-1 in that in the Eastside Sub-Area, located east of Pabco Road, NERT is only responsible for evaluating the nature and extent of perchlorate and chlorate in the environment.

In accordance with the NDEP-approved BHRA Work Plan for OU-1 and OU-2 Soil Gas and Groundwater, Revision 1 (Ramboll 2018a), the potential risks associated with the vapor intrusion pathway from soil gas and groundwater is only being evaluated west of Pabco Road since NERT is only obligated to address risk associated with perchlorate and chlorate (which are not volatile organic compounds) east of Pabco Road. Although perchlorate and chlorate are present in groundwater in the East Sub-Area, there are no complete pathways for human exposures to these non-volatile chemicals due to depth to groundwater being greater than 10 feet below ground surface (bgs) in the Eastside Sub-Area. In addition, groundwater within the entire NERT RI Study Area is not used as drinking water. Therefore, consistent with the 2018 NDEP-approved BHRA Work Plan, the scope of this BHRA, and thus NERT's health risk assessments in OU-2, is limited to the portion of OU-2 located west of Pabco Road.

The NERT Off-Site Study Area component of OU-2 located west of Pabco Road has been the subject of subsurface investigations related to the downgradient migration of chemicals in groundwater originating from upgradient sources, including the NERT Site (or "Site"). It is bordered to the south by Warm Springs Road, to the north by the OU-2/OU-3 boundary, to the east by Pabco Road, and to the west by the western border of the NERT RI Study Area, including areas previously owned by Tronox, LLC (Tronox) or the Trust, referred to as Parcels A, B, I, and J in the southwestern portion of OU-2 (Figure ES-2).

NDEP has determined no further action or remediation is required for both soil direct contact pathways for former Parcels A and B (NDEP 2008a) and the vapor intrusion pathway for former Parcel A and the western portion of former Parcel B (NDEP 2013). Former Parcel I

[1] A separate BHRA report is being prepared for OU-1 soil gas and groundwater.

has received a No Further Action (NFA) determination for the top 10 feet of soil for the direct contact pathway but not for the vapor intrusion pathway through soil gas or groundwater (NDEP 2009). Former Parcel J has not received any NFA determination to date.[2] As a result, the NERT Off-Site Study Area in OU-2, excluding former Parcel A and the western portion of Parcel B, is referred to as the OU-2 BHRA Area and is the subject of this report (Figure ES-2).

Performing this BHRA is one step of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) process. The BHRA was conducted using the data collected from the Remedial Investigation (RI) and Groundwater Monitoring and Groundwater Extraction and Treatment System (GWETS) Remedial Performance reporting program for OU-1 and OU-2 (Ramboll 2021a). The results and conclusions from the BHRA will then be evaluated in the upcoming Feasibility Study (FS) to determine if remediation is necessary in the OU-2BHRA Area to satisfy the remedial action objectives and which remedial action alternative(s) will be implemented to mitigate the potential health risks to acceptable levels.

Separate BHRA reports are being prepared for OU-1 and OU-3. The forthcoming BHRAs for OU-1 will address the potential health risks associated with the vapor intrusion pathway for VOCs released from soil gas and groundwater, and direct contact with surface soil in OU-1. The forthcoming BHRA for OU-3 will address the potential health risks due to exposures to contaminants migrating from OU-1, through OU-2, and into OU-3.

This BHRA followed the procedures outlined in the United States Environmental Protection Agency (USEPA) risk assessment guidance and applicable NDEP guidance. The National Contingency Plan (NCP) (40 Code of Federal Regulations [CFR] § 300) is cited as the basis for the target cancer risk range established by NDEP (2017a). According to the NCP, lifetime incremental cancer risks posed by a site should not exceed one in a million (1×10^{-6}) to one hundred in a million (1×10^{-4}). According to the NCP and NDEP (2017a), noncarcinogenic chemicals should not be present at levels expected to cause adverse health effects (i.e., a hazard index [HI] greater than one). It should be noted that the cancer risk and noncancer hazard estimated in this BHRA do not represent absolute estimates, since generic and conservative assumptions were used, which are likely to overestimate actual exposures and calculated risks.

Consistent with the NDEP-approved BHRA Work Plan for OU-1 and OU-2 Soil Gas and Groundwater, Revision 1 (Ramboll 2018a) and agency guidance from USEPA (USEPA 2015), multiple lines of evidence were utilized in the BHRA. Specifically, soil gas collected since 2008 and shallow groundwater (i.e. at monitoring wells with top of well screens less than 60 feet bgs) collected between 2016 and 2020 within the OU-2 BHRA Area were used to evaluate potential exposure for current and future residents and workers via inhalation of vapors migrating from the subsurface to indoor air, outdoor air, and trench air to provide multiple lines of evidence. The soil gas data used in this BHRA was specifically collected to evaluate the vapor intrusion pathway. Soil gas data is the preferred line of evidence for

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[2] Parcel J was never owned by the Trust. Based on email communication with NDEP on May 15, 2018 (NDEP 2018a), Parcel J was sold but NDEP does not have additional information about it. Assuming Parcel J has not received its NFA determination to date, this parcel is included in the soil gas and groundwater evaluations for the vapor intrusion pathways in this BHRA.

assessing vapor intrusion risks as opposed to groundwater or soil data primarily due to higher uncertainties associated with vapor intrusion modeling based solely on groundwater or soil data (i.e., uncertainty in predicting contaminant partitioning from groundwater or soil moisture to soil gas and in predicting transport through the capillary fringe). Therefore, this BHRA considers the soil gas data as the primary line of evidence for evaluation of the vapor intrusion pathway; groundwater data were evaluated to provide a secondary line of evidence and to check consistency between soil gas and groundwater results.

In this BHRA report, the preliminary soil gas and shallow groundwater BHRA data sets presented in the OU-1 and OU-2 Soil Gas and Groundwater BHRA Work Plan (Ramboll 2018a) have been updated by incorporating additional soil gas and shallow groundwater data from the most recent investigations. Potential health risks associated with exposure to VOCs in air migrating from soil gas and groundwater in the OU-2 BHRA Area were evaluated.

The OU-2 BHRA Area has been the subject of extensive environmental investigations. The primary field investigations for soil gas since the 2005 conceptual site model (CSM) report (ENSR Corporation [ENSR] 2005) have included the following[3]:

- Phase B Soil Gas Investigation in 2008;
- Phase 1 RI in 2015;
- Phase 2 RI Modification No. 11 in 2019; and
- Phase 3 RI Modification No. 9 in 2019-2020.

The primary field investigations for shallow groundwater (i.e. at monitoring wells with top of well screens less than 60 feet bgs) conducted by the Trust since 2015 have included the following:

- Phase 1 RI in 2015;
- Phase 2 RI in 2017-2018;
- Phase 3 RI in 2018; and
- Groundwater Monitoring and GWETS Remedial Performance reporting in 2016-2020.

Analytical results of soil gas and shallow groundwater samples collected within the OU-2 BHRA Area were assessed through the data processing and data usability evaluation (DUE) steps (see Section 4.1), and data representative of current conditions were selected for purposes of the BHRA. The VOCs selected for evaluation, the CSM and the estimated excess lifetime cancer risks and chronic HIs are summarized as follows:

- All VOCs detected in one or more soil gas or shallow groundwater samples in the BHRA data sets were evaluated in the risk assessment. As summarized in Table ES-

[3] The soil gas investigations were conducted historically by other parties in 2008, and more recently by the Trust in 2019 and 2020.

1, a total of 71 VOCs were detected in soil gas and a total of 23 VOCs were detected in shallow groundwater.

- Based on the CSM for the OU-2 BHRA Area, potential exposure to soil gas and shallow groundwater was evaluated for residents, indoor commercial/industrial workers, outdoor commercial/industrial workers, and construction workers via inhalation of vapors migrating from soil gas and shallow groundwater to indoor air, outdoor air, and trench air. In addition, a trailer scenario was evaluated for residents living in residential trailers in a limited area in the OU-2 BHRA Area. To be conservative, construction workers were assumed to be exposed to vapors migrating from soil gas/shallow groundwater while standing in a 10-foot trench in the unsaturated zone, placing them closer to the potential sources.

- Excess lifetime cancer risks and noncancer HIs associated with inhalation of vapors migrating from soil gas and shallow groundwater were estimated for detected VOCs in soil gas and shallow groundwater for each sample for indoor air and trench air scenarios, and based on the 95% upper confidence limits (UCLs) on the mean concentrations over the entire OU-2 BHRA Area (or the maximum outdoor air concentrations predicted over the entire OU-2 BHRA Area if 95% UCLs could not be calculated due to limited detections or higher than the maximum outdoor concentrations) for outdoor air scenarios. The risk results based on the soil gas data evaluation are presented in Table ES-2 and summarized below.

- For the residential slab-on-grade scenario, the estimated excess lifetime cancer risk ranged from 6×10^{-8} to 2×10^{-5} and 2×10^{-7} to 2×10^{-5} for soil gas at 5 feet bgs and 10-15 feet bgs, respectively. As shown on Figures ES-3 and ES-4, the highest risk estimates for both depth intervals correspond to sample location RISG-1. For the residential trailer scenario, the estimated excess lifetime cancer risks ranged from 5×10^{-7} to 1×10^{-5} and 3×10^{-7} to 7×10^{-6} for soil gas at 5 feet bgs and 10-15 feet bgs, respectively. As shown on Figures ES-3 and ES-4, the highest risk estimates at both depth intervals correspond to sample location RISG-77. All of these excess lifetime cancer risk estimates are within the NDEP acceptable risk range of 10^{-6} to 10^{-4}. The cancer risk driver for the soil gas samples was chloroform, contributing to over 97% of the total cancer risk for the location with the highest estimated cancer risks for residents. Soil gas sample locations with cancer risks above 10^{-6} for residential indoor air scenarios were located over the area of higher chloroform concentrations in groundwater in the residential area in the OU-2 BHRA Area. This confirms that chloroform in groundwater is the source of chloroform in soil gas.
- For indoor commercial/industrial workers, the estimated excess lifetime cancer risks ranged from 5×10^{-9} to 3×10^{-6} and 4×10^{-9} to 2×10^{-6} for soil gas at 5 feet bgs and 10-15 feet bgs, respectively. As shown on Figures ES-5 and ES-6, the highest risk estimates correspond to sample location RISG-6. All of these excess lifetime cancer risk estimates were within the NDEP acceptable risk range of 10^{-6} to 10^{-4}. The cancer risk driver for the soil gas samples was chloroform, contributing to over 99% of the total cancer risk at the location with the highest estimated cancer risk for indoor commercial/industrial workers. Soil gas sample locations with cancer risks above 10^{-6} for commercial/industrial indoor air scenarios were located over the area

of higher chloroform concentrations in groundwater confirming that groundwater contamination is the source of constituents detected in soil gas.

- The estimated excess lifetime cancer risks for outdoor commercial/industrial workers and construction workers exposed to soil gas at 5 feet bgs and at 10-15 feet bgs were below the lower end of the NDEP acceptable risk range of 10^{-6} to 10^{-4}.
- The estimated total noncancer HIs for all the soil gas scenarios were below the NDEP target HI of greater than one.

As discussed above, this BHRA considers the soil gas data as the primary line of evidence for evaluation of the vapor intrusion pathway; the groundwater data was evaluated to provide a secondary line of evidence and to check consistency between soil gas and groundwater results. Groundwater results for VOCs from shallow monitoring wells (with top of well screens less than 60 feet bgs) collected from 2015 to 2020 within the OU-2 BHRA Area were included in this BHRA analysis. Similar to soil gas, the estimated excess lifetime cancer risks for vapor intrusion from shallow groundwater were estimated within the NDEP acceptable risk range of 10^{-6} to 10^{-4}, and chloroform was the primary chemical contributor to the estimated total cancer risk. All estimated total noncancer HIs for all the groundwater scenarios were below the NDEP target HI of greater than one.

The spatial distribution of locations with cancer risk above 10^{-6} for shallow groundwater are also generally consistent with those for soil gas in the OU-2 BHRA Area. The soil gas location with the highest cancer risk estimates (i.e. RISG-1 in the residential area) is co-located with the shallow groundwater well with the highest residential cancer risk estimate (i.e. PC-67). The soil gas location with the highest cancer risk estimates for indoor commercial/industrial workers (i.e. RISG-6 in the commercial area) is also co-located with a shallow groundwater well that is among the wells with the highest cancer risk estimate (i.e. PC-122). The results and conclusions of the groundwater risk evaluation are generally consistent with the results and conclusions of the soil gas risk evaluations for the OU-2 BHRA Area, supporting the OU-2 CSM developed in the RI Report for OU-1 and OU-2 (Ramboll 2021a) which identified that chloroform in groundwater is the main source of chloroform detected in soil gas in this area. The highest cancer risk estimates occur at locations where the highest chloroform concentrations were detected in groundwater within the OU-2 BHRA Area and are located generally downgradient of the upgradient sources (Figure ES-7).

Exposure via domestic use of groundwater was not evaluated because groundwater is not currently used as a domestic water supply consistent with the approved 2018 BHRA Work Plan (Ramboll 2018a).[4] Incidental ingestion of groundwater and dermal contact with groundwater during short-term construction activities is possible in very limited areas near PC-161 and PC-162, where depth to groundwater is less than 10 feet bgs. Due to the limited number of monitoring wells and the low concentrations detected at these wells, significant health risks during short-term construction activities are not expected to occur

[4] TDS concentrations exceed the drinking water standard in most areas throughout the Las Vegas Valley. https://www.lasvegasgmp.com/wells-groundwater/facts/index.html

through the groundwater direct contact pathway in this area. This potential pathway is discussed as part of the uncertainty analysis of this BHRA.

In summary, potential exposure to VOCs in soil gas and shallow groundwater in the OU-2 BHRA Area through the vapor intrusion pathway does not pose unacceptable carcinogenic and noncarcinogenic human health risks to residents, indoor and outdoor commercial/industrial workers, and construction workers under the conditions and assumptions evaluated. For all scenarios evaluated in the BHRA, the calculated cancer risks are within the NDEP acceptable risk range of 10^{-6} to 10^{-4}. Therefore, additional assessment is not warranted based on the risk characterization results for the OU-2 BHRA Area.

1. INTRODUCTION

This report has been prepared by Ramboll US Consulting, Inc. (Ramboll) on behalf of the Nevada Environmental Response Trust (NERT or the Trust) and presents the Baseline Health Risk Assessment (BHRA) for soil gas and groundwater in the western portion of Operable Unit 2 (OU-2) in the NERT Remedial Investigation (RI) Study Area in Henderson, Nevada. The potential health risks to future residents and workers in OU-2 associated with inhalation of volatile organic compounds (VOCs) released from soil gas and groundwater to indoor, outdoor, and trench air were evaluated and are presented herein. The risk to construction workers from direct contact to groundwater is very limited and is addressed in the uncertainty analysis of this BHRA.

NERT is implementing a RI consistent with the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). The NERT RI Study Area occupies approximately 5,200 acres (8.1 square miles) within the City of Henderson (COH) and Clark County, Nevada (Figure 1-1). The southern-most portion of the NERT RI Study Area is located within a portion of the Black Mountain Industrial (BMI) Complex. The NERT RI Study Area then extends north towards the Las Vegas Wash and east towards Lake Mead Parkway, as depicted in Figures 1-2 and 1-3. The BMI Complex was initially developed for industrial purposes in the early 1940s and continues to house several industrial manufacturing operations. As depicted within Figure 1-3, currently, the NERT RI Study Area collectively consists of four study areas. These are the NERT Site Study Area[5] and the NERT Off-Site Study Area (established in 2012 as the original NERT RI Study Area), the Downgradient Study Area (added in 2015), and the Eastside Study Area (added in 2016 and comprised of the Eastside Sub-Area and the Northeast Sub-Area). The NERT RI Study Area has been divided into three Operable Units (OUs). Operable Unit 1 (OU-1) is approximately 346 acres and includes the NERT Site. OU-2 is approximately 2,645 acres and is located immediately north of OU-1 and extends to the east; it comprises the southern portion of the NERT Off-Site Study Area and the Eastside Sub-Area. Operable Unit 3 (OU-3) is approximately 2,100 acres and is located north of OU-2; it encompasses the Downgradient Study Area, the Northeast Sub-Area and the northern portion of the NERT Off-Site Study Area.

From an investigative and risk assessment standpoint, OU-2 is divided into two areas: 1) the NERT Off-Site Study Area component of OU-2 located west of Pabco Road; and 2) the Eastside Sub-Area component of OU-2 located east of Pabco Road, as shown on Figure ES-1. Pabco Road serves as a boundary demarcating differing historical land use within OU-2 and is also used to identify NERT's obligations related to the remedial investigation and feasibility study (RI/FS). NERT's obligations in OU-2 are different than in OU-1 in that in the Eastside Sub-Area, located east of Pabco Road, NERT is only responsible for evaluating the nature and extent of perchlorate and chlorate in the environment.

In accordance with the NDEP-approved BHRA Work Plan for OU-1 and OU-2 Soil Gas and Groundwater, Revision 1 (Ramboll 2018a), the potential risks associated with the vapor intrusion pathway from soil gas and groundwater is only being evaluated west of Pabco

[5] The original "NERT Site Study Area" was established as part of the original NERT RI/FS Work Plan in 2012 where it was referred to as simply the "NERT Site." The NERT Site Study Area is identical to the OU-1 area, includes Sale Parcels C, D, and H, and refers to the property owned by the Trust after February 14, 2011 and prior to May 8, 2020 when Sale Parcels C, D, and H were sold by the Trust.

Road since NERT is only obligated to address risk associated with perchlorate and chlorate (which are not volatile organic compounds). Although perchlorate and chlorate are present in groundwater in the East Sub-Area, there are no complete pathways for human exposures to these non-volatile chemicals due to depth to groundwater being greater than 10 feet below ground surface (bgs) in the Eastside Sub-Area. In addition, groundwater within the entire NERT RI Study Area is not used as drinking water. Therefore, consistent with the NDEP-approved BHRA Work Plan, the portion of OU-2 east of Pabco Road is not included in this BHRA.

The NERT Off-Site Study Area in OU-2 has been the subject of subsurface investigations related to the downgradient migration of groundwater contaminants originating from upgradient sources including the NERT Site. It is bordered to the south by Warm Springs Road, to the north by the OU-2/OU-3 boundary,[6] to the east by Pabco Road, and to the west by the western border of the NERT RI Study Area, including areas previously owned by Tronox, LLC (Tronox) or the Trust, referred to as Parcels A, B, I, and J in the southwestern portion of OU-2 (Figure 1-4). This area is primarily residential housing, known as the Pittman Neighborhood, with commercial operations adjacent to major roadways. Former Parcels A and the western portion of former B were sold by NERT in 2013 and Parcels I and J were sold by Tronox in 2008.[7] The central and eastern portions of former Parcel B were sold by Tronox in 2008. These parcels now represent neighboring properties to the north of the NERT Site (Figure 1-4). NDEP has determined no further action or remediation is required for the soil direct contact pathways for former Parcels A and B (NDEP 2008a) and the vapor intrusion pathway for former Parcel A and the western portion of Parcel B (NDEP 2013). Former Parcel I has also received a No Further Action (NFA) determination for the top 10 feet of soil for the direct contact pathway but not for the vapor intrusion pathway through groundwater or soil gas (NDEP 2009). Parcel J has not received an NFA determination to date.[8] Former Parcels A and the western portion of former Parcel B are excluded from this BHRA. For purposes of this BHRA, the NERT Off-Site Study Area in OU-2 excluding former Parcel A and the western portion of Parcel B is referred to as the OU-2 BHRA Area (Figure 1-4). However, soil gas and shallow groundwater data collected in the entire former Parcel B were used to obtain better spatial coverage in evaluation of the health risks for the vapor intrusion pathway in the neighboring Parcels I and J.

As noted in the Remedial Investigation and Feasibility Study Work Plan (RI/FS Work Plan) (ENVIRON 2014a), businesses and residences located within or downgradient of the Site are connected to a municipal water supply. NDEP has conducted a survey of identified private well owners in the area downgradient of the Site to confirm that the wells are no longer present, and none were identified. Based on the available information, shallow groundwater

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[6] The mid-plume containment boundary line is the boundary between OU-2 and OU-3 and represents the RAO for OU-2 of mid-plume containment and mass removal.

[7] According to assessor's office records from Clark County, Parcels A and the western portion of Parcel B were sold by the Trust to Treco LLC on December 4, 2013; Parcel I was sold by Tronox to Rolly Properties LLC on June 27, 2008; Parcel J was sold by Tronox to Ellis Living Trust on January 31, 2008 (Clark County Assessor's Office Open Web Mapping Applications; Accessed May 9, 2018). http://www.clarkcountynv.gov/gis/services/Pages/OpenWeb.aspx.

[8] Parcel J was never owned by NERT. Based on email communication with NDEP on May 15, 2018 (NDEP 2018a), Parcel J was sold but NDEP does not have additional information about it. Assuming Parcel J has not received its NFA determination to date, this parcel will be included in the soil gas and groundwater evaluations for the vapor intrusion pathways in the BHRA for OU-2.

is not currently used as a source of drinking water, and given the high concentrations of total dissolved solids (TDS), [9] is not anticipated to be used in the future as a drinking water source in the OU-2 BHRA Area.

The BHRA is one step of the CERCLA process. The BHRA was conducted using the data collected from the RI. The results and conclusions from the BHRA will then be evaluated in the upcoming FS to determine if remediation is necessary in the OU-2 BHRA Area to satisfy the remedial action objectives and which remedial action alternative will be implemented to mitigate the potential health risks to acceptable levels.

Separate BHRA reports are being prepared for OU-1 and OU-3. The forthcoming BHRAs for OU-1 will address the potential health risks associated with the vapor intrusion pathway for volatile compounds released from soil gas and groundwater, and direct contact with surface soil in OU-1. The forthcoming BHRA for OU-3 will address the potential health risks due to exposures to contaminants migrating from OU-1 to OU-3. Finally, and as discussed, NERT will not be assessing risk in the Eastside Sub-Area component of OU-2 east of Pabco Road.

1.1 Scope of BHRA

OU-1, and specifically the NERT Site, has been the subject of extensive environmental investigations since the 1970s, during which time health risk assessments (HRAs) have been prepared for specific subareas of the NERT Site to evaluate potential risks associated with soil and soil gas exposure pathways. In 2010, prior to the inception of NERT and thus NERT's ownership of the Site, Northgate Environmental Management, Inc. (Northgate) and Exponent, Inc. (Exponent) prepared a HRA Work Plan (the 2010 HRA Work Plan) that described the risk assessment methodology for evaluating soil and soil gas exposure pathways in future HRAs prepared for the NERT Site (Northgate and Exponent 2010a). The 2010 HRA Work Plan was approved by NDEP on March 16, 2010 (NDEP 2010a).

Northgate and Exponent (2010b) conducted a Site-Wide Soil Gas Human Health Risk Assessment (2010 Site-Wide Soil Gas HRA), which evaluated the soil gas samples collected in May 2008 during the Phase B soil gas investigation (ENSR Corporation [ENSR] 2008a), but this HRA was not reviewed by NDEP.[10]

In 2014, a new BHRA work plan (2014 BHRA Work Plan), the first BHRA work plan prepared by the Trust as part of the RI/FS Work Plan, was prepared (ENVIRON 2014b). The 2014 BHRA Work Plan incorporated relevant elements from the 2010 HRA Work Plan, updated background information at the Site, and presented preliminary summary statistics for the soil and soil gas data sets representative of current conditions and available for the BHRA. The 2014 BHRA Work Plan was submitted to NDEP on February 28, 2014, and approved by NDEP on May 20, 2014. In addition, the conceptual site model (CSM) (ENSR 2005) was significantly revised in the 2014 BHRA Work Plan to identify additional transport pathways, evaluate off-Site populations in the downgradient groundwater Study Area (not previously

[9] TDS concentrations exceed the drinking water standard in most areas throughout the Las Vegas Valley. https://www.lasvegasgmp.com/wells-groundwater/facts/index.html

[10] The Draft Soil Gas HRA was submitted in 2010, but not approved by NDEP since upon establishment of NERT in February 2011, it was recognized that NERT would be performing health risk assessments as part of the RI being planned at the time.

included in the 2010 HRA Work Plan), and consider soil removal actions that have been completed since 2010.

A BHRA Work Plan for OU-1 and OU-2 Soil Gas and Groundwater, which focused on the vapor intrusion pathways, was submitted to NDEP on December 18, 2018, and approved by NDEP on January 24, 2019 (Ramboll 2018a). This BHRA report for OU-2 soil gas and groundwater has been prepared according to the methodology as described in the 2018 BHRA Work Plan. In this BHRA report, the preliminary soil gas and shallow groundwater BHRA data sets presented in the 2018 BHRA Work Plan (Ramboll 2018a) have been updated by incorporating additional soil gas and shallow groundwater data from recent investigations. Potential health risks associated with exposure to VOCs in air migrating from soil gas and groundwater to indoor air, outdoor air, or trench air in the OU-2 BHRA Area were evaluated. Because groundwater in OU-2 is not used as a drinking water source, direct contact with groundwater is not a complete exposure pathway for current and future populations. Incidental ingestion of groundwater and dermal contact with groundwater during short-term construction activities is possible in the very limited areas where depth to groundwater is less than 10 feet bgs. Due to the limited number of wells and the low concentrations detected at these wells, significant health risks are not expected to occur through the groundwater direct contact pathway in this area. This potential pathway is discussed as part of the uncertainty analysis in Section 6.2.4 of this BHRA. Accordingly, this risk assessment will only quantitatively evaluate the risk associated with VOCs in soil gas and groundwater within the OU-2 BHRA Area. The findings of this BHRA will be used in the forthcoming FS for OU-2 to determine which areas (if any) may require remediation to address unacceptable risk to the current and future residents and workers.

Leaching of soil contaminants to groundwater is being addressed as a separate evaluation within the RI/FS process, i.e., in the RI Report for OU-1 and OU-2 (Ramboll 2021a). The Remedial Action Objectives (RAOs) were established within the approved Phase 3 RI Work Plan (Ramboll Environ 2017a). Generally speaking, the RAOs focus on achieving the Trust's overarching objective of protecting the Las Vegas Wash and downstream interests over a long-term time frame (i.e., greater than five years). For OU-2, the migration of chemicals present in off-site groundwater within OU-2 will be mitigated through a combination of plume containment and (where feasible) contaminant mass removal.

1.2 Report Organization

The remainder of this report is organized as follows:

- Section 2 provides an overview of OU-2, including background, climate, and geologic and hydrogeologic setting.
- Section 3 summarizes the environmental investigations of soil gas and groundwater conducted within the OU-2 BHRA Area.
- Section 4 identifies the sources of soil gas and shallow groundwater data available for this BHRA and presents the data usability evaluation (DUE), including the data analysis step of the DUE.
- Section 5 presents the methodology and results from each of the four steps of the risk assessment, i.e., 1) identification of chemicals to be evaluated in the BHRA, 2) exposure assessment, 3) toxicity assessment, and 4) risk characterization.

- Section 6 presents the uncertainty analysis, which discusses the relative impact of data uncertainties and the primary assumptions used in the BHRA on the risk results.
- Section 7 provides the data quality assessment.
- Section 8 provides a summary of the BHRA and presents conclusions regarding current conditions within the OU-2 BHRA Area.
- Section 9 lists the references cited in this report.
- Supporting tables, figures, and appendices follow the text of the report.

2. OVERVIEW

2.1 Background

OU-2 comprises approximately 2,645 acres and mostly consists of developed and undeveloped residential and commercial property (Figures 1-2 and 1-3), and it is generally divided into two areas: 1) the NERT Off-Site Study Area component of OU-2 located west of Pabco Road; and, 2) the Eastside Sub Area component of OU-2 located east of Pabco Road. (see Figure 1-3). The following presents a summary of relevant information previously provided in the NERT RI Report for OU-1 and OU-2.

The majority of the Eastside Sub-Area was historically operated by BMI for general facility and utility operations in areas referred to as the BMI Common Areas, which included the Upper BMI Ponds and much of the area south of the Beta Ditch within the Eastside Study Area. Much of this area is being redeveloped, primarily for residential use, as part of a Master-Planned Community. As of June 2021, per communications with the developer, The LandWell Company, approximately 25% of the Master-Planned Community has been redeveloped, with the future pace of development to be driven by real estate market conditions.

Unlike that of the Eastside Sub-Area, the Off-Site Study Area of OU-2 was mostly vacant in the early 1950s with scattered structures located north and south of what is now North Boulder Highway. By 1950, the Northwest Ditch and Alpha Ditch, which conveyed primarily storm water and non-contact cooling water, were located along the southern and eastern boundaries of the Off-Site Study Area of OU-2, respectively. By the early 1980s, much of the Off-Site Study Area of OU-2 had been developed with a combination of commercial and residential structures, including the Pittman Neighborhood. The portion of OU-2 located west of Pabco Road continues to be used primarily for residential housing (generally northeast of Boulder Highway, west of Pabco Road, and south of Sunset Road) with commercial and light industrial operations to the north (between Sunset Road and Galleria Drive) and the southwest (along Boulder Highway and between Boulder Highway and Warm Springs Road). The residential community in this area, which is known as the Pittman Neighborhood, currently includes approximately 1,500 single-family dwellings, 30 multi-family dwellings, and two mobile home parks. The Athens Road Well Field (AWF) extraction wells, a component of the NERT groundwater extraction and treatment system (GWETS), are located immediately north of Galleria Drive near the OU-2/OU-3 boundary (Figure 1-4).

2.2 Climate

The climate of the Las Vegas Valley is arid with mild winters and dry hot summers. Average annual precipitation as measured in Las Vegas between 1980 and 2020 was 4.15 inches (National Oceanic and Atmospheric Administration 2020). Precipitation generally occurs during two periods, December through March and July through September. Winter storms generally produce low intensity rainfall over a large area. Summer storms generally produce high intensity rainfalls over a smaller area for a short duration. These violent summer thunderstorms account for most of the documented floods in the Las Vegas area. Winds frequently blow from the south or northwest at a mean velocity of approximately 9 miles per hour (mph); however, velocities in excess of 50 mph are not atypical when weather fronts move through the area. During these windy events, dust, sand, and soil at the ground surface can become airborne and may travel several miles. Temperatures can rise to 120°F in the summer, and the average relative humidity is approximately 20%. The mean annual evaporation from lake and reservoir surfaces ranges from 60 to 82 inches per year (Shevenell 1996).

2.3 Geologic and Hydrological Setting

OU-2, as part of the NERT RI Study Area, is located within Las Vegas Valley, which occupies a topographic and structural basin trending northwest-southeast and extending approximately 55 miles from near Indian Springs on the north to Railroad Pass on the south. The valley is bounded by the Las Vegas Range, Sheep Range, and Desert Range to the north, by the Frenchman and Sunrise Mountains to the east, by the McCullough Range and River Mountains to the south and southeast, and the Spring Mountains to the west. The mountain ranges bounding the east, north, and west sides of the valley consist primarily of Paleozoic and Mesozoic sedimentary rocks (limestones, sandstones, siltstones, and fanglomerates), whereas the mountains on the south and southeast consist primarily of Tertiary volcanic rocks (basalts, rhyolites, andesites, and related rocks) that overlie Precambrian metamorphic and granitic rocks (ENSR 2007).

OU-2 is located on Quaternary alluvial deposits (Qal) that slope north toward Las Vegas Wash. The portion of the NERT Off-Site Study Area within OU-2 is located north of the NERT Site between Warm Springs Road and just north of Galleria Drive. Topographic elevations in this area range from 1,605 to 1,701 feet msl. The topographic surface continues to decrease from south to north at approximately the same gradient as within the NERT Site, extending to approximately Sunset Road, at which point it flattens to a gradient of approximately 0.01 feet/foot to the Las Vegas Wash.

A major feature of the alluvial deposits in OU-2 is the stream-deposited sands and gravels that were laid down within paleochannels that were eroded into the surface of the Upper Muddy Creek Formation (UMCf) during infrequent flood runoff periods. These deposits are thickest within the paleochannel boundaries, which are narrow and linear and trend northeastward. The paleochannels act as preferential pathways for groundwater flow, which may significantly influence the chemical distribution in the alluvium (ENSR 2005, Ramboll 2021a). Within OU-2, the UMCf-first fine-grained facies (fg1) deposits become very fine-grained with abundant gypsum deposits, reflecting the saline mudflat depositional environment characteristic of the basin interior. The lower permeability UMCf is the unit in which most of the contaminant mass is stored and chemicals present in the UMCf would slowly migrate upwards into the overlying alluvium, where it is saturated. Additional details on the regional and local geology and hydrogeology, including information on the water-bearing zones, are provided in the RI Report for OU-1 and OU-2 (Ramboll 2021a).

Within OU-2, groundwater is generally encountered between 20 and 60 feet bgs, becoming shallower to the north. The depths to groundwater in a very limited area near PC-161 and PC-162 are shallower than 10 feet bgs. The groundwater flow direction within OU-2 is generally north-northeast toward Las Vegas Wash, which is the major drainage outlet for the Las Vegas basin (Ramboll 2021a).

3. ENVIRONMENTAL INVESTIGATIONS

As previously indicated, the OU-2 BHRA Area is limited to the NERT Off-Site Study Area component of OU-2 located west of Pabco Road. The following sections summarize soil gas investigations conducted within this area since 2008 and groundwater sampling for VOCs conducted from shallow monitoring wells (with top of well screens less than 60 feet bgs) since the 2015 Phase 1 RI.[11] The data from the soil gas and groundwater samples collected during these investigations are used as multiple lines of evidence to support the vapor intrusion analysis of this BHRA.

3.1 Soil Gas Investigations

The following sections present the soil gas investigations conducted in the OU-2 BHRA Area, which were used as the data sources for this BHRA.

3.1.1 Phase B Soil Gas Investigation

The Phase B soil gas investigation was conducted in May 2008 prior to inception of the Trust. Details of the soil gas sampling are provided in the *Phase B Source Area Investigation Soil Gas Survey Work Plan* (ENSR 2008a) and summarized in the draft 2010 *Site-Wide Soil Gas Human Health Risk Assessment* (Northgate and Exponent 2010b).[12] The majority of the Phase B soil gas samples were located in OU-1 with some of the soil gas samples located in the former sale parcels including former Parcels A and B in OU-2. These locations were selected based on the following: 1) results of the Phase A investigation (ENSR 2007), which identified the presence of several VOCs in soil and/or groundwater samples collected at the NERT Site; 2) historic groundwater data collected during investigations prior to 2006; and 3) an assessment of former chemical usage at the individual Letter of Understanding (LOU) potential source areas.[13]

A total of 11 soil gas samples were collected in 2008 at 10 locations within the OU-2 BHRA Area, all of which were collected at 5 feet bgs in Parcel B.

Analytical results for samples collected during the Phase B soil gas investigation were presented in a data validation summary report (DVSR) (ENSR 2008b) that was submitted to NDEP on October 13, 2008, and approved by NDEP on October 20, 2008.

3.1.2 Phase 1 RI

In accordance with the 2011 Interim Consent Agreement between the Trust and NDEP, the Trust is in the process of conducting a RI/FS. Per the RI/FS Work Plan (ENVIRON 2014a), Ramboll Environ collected soil gas samples as part of a Phase 1 RI data gap investigation (Phase 1 RI) in March 2015. As described in the Phase 1 RI Field Sampling Plan (ENVIRON 2014c) and the Technical Memorandum, Remedial Investigation Data Evaluation (the "RI Data Evaluation Technical Memorandum", Ramboll Environ 2016a), soil gas samples were

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[11] Shallow groundwater data since the Phase 1 RI are considered to provide an adequate spatial coverage and reflect the current conditions within the OU-2 BHRA Area.

[12] The Draft Soil Gas HRA was submitted in 2010, but not approved by NDEP since upon establishment of NERT in February 2011, it was recognized that NERT would be performing health risk assessments as part of the RI being planned at the time.

[13] In 1994, in a Letter of Understanding (LOU), NDEP identified 69 LOU Potential Source Areas (NDEP 1994) (referred to in this and other reports as LOUs).

collected adjacent to the three monitoring wells in the OU-2 BHRA Area with the highest chloroform concentrations in groundwater. Soil gas samples were collected from depths of 5 feet and 13 feet at RISG-1 and from depths of 5 feet and 15 feet at RISG-2 and RISG-3 using temporary soil gas probes.

Analytical results for soil gas samples collected during the Phase 1 RI were presented in a DVSR (Ramboll Environ 2017b) that was submitted to NDEP on November 3, 2017, and approved by NDEP on January 25, 2018.

3.1.3 Phase 2 RI

Because groundwater is considered to be the primary source of VOCs in soil gas, review and identification of data gaps in the existing soil gas data sets was completed following further evaluation of VOC data in shallow groundwater in the OU-2 BHRA Area. In the *Phase 2 RI Modification No. 11* (Ramboll 2018b), which was submitted on May 23, 2018, and approved by NDEP on June 21, 2018 (NDEP 2018b), Ramboll proposed soil gas sampling for VOCs at 17 locations in OU-1 and 13 locations in the OU-2 BHRA Area.

In accordance with the *Phase 2 RI Modification No. 11,* soil gas samples were collected from 13 locations in the OU-2 BHRA Area in March 2019 to evaluate areas where high chloroform concentrations were detected in the previous soil gas and/or groundwater sampling, and to obtain data at a deeper depth (either 10 or 15 feet bgs, depending on depth to groundwater) consistent with current vapor intrusion guidance (United States Environmental Protection Agency [USEPA] 2015) recommending samples closer to the source (i.e., VOCs in groundwater). The results of the soil gas samples collected during this investigation were summarized in the Technical Memorandum, Soil Gas Sampling Results for OU-1 and OU-2 (Ramboll 2020a; with comments on the submittal provided by NDEP on January 28, 2021) and the RI report for OU-1 and OU-2 (Ramboll 2021a). The 13 soil gas sample locations are summarized as below:

- Seven locations are within the chloroform groundwater plume with relatively higher concentrations which were sampled at both 5 and 15 feet bgs; and
- Six locations were sampled to better understand the lateral extent of VOCs in soil gas where chloroform concentrations in groundwater are lower, which were sampled at 5 and either 10 or 15 feet bgs, depending on depth to groundwater.

The infrastructure and soil cover within 100 feet (defined as the zone of influence, USEPA 2015) of each 5-foot Phase 2 RI soil gas sample location in OU-2 is documented in Appendix A-1, which indicates that the soil gas data collected are representative of the OU-2 BHRA Area and are used for the vapor intrusion evaluation. All soil gas data collected in the OU-2 BHRA Area are considered in this BHRA.

In addition, to perform a more representative site-specific vapor intrusion modeling, soil physical properties, including soil classification (grain size distribution/Atterberg Limits), total organic carbon, bulk density, water content, and total porosity were collected at 5 feet bgs, 10 feet bgs, and 15 feet bgs at nine soil gas sample locations (RISG-1 through RISG-9) in the OU-2 BHRA Area where soil properties had not been collected previously (Ramboll 2018b).[14]

VOCs in the soil gas samples were analyzed using USEPA Method TO-15, as described in the RI/FS Work Plan (ENVIRON 2014a) and the *NERT RI Quality Assurance Project Plan* (QAPP) (Ramboll Environ 2017c). Analytical results for soil gas samples collected during the Phase 2 RI Modification No. 11 were presented in a DVSR (Ramboll 2020b) that was submitted to NDEP on February 12, 2020 and approved by NDEP on April 9, 2020. All soil gas data collected in the OU-2 BHRA Area from the Phase 2 RI Modification No. 11 investigation are considered in this BHRA.

3.1.4 Phase 3 RI

Upon evaluation of the 2019 soil gas sampling results from the Phase 2 RI Modification No. 11, it was determined that additional soil gas samples were necessary to delineate the horizontal and vertical extent of VOCs in soil gas as required for completion of the OU-1 and OU-2 RI and to assess potential vapor intrusion risks as part of the OU-1 and OU-2 BHRAs. In accordance with the Phase 3 RI Modification No. 9 (Ramboll 2019a), which was submitted on October 7, 2019, and approved by NDEP on October 14, 2019, soil gas sampling for VOCs was conducted at 5 and 10-15 feet bgs at 40 locations identified in the OU-2 BHRA Area in November 2019 to January 2020. Twenty-eight of the sample locations were within the residential area northeast of Boulder Highway. Eight were within commercial areas north of Sunset Road and four were within the commercial area southwest of Boulder Highway. Among these soil gas sample locations, the original 13 locations in OU-2 sampled during the Phase 2 RI Modification No. 11 were resampled for soil gas at 5 and 10-15 feet bgs, depending on the depth to groundwater. The results of the soil gas samples collected during this RI modification were summarized in the *Technical Memorandum, Soil Gas Sampling Results for OU-1 and OU-2* (Ramboll 2020a; with comments on the submittal provided by NDEP on January 28, 2021) and the RI report for OU-1 and OU-2 (Ramboll 2021a).

The infrastructure and soil cover within 100 feet (defined as the zone of influence) of each 5-foot Phase 3 RI Modification No. 9 soil gas sample location collected in OU-2 is documented in Appendix A-2, which indicates that the soil gas data collected are representative for use in the vapor intrusion evaluation.

VOCs in the soil gas samples were analyzed using USEPA Method TO-15, as described in the RI/FS Work Plan (ENVIRON 2014a) and the NERT RI QAPP (Ramboll Environ 2017c). Analytical results for soil gas samples collected during the Phase 3 RI Modification No. 9 were presented in a DVSR (Ramboll 2021b) that was submitted to NDEP on January 13, 2021, and approved by NDEP on January 27, 2021. All soil gas data collected within the OU-2 BHRA Area from the Phase 3 RI Modification No. 9 investigation are considered in this BHRA.

[14] Soil classification (grain size distribution/Atterberg Limits) and total organic carbon were previously collected at PC-172 (co-located with RISG-4, at 13.5 feet bgs), PC-167 (co-located with RISG-7, at 11.0 feet bgs), and PC-166 (co-located with RISG-9, at 11.5 feet bgs) during the Phase 2 RI.

3.2 Groundwater Investigations

The following sections present the groundwater investigations conducted in the OU-2 BHRA Area, which were used as the data sources for the BHRAs.

3.2.1 Phase 1 RI

Per the RI/FS Work Plan (ENVIRON 2014c), field work for the Phase 1 RI was conducted between October 2014 and May 2015. The purpose of the Phase 1 RI was to determine the nature and extent of chemicals in soil and groundwater at the NERT Site (OU-1) and in the NERT Off-Site Study Area (including what is now parts of OU-2 and OU-3).

The Phase 1 RI included installation of new monitoring wells, collection of grab groundwater samples, performance of slug tests, and sampling of existing groundwater monitoring wells.

The results of the Phase 1 RI were summarized in the RI Data Evaluation Technical Memorandum (Ramboll Environ 2016a). Data gaps to be addressed in the Phase 2 RI were identified in the same submittal. Analytical results for groundwater samples collected during the Phase 1 RI were presented in the DVSR (Ramboll 2018c) that was submitted on June 22, 2018, and approved by NDEP on August 13, 2018.

In the OU-2 BHRA Area, 13 groundwater samples (including two field duplicate samples) were collected at 11 shallow groundwater well locations with the top of well screens less than 60 feet bgs during the Phase 1 RI, and the VOC data from these shallow groundwater samples are considered in this BHRA.

3.2.2 Phase 2 RI

In accordance with the RI Data Evaluation Technical Memorandum (Ramboll Environ 2016a), the Trust implemented a second phase of remedial investigation (Phase 2 RI) from February to November 2017. In addition, 15 Phase 2 RI Modifications were also conducted from April 2017 to April 2019, and VOC data were collected at shallow groundwater monitoring wells within the NERT Off-Site Study Area (including part of OU-2 and OU-3). The primary purposes of the Phase 2 RI were to obtain data necessary to further understand the nature and extent of impacts to soil and groundwater and support feasibility study evaluations for the selection of the final remedy.

In the OU-2 BHRA Area, new monitoring wells were installed as part of the Phase 2 RI to further characterize the lateral and vertical extent of chemicals in groundwater within the alluvium and underlying UMCf.

Groundwater at each newly installed monitoring well was sampled twice, including during the initial round immediately following well development and during the second round a few months after well development when groundwater conditions had stabilized. In addition, existing monitoring wells were sampled once during the Phase 2 RI.

Analytical results for groundwater samples collected during the Phase 2 RI were presented in three DVSRs, including the Data Validation Summary Report, Revision 1, Soil and Groundwater Remedial Investigation Phase 2, February through June 2017 (Ramboll 2019b), submitted on June 26, 2019, and approved by NDEP on July 10, 2019; the Data Validation Summary Report, Revision 1, Soil and Groundwater Remedial Investigation Phase

2, July through November 2017 (Ramboll 2019c), submitted on May 29, 2019, and approved by NDEP on June 3, 2019; and the Data Validation Summary Report, Remedial Investigation Sampling Phase 2, March 2018 through March 2019, Revision 1 (Ramboll 2020b), submitted on February 14, 2020, and approved by NDEP on April 9, 2020.

In the OU-2 BHRA Area, 70 shallow groundwater samples (including eight field duplicate samples) were collected at 33 monitoring wells with the top of the well screen less than 60 feet bgs during the Phase 2 RI, and the VOC data from these groundwater samples are considered in this BHRA.

3.2.3 Phase 3 RI

As discussed in the RI/FS Work Plan Addendum: Phase 3 Remedial Investigation, Revision 1 (Ramboll Environ 2017a), submitted to NDEP on October 27, 2017, and approved by NDEP on November 8, 2017, the Trust implemented a third phase of remedial investigation (Phase 3 RI) within the Eastside Study Area (including the Eastside Sub-Area in OU-2 and Northeast Sub-Area in OU-3), located immediately east of the NERT Site and NERT Off-Site Study Area. The investigation was designed to determine the extent of contamination that migrated from the NERT Site to the Eastside Study Area via the Beta Ditch and to obtain data to support future feasibility study evaluations to address these constituents. In addition to the sampling in the RI Eastside Study Area, the Phase 3 RI also included samples collected from three locations in the OU-2 BHRA Area that were part of the proposed Phase 2 RI sampling as described the RI Data Evaluation Technical Memorandum (Ramboll Environ 2016a) but could not be installed during the Phase 2 RI field effort. Two shallow groundwater samples were collected from wells PC-168 and PC-172D located in the OU-2 BHRA Area during the Phase 3 RI, and the VOC data from these two groundwater samples are considered in this BHRA. Analytical results for these two groundwater samples collected during the Phase 3 RI were presented in the Phase 3 Remedial investigation Data Validation Summary Report for December 2017 through November 2018 Data (Ramboll 2019d) submitted on September 26, 2019, and approved by NDEP on October 28, 2019.

3.2.4 Groundwater Monitoring and GWETS Performance Reporting

Monitoring for VOCs was first added to the groundwater monitoring program as part of the 2016 Groundwater Monitoring Optimization Plan (Ramboll Environ 2016b) after initial evaluations of Phase 1 RI data suggested that these chemicals were present at detectable levels throughout the NERT Site and the NERT Off-Site Study Area (Ramboll Environ 2016a). The 2016 Annual Remedial Performance Report for Chromium and Perchlorate (Ramboll Environ 2016c) detailed the results of groundwater sampling from the second half of 2015 through the first half of 2016, which was submitted to NDEP on October 31, 2016, and approved by NDEP on December 6, 2016. The analytical results for groundwater samples were also presented in the DVSR (Ramboll 2018d) submitted on June 20, 2018, and approved by NDEP on July 10, 2018. Groundwater samples collected in February and June 2016 were analyzed for VOCs.

Subsequent to the above sampling, additional groundwater sampling for VOCs was conducted in the third quarter of 2016 as part of the Phase 1 RI. The analytical results for groundwater samples collected during this sampling event were detailed in the 2017 Annual Remedial Performance Report for Chromium and Perchlorate (Ramboll Environ 2017d) submitted on December 8, 2017 and approved by NDEP on February 6, 2018, and were also presented in the DVSR (Ramboll Environ 2017e) submitted on July 26, 2017, and approved by NDEP on August 17, 2017.

Comprehensive groundwater sampling for VOCs has been conducted on an annual basis (usually in May every year) as part of the groundwater monitoring program since 2017. The results of groundwater sampling for VOCs conducted in May-June 2017, May 2018, May 2019, and May 2020 were presented in the Annual Remedial Performance Report for Chromium and Perchlorate for 2017 (Ramboll Environ 2017d), 2018 (Ramboll 2018e), 2019 (Ramboll 2019e), and the Annual Groundwater Monitoring and GWETS Performance Report, July 2019 - June 2020 (Ramboll 2021c), respectively.

In summary, in the OU-2 BHRA Area, 225 groundwater samples (including 12 field duplicate samples) were collected at 57 monitoring wells with the top of the well screen less than 60 feet bgs during the February 2016 – May 2020 groundwater remedial performance monitoring sampling events. The VOC data from these groundwater samples are included in this BHRA.

4. DATA USABILITY EVALUATION AND DATA ANALYSIS

This section presents the DUE conducted for the soil gas and groundwater BHRA data sets. Section 4.1 presents the first component of the DUE, in which the available soil gas and groundwater BHRA data sets are reviewed to ensure that the quality of the data is sufficient to support the BHRA; this component of the evaluation focuses on the quality of each individual data point. Section 4.2 presents the data analysis component of the DUE, which focuses on the entire BHRA data set. As described in NDEP guidance (NDEP 2010b), the purpose of the data analysis step is to "use simple exploratory data analysis (EDA) to compare data to the expectations of the CSM for the OU-2 BHRA, to determine if the data adequately represent the source terms and exposure areas or evaluation areas." In particular, through statistical summaries, spatial plots, and other exploratory analyses, the data are reviewed relative to our current understanding of the OU-2 BHRA Area (as represented by the CSM) and for possible data gaps or other investigation issues. A discussion of results from the EDA and a comparison of the BHRA data set to expectations of the CSM for the OU-2 BHRA is presented in Section 4.2.

4.1 Data Usability Evaluation

The DUE was conducted in accordance with NDEP's Supplemental Guidance for Assessing Data Usability for Environmental Investigations at the BMI Facility in Henderson, NV (NDEP 2010b), which is based on the USEPA's Guidance for Data Usability in Risk Assessment (Parts A and B) (USEPA 1992a,b). The USEPA DUE framework provides the basis for identifying and evaluating uncertainties in HRAs with regard to site characterization data. USEPA (1992a) states that "data usability is the process of assuring or determining that the quality of data generated meets the intended use," and that when risk assessment is the intended use, USEPA's guidance "provide[s] direction for planning and assessing analytical data collection activities for the HRA." USEPA has established a specific framework to provide risk assessors a consistent basis for making decisions about the minimum quality and quantity of environmental analytical data to support risk assessment decisions (USEPA 1992a,b; NDEP 2010a). The USEPA data usability guidance identifies the following data quality criteria for evaluating the usability of site investigation data in the risk assessment process:

- Criterion I – Reports to Risk Assessor;
- Criterion II – Documentation;
- Criterion III – Data Sources;
- Criterion IV – Analytical Methods and Detection Limits;
- Criterion V – Data Review; and
- Criterion VI – Data Quality Indicators.

The soil gas and groundwater data sets evaluated using the data quality criteria are identified in Section 4.1.1. Sections 4.1.2 through 4.1.7 briefly describe the evaluation criteria and results of the evaluation. The detailed results are presented in tabular form (Tables 4-1 and 4-2) using the worksheet templates provided by NDEP (2010b).

4.1.1 Soil Gas and Shallow Groundwater Data Sets and Data Processing

Consistent with agency guidance from USEPA (2015), soil gas data collected within the OU-2 BHRA Area since 2008 were used to evaluate potential exposure for current and future residents and workers via inhalation of vapors migrating from the subsurface to indoor air, outdoor air, and trench air. The soil gas data used in this BHRA were specifically collected to evaluate the vapor intrusion pathway. Soil gas data is generally the preferred line of evidence for assessing vapor intrusion risks as opposed to groundwater or soil data primarily due to higher uncertainties associated with vapor intrusion modeling based on groundwater or soil data (i.e., uncertainty in predicting contaminant partitioning from groundwater or soil moisture to soil gas and in predicting transport through the capillary fringe). In addition, the groundwater data used in this BHRA was collected to delineate the groundwater plume and not necessarily for the evaluation of vapor intrusion. Therefore, this BHRA considers the soil gas data as the primary line of evidence for evaluation of the vapor intrusion pathway; the groundwater data were evaluated to provide a secondary line of evidence and to check consistency between soil gas and groundwater results.

Soil Gas

The soil gas BHRA data set comprises the analytical results that are representative of current conditions within the OU-2 BHRA Area. The soil gas sampling locations included in the BHRA data set are presented in Table 4-3. Specifically, the data set includes data for VOCs from soil gas samples collected as part of the following investigations[15]:

- Shallow soil gas samples collected at 5 feet bgs from the 2008 Phase B Soil Gas Investigation;
- Shallow soil gas samples collected at 5 feet bgs and deep soil gas samples collected at 10-15 feet bgs from the 2015 Phase 1 RI;
- Shallow soil gas samples collected at 5 feet bgs and deep soil gas samples collected at 10-15 feet bgs from the Phase 2 RI Modification No. 11; and
- Shallow soil gas samples collected at 5 feet bgs and deep soil gas samples collected at 10-15 feet bgs from the Phase 3 RI Modification No. 9.

Groundwater

Consistent with USEPA's most recent vapor intrusion guidance (USEPA 2015), shallow groundwater data were incorporated in this BHRA to provide a secondary line of evidence for the vapor intrusion risk analysis. All wells with the top of the screen shallower than 60 feet bgs were conservatively included in this BHRA for better spatial coverage. The monitoring wells from which groundwater samples were analyzed for VOCs and included in the BHRA data set are presented in Table 4-4.

According to USEPA (2015), when collecting groundwater data for vapor intrusion analysis it is recommended that groundwater samples be taken from wells screened (preferably over

[15] In the RI soil gas investigations, in addition to sampling at a shallow depth interval (i.e. 5 feet bgs), soil gas sampling data were also collected at a deeper depth (either 10 or 15 feet bgs, depending on depth to groundwater) consistent with current vapor intrusion guidance (USEPA 2015) recommending samples closer to the source (i.e., VOCs in groundwater). The majority of the deeper soil gas samples were collected at 15 feet bgs except that seven soil gas samples were collected at either 10 feet bgs or 13 feet bgs. The soil gas samples collected at 10-15 feet bgs were grouped and evaluated together as deeper soil gas samples in this BHRA.

short intervals) across the top of the water table and that to the extent practical, groundwater samples be collected over a narrow interval (e.g., a few feet or less) just below the water table. As shown in Table 4-4, some of the groundwater VOC data were collected at depths below the first encountered groundwater and may not be the most representative data for evaluating the vapor intrusion pathway. The uncertainties associated with the groundwater well selection is discussed in Section 6.1.1.

The shallow groundwater BHRA data set comprises the analytical results that are representative of current conditions within the OU-2 BHRA Area (Table 4-4). Specifically, the data set includes VOC data from groundwater samples collected from shallow monitoring wells with the top of the well screen less than 60 feet bgs as part of the following groundwater investigations since 2015:

- 2015 Phase 1 RI;[16]
- 2017-2018 Phase 2 RI;
- 2018 Phase 3 RI; and
- 2016-2020 Groundwater Remedial Performance Monitoring.

After identifying the preliminary set of data for the BHRA, an initial task before the DUE was implemented to 1) identify and correct inconsistencies in data field entries and 2) create additional fields to support data management and interpretation for the BHRA data set. The following items were completed:

- Standardize chemical names and Chemical Abstract Service (CAS) registry numbers.
- Standardize reporting units, e.g., micrograms per liter (µg/L) for groundwater and micrograms per cubic meter ($\mu g/m^3$) for soil gas.
- Standardize analytical method names.
- Correct errors in data entry (e.g., typos in sample identification codes).
- Identify a unique result for use in the BHRA for sample/analyte pairs for which more than one result was reported. For example, if two results were reported for 1,2,3-trichloropropane in the same sample – one by USEPA Method 8260 and the other by USEPA Method 8260 Selective Ion Monitoring (SIM) – the result used in the BHRA was identified as that from the 8260 SIM analysis because of the greater sensitivity (lower reporting limits) of this method.
- Calculate the data for total mixtures of a chemical which was analyzed for individual isomers. The purpose of this step is to generate the data to use in the BHRA to match the toxicity values. For example, the data for m,p-xylenes and o-xylene in the same sample were summed to calculate the data for xylenes (total) for which the toxicity values are reported; the data for cis-1,3-dichloropropene and trans-1,3-dichloropropene in the same sample were summed to calculate the data for 1,3-dichloropropene (total) for which the toxicity values are reported.

[16] The Phase 1 RI investigation started in 2014, but the groundwater sampling was conducted in 2015.

- Develop database queries and confirm that queries returned the correct output.

The above steps were necessary due to the approximately 12-year period over which the soil gas data were collected and the approximately six-year period over which the groundwater data were collected. This can be understood in the context of soil gas and groundwater samples collected by different entities, analyzed by different analytical laboratories for overlapping suites of chemicals, and the use of different reporting conventions.

No change was made to a datum without first understanding the issue and the steps necessary to correct the issue. As needed, sampling plans, laboratory reports, DVSRs, and other supporting documents were reviewed. Data points were considered unusable for risk assessment if information could not be located to confirm and/or correct an identified issue. No soil gas data were excluded from the BHRA data set during data processing. Shallow groundwater data excluded from the BHRA data set during data processing are summarized in Appendix C, Table C-1.

The soil gas and groundwater BHRA data sets are presented in Appendices D and E (Table D-1 for soil gas and Table E-1 for groundwater). The soil gas BHRA data set includes a total of 136 soil gas samples collected at 50 locations, consisting of 11 soil gas samples at 10 locations collected from the Phase B soil gas investigation (ENSR 2008a) and 125 soil gas samples collected at 40 locations during the RI (i.e., Phase 1 RI, Phase 2 RI Modification No. 11, and Phase 3 RI Modification No. 9). The groundwater data set includes 310 groundwater samples collected from 79 locations, consisting of 85 groundwater samples at 44 locations collected during the RI (i.e., Phase 1 RI, Phase 2 RI, and Phase 3 RI), and 225 groundwater samples at 52 locations collected as part of the groundwater monitoring and GWETS performance reporting program.[17]

4.1.2 Criterion I – Reports to Risk Assessor

Criterion I requires confirmation that the reports relied upon are complete and appropriate for use in the HRA. The required information specified under this criterion was verified and is available in the documents associated with the data collection efforts, as listed in Tables 4-1 and 4-2.

4.1.3 Criterion II – Documentation

The objective of the documentation review is to confirm that each analytical result can be associated with a specific sampling location and that the procedures used to collect the samples are appropriate. As part of this DUE step, Ramboll completed a comprehensive review of the soil gas and groundwater samples collected and reported in the documents listed under Criterion I and/or in the NERT project database. The steps completed during the review are listed in Tables 4-1 and 4-2. Figure 4-1 depicts all soil gas and shallow groundwater sampling locations (groundwater wells and soil gas probes) included in the BHRA data set. The analytical results for each soil gas and shallow groundwater sample are included in Appendices D and E, respectively.

[17] Some of the monitoring wells were sampled as part of the RI and in the groundwater monitoring program.

4.1.4 Criterion III – Data Sources

The objective of the data sources review is to ensure that adequate sample coverage of source areas has been obtained and that the analytical methods are appropriate to identify chemicals and derive associated exposure point concentrations (EPCs) for the BHRA.

The review of sample coverage from the BHRA data sets are described in Tables 4-1 and 4-2, which are based on the distribution of sample locations from both historical and recent investigations. Based on this review, sample coverage is considered adequate for purposes of the BHRA.

The analytical methods used in the soil gas investigations conducted in the OU-2 BHRA Area are described in Tables 4-1 and 4-2. The USEPA analytical methods were appropriate for characterizing potential VOCs in soil gas and shallow groundwater and provide quantitative analytical results that are of adequate quality for deriving EPCs.

4.1.5 Criterion IV – Analytical Methods and Detection Limits

Criterion IV requires that the analytical method appropriately identifies the chemical form or species, and that for each chemical, the sample quantitation limit (SQL) is sufficiently low for risk characterization. The analytical methods used for the historical and recent investigations are listed in Tables 4-1 and 4-2.

For analytes where the detection frequency was less than 100%, the SQLs from the BHRA data set were compared to 0.1 times the risk-based target concentration (RBTC) to confirm that they were sufficiently low for risk characterization. For chemicals where a RBTC was not available, representative surrogates were identified and used for the comparison. Tables 4-5, 4-6, and 4-7 present the results of the SQL evaluation along with the RBTCs for soil gas at 5 feet bgs, 10-15 feet bgs, and groundwater, respectively. Chemicals with SQLs above 0.1 x RBTCs in soil and groundwater are summarized under Criterion IV in Tables 4-1 and 4-2, respectively.

Overall, the SQLs were sufficiently low for risk characterization. The impacts of the few exceptions with elevated SQLs on the overall risk evaluation are further discussed in the uncertainty section (Section 6.1.2).

4.1.6 Criterion V – Data Review

The data review included evaluation of completeness, instrument calibration, laboratory precision, laboratory accuracy, blanks, adherence to method specification and quality control (QC) limits, and method performance in sample matrix. Details of this review are presented in Tables 4-1 and 4-2. In summary, the tabular summaries of the data qualifications included in the NDEP-approved DVSRs listed in Criterion I were reviewed, and with the exception of the rejected data discussed in the DVSRs, all data are deemed to be usable for risk assessment purposes. These data qualifications are further discussed in Section 4.1.7 as a component of Criterion VI.

4.1.7 Criterion VI – Data Quality Indicators

The project QAPPs (ENSR 2008c, ENVIRON 2014d, Ramboll Environ 2017c, and Ramboll 2019f) identified five data quality indicators (DQIs) to ensure that the overall quality of the data is sufficient to support the risk assessment, as follows: completeness, comparability, representativeness, precision, and accuracy. The DQIs provide quantitative and qualitative measures for evaluating the risk assessment data as they relate to uncertainties in the selection of VOCs, characterization of EPCs, and risk descriptors used in support of the BHRA and the risk management decisions that will be made for the OU-2 BHRA Area. Specifically, the DQIs address field and analytical data quality aspects as they affect uncertainties in the data collected for site characterization and risk assessment.

The DQI evaluation is presented in Tables 4-1 and 4-2. Based on the evaluation, the overall goals for data quality for risk assessment were achieved, and all DVSRs were reviewed and approved by NDEP. In summary, except the rejected data discussed in Tables 4-1 and 4-2 and listed in Appendix C, Table C-2, all data are deemed to be usable for risk assessment purposes.

4.2 Data Analysis

As described in NDEP guidance (NDEP 2010a), the purpose of the data analysis step is to "use simple exploratory data analysis to compare data to the expectations of the CSM, to determine if the data adequately represent the source terms and exposure areas or evaluation areas." Consistent with guidance, the steps of the EDA, as described in the following sections, include 1) preparation of summary statistics for the BHRA data set (Section 4.2.1), 2) preparation and review of spatial plots for detected analytes (Section 4.2.2), 3) preparation and review of temporal trends of VOC concentrations in groundwater (Section 4.2.3), 4) preparation and review of plots of VOC concentrations in co-located soil gas and shallow groundwater samples (Section 4.2.4), and 5) review and discussion of the EDA in the context of current and former land use and operations within the OU-2 BHRA Area and the CSM (Section 4.2.5).

4.2.1 Summary Statistics

This section presents summary statistics for the analytical data for soil gas samples and shallow groundwater samples included in this BHRA.

Summary statistics for analytical data are presented in Tables 4-8 and 4-9 for the soil gas samples collected at 5 feet bgs and at 10-15 feet bgs, respectively. Summary statistics for analytical data collected from the shallow groundwater samples are presented in Table 4-10. Individual sample locations are shown in Figure 4-1.

In developing the summary statistics, soil gas and groundwater samples with primary and field duplicate results were treated as independent samples. The effects of duplicate treatment on the overall risk evaluation are further discussed in Section 6.1.5.

For most analytes, the summary statistics are based on the results of between 40 and 80 samples for soil gas and 270-290 samples for groundwater, although the soil gas analytical data set for some analytes is much more limited (<20 samples). However, the analytes with limited sample size were never detected and/or were not site-related. Therefore, the limited sample size for these analytes does not have any impact on the overall risk evaluation.

Considering the data review conducted by both Ramboll and NDEP for each soil gas and groundwater investigation, the OU-2 soil gas and groundwater BHRA data sets are considered adequate for risk assessment purposes.

4.2.2 Spatial Analysis of VOCs in Soil Gas and Groundwater

Spatial quartile plots (Figures 4-2 through and 4-4) were prepared for chloroform which is the most widespread VOC in the OU-2 BHRA Area (Ramboll 2021a), to illustrate the spatial distribution of the data, identify potential locations where risk exceeds target thresholds, and compare the results to the expectations of the CSM. Each spatial quartile plot presents the following information:

- Sample locations;
- Chloroform plume; and
- Chemical concentrations. The concentration shown at each location is the maximum detected concentration among all samples, unless results for all samples at that location were reported as less than the detection limits; concentration bins are defined as follows:
  - ✓ Dark green – concentrations < detection limits;
  - ✓ Light green – concentrations <Q1 (25th percentiles);
  - ✓ Yellow – concentrations within the interquartile range (IQR, the difference between the 75th and 25th percentiles);
  - ✓ Orange – concentrations >Q3 (75th percentiles) and <= (Q3 + 1.5×IQR); and
  - ✓ Red – concentrations >(Q3 + 1.5×IQR).

The spatial quartile plots are presented in Figures 4-2 through 4-4 for chloroform in soil gas at 5 feet bgs, in soil gas at 10-15 feet bgs, and in shallow groundwater, respectively.

4.2.3 Temporal Trends of Chloroform in Soil Gas and Groundwater

Soil Gas

To analyze the temporal trend of chloroform concentrations in soil gas in the OU-2 BHRA Area, soil gas samples collected from 5 feet bgs and 10-15 feet bgs during the Phase 1 RI in March 2015, Phase 2 RI Modification No. 11 in March 2019, and Phase 3 RI Modification No. 9 in March 2019 to November 2019 were extracted from the OU-2 soil gas BHRA data set (Appendix D) and selected for temporal trend plotting. The locations for the time series plots were selected based on the following criteria:

- Locations sampled in at least three investigations (see Table 4-3);
- Locations co-located with shallow groundwater wells; and
- Locations with high chloroform concentrations (i.e., approximately 1,000 µg/m3 or above).
- The locations selected for time series plots were RISG-1, RISG-2, and RISG-3. As indicated in Figures 4-5 and 4-6, the soil gas concentrations of chloroform in RISG-1, RISG-2, and RISG-3 at 10 to 15 feet bgs were generally greater than the

concentrations of chloroform in the same wells at 5 feet bgs. At 5 feet bgs, the concentrations of chloroform at RISG-2 and RISG-3 decreased approximately 66% and 87%, respectively, from 2015 to 2019. The chloroform concentration in RISG-1 remained relatively stable and changes are within 8% from 2015 to 2019. At 10 to 15 feet bgs, the concentrations of chloroform in RISG-2 and RISG-3 decreased approximately 66% and 65%, respectively from 2015 to 2019. The chloroform concentrations in RISG-1 decreased approximately 24% from 2015 to March 2019, then increased approximately 38% from March to November 2019.

Shallow Groundwater

To analyze the temporal trend of chloroform concentrations in shallow groundwater in the OU-2 BHRA Area, chloroform concentrations in selected wells were extracted from the OU-2 shallow groundwater BHRA data set (Appendix E) and plotted over the time period from 2015 to 2020 (see Figure 4-7). These groundwater chloroform results were collected during Phase 1 RI in January 2015 and the groundwater performance monitoring programs from May 2017, May 2018, May 2019, and May 2020. The wells for the time series plots were selected based on the following criteria:

- Wells sampled in at least three sampling events (see Table 4-4);
- Wells co-located with higher concentrations in soil gas; and
- Wells at locations with cancer risk above 1 x 10-6 (see Section 5.4.2).

The wells selected for time series plots were PC-21A (located near RISG-3), PC-24 (located near RISG-2), PC-28, and PC-67 (located near RISG-1). As indicated in Figure 4-7, the concentrations of chloroform for all wells generally decreased from 2015 to 2020. The chloroform concentrations in PC-21A decreased approximately 68% from 2015 to 2020. The chloroform concentrations in PC-24 decreased approximately 83% from 2015 to 2019, then remained relatively stable with changes within 11% from 2019 to 2020. The chloroform concentrations in PC-28 decreased approximately 53% from 2015 to 2017, then remained relatively stable with changes within 11% from 2017 to 2020. The chloroform concentrations in PC-67 decreased 58% from 2015 to 2019, then slightly increased approximately 19% from 2019 to 2020. The temporal trend of chloroform concentrations detected in the shallow groundwater samples are generally consistent with the chloroform concentrations detected in the co-located soil gas samples.

4.2.4 Chloroform in Co-located Soil Gas and Groundwater Samples

A comparison of chloroform concentrations in co-located soil gas and shallow groundwater samples was conducted to confirm that groundwater is the source of chloroform detected in soil gas. The soil gas and shallow groundwater samples used to examine the correlation were collected within the same general timeframe, (i.e., soil gas samples were collected during the RI sampling in March 2019) and shallow groundwater samples were collected during the groundwater monitoring sampling event in May 2019. Only the shallow groundwater samples most representative for characterizing representative vapor source concentrations for vapor intrusion assessment were included in the analysis.

The data and scatterplots of chloroform concentrations are presented in Figure 4-8 for co-located 5 feet bgs soil gas and shallow groundwater samples, and in Figure 4-9 for co-located 15 feet bgs soil gas and shallow groundwater samples. Data were plotted on both arithmetic and logarithmic scales. Given the wide range of reported chloroform concentrations, the logarithmic scale generally provides a more even data distribution across the concentration range and a better visualization of results reported at low concentrations. As indicated in Figures 4-8 and 4-9, strong and statistically significant positive correlations between chloroform concentrations in soil gas (both 5 and 10-15 feet bgs) and shallow groundwater were observed in plots on both arithmetic and logarithmic scales for soil gas concentrations at 5 feet bgs and for plots on an arithmetic scale for soil gas concentrations at 10 to 15 feet bgs, with squared correlation coefficients (R^2 values) greater than 0.6 and p values less than 0.05. For the plot on an arithmetic scale for soil gas concentrations at 10 to 15 feet bgs, the square correlation coefficient (R^2 value) is 0.49 and the p value is 0.12. However, some limitations in the data set must be considered when interpreting the correlations:

- Eight pairs of co-located soil gas at 5 feet bgs samples and shallow groundwater samples and six pairs of co-located soil gas samples at 10 to 15 feet bgs and shallow groundwater samples were included in this analysis. Some of the pairs have relatively low chloroform concentrations reported in soil gas and/or shallow groundwater and the correlation between these low chloroform concentrations in soil gas and groundwater tends to show higher variability. As a result, the strength of the correlation is determined primarily by the sample pairs in the high concentration range when data are plotted on an arithmetic scale. For plots on a logarithmic scale, the data are more evenly distributed across the concentration range and show stronger and more statistically significant positive correlations between the co-located soil gas and chloroform concentrations.
- For sample pair RISG-9/PC-31, the soil gas sample location (RISG-9) was near but not immediately adjacent to the shallow groundwater well (PC-31) (see Figure 4-1).[18] The results in this sample pair fall in the low concentration range, where the data tends to show higher variability.

In summary, based on the data evaluated, strong and statistically significant positive correlations were observed between the chloroform concentrations in soil gas (both 5 and 10 to 15 feet bgs) and shallow groundwater. In addition, the chloroform concentrations detected in the deeper soil gas samples collected at 10-15 feet bgs are consistently higher than the ones detected in shallow soil gas samples collected at 5 feet bgs. These results all support the CSM that groundwater is the source of chloroform detected in soil gas in OU-2 rather than a source in the vadose zone.

4.2.5 Comparison with Conceptual Site Model

As the last step of the DUE, results from the EDA (i.e., summary statistics, background evaluation, spatial analysis, temporal analysis, and correlation analysis based on co-located soil gas and groundwater results) should be used to compare the data included in the OU-2 BHRA to the expectations of the CSM. The Site-wide CSM was summarized in the RI Report for OU-1 and OU-2 (Ramboll 2021a). This section focuses on the comparison of EDA results to the applicable CSM components, specifically those related to the OU-2 BHRA Area,

[18] PC-166 is co-located with RISG-9; however, this well was not sampled in 2019.

including historical operations, sources of impacts, and migration and distribution of contaminants in soil gas and shallow groundwater, which are summarized below:

- Soil gas concentrations generally increased with depth indicating that chloroform present in soil gas is from groundwater rather than a source in the vadose zone.
- Elevated chloroform concentrations in shallow groundwater in the OU-2 BHRA Area result from migration from upgradient source(s) of contamination (i.e., the OSSM site, OU-1, and the TIMET site).

The details of the EDA (including the review of the spatial quartile plots, Figures 4-2 through 4-4) are presented in Sections 4.2.1 through 4.2.4. Comparison of EDA results to the westside CSM is discussed below.

As part of the ongoing RI/FS, NERT completed an extensive review of existing information and data generated previously in the NERT RI Study Area and developed a preliminary Site-wide CSM, as presented in the RI/FS Work Plan (ENVIRON 2014a). More recently, NERT conducted further review and analysis of historical and recently collected sampling results to assess the magnitude and extent of contaminants (including chloroform) in soil, soil gas, and groundwater within OU-1 and OU-2, including groundwater sampling within the OU-2 BHRA Area and development of an updated Site-wide CSM which is presented in the RI Report for OU-1 and OU-2 (Ramboll 2021a).

As discussed in the Site-wide CSM in the RI Report for OU-1 and OU-2 (Ramboll 2021a) and shown in Figure 4-10, OU-2 is immediately north (downgradient) of OU-1 and extends to the east. Due to substantial differences in historical land use and source areas in OU-2 east and west of Pabco Road, separate CSMs have been established (i.e., East Side and West Side CSMs). The West Side CSM is comprised of OU-1 and the NERT Off-Site Study Area component of OU-2, west of Pabco Road. As depicted in the West Side CSM (Figure 4-11), property in the OU-2 BHRA Area has been used for residential or commercial purposes unrelated to the historic and current operations of the BMI Complex, inclusive of OU-1. There are no current sources of NERT Site-related contamination within the OU-2 BHRA Area; however, groundwater contamination is present within this area resulting from migration in groundwater from upgradient sources (including OU-1). In addition, chemical migration in groundwater associated with releases that occurred during the early years of manufacturing within OU-1 and adjacent properties within the BMI Complex has resulted in residual contamination in the UMCf which acts as an on-going source of contamination to the overlying alluvium via slow upward matrix diffusion (Ramboll 2021a and Figure 4-11).

As discussed in detail in the RI Report for OU-1 and OU2, within the OU-2 BHRA Area, the primary source of VOC contamination in groundwater is the migration in groundwater from upgradient sites, including OU-1, the OSSM site, and the TIMET site. The locations of these upgradient properties are shown on Figure 1-2. Chloroform and other VOCs migrating from OU-1 originates from multiple source areas including former manufacturing operations within OU-1, OSSM's dense non-aqueous phase liquid (DNAPL) and groundwater plume, and the TIMET site. The highest concentrations of chloroform migrating into OU-2 are associated with OSSM's trespassing plume which migrates into OU-1 across the western border of OU-1, migrates across OU-1 within the UMCf in a northwesterly direction, passes between OSSM's and NERT's GWETS, and migrates into OU-2. Migration of chemicals offsite north of the OSSM property was largely mitigated after the installation of the OSSM groundwater extraction and treatment system in 1983. However, VOCs still remain in groundwater downgradient of the OSSM extraction wells. These VOCs are a combination of legacy contamination that migrated to this area prior to construction of OSSM's GWETS and contaminants that migrated into OU-1 from the OSSM site and then migrated into OU-2 between the OSSM and NERT GWETS. As indicated previously, VOCs related to the TIMET site have also been identified in the OU-2 BHRA Area and continue to migrate northward across OU-2. A bentonite-slurry barrier wall and GWETS were installed by TIMET in 2014 along the northern boundary of the TIMET property to capture and treat groundwater contaminated by VOCs. Prior to the installation of the barrier wall and groundwater extraction and treatment system, VOCs in groundwater migrated from the TIMET site offsite into OU-2. Given when the extraction systems were installed at each property (1983 for OSSM, 1987 for NERT, and 2014 for TIMET), uncontrolled chloroform migrated from the TIMET site into OU-2 for approximately 30 years longer than from the OSSM site and OU-1. As shown in Figures 4-8 and 4-9, the strong and statistically significant positive correlations between chloroform concentrations in soil gas (both at 5 and 10 - 15 feet bgs) and shallow groundwater support the CSM that groundwater is the source of chloroform detected in soil gas in the OU-2 BHRA Area. Additionally, soil gas concentrations generally increase with depth, indicating that VOCs present in soil gas are migrating upward from groundwater rather than a source in the vadose zone. This is consistent with the CSM for the OU-2 BHRA Area because no industrial activities were reported to have occurred in this area.

As shown in Figures 4-2 through 4-4, the highest chloroform concentrations are in the area which is located downgradient of the TIMET site and OSSM's plume (which migrates across OU-1 into OU-2). This is consistent with the findings in the West Side CSM for OU-2 in the RI Report for OU-1 and OU-2 (Ramboll 2021a) because the particle tracking, and plume geometry evaluations indicate that sources within the TIMET site are the primary sources of the chloroform plume in the OU-2 BHRA Area (Ramboll 2021a). OSSM's trespassing plume contains higher concentration of chloroform but has not migrated north of Boulder Highway. VOCs in the dissolved phase migrating from the upgradient sources and are present in the shallow and middle water bearing zones (WBZs) are expected to have impacts on concentrations in soil gas in the western portion of OU-2 (Ramboll 2021a).

In summary, the soil gas and shallow groundwater data are consistent with the expectations of the NERT Westside CSM, indicating that groundwater is the main source of chloroform detected in soil gas in the OU-2 BHRA Area.

5. BASELINE HEALTH RISK ASSESSMENT

The following sections describe the methodology for evaluating potential health risks associated with vapor migration from soil gas and groundwater, which includes the following elements:

- Identification of chemicals to be evaluated;
- Exposure assessment;
- Toxicity assessment; and
- Risk characterization

The soil gas and groundwater BHRA for the OU-2 BHRA Area uses the approach described in the NDEP-approved 2018 BHRA Work Plan (Ramboll 2018a), with incorporation of additional recent soil gas and shallow groundwater VOC data.

This BHRA follows the procedures outlined in the USEPA's Risk Assessment Guidance for Superfund: Volume I—Human Health Evaluation Manual (USEPA 1989). Other guidance documents consulted in preparing the BHRAs include:

- Guidelines for Exposure Assessment (USEPA 1992c);
- Soil Screening Guidance: Technical Background Document (USEPA 1996);
- Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites (USEPA 2002a);
- Office of Solid Waste and Emergency Response (OSWER) Draft Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway from Groundwater and Soils (Subsurface Vapor Intrusion Guidance) (USEPA 2002b);
- User's Guide for Evaluating Subsurface Vapor Intrusion into Buildings (USEPA 2004b);
- Technical and Regulatory Guidance, Vapor Intrusion Pathway: A Practical Guideline (Interstate Technology & Regulatory Council [ITRC] 2007);
- Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual (Part F, Supplemental Guidance for Inhalation Risk Assessment) (USEPA 2009);
- Soil Physical and Chemical Property Measurement and Calculation Guidance, BMI Plant Sites and Common Areas Projects, Henderson, Nevada (NDEP 2010d).
- OSWER Technical Guide for Assessing and Mitigating the Vapor Intrusion Pathway from Subsurface Vapor Sources to Indoor Air (USEPA 2015);
- User's Guide and Background Technical Document for NDEP Basic Comparison Levels (BCLs) for Human Health for the BMI Complex and Common Areas (NDEP 2017a); and
- Regional Screening Levels – User's Guide (USEPA 2021).

5.1 Identification of Chemicals to be Evaluated

As indicated previously, this BHRA quantitatively evaluates the risk associated with VOCs in soil gas and groundwater within the OU-2 BHRA Area.[19] All VOCs detected in one or more soil gas or groundwater samples in the BHRA data sets described in Section 4 were quantitatively evaluated in this BHRA. The list of VOCs detected in soil gas and groundwater is presented in Table 5-1. A total of 67 and 51 VOCs were detected in soil gas collected at 5 feet bgs and 10-15 feet bgs, respectively. A total of 23 VOCs were detected in shallow groundwater.

5.2 Exposure Assessment

The exposure assessment analyzes chemical releases and the physical setting, identifies exposed populations and exposure pathways, and estimates exposure concentrations and chemical intakes for the identified pathways. The exposure assessment includes the CSM, fate and transport modeling, and exposure assumptions and calculations, as discussed in the following sections.

5.2.1 Conceptual Site Model and Exposure Scenarios

To evaluate the human health risks posed by a site, it is necessary to identify the populations that may potentially be exposed to the chemicals present and to determine the pathways by which these exposures may occur. A CSM was developed in order to characterize potential human exposures in the OU-2 BHRA Area. The CSM outlines information relevant to conducting the exposure assessment by 1) evaluating potential chemical sources and releases, 2) identifying populations that could potentially be exposed to chemicals present in the OU-2 BHRA Area, and 3) identifying exposure pathways and routes through which human exposure might occur. The CSM can be an important tool in guiding site characterization, evaluating data quality in the context of potential risks to exposure populations, and developing exposure scenarios.

Development of the CSM is an iterative process; the CSM is revised, as appropriate, over the course of an RI based on additional information and understanding gained following review of existing and newly collected data. A CSM was first developed for the NERT Site in 2005 based on the information available at that time (ENSR 2005). The 2005 CSM presented detailed information on the LOU source areas identified by NDEP, summarized available analytical results for each LOU, and identified the NERT Site-related chemicals based on a review of the activities and/or processes associated with each LOU. Potential contaminant migration pathways and receptors were also described. The CSM was updated in 2014 during development of the RI/FS Work Plan (ENVIRON 2014a) and covered both the NERT Site and downgradient areas, which provided a refined, but still preliminary, identification of sources, release mechanisms, exposure media, exposure routes, and potentially exposed populations based on a then current understanding of on-Site and off-Site environmental conditions. The Site-wide CSM was revised and summarized in the RI Report for OU-1 and OU-2 (Ramboll 2021a). In this BHRA, the CSM for the OU-2 BHRA

[19] Incidental ingestion of groundwater and dermal contact with groundwater during short-term construction activities is possible in the very limited areas where depth to groundwater is less than 10 feet bgs. Due to the limited number of monitoring wells and the low concentrations detected at these wells, significant health risks are not expected to occur through the groundwater direct contact pathway in this area. This potential pathway is discussed as part of the uncertainty analysis in Section 6.2.4 of this BHRA.

Area has been updated by incorporating the findings from the RI Report for OU-1 and OU-2 (Ramboll 2021a) and is presented in Figure 5-1. The major elements of the CSM are discussed below.

5.2.1.1 Potential Chemical Sources and Release Mechanisms

As discussed in Section 1, OU-2 is immediately downgradient of OU-1 and extends east/northeast for approximately two miles. The subject of this BHRA is the NERT Off-Site Study Area component of OU-2 located west of Pabco Road, also referred to the OU-2 BHRA Area. In summary, the following are the identified sources of groundwater VOC contamination in the OU-2 BHRA Area (Ramboll 2021a):

- Migration of groundwater from OU-1 into OU-2. As discussed in Section 9 of the RI Report for OU-1 and OU-2, the sources of VOCs in OU-1 groundwater are related to releases from historic operations at the Unit 4 and 5 Buildings, the former P and S Ponds, the former unlined Beta Ditch, the former AP Plant and associated facilities, and features north of the interceptor well field (IWF)/barrier wall (e.g., the former Trade Effluent Ponds and recharge trenches). In addition, trespassing VOCs from the OSSM plume have impacted groundwater in OU-1 and continue to migrate uncontrolled from OU-1 into OU-2.
- Migration of chemicals in groundwater from the OSSM site, across OU-1 and into OU-2. The highest concentrations of chloroform in groundwater within OU-2 are located downgradient of OSSM's plume (which migrates across OU-1 into OU-2). This VOC plume contains the highest concentrations of chloroform found in OU-2.
- Migration of VOCs in groundwater directly downgradient from the OSSM site into OU-2. VOCs including chloroform and elevated TDS originating from the OSSM site are detected in OU-2 groundwater in the area downgradient of the OSSM extraction wells. Migration of VOCs north of the OSSM property was mitigated after the installation of their groundwater extraction and treatment system. However, VOCs still remain in groundwater downgradient of the OSSM extraction wells.
- Migration of VOCs in groundwater directly downgradient from the TIMET Site into OU-2. Elevated PCE and chloroform are detected in OU-2 groundwater in the area downgradient of the TIMET Site.
- Upward migration. Residual contamination in the UMCf has been and will continue to be an ongoing source to shallower groundwater within OU-2 via upward migration due to matrix diffusion and the upward gradient. Upward migration will be significant for the chemicals that have impacted the UMCf first in OU-1 and the OSSM and TIMET sites and then migrated within the UMCf to OU-2, including perchlorate, chlorate, chromium, and chloroform. The mass of these chemicals in the UMCf will continue to slowly migrate upwards into the alluvium for an extended period of time.

As discussed in Section 1, land in the OU-2 BHRA Area has been used for residential or commercial purposes unrelated to operation of OU-1 or the BMI Complex. Therefore, the source of Site-related contamination within this area is groundwater contamination that resulted from migration of chemicals in groundwater from upgradient sources. As discussed in the RI Report for OU-1 and OU-2 (Ramboll, 2021) some impacts from the infiltration of contaminants from wastewater that migrated through former ditches may have impacted groundwater. In addition, residual contamination in the UMCf represents a long-term secondary source to shallow groundwater.

Historical releases from potential source areas have been documented or inferred from field investigations. As indicated in the CSM (Figure 5-1), chemicals were released from upgradient sources through several primary release mechanisms, such as spills/leaks and infiltration/overtopping to soils and runoff to surface water. In addition to the primary release mechanisms, secondary/tertiary release mechanisms included leaching of chemicals into groundwater, transport to the OU-2 BHRA Area, and, finally, migration of VOCs in the subsurface through the soil column to indoor air, outdoor air, or trench air. The potentially contaminated exposure media in the OU-2 BHRA Area include air and groundwater. Potential exposures to surface water (i.e., runoff) by populations located in the OU-2 BHRA Area were not quantitatively evaluated in the BHRA because there are no significant surface water bodies in the area. As discussed in Section 1, exposure via domestic use of groundwater was not evaluated because groundwater in OU-2 is not and is not anticipated to be used as a domestic water supply. Incidental ingestion of and dermal contact with groundwater during short-term construction activities are not considered complete exposure pathways in most of the OU-2 BHRA Area to the groundwater depth being greater than 10 feet bgs. Depths to groundwater in a very limited area near monitoring wells PC-161 and PC-162 were identified to be shallower than 10 feet bgs. Potential exposures through direct contact with groundwater may occur during construction excavation activities in this area. Due to limited numbers of wells with depth to groundwater shallower than 10 feet bgs in the OU-2 BHRA Area and the low concentrations detected at these two wells, significant health risks are not expected to occur through the groundwater direct contact pathway in this area. The health risks associated with this pathway are semi-quantitatively discussed as part of the uncertainty analysis in Section 6.2.4.

5.2.1.2 Potentially Exposed Human Populations and Exposure Pathways

For a complete exposure pathway to exist, all of the following elements must be present (USEPA 1989):

- A source and mechanism for chemical release;
- An environmental transport medium (i.e., air, water, soil);
- A point of potential human contact with the exposure medium; and
- A route of exposure (e.g., inhalation, ingestion, dermal contact).

The current and future land use in the OU-2 BHRA Area is mixed commercial/light industrial and residential use. Accordingly, the potentially exposed populations identified for the BHRA include indoor industrial/commercial workers, outdoor industrial/commercial workers, short-term construction workers, and residents, consistent with USEPA guidance (2002b).

Based on the source and release mechanisms presented in the CSM, the following exposure pathways are identified for quantitative evaluation in this BHRA:

- Residents

- ✓ Inhalation of vapors migrating from soil gas/groundwater to indoor air in a slab-on-grade building
- ✓ Inhalation of vapors migrating from soil gas/groundwater to indoor air in a residential trailer

- Indoor commercial/industrial workers
  - ✓ Inhalation of vapors migrating from soil gas/groundwater to indoor air
- Outdoor commercial/industrial workers
  - ✓ Inhalation of vapors migrating from soil gas/groundwater to outdoor air
- Construction workers
  - ✓ Inhalation of vapors migrating from soil gas/groundwater to trench air[20]

To be conservative, construction workers are assumed to be exposed to vapors migrating from soil gas/groundwater while standing in a 10-foot trench in the unsaturated zone, placing them closer to the potential sources.

5.2.2 Fate and Transport Modeling

Fate and transport modeling was conducted to characterize the VOCs migrating from soil gas or groundwater into indoor air, outdoor air, and trench air for the residents and workers in the OU-2 BHRA Area. The physical and chemical properties, soil properties, and modeling parameters used in the fate and transport modeling are summarized in Tables 5-2, 5-3, and 5-4, respectively.

The migration of VOCs detected in soil gas or groundwater were quantified through an intermedia transfer factor. When the transfer factor is multiplied by the source concentration of a chemical in soil gas (in $\mu g/m^3$) or groundwater (in µg/L), the product is the predicted steady-state concentration in indoor, outdoor, or construction trench air (in $\mu g/m^3$), which represents the EPC in the air to which a receptor (i.e., a member of a potentially exposed population) is exposed over an assumed duration of exposure. In general, we use the term "transfer factor" to refer to transport from either soil gas or groundwater in lieu of the term "attenuation factor", which is applicable to only transport from soil gas to air (i.e., within the same medium).

For populations in the western portion in OU-2, Ramboll developed transfer factors for the following scenarios:

- Transport of soil gas from five, 10 and 15 feet bgs into a current/future residential slab-on-grade building.

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[20] Potential exposures through direct contact with groundwater may occur during construction excavation activities. However, due to limited numbers of wells with depth to groundwater shallower than 10 feet bgs in the OU-2 BHRA Area and the low concentrations detected at these wells, significant health risks are not expected to occur through the groundwater direct contact pathway. Therefore, quantitative evaluation for the groundwater direct contact pathway were not conducted and the health risks associated with this pathway were semi-quantitatively discussed as part of the uncertainty analysis in Section 6.2.4.

- Transport of soil gas from five, 10, and 15 feet bgs into a current/future residential trailer.
- Transport of soil gas from five, 10, and 15 feet bgs into a commercial/industrial slab-on-grade building.
- Transport of soil gas from five, 10, and 15 feet bgs to outdoor air for an outdoor commercial/industrial worker scenario.
- Transport of soil gas from five feet away from the wall and five feet below the base into a 10-foot construction trench.
- Transport of vapors from groundwater at 10 and 20 feet bgs into a current/future residential slab-on-grade building.
- Transport of vapors from groundwater at 10 and 20 feet bgs into a current/future residential trailer.
- Transport of vapors from groundwater at 10 and 20 feet bgs into a commercial/industrial slab-on-grade building.
- Transport of vapors from groundwater at 10 and 20 feet bgs to outdoor air for an outdoor commercial/industrial worker scenario.
- Transport of vapors from groundwater at one foot below the base of a 10-foot dry construction trench into the trench for wells with depth to groundwater shallower than 20 feet bgs.
- Transport of vapors from groundwater at 10 feet below the base of a 10-foot dry construction trench into the trench for wells with depth to groundwater at 20 feet bgs or deeper.

The intermediate transfer factors were estimated using the screening-level model described by Johnson and Ettinger (1991). Specifically, the USEPA Spreadsheet Modeling Subsurface Vapor Intrusion, version 6.0 (USEPA 2017) was used. The Johnson and Ettinger model was originally developed to predict vapor intrusion into buildings using a combination of diffusion and advection. However, as described below, it is easily adapted to predict vapor intrusion into outdoor air or trench air. The calculation of transfer factors was based on parameters describing the properties of the chemicals evaluated, the vadose zone, the surface barrier, and the air dispersion zone. The physical/chemical properties for the VOCs detected in soil gas and groundwater that were used in these calculations are presented in Table 5-2. Based on guidance from USEPA (2018a), only chemicals that easily volatilize were included in the evaluation of vapor migration. These include chemicals with a Henry's Law constant of greater than 1×10^{-5} atm-m^3/mole or a vapor pressure of greater than 1 millimeter of mercury (mm Hg). The source of all physical/chemical properties is noted in Table 5-2. In general, priority is given to the most recent physical/chemical data as well as the most relevant data for a site located in Nevada. As such, the hierarchy for selecting physical/chemical properties is:

1. NDEP values from the BCL tables (NDEP 2017a);
2. USEPA values from the Johnson and Ettinger model (USEPA 2017);
3. USEPA values from the regional screening level (RSL) tables (USEPA 2021b); and

4. USEPA values from EPISuite (2012) combined with using surrogate chemicals for diffusivities in air and water.

Soil physical properties, including soil classification (grain size distribution/Atterberg Limits), total organic carbon, bulk density, water content, and total porosity were collected at 5 feet bgs and 10-15 feet bgs at nine soil gas sample locations during the Phase 2 RI Modification No. 11 sampling, where the soil properties had not been collected previously[21] in the OU-2 BHRA Area. The Phase 2 RI Modification No. 11 soil physical property testing reports are included in Appendix F; the soil property data are summarized in Table 5-3.

Depth to groundwater was determined by evaluating both current and historic groundwater elevations for non-artisanal shallow wells within the OU-2 BHRA Area. Depth to groundwater ranges from approximately 20 to 60 feet bgs, with depth to groundwater shallower than 20 feet at some locations (see Table 4-4). To be conservative, a depth of groundwater of 10 and 20 feet bgs were selected for modeling in this BHRA.[22]

A conservative default commercial/industrial building was assumed for the indoor air scenario with a building area of 16145.9 square feet (or 1,500 square meters) and a vapor flow rate of 337.5 L/minute into the building (USEPA 2017). USEPA's default air exchange rate of 1.5 air change per hour for a commercial/industrial building (USEPA 2017) was used. A conservative building height of 9.8 feet (or 3 meters) was assumed.

A conservative default residential slab-on-grade building was assumed for the indoor air scenario with a building area of 150 square meters and a vapor flow rate of 8.2 L/minute into the building (USEPA 2017). USEPA's default air exchange rate of 0.45 air change per hour and building height of 2.44 meters for a residential building (USEPA 2017) were used. A residential trailer with a dirt floor was also assessed. The residential trailer was modeled as a crawl space with dirt floor using the USEPA's default building parameters and air exchange rate for a residential building (USEPA 2017), as described above.

For the trench scenario, a box model was used to simulate dispersion. Trench dimensions of 10 feet deep, 20 feet long, and five feet wide were assumed. For this box model, the air flow through the trench was controlled by a site-specific windspeed that is reduced by a factor of 10 to ensure it is conservative for a trench scenario where the breathing zone may be a few feet bgs. Additionally, soil gas samples were assumed to be within five feet away from the wall and below the base of the trench and VOCs were emitted from all the trench walls in addition to the base of the trench.

Benzene readily biodegrades under natural aerobic conditions in shallow soil. In the NERT RI Study Area, measured concentrations of benzene at shallower depths are consistently lower than would be predicted from deeper sources (soil gas and groundwater) using the

[21] Soil classification (grain size distribution/Atterberg Limits) and total organic carbon had previously been collected at PC-172 (co-located with RISG-4, at 13.5 feet bgs), PC-167 (co-located with RISG-7, at 11.0 feet bgs), and PC-166 (co-located with RISG-9, at 11.5 feet bgs) during the Phase 2 RI.

[22] Depths to groundwater in a very limited area near monitoring wells PC-161 and PC-162 were identified to be shallower than 10 feet bgs. Due to limited numbers of wells with depth to groundwater shallower than 10 feet bgs in the OU-2 BHRA Area and the low concentrations of VOCs detected at these two wells, significant health risks are not expected to occur. The health risks associated with a wet trench scenario are qualitatively discussed as part of the uncertainty analysis in Section 6.2.4.

Johnson and Ettinger model which conservatively assumes that there is no biodegradation. Consistent with the BHRA Work Plan, the BioVapor (American Petroleum Institute [API] 2012) was used to calculate the relative impact of benzene biodegradation within the unsaturated zone for all soil gas and groundwater scenarios. BioVapor is virtually identical to the Johnson and Ettinger model except it includes biodegradation. The model breaks the soil into a shallow soil layer near the surface where oxygen is present and first-order biodegradation occurs, and a deeper anaerobic layer where no biodegradation occurs. To quantify the effect of biodegradation in the unsaturated zone, the ratio of the BioVapor results with biodegradation and without biodegradation was calculated. This ratio was then multiplied by the indoor and outdoor transfer factors for benzene calculated the approach described above. Consistent with the 2018 BHRA Work Plan, biodegradation was only quantified for benzene. The input parameters for this calculation are also presented in Table 5-4. The biodegradation rate for benzene used in the evaluation is the BioVapor default value, which represents the median of measured rates for benzene, ethylbenzene, toluene, xylenes, and alkylbenzenes.

Tables 5-5 and 5-6 summarize the transfer factors for all VOCs analyzed in the soil gas and shallow groundwater BHRA data sets migrating to indoor air, outdoor air, and trench air. The conservative nature of the model input parameters and modeling uncertainties are discussed in Section 6.2.2.

5.2.3 Exposure Assumptions and Calculations

The magnitude of exposure for any given receptor is a function of the amount of chemical in the exposure medium (e.g., air, groundwater, soil), and the frequency, intensity, and duration of contact with that medium. In order to quantify inhalation exposures, the air EPC adjusted by the intake factor, rather than exposure dose, is used as the basis for estimating inhalation risks based on Risk Assessment Guidance for Superfund, Part F, Supplemental Guidance for Inhalation Risk Assessment (USEPA 2009).

As shown in Table 5-7, exposure assumptions recommended by NDEP (2017a) were used for residents and indoor/outdoor commercial/industrial workers. For the construction workers, exposure assumptions recommended by USEPA (2021a) were used, except that a utility trench scenario was evaluated assuming that the construction workers could be exposed to VOCs migrating from soil gas and groundwater to air in a 10-foot construction trench when conducting excavation activities for four hours per day, 30 days per year for one year (NDEP 2017b, General Comment #3). In general, the exposure assessment in this BHRA is based on a reasonable maximum exposure (RME) scenario, which is defined by USEPA as the highest exposure that could reasonably be expected to occur for a given exposure pathway at a site (USEPA 1989).

The intake factor for inhalation of volatile compounds migrating from soil gas or groundwater to air were calculated using the following equation (USEPA 2009):

$$IF_{inh} = \frac{ET \times EF \times ED}{AT \times CF}$$

where:

IF_{inh} = Intake Factor for air inhalation (unitless)

ET	=	Exposure Time (hour/day)
EF	=	Exposure Frequency (day/year)
ED	=	Exposure Duration (year)
AT	=	Averaging Time (day)
CF	=	Conversion Factor (hour/day)

For carcinogens, the intake factor averaged over a 70-year lifetime was used in the risk characterization, while for non-carcinogens, the intake factor averaged over the exposure period was used (USEPA 1989).

5.3 Toxicity Assessment

The purpose of a toxicity assessment is to present the weight-of-evidence regarding the potential for a chemical to cause adverse effects in exposed individuals, and to quantitatively characterize, where possible, the relationship between exposure to a chemical and the increased likelihood and/or severity of adverse effects (i.e., the dose-response assessment). Well conducted epidemiological studies that show a positive association between exposure to a chemical and a specific health effect are the most convincing evidence for predicting potential hazards for humans. However, human data that would be adequate to serve as the basis for the dose-response assessment are available for only a few chemicals. In most cases, toxicity assessment for a chemical has to rely on information derived from experiments conducted on non-human mammals, such as rat, mouse, rabbit, guinea pig, hamster, dog, or monkey.

Chemicals are usually evaluated for their potential health effects in two categories, carcinogenic and noncarcinogenic. Different methods are used to estimate the potential for carcinogenic and noncarcinogenic health effects to occur. Several chemicals produce noncarcinogenic effects at sufficiently high doses but only some chemicals are associated with carcinogenic effects. Most regulatory agencies consider carcinogens to pose a risk for cancer at all exposure levels (i.e., a “no-threshold” assumption); that is, any increase in dose is associated with an increase in the probability of developing cancer. In contrast, noncarcinogens generally are thought to produce adverse health effects only when some minimum exposure level is reached (i.e., a threshold dose).

Inhalation unit risks (IURs), which are expressed in units of $(\mu g/m^3)^{-1}$, are chemical-specific and experimentally derived potency values that are used to calculate the risk of cancer resulting from inhalation exposure to potential carcinogenic chemicals. The IUR is defined as an upper-bound estimate of the probability of an individual developing cancer per unit concentration of a potential carcinogen over a lifetime. With IURs, a higher value implies a more potent carcinogenic potential.

Inhalation reference concentrations (RfCs), which are expressed in units of $\mu g/m^3$, are experimentally derived levels not expected to cause adverse health effects that are used to quantify the extent of toxic effects other than cancer due to inhalation exposure to chemicals. The RfC is intended to represent the concentration of a chemical that is not expected to cause adverse health effects, assuming daily exposure over the exposure duration, even in sensitive individuals, with a substantial margin of safety. With RfCs, a lower value implies a more potent toxicant.

For the VOCs detected in soil gas and groundwater, an initial list of chronic toxicity values was developed based on the values used by NDEP for the derivation of the 2017 BCLs (NDEP 2017a). For most chemicals in the BCL table, NDEP selected toxicity values from the USEPA's Integrated Risk Information System (IRIS); however, on a case-by-case basis, values provided by other sources, e.g., California Office of Environmental Health Hazard Assessment (OEHHA) Toxicity Criteria Database, were selected over the IRIS values. For chemicals not included in IRIS, NDEP relied on other sources for toxicity values. Ramboll checked the chronic toxicity values from the 2017 BCL table against the identified source to confirm that the most current values were being used.

For chemicals not listed in the 2017 BCL table, the following approach was used:

- Toxicity values from IRIS were selected; if not in IRIS, toxicity values from the USEPA RSL table (USEPA 2021b) were used; and
- For chemicals for which toxicity values are not available from any of the sources listed, Ramboll used the toxicity values from surrogate chemicals (chemicals with similar chemical structure), when available.

For construction workers who were assumed to be present in the OU-2 BHRA Area for one year, subchronic toxicity values were used whenever available for the evaluation of adverse noncancer effects in accordance with recommendations by USEPA (USEPA 2021a). The subchronic toxicity values were obtained from the USEPA RSL table (USEPA 2021d), which generally follows the hierarchy of sources as below:

- USEPA Provisional Peer Reviewed Toxicity Values for Superfund (PPRTV);
- Agency for Toxic Substances & Disease Registry (ATSDR) Minimal Risk Levels (MRLs);
- USEPA PPRTV Appendix Values; and
- USEPA's Health Effects Assessment (HEAST) Summary Tables.

Route-to-route extrapolation was not applied, which is consistent with the updated BCL Guidance (NDEP 2017a) and Risk Assessment Guidance for Superfund, Part F, Supplemental Guidance for Inhalation Risk Assessment (USEPA 2009a).

In addition, for each carcinogen, the USEPA weight-of-evidence classification was also identified.

The chronic and subchronic toxicity values for all the analyzed VOCs in the soil gas and shallow groundwater BHRA data sets are presented in Table 5-8. The uncertainties in the selection of toxicity values are further discussed in Section 6.2.3.

5.4 Risk Characterization

Risk characterization represents the final step in the risk assessment process. In this step, the results of exposure and toxicity assessments are integrated into quantitative or qualitative estimates of potential health risks. In order to evaluate the potential human health risk from each exposure medium (i.e., soil gas and shallow groundwater) to the potentially exposed populations, RBTCs, representing the concentration of a chemical protective of human health, were first developed for all the analyzed VOCs in the soil gas and shallow groundwater BHRA data sets (Appendices D and E). Then, potential excess lifetime cancer risks and noncancer adverse health effects for each VOC in soil gas and shallow groundwater were characterized separately by comparing concentrations detected in each soil gas and shallow groundwater sample to the RBTCs. Cancer risks and noncancer hazards associated with the vapor intrusion pathway were evaluated for each sample, and the highest estimated cancer risk and noncancer hazard for individual sampling location (i.e., statistical averages are not estimated) were reported. In addition, 0.1 x RBTC was used to evaluate the SQLs for the nondetects as discussed in Section 4.1.5. The uncertainties associated with the SQLs higher than 0.1 x RBTC are discussed in Section 6.1.2.

The NCP (40 Code of Federal Regulations [CFR] § 300) is cited as the basis for the target risk range by NDEP (2017a). According to NDEP (2017a), the lifetime incremental cancer risks posed by a site should not exceed one in a million (1×10^{-6}) to one hundred in a million (1×10^{-4}).[23] According to the NCP and NDEP (2017a), noncarcinogenic chemicals should not be present at levels expected to cause adverse health effects (i.e., a hazard index [HI] greater than one). As a conservative measure, the RBTCs were calculated to correspond to a target cancer risk of 1×10^{-6} and a target noncancer hazard quotient (HQ) of one.

It should be noted that the cancer risk and noncancer hazard estimated in this BHRA does not represent absolute estimates in the OU-2 BHRA Area, since generic and conservative assumptions were used, which are likely to overestimate actual exposures and calculated risks. Exceedance of the target cancer risk range of 10^{-6} to 10^{-4} or the target noncancer HI of one does not indicate that adverse impacts to human health are occurring or will occur but suggests that further evaluation may be warranted.

Consistent with agency guidance from USEPA (2015), soil gas data collected within the OU-2 BHRA Area since 2008 were used to evaluate potential exposure for current and future residents and workers via inhalation of vapors migrating from the subsurface to indoor air, outdoor air, and trench air. The soil gas data used in this BHRA were specifically collected to evaluate the vapor intrusion pathway. Soil gas data is generally preferred as a line of evidence for assessing vapor intrusion risks as opposed to groundwater or soil data primarily due to higher uncertainties associated with vapor intrusion modeling based on groundwater or soil data (i.e., uncertainty in predicting contaminant partitioning from groundwater or soil moisture to soil gas and in predicting transport through the capillary fringe). In addition, the groundwater data used in this BHRA was collected to delineate the groundwater plume and not necessarily for the evaluation of vapor intrusion. For this reason, some of the groundwater data has been collected at depths below the first encountered groundwater. Therefore, this BHRA considers the soil gas data as the primary line of evidence for the vapor intrusion pathway; the groundwater data were evaluated to

[23] According to NDEP (2017a), the acceptability of any calculated incremental cancer risk is generally evaluated relative to the target risk range of 10^{-6} to 10^{-4} described in the NCP.

provide a secondary line of evidence for a more comprehensive understanding of the evaluation and to check consistency between soil gas and groundwater results.

5.4.1 Soil Gas

5.4.1.1 Cancer Risks

The excess lifetime cancer risk is estimated as the upper-bound incremental probability of an individual developing cancer over a lifetime (i.e., 70 years) as a result of exposure to a potential carcinogen at a given concentration. The equation used to calculate soil gas RBTCs for vapor migration to air for the carcinogenic endpoint is as follows:

$$RBTC_{SG.c} = \frac{TR}{IF_{inh} \times \alpha \times IUR}$$

where:

$RBTC_{SG.c}$	=	Risk-Based Target Concentration, soil gas, carcinogenic endpoint (μg/m^3)
TR	=	Target Risk (unitless)
IF_{inh}	=	Inhalation Intake Factor (unitless)
α	=	Transfer Factor for soil gas migrating to air (μg/m^3 per μg/m^3)
IUR	=	Inhalation Unit Risk (μg/m^3)$^{-1}$

The RBTCs for VOCs in soil gas for vapor migration from soil gas to air based on the carcinogenic endpoint are presented in Tables 5-9 through 5-12 for residents (for both the slab-on-grade building and trailer scenarios), indoor commercial/industrial workers, outdoor commercial/industrial workers,[24] and construction workers, respectively.

The equation used to calculate excess lifetime cancer risk due to exposure via inhalation of VOCs migrating from soil gas to air is as follows:

$$Cancer\ Risk = \frac{Soil\ Gas\ Concentration}{Cancer\ RBTC} \times 10^{-6}$$

The methodology for estimating excess lifetime cancer risks for soil gas using the soil gas RBTCs developed for various exposure scenarios are summarized below:

- For the residents under the slab-on-grade building scenario, soil gas data collected at approximately 5, 10, and 15 feet bgs at sample locations in the residential area were compared to the residential soil gas RBTCs modeled at 5, 10, and 15 feet bgs for the slab-on-grade building scenario. Data from one soil gas sample collected slightly

[24] For the outdoor commercial/industrial worker scenario, RBTCs were developed for outdoor air (Table 5-11) to compare to outdoor air EPCs. The outdoor air EPCs were developed by calculating 95% UCLs for model-predicted outdoor air concentrations for each VOC migrating from soil gas or shallow groundwater. The 95% UCL inputs were developed by multiplying detected soil gas or shallow groundwater concentrations with medium and depth-specific transfer factors within commercial/industrial areas in the western portion of OU-2.

shallower than 15 feet bgs (i.e., 13 feet bgs at RISG-1) were conservatively compared to the soil gas RBTCs modeled at 10 feet bgs.

- For the residents under the trailer scenario, shallow soil gas data collected at approximately 5 feet bgs and 15 feet bgs at two sample locations (RISG-77 and RISG-78) near the residential trailer area were compared to the residential soil gas RBTCs modeled at 5 feet bgs and 15 feet bgs for the residential trailer scenario, respectively.
- For the indoor commercial/industrial worker scenario, soil gas data collected at approximately 5, 10, and 15 feet bgs at sample locations in the commercial area were compared to the soil gas RBTCs modeled at 5, 10, and 15 feet bgs for the indoor commercial/industrial workers, respectively.
- For the construction worker scenario, the soil gas data collected from the OU-2 BHRA Area (regardless if a sample was collected in a residential or commercial area or depth intervals) were compared with soil gas RBTCs developed for construction workers assuming the soil gas sample is either 5 feet away from the wall (for the 5 feet and 10 feet bgs soil gas samples) or below the base of a 10-foot construction trench (for the 15 feet bgs soil gas samples).
- For the resident (for both the slab-on-grade building and trailer scenarios), indoor commercial/industrial worker, and construction worker scenarios, the concentration for each detected carcinogenic VOC in a soil gas sample was used in the cancer risk calculations for each sample. Also, the estimated excess lifetime cancer risk for each carcinogenic VOC was summed for each sample and the highest total cancer risk estimates were reported for each applicable scenario at each location.
- For the outdoor commercial/industrial worker scenario, outdoor air EPCs were developed using 95% UCLs based on model predicted outdoor air concentrations for VOCs migrating from soil gas using depth-specific transfer factors over the commercial/industrial areas in the OU-2 BHRA Area and compared to the outdoor air RBTCs (Table 5-11).

The total estimated excess lifetime cancer risks at both 5 and 10-15 feet bgs for the most conservative exposure scenarios (i.e. for residents under both the slab-on-grade and trailer scenarios in the residential area and for the indoor commercial/industrial worker scenario in the commercial area) at each soil gas sample location in relation to the nearby chloroform groundwater plume (as defined by >70 ug/L chloroform concentration) are shown in Figures 5-2 through 5-5. The range of total excess lifetime cancer risk estimates for soil gas at 5 feet bgs and 10-15 feet bgs for each exposure scenario is summarized in Table 5-13. The source concentration, air EPC, and cancer risk for each VOC detected in the soil gas sample with the maximum cancer risk estimate for all the exposure scenarios are shown in Tables G-1 through G-10.

As shown in Table 5-13, the maximum total estimated excess lifetime cancer risks for soil gas at 5 feet bgs and 10-15 feet bgs for each evaluated exposure scenario are summarized below:

- 2×10^{-5} for a resident in a slab-on-grade building at both 5 feet bgs and 10-15 feet bgs (at RISG-1, see Figures 5-2 and 5-3);

- 1×10^{-5} and 7×10^{-6} for a resident in a trailer at 5 feet bgs and 10-15 feet bgs, respectively (at RISG-77, see Figures 5-2 and 5-3);
- 3×10^{-6} and 2×10^{-6} for an indoor commercial/industrial worker at 5 feet bgs and 10-15 feet bgs, respectively (at RISG-6, see Figures 5-4 and 5-5);
- 2×10^{-10} for an outdoor commercial/industrial worker at both 5 feet bgs and 10-15 feet bgs;[25] and
- 1×10^{-11} and 2×10^{-11} for a construction worker at 5 feet bgs and 10-15 feet bgs, respectively (at RISG-6);

All cancer risk estimates for soil gas were within or below the NDEP acceptable risk range of 10^{-6} to 10^{-4}. Therefore, potential exposure to VOCs in soil gas in the OU-2 BHRA Area is not expected to pose an unacceptable carcinogenic health effect under the conditions evaluated and additional assessment is not warranted based on the cancer risk results for soil gas in the OU-2 BHRA Area.

The cancer risk driver for the soil gas samples was chloroform, contributing 90% or higher of the total cancer risk for all soil gas samples. The cancer risk estimates for the outdoor commercial/industrial workers and construction workers for all evaluated soil gas sample locations are well below the lower end of the NDEP acceptable risk range of 10^{-6} to 10^{-4}.[26] As shown in Figures 5-2 and 5-3, soil gas sample locations with cancer risks above 1×10^{-6} were identified within the groundwater plume of chlorinated VOCs (as defined by >70 ug/L chloroform concentration). The locations with the highest residential cancer risks (RISG-1, RISG-68, RISG-71, and RISG-77) are all located in the southeastern portion of the Pittman neighborhood which is closest to the upgradient sources, consistent with the spatial distribution of chloroform found in shallow groundwater in the OU-2 BHRA Area. As shown in Figures 5-4 and 5-5, there is only one soil gas location (RISG-6) with cancer risks above 1×10^{-6} for the indoor commercial/industrial worker scenario. This location is in the commercial area north of East Galleria Drive and just south of the AWF extraction wells, also within the groundwater plume of chlorinated VOCs in the OU-2 BHRA Area.

5.4.1.2 Noncancer Health Effects

The likelihood of noncancer adverse effects is quantified by the development of an HQ. The equation used to calculate soil gas RBTCs for vapor migration to air for the non-carcinogenic endpoint is as follows:

$$RBTC_{SG.nc} = \frac{THQ}{IF_{inh} \times \alpha / RfC_{inh}}$$

where:

[25] The cancer risk and noncancer chronic HI for the outdoor commercial/industrial workers were estimated based on the 95% UCLs calculated using the soil gas VOC data collected in commercial/industrial areas in the OU-2 BHRA Area.

[26] Due to the low risk levels for the outdoor commercial/industrial workers and construction workers, figures presenting the risk results for these two scenarios are not shown in this BHRA report.

$RBTC_{SG.nc}$	=	Risk-Based Target Concentration, soil gas, noncarcinogenic endpoint (μg/m^3)
THQ	=	Target Hazard Quotient (unitless)
IF_{inh}	=	Inhalation Intake Factor (unitless)
A	=	Transfer Factor for soil gas migrating to air (μg/m^3 per μg/m^3)
RfC_{inh}	=	Inhalation Reference Concentration (μg/m^3)

The RBTCs for vapor migration from soil gas to air for the noncarcinogenic endpoint are presented in Tables 5-9 through 5-12 for residents (for both the slab-on-grade building and trailer scenarios), indoor commercial/industrial workers, outdoor commercial/industrial workers,[27] and construction workers, respectively.

The equation used to calculate the HQ due to exposure via inhalation of VOCs migrating from soil gas to air is as follows:

$$HQ = \frac{Soil\ Gas\ Concentration}{Noncancer\ RBC}$$

Similar methodology and data sets were used to estimate the HQs for soil gas for each evaluated scenario as the methodology and data sets used for estimating the excess lifetime cancer risks for soil gas, as discussed in Section 5.4.1.1.

The range of the estimated total HIs associated with exposures through vapor inhalation for residents (for both the slab-on-grade building and trailer scenarios), indoor commercial/industrial workers, outdoor commercial/industrial workers, and construction workers to VOCs migrating from soil gas at 5 feet bgs and 10-15 feet bgs to indoor, outdoor air, and trench air in the OU-2 BHRA Area are summarized in Table 5-13. The source concentration, air EPC, and HQ for each VOC detected in soil gas at the locations with the highest estimated HIs for all the exposure scenarios are shown in Tables G-1 through G-10.

As shown in Table 5-13, the maximum total HI estimate is 0.03 for a resident (for both the slab-on-grade and trailer scenarios), 0.01 for an indoor commercial/industrial worker, 0.00006 for an outdoor commercial/industrial worker, and 0.00001 for a construction worker, all well below the NDEP target HI of greater than one. Therefore, potential exposure to VOCs in soil gas is not expected to pose an unacceptable non-carcinogenic health effect under the conditions evaluated and additional assessment is not warranted based on the noncancer HI results for soil gas in the OU-2 BHRA Area.

[27] For the outdoor commercial/industrial worker scenario, RBTCs were developed for outdoor air (Table 5-11) to compare to outdoor air EPCs. The outdoor air EPCs were developed by calculating 95% UCLs for model-predicted outdoor air concentrations for each VOC migrating from soil gas or shallow groundwater. The 95% UCL inputs were developed by multiplying detected soil gas or shallow groundwater concentrations with medium and depth-specific transfer factors within commercial/industrial areas in the OU-2 BHRA Area.

5.4.2 Shallow Groundwater

5.4.2.1 Cancer Risks

The equation used to calculate shallow groundwater RBTCs for vapor migration to air for the carcinogenic endpoint is as follows:

$$RBTC_{GW.c} = \frac{TR}{IF_{inh} \times \alpha \times IUR}$$

where:

$RBTC_{GW.c}$	=	Risk-Based Target Concentration, groundwater, carcinogenic endpoint (µg/L)
TR	=	Target Risk (unitless)
IF_{inh}	=	Inhalation Intake Factor (unitless)
A	=	Transfer Factor for groundwater vapor migrating to air (µg/m^3 per µg/L)
IUR	=	Inhalation Unit Risk (µg/m^3)

The RBTCs for VOCs in shallow groundwater based on the carcinogenic endpoint are presented in Tables 5-14, 5-15, 5-11, and 5-16 for residents (for both the slab-on-grade building and trailer scenarios), indoor commercial/industrial workers, outdoor commercial/industrial workers,[28] and construction workers, respectively.

The equation used to calculate excess lifetime cancer risk due to exposure via inhalation of VOCs migrating from shallow groundwater to air is as follows:

$$Cancer\ Risk = \frac{Shallow\ Groundwater\ Concentration}{Cancer\ RBTC} \times 10^{-6}$$

The methodology and data sets for estimating excess lifetime cancer risks for groundwater using the groundwater RBTCs developed for various exposure scenarios are summarized below:

- For the residential slab-on-grade building scenario, the groundwater BHRA data set collected from wells with depth to groundwater at 20 feet bgs or deeper and from wells with depth to groundwater shallower than 10 feet bgs in the residential area were conservatively compared to the residential groundwater RBTCs modeled at 20 feet bgs and 10 feet bgs for the residential slab-on-grade building scenario, respectively.

[28] For the outdoor commercial/industrial worker scenario, RBTCs were developed for outdoor air (Table 5-11) to compare to outdoor air EPCs. The outdoor air EPCs were developed by calculating 95% UCLs for model-predicted outdoor air concentrations for each VOC migrating from soil gas or shallow groundwater. The 95% UCL inputs were developed by multiplying detected soil gas or shallow groundwater concentrations with medium and depth-specific transfer factors within commercial/industrial areas in the OU-2 BHRA Area.

- For the residential trailer scenario, the groundwater data collected at two wells (PC-174 and PC-175) near the residential trailer area were compared to the residential groundwater RBTCs modeled at 20 feet bgs for the residential trailer scenario.
- For the commercial/industrial worker scenario, the groundwater BHRA data set collected from wells with depth to groundwater at 20 feet bgs or deeper and from wells with depth to groundwater shallower than 10 feet bgs in the commercial area were conservatively compared to the groundwater RBTCs modeled at 20 feet bgs and 10 feet bgs for the indoor commercial/industrial worker scenario, respectively.
- For the construction worker scenario, the groundwater BHRA data set (regardless if a sample was collected in a residential or commercial area) collected from wells with depth to groundwater at 20 feet bgs or deeper and from wells with depth to groundwater shallow than 20 feet bgs were compared with depth-specific groundwater RBTCs developed for construction workers, assuming the groundwater is at a depth of 10 feet bgs or one foot below the base of a 10-foot construction trench, respectively.
- For the resident (for both the slab-on-grade building and trailer scenarios), indoor commercial/industrial worker, and construction worker scenarios, the concentration for each VOC detected in each shallow groundwater sample was used in the cancer risk calculation. Also, the estimated excess lifetime cancer risk for each carcinogenic VOC was conservatively summed for each sample to estimate the total cancer risk from shallow groundwater for an exposed individual at each location.
- For the outdoor commercial/industrial worker scenario, outdoor air EPCs were developed using 95% UCLs based on model predicted outdoor air concentrations for VOCs migrating from shallow groundwater using depth-specific transfer factors over the commercial/industrial area in the OU-2 BHRA Area and compared to the outdoor air RBTCs (Table 5-11).

The total estimated excess lifetime cancer risks for the most conservative exposure scenarios (i.e. for the resident under both the slab-on-grade and trailer scenarios in the residential area and for the indoor commercial/industrial worker scenario in the commercial area) at each shallow groundwater sample location in relation to the nearby chloroform groundwater plume (as defined by >70 µg/L chloroform concentration) are shown in Figures 5-6 and 5-7, respectively. The range of total excess lifetime cancer risks for shallow groundwater for all the exposure scenarios are summarized in Table 5-17. The source concentration, air EPC, and cancer risk for each VOC detected in shallow groundwater at the maximum location for all the exposure scenarios are shown in Tables G-11 through G-15.

As shown in Table 5-17 and Figures 5-6 and 5-7, the maximum total estimated excess lifetime cancer risks for shallow groundwater for each evaluated exposure scenario are summarized below:

- 1×10^{-4} for a resident in a slab-on-grade building (at PC-67);
- 4×10^{-5} for a resident in a trailer (at PC-175);
- 3×10^{-6} for an indoor commercial/industrial worker (at PC-187);

- 2 × 10^{-8} for an outdoor commercial/industrial worker;[29] and
- 7 × 10^{-9} for a construction worker (at PC-67).

All cancer risk estimates for shallow groundwater were within or below the NDEP acceptable risk range of 10^{-6} to 10^{-4}. Consistent with the soil gas results, potential exposure to VOCs in shallow groundwater in the OU-2 BHRA Area is not expected to pose an unacceptable carcinogenic health effect under the conditions evaluated and additional assessment is not warranted based on the cancer risk results for shallow groundwater in the OU-2 BHRA Area.

The cancer risk driver for the shallow groundwater samples was chloroform, contributing to 90% or higher in the total cancer risk for all soil gas samples. The cancer risk estimates for the outdoor commercial/industrial workers and construction workers for all evaluated shallow groundwater samples are well below the lower end of the NDEP acceptable risk range of 10^{-6} to 10^{-4}.[30] As shown in Figure 5-6, shallow groundwater wells in the residential area with cancer risks above 1 x 10^{-6} were identified within the groundwater plume of chlorinated VOCs (as defined by >70 ug/L chloroform concentration). The locations with the highest residential cancer risks (PC-67, PC-168, and PC-175) are located in an area closer to the upgradient sources, consistent with the spatial distribution of chloroform found in soil gas in the OU-2 BHRA Area. As shown in Figure 5-7, there are a few wells (i.e. PC-24, PC-122, PC-124, PC-126, PC-187, PC-187R, and PC-188) with cancer risks above 1 x 10^{-6} for the indoor commercial/industrial worker scenario either in the commercial areas north of Warm Springs Road or north of Sunset Road, all within the groundwater plume of chlorinated VOCs in the OU-2 BHRA Area.

The soil gas location with the highest cancer risk estimates for the resident scenarios (i.e. RISG-1) is co-located with the shallow groundwater well with the highest residential cancer risk estimate (i.e. PC-67). The soil gas location with the highest cancer risk estimates for the indoor commercial/industrial worker scenario (i.e. RISG-6) is also co-located with a shallow groundwater well that is among the wells with the highest cancer risk estimates (i.e. PC-122).

As discussed previously, this BHRA considers the soil gas data as the primary line of evidence for evaluation of the vapor intrusion pathway; the groundwater data were evaluated to provide a secondary line of evidence and to check consistency between soil gas and groundwater results. The spatial distribution of locations with cancer risk above 10^{-6} for shallow groundwater are also generally consistent with those for soil gas in the OU-2 BHRA Area. The results and conclusions of the groundwater risk evaluation are generally consistent with the results and conclusions of the soil gas risk evaluations for the OU-2 BHRA Area, supporting the OU-2 CSM developed in the RI Report for OU-1 and OU-2 (Ramboll 2021a) which identified that groundwater is the main source of chloroform detected in soil gas in this area. The highest cancer risk estimates occur at locations where

[29] The cancer risk and noncancer chronic HI for the outdoor commercial/industrial workers were estimated based on the 95% UCLs calculated using the soil gas VOC data collected within commercial/industrial areas in the OU-2 BHRA Area.

[30] Due to the low risk levels for the outdoor commercial/industrial workers and construction workers, figures presenting the risk results for these two scenarios are not shown in this BHRA report.

the highest chloroform concentrations were detected in groundwater within the OU-2 BHRA Area and are located generally downgradient of the upgradient sources.

5.4.2.2 Noncancer Health Effects

The equation used to calculate shallow groundwater RBTCs for vapor migration to air for the noncarcinogenic endpoint is as follows:

$$RBTC_{GW.nc} = \frac{THQ}{IF_{inh} \times \alpha / RfC_{inh}}$$

where:

$RBTC_{GW.nc}$	=	Risk-Based Target Concentration, groundwater, noncarcinogenic endpoint (μg/L)
THQ	=	Target Hazard Quotient (unitless)
IF_{inh}	=	Inhalation Intake Factor (unitless)
α	=	Transfer Factor for soil gas migrating to air (μg/m^3 per μg/L)
RfC_{inh}	=	Inhalation Reference Concentration (μg/m^3)

The RBTCs for VOCs detected in shallow groundwater for the noncarcinogenic endpoint are presented in Tables 5-14, 5-15, 5-11, and 5-16 for residents (for both a slab-on-grade building and trailer scenarios), indoor commercial/industrial workers, outdoor commercial/industrial workers,[31] and construction workers, respectively. The RBTCs for VOCs in the shallow groundwater BHRA data set (Appendix E) are presented in Tables G-11 through G-15 for residents, indoor commercial/industrial workers, outdoor commercial/industrial workers, and construction workers, respectively.

The equation used to calculate the HQ due to exposure via inhalation of VOCs migrating from shallow groundwater to air is as follows:

$$HQ = \frac{Shallow\ Groundwater\ Concentration}{Noncancer\ RBTC}$$

Similar methodology and data sets were used to estimate the HQs for groundwater for each evaluated scenario as the methodology and data sets used for estimating the excess lifetime cancer risks for groundwater, as discussed in Section 5.4.2.1.

The range of the estimated total HIs associated with exposures through vapor inhalation for residents (for both the slab-on-grade building and trailer scenarios), indoor commercial/industrial workers, outdoor commercial/industrial workers, and construction workers to VOCs migrating from shallow groundwater to indoor, outdoor air, and trench air in the OU-2 BHRA Area are summarized in Table 5-17. The source concentration, air EPC,

[31] For the outdoor commercial/industrial worker scenario, RBTCs were developed for outdoor air (Table 5-11) to compare to outdoor air EPCs. The outdoor air EPCs were developed by calculating 95% UCLs for model-predicted outdoor air concentrations for each VOC migrating from soil gas or shallow groundwater. The 95% UCL inputs were developed by multiplying detected soil gas or shallow groundwater concentrations with medium and depth-specific transfer factors within commercial/industrial areas in the western portion of OU-2.

and HQ for each VOC detected in soil gas at the locations with the highest estimate HIs for all the exposure scenarios are shown in Tables G-11 through G-15.

As shown in Table 5-17, the maximum total HI estimate for shallow groundwater through vapor inhalation is 0.1 for a resident in a slab-on-grade building, 0.08 for a resident in a residential trailer, 0.004 for an indoor commercial/industrial worker, 0.00006 for an outdoor commercial/industrial worker, and 0.0001 for a construction worker, all well below the NDEP target HI of greater than one. Consistent with the soil gas results, potential exposure to VOCs in shallow groundwater through the vapor inhalation pathway is not expected to pose an unacceptable non-carcinogenic health effect under the conditions evaluated and additional assessment is not warranted based on the non-cancer HI results for shallow groundwater in the OU-2 BHRA Area.

As discussed previously, this BHRA considers the soil gas data as the primary line of evidence for evaluation of the vapor intrusion pathway; the groundwater data were evaluated to provide a secondary line of evidence and to check consistency between soil gas and groundwater results. The results and conclusions of the groundwater risk evaluation are generally consistent with the results and conclusions of the soil gas risk evaluations for the OU-2 BHRA Area, supporting the OU-2 CSM developed in the RI Report for OU-1 and OU-2 (Ramboll 2021a) which identified that chloroform in groundwater is the main source of chloroform detected in soil gas in this area.

6. UNCERTAINTY ANALYSIS

The process of risk assessment has inherent uncertainties associated with the calculations and assumptions used in the assessment. The approach used in this BHRA is health protective and tends to overestimate potential exposure, resulting in estimated cancer risks and hazard levels that are likely to be higher than the actual risks or hazards experienced by the potentially exposed populations. These uncertainties are generally difficult to quantify. A qualitative discussion of key uncertainties associated with the available data and the methodology used in this BHRA is presented below.

6.1 Uncertainties Identified in the Data Usability Evaluation

6.1.1 Site Characterization Data

For field sampling, it is unrealistic to collect samples from every possible location; therefore, there are always some uncertainties associated with the representativeness of site characterization data.

Sample locations for soil gas data used in the BHRA were selected based on the previous soil gas and groundwater sampling and the presence of several VOCs in the soil gas and groundwater samples in the OU-2 BHRA Area. Soil gas samples collected from these locations were analyzed for the full suite of VOCs using USEPA Method TO-15.

Sample locations for shallow groundwater data used in the BHRA were identified based on the review of available historical groundwater data to characterize the vertical and horizontal extent of impacted groundwater. It should be noted that only soil gas samples were specifically collected to support evaluation of the vapor intrusion pathway. The objectives of groundwater sampling in the OU-2 BHRA Area have been primarily to characterize chemicals in groundwater near suspected source areas and plume delineation; that is, no groundwater investigation was conducted to specifically provide data to evaluate the vapor intrusion pathway. However, along with the soil gas data, shallow groundwater data are sufficient to provide a secondary line of evidence for the vapor intrusion risk analysis. In addition, maximum shallow groundwater results at each well were used in the risk analysis which is a conservative approach.

Overall, the placement of the soil gas and shallow groundwater sample locations was deemed representative to evaluate the current conditions within the OU-2 BHRA Area in the context of the CSM, and the relative uncertainty in the characterization data was considered to be low.

6.1.2 Detection Limits

For VOCs detected in soil gas and shallow groundwater for which the detection frequency was less than 100%, the SQLs from the soil gas and shallow groundwater BHRA data sets were compared to 0.1 x RBTC to confirm that they were sufficiently low for risk characterization (see Section 4.1.5). As presented in Tables 4-5 through 4-7, most of the

SQLs in the Study Area were less than 0.1 x RBTC, with a few exceptions. The impacts of elevated SQLs on the overall risk evaluation are discussed below.[32]

Soil Gas at 5 feet bgs:

- For eight analytes (acrolein, acrylonitrile, benzyl chloride, bromodichloromethane, 1,2-dichloroethane, 1,2-dichloropropane, hexachlorobutadiene, and 1,1,2,2-tetrachloroethane), the SQL exceeded 10% of the minimum RBTC (0.1 x RBTC) in 1.3 to 36% of non-detected samples, with no SQLs exceeding the minimum RBTC (Table 4-5). The maximum estimated excess lifetime cancer risks associated with the elevated SQLs of these VOCs fall within the range of 7 x 10^{-9} to 4 x 10^{-7}, which is below the lower end of the target cancer risk range of 10^{-6} to 10^{-4}. The maximum estimated HQs associated with the exceeded SQLs for the detected VOCs fall within the range of 0.000001 to 0.2, which is well below the NDEP target HQ of greater than one. Therefore, elevated SQLs for these chemicals are not expected to have a significant impact on the overall soil gas risk evaluation at 5 feet bgs.
- 1,2-dibromoethane was detected in six out of 78 samples; the SQL exceeded 10% of the minimum RBTC in 32% of the nondetected samples, with the SQL in one sample exceeding the minimum RBTC (Table 4-5). The maximum estimated excess lifetime cancer risk associated with the exceeded SQLs of 1,2-dibromoethane would be 5 x 10^{-7} for a residential trailer or residential slab-on-grade building scenario, which is below the lower end of the target cancer risk range of 10^{-6} to 10^{-4}. The maximum estimated HQ associated with the exceeded SQLs is 0.0003 for a trailer residential scenario, which is well below the NDEP target HQ of greater than one. Therefore, elevated SQLs for 1,2-dibromoethane are not expected to have a significant impact on the overall soil gas risk evaluation at 5 feet bgs.
- 1,2-dibromo-3-chloropropane was not detected in any samples; the SQL exceeded 10% of the minimum RBTC in 81% of these nondetected samples and exceeded the minimum RBTC in 78% of the nondetected samples (Table 4-5). The maximum estimated excess lifetime cancer risk associated with the elevated SQLs of 1,2-dibromo-3-chloropropane would be 5 x 10^{-5} for a trailer residential scenario, which is within the target cancer risk range of 10^{-6} to 10^{-4}. The maximum estimated HQ associated with the SQLs would be 0.1 for a trailer residential scenario, which is well below the NDEP target HQ of greater than one. Therefore, if 1,2-dibromo-3-chloropropane had been detected in soil gas at 5 feet bgs for the OU-2 BHRA Area, it is not expected to have a significant impact on the overall soil gas risk evaluation.

Soil Gas at 10 to 15 feet bgs:

- For five analytes (acrolein, acrylonitrile, benzyl chloride, 1,2-dibromoethane, and hexachlorobutadiene), the SQL exceeded 10% of the minimum RBTC (0.1 x RBTC) in 3.5 to 38% of non-detected samples, with no SQLs exceeding the minimum RBTC (Table 4-6). The maximum estimated excess lifetime cancer risk associated with the

[32] SQLs were first screened against the minimum RBTCs (i.e., residential RBTCs) as a conservative first tier analysis. For chemicals with SQLs exceeding 10% of the minimum RBTCs (0.1xRBTC), cancer risk and noncancer HQ estimates were calculated using land-use-specific/scenario-specific RBTCs. For chemicals with SQLs exceeding the minimum RBTCs, maximum cancer risks and noncancer HQs are reported in detail.

SQLs for these VOCs fall within the range of 6 x 10^{-9} to 3 x 10^{-7}, which is below the lower end of the target cancer risk range of 10^{-6} to 10^{-4}. The maximum estimated HQ range associated with the elevated SQLs for these VOCs is 0.000004 to 0.2, which is well below the NDEP target HQ of greater than one. Therefore, the maximum SQLs of these chemicals are not expected to have a significant impact on the overall soil gas risk evaluation at 10 to 15 feet bgs.

- 1,2-dibromo-3-chloropropane was detected in one out of 46 samples; the SQL exceeded 10% of the minimum RBTC in 93% of nondetected samples and exceeded the minimum RBTC in 91% of the nondetected samples (Table 4-6). The maximum estimated excess lifetime cancer risk associated with the elevated SQLs of 1,2-dibromo-3-chloropropane would be 3 x 10^{-5} for a trailer scenario, which is within the target cancer risk range of 10^{-6} to 10^{-4}. The maximum estimated HQ would be 0.06 for a trailer scenario, which is well below the NDEP target HQ of greater than one. Therefore, the elevated SQLs for 1,2-dibromo-3-chloropropane are not expected to have a significant impact on the overall soil gas risk evaluation at 10 to 15 feet bgs.

In summary, elevated SQLs are not expected to have a significant impact on the overall soil gas risk evaluation for the OU-2 BHRA Area.

Shallow Groundwater:

- For seven analytes (bromodichloromethane, carbon tetrachloride, 1,2-dibromoethane, 1,2-dichloroethane, hexachlorobutadiene, trichloroethene, and vinyl chloride), the SQL exceeded 10% of the minimum RBTC (0.1 x RBTC) in 3.1 to 10% of nondetected samples, with no SQLs exceeding the minimum RBTC (Table 4-7). The maximum estimated excess lifetime cancer risk range associated with the elevated SQLs of these analytes is 4 x 10^{-9} to 8 x 10^{-7}, which are below the lower end of the target cancer risk range of 10^{-6} to 10^{-4}. The maximum estimated HQ range associated with the elevated SQLs of these analytes is 0.0000004 to 0.04, which are well below the NDEP target HQ of greater than one. Therefore, the elevated SQLs of these chemicals are not expected to have a significant impact on the overall groundwater risk evaluation.
- 1,2-dibromo-3-chloropropane was not detected in any samples; the SQL exceeded 10% of the minimum RBTC in 100% of these nondetected samples and exceeded the minimum RBTC in 7.2% of the nondetected samples (Table 4-7). The maximum estimated excess lifetime cancer risk associated with the elevated SQLs of 1,2-dibromo-3-chloropropane is 4 x 10^{-6} for a residential scenario, which is within the target cancer risk range of 10^{-6} to 10^{-4}. The maximum estimated HQ associated with the elevated SQLs is 0.008 for a residential scenario, which is well below the NDEP target HQ of greater than one. Therefore, if 1,2-dibromo-3-chloropropane had been quantitatively included in the BHRA, it is not expected to have any significant impact on the overall groundwater risk evaluation.

In summary, elevated SQLs are not expected to have a significant impact on the overall shallow groundwater risk evaluation for the OU-2 BHRA Area.

6.1.3 Completeness

No soil gas data were rejected, and the percent completeness for the soil gas BHRA data set is 100%. Therefore, the completeness of soil gas BHRA data set has no impact on the overall risk evaluation.

The rejected ("R" qualified) data associated with shallow groundwater samples are summarized in Appendix C, Table C-2. The percent completeness for the shallow groundwater BHRA data set is 99.98%. The only analyte with rejected data is styrene. Given the small percentage of rejected data (three samples out of 278 shallow groundwater samples), these rejected data are not expected to have a significant impact on the spatial coverage of the shallow groundwater BHRA data set. Meanwhile, all the rejected data were nondetects, and styrene was never detected at any well locations. Additionally, the rejected data were all well below the lowest RBTCs among different exposure scenarios, indicating low potential risks. Therefore, even if these shallow groundwater data are not rejected, it is not expected to have a significant impact on the overall risk evaluation.

6.1.4 Comparability

As discussed in Tables 4-1 and 4-2, different reporting limits for the same analyte in soil gas or shallow groundwater may impact the comparability of the data sets. For most of the analytes, the SQLs are well below 0.1 x RBTC. There are some soil gas and shallow groundwater analytes with SQLs exceeding 0.1 x RBTC, as summarized in Tables 4-5 through 4-7, and their impacts on the overall risk evaluation are discussed in Section 6.1.2. In summary, different reporting limits for the same soil gas or shallow groundwater analyte are not expected to have a significant impact on the overall risk evaluation.

For the soil gas data used in the BHRA, the objective of the 2008 Phase B Investigation and RI was to provide sufficient spatial coverage to support this BHRA: samples from the 2008 Phase B investigation were taken primarily from former sale parcels (i.e. limited to the southern boundary of the OU-2 BHRA Area), while samples from the RI were taken throughout the OU-2 BHRA Area. Temporal trends are discussed in Section 4.2.3, and spatial representativeness is discussed in Section 4.2.2. Collectively, the soil gas data set provides sufficient coverage of the OU-2 BHRA Area, and the use of the maximum detected concentrations for the exposure estimates is considered conservative.

For the groundwater data used in the BHRA, as discussed in Section 4.1.5, the same analytical methods were used across most investigations; specifically, USEPA Method SW-8260 for VOCs. When a VOC was analyzed by both SW-8260 and 8260B SIM in some investigations, the results from the more sensitive SW-8260B SIM were used. Temporal trends are discussed in Section 4.2.3, and spatial representativeness is discussed in Section 4.2.2. Collectively, the shallow groundwater data set provides sufficient coverage of the OU-2 BHRA Area, and the use of the maximum detected concentrations for the risk estimates is considered conservative.

6.1.5 Precision

Soil Gas

As presented in Appendix B, Table B-1, in the soil gas BHRA data set, a total of 16 pairs of primary and field duplicate results were qualified due to practical quantitation limit (PQL) criterion exceedance, and no primary and field duplicate results were qualified due to relative percent difference (RPD) criterion exceedance. For laboratory duplicates, there were no data points qualified due to RPD or PQL criterion exceedance (see DVSRs tables in Appendix B). The impacts of field duplicate data qualified due to PQL criterion exceedance are discussed as follows:

- Nine pairs of qualified field duplicate results came from the 2008 Phase B Investigation, one pair of qualified field duplicate results came from Phase 1 RI, and six pairs of qualified field duplicate result came from Phase 3 RI. However, none of these qualified field duplicate results include risk-driving chemicals, therefore they do not have a significant impact on risk results.
- Further, all the qualified field duplicate data were well below the lowest RBTCs among different exposure scenarios, indicating low potential risks.

Therefore, the field duplicate data qualified due to PQL criterion exceedance are not expected to have a significant impact on the overall risk evaluation.

Shallow Groundwater

As presented in Appendix C, Table C-3, in the shallow groundwater BHRA data set, a total of two pairs of primary and field duplicate results were qualified due to PQL criterion exceedance, and no primary and field duplicate results were qualified due to RPD criterion exceedance. For laboratory duplicates, there were no data points qualified due to RPD or PQL criterion exceedance (see DVSRs tables in Appendix B). The impacts of field duplicate data qualified due to PQL criterion exceedance are discussed as follows:

- One pair of qualified field duplicate results came from the 2016 Semi-Annual Groundwater Monitoring sampling, and one pair of qualified field duplicate results came from the 2020 Annual Groundwater Monitoring sampling. However, none of these qualified field duplicate results include risk-driving chemicals; therefore, they do not have significant impacts on risk results.
- Further, all the qualified field duplicate data were well below the lowest RBTCs among different exposure scenarios, indicating low potential risks.

Therefore, the field duplicate data qualified due to PQL criterion exceedance are not expected to have a significant impact on the overall risk evaluation.

6.1.6 Accuracy

Soil Gas

The soil gas analytical data were evaluated in DVSRs presented in Appendix B, with a subset of the data qualified with a J qualifier (J, J-, or J+) based on method blank, field duplicate, and/or other quantitation issues (1,281 out of 7,731 data points, see Appendix D); that is, the reported value was estimated, with no (J), low (J-), or high (J+) bias. The potential impact of the J qualified data on the overall risk analysis was evaluated:

- J and J+ Qualified Data: A review of the J and J+ qualified data indicated that the estimated results were well below the lowest RBTCs among different exposure scenarios, except for 1,2-dibromo-3-chloropropane at 5 and 15 feet bgs (Appendix B,

Table B-3). The estimated nondetected 1,2-dibromo-3-chloropropane results from two soil gas samples at RISG-1 (5 feet and 15 feet bgs) were above the lowest RBTC. However, since chloroform was the primary risk driver at RISG-1, correction for the bias of these two results is not expected to have a significant impact on the risk estimates for residents. Further, the estimated cancer risk associated with these two results would be 2 x 10^{-6}, which is within the target cancer risk range of 10^{-6} to 10^{-4}. As discussed in Section 6.1.2, the SQL exceeded 10% of the minimum RBTC in 81% and 93% of nondetected samples at 5 feet bgs and 10 to 15 feet bgs, respectively, and exceeded the minimum RBTC in 78% and 91% of nondetected samples at 5 feet bgs and 10 to 15 feet bgs, respectively. In summary, correction for the bias of the J and J+ qualified data is not expected to have a significant impact on the overall risk evaluation.

- J- Qualified Data: A review of the J- qualified data indicated that only one estimated result with low bias was included in the risk calculation and it was well below the lowest RBTCs among different exposure scenarios. Therefore, correction for the low bias of the J- qualified data is not expected to have a significant impact on the overall risk evaluation.

As discussed in Table 4-1, in accordance with the most recent guidance (NDEP 2012) for evaluating data associated with blank contamination, Ramboll queried the censored (or nondetect) data for blank contamination from the project database and changed them from nondetected values at the PQLs (U qualified) to detected values at reported concentrations (J qualified) if the PQLs were higher than the reported concentrations. The revisions of censored data for blank contamination are summarized in Appendix B, Table B-2. The corrected results were well below the lowest RBTCs among different exposure scenarios, indicating the risks of these results were low. Therefore, the revisions of data associated with blank contamination to estimated detected values are not expected to have a significant impact on the overall risk evaluation.

Shallow Groundwater

The shallow groundwater analytical data were evaluated in DVSRs presented in Appendix C, with a subset of the data qualified with a J qualifier (J, J-, or J+) based on method blank, field duplicate, and/or other quantitation issues (541 out of 16,709 data points, see Appendix E); that is, the reported value was estimated, with no (J), low (J-), or high (J+) bias. The potential impact of the J qualified data on the overall risk analysis was evaluated:

- J and J+ Qualified Data: A review of the J and J+ qualified data indicated that the estimated results were all well below the lowest RBTCs among different exposure scenarios (Appendix C, Table C-4). Therefore, correction for the bias of the J and J+ qualified data is not expected to have a significant impact on the overall risk evaluation.
- J- Qualified Data: A review of the J- qualified data indicated that the estimated results with low bias were all below the lowest RBTCs among different exposure scenarios (Appendix C, Table C-4). Therefore, correction for the low bias of the J- qualified data is not expected to have a significant impact on the overall risk evaluation.

6.1.7 Duplicate Treatment

For soil gas and shallow groundwater samples with primary and field duplicate results, the maximum detected concentrations at the same locations were conservatively used in the risk evaluation. The impacts are discussed as follows.

Soil Gas

As previously indicated, chloroform is the cancer risk driver in soil gas. Among the soil gas BHRA data used in the risk calculation, a total of eight pairs of field duplicate samples collected at five soil gas sample locations (RISG-5, RISG-6, RISG-68, RISG-71, and RISG-74) have an estimated excess lifetime cancer risk above 10^{-6} for residents or indoor commercial/industrial workers. Among these samples, RISG-6 has the highest risk for the workers scenarios for soil gas at 5 feet bgs, and the associated chloroform concentrations were 10,000 $\mu g/m^3$ and 11,000 $\mu g/m^3$ in the primary and field duplicate samples. The field duplicate samples were treated as independent samples and the highest by sample risk estimate were selected to report for each location and depth interval for each scenario. Therefore, this approach is considered conservative for estimating the health risks for soil gas at locations where field duplicate samples were collected.

Shallow Groundwater

Chloroform is also the cancer risk driver in shallow groundwater. Among the shallow groundwater BHRA data set used in the risk calculation, a total of five pairs of field duplicate samples collected at four shallow groundwater wells (PC-28, PC-124, PC-126, and PC-187) have estimated excess lifetime cancer risk above 10^{-6} for residents or indoor commercial/industrial workers. None of the cancer risk estimates for these groundwater samples are the highest for the evaluated scenarios. The field duplicate samples were treated as independent samples and the highest by sample risk estimate were selected to report for each well for the evaluated scenarios. Therefore, this approach is considered conservative for estimating the health risks for shallow groundwater wells where the field duplicate samples were collected.

6.2 Uncertainties Identified in the Risk Assessment

6.2.1 Identification of Chemicals to Include in Quantitative Risk Assessment

All VOCs detected in one or more soil gas or shallow groundwater samples in the BHRA data sets were evaluated in the quantitative risk assessment. Among the 77 soil gas analytes, 67 and 51 detected VOCs were identified for samples collected at 5 feet bgs and 10-15 feet bgs, respectively. A total of 23 out of 91 analytes were identified as detected VOCs for shallow groundwater samples. For most of the chemicals that were not quantitatively evaluated in this BHRA, the SQLs were well below 0.1 x RBTC; therefore, exclusion of these chemicals from the quantitative risk assessment is not expected to have a significant impact on the overall results of the BHRA. It should be noted that, for a few chemicals, the SQLs were higher than 0.1 x RBTC in a few soil gas or shallow groundwater samples (see Tables 4-5 through 4-7). The impacts of elevated SQLs on the risk evaluation are discussed in Section 6.1.2.

6.2.2 Exposure Assessment

6.2.2.1 Exposure Scenarios

The exposure assessment in this BHRA is based on a RME scenario, which is defined by USEPA as the highest exposure that could reasonably be expected to occur for a given exposure pathway at a site (USEPA 1989). To achieve this goal, the RME scenario uses highly conservative exposure assumptions. For example, this BHRA assumes that the residents spend every hour of every day in their home for 26 years. The USEPA has estimated that the 50th percentile for years lived in current home is 8 years, with a 90th percentile value of 32 years (USEPA 2011x, Table 16-90). Further, adults, and most children, do not typically spend 100% of their total daily time at home (USEPA 2011x), as assumed in this BHRA. The exposure assessment for an outdoor commercial/industrial worker assumes the worker would inhale vapor migrating from soil gas or shallow groundwater to outdoor air eight hours per day, 225 days per year for 25 years. These and other upper-bound, default exposure assumptions overestimate the potential health risks associated with the OU-2 BHRA Area.

6.2.2.2 EPCs

The maximum detected concentrations in soil gas and shallow groundwater at each individual sample location were multiplied by the transfer factors estimated from the fate and transport modeling to predict the air EPCs in indoor air and trench air. This approach is expected to overestimate the EPCs (and associated risks), because the maximum concentration at a single location is not likely representative for an entire exposure area (e.g., rooms within an entire building). Furthermore, this is a conservative procedure for the purposes of estimating potential health risks associated with the inhalation of vapors in a construction trench, because it is unlikely that a construction worker would stay at only a single location over an extended period of time.

The 95% UCL on the average soil gas and shallow groundwater concentrations over the OU-2 BHRA Area were multiplied by the transfer factors estimated from the fate and transport modeling to predict the air EPCs in outdoor air (unless a 95% UCL could not be calculated due to limited number of detections, in which case the maximum detected concentrations in the OU-2 BHRA Area were used). This assumption is representative for a RME estimate. It is very unlikely that an outdoor commercial/industrial worker is exposed to VOCs in soil gas and shallow groundwater at concentrations higher than the 95% UCLs over an extended period of time.

6.2.2.3 Fate-and-Transport Modeling

Fate-and-transport models were used to estimate indoor, outdoor, and trench air concentrations from measured soil gas or shallow groundwater concentrations. For indoor air, the USEPA Johnson and Ettinger model spreadsheet (USEPA 2017) was used. The Johnson and Ettinger model has numerous assumptions and limitations, each of which may over- or underestimate the predicted indoor air concentration. In this BHRA, site-specific soil physical parameters were used in the modeling, which should reduce the uncertainty in the model estimates. For outdoor air, an approach analogous to that used by USEPA to estimate outdoor air concentrations from chemicals in soil was used. Similarly, this approach also has assumptions that may over- or underestimate the predicted outdoor air concentrations.

The soil properties specific for the OU-2 BHRA Area used for the Johnson and Ettinger model (Table 5-3) were based on soil samples collected from 5 feet bgs and 10-15 feet bgs in the Qal at soil gas sample locations RISG-1 through RISG-9. Additionally, to be conservative the one soil sample collected from approximately 10 feet bgs at RISG-7 was not used in our evaluation due to extraordinarily wet soil properties measured at that location. The assumption that the entire unsaturated zone in the OU-2 BHRA Area is Qal is conservative, because for areas where the UMCf is part of the unsaturated zone, the finer-grained UMCf would act to reduce vapor transport of VOCs. If default soil properties for loamy sand recommended by USEPA (2017) were used in the evaluation, the risk results would increase by approximately a factor of one to six. Currently, the maximum estimated excess lifetime cancer risk was 2×10^{-5} and 1×10^{-4} for soil gas and shallow groundwater, respectively; and the maximum estimated noncancer HI was 0.03 for soil gas and 0.1 for shallow groundwater (Tables 5-13 and 5-17).

Soil gas data collected at approximately 5 feet bgs, 10 feet bgs, and 15 feet bgs were compared to soil gas RBTCs modeled at 5 feet, 10 feet, and 15 feet bgs, respectively. Data from one soil gas sample collected at 13 feet bgs at RISG-1 were conservatively compared to the soil gas RBTCs modeled at 10 feet bgs. The transfer factors at a shallower depth (10 feet bgs) would be higher (more conservative) than those at a deeper depth (13 feet bgs) due to shorter diffusion up through the vadose zone, resulting in slightly increased risks. Overall, the slight variation in soil gas sampling depth is not expected to have a significant impact on the overall risk results for soil gas. In addition, as shown in Appendix A, most of the soil gas samples in the OU-2 BHRA Area were collected at areas with a land cover (i.e. asphalt street) which creates a barrier between the soil and the air. The presence of a land cover tends to decrease the migration of VOCs to air and increase the amount of VOCs accumulating and remaining in the subsurface and is considered similar to the conditions when a building is present. The soil gas samples were collected near actual residential homes or commercial buildings. Therefore, the soil gas samples were collected at locations that are considered representative of the conditions for residents and indoor workers that may be exposed to VOCs migrating from soil gas to indoor air in the OU-2 BHRA Area.

Depths to groundwater used in the Johnson and Ettinger model were based on measurements for wells located in the OU-2 BHRA Area and selected to be conservative considering both current and historical data for this area. Groundwater data from wells with depth to groundwater deeper than 20 feet bgs were conservatively compared to the groundwater RBTCs modeled at 20 feet bgs, and groundwater data from wells with depth to groundwater from 10 -20 feet bgs were conservatively compared to RBTCs modeled at 10 feet bgs. Depths to groundwater in a very limited area near monitoring wells PC-161 and PC-162 were identified to be shallower than 10 feet bgs. Potential construction worker exposure to shallow groundwater is addressed in Section 6.2.4. In general, the depth assumptions used in the modeling would overestimate the exposures and health risks for the vapor intrusion pathway for shallow groundwater.

For the indoor air scenario, a conservative default residential slab-on-grade building, a residential trailer, and a commercial building (with the building characteristics shown on Table 5-4), were assumed for modeling. The default floor space area used in the modeling might be different from the actual residential or commercial buildings in the OU-2 BHRA Area. However, the size of building footprint is expected to have little impact on the modeling of transfer factors, because when the size of building footprint changes, the air flow into the building would be changed accordingly, which would offset the effects. A conservative (lower) building height of three meters was assumed for the commercial building which would result in higher transfer factors, although many commercial buildings have higher first floor ceilings.

The residential trailer scenario was modeled as a crawl space with a dirt floor using the USEPA's default assumptions as discussed in Section 5.2.2. When removing the building foundation (i.e. the barrier) it should increase the airflow into the building, making the model more conservative. However, the transport of air into the trailer is limited by diffusion through the vadose zone instead of advection. Therefore, the overall results are very similar to the modeling results with a building foundation (i.e. slab-on-grade scenario) and the impacts on the risk results are considered low.

For the outdoor air scenario, the 95% UCLs on the mean VOC concentrations in soil gas or shallow groundwater samples within commercial/industrial areas in the western portion of OU-2 were used as EPCs, which would offset the impacts of conservatively using the entire area of the chloroform groundwater plume (as defined by chloroform concentration >70 ug/L) in the OU-2 BHRA Area as the source area in the modeling.

When evaluating the construction trench scenario, it was conservatively assumed that air containing VOCs would be migrating from the walls of the construction trench in addition to the base to maximize exposure potential. A box model was used to simulate dispersion, and the air flow through the construction trench was controlled by a site-specific windspeed that was reduced by a factor of 10 to ensure it would be conservative for a construction trench scenario where the breathing zone may be a few feet bgs. This is especially conservative because many construction trenches include a fan to increase air flow through the construction trench or are shallower than 10 feet, potentially increasing the breathing zone to above the ground surface.

For BioVapor modeling, the default building parameters from the Johnson and Ettinger model (USEPA 2017), instead of the default BioVapor building parameters, were used for consistency. The BioVapor model is very sensitive to the air flow through the building foundation, and the default building parameters from the Johnson and Ettinger model corresponded to a lower air flow through the building foundation, which resulted in a decreased biodegradation ratio by two to three orders of magnitude (a lower attenuation factor with biodegradation) when compared to the default BioVapor building parameters. However, since the risk contributions from benzene were extremely low when considering biodegradation (see Appendix G), the use of default building parameters from the Johnson and Ettinger model is not expected to have a significant impact on the overall risk evaluation. In addition, the biodegradation ratios for indoor air scenarios were used as the surrogates for outdoor and trench scenarios at the corresponding depths. This is a conservative approach because there is likely more oxygen and biological activities available when no slab/building is present, and higher biodegradation (lower attenuation factors with biodegradation) is expected for outdoor and trench scenarios.

6.2.3 Toxicity Assessment

One of the largest sources of uncertainty in any risk assessment is the limited understanding of toxicity to humans who are exposed to lower concentrations generally encountered in the environment than those used in the toxicity studies. The majority of the available toxicity data are from animal studies; these data are extrapolated using mathematical models or multiple uncertainty factors to predict what might occur in humans. Sources of uncertainty and/or conservatism in the toxicity criteria used in this BHRA include:

- The use of conservative methods and assumptions to extrapolate from high-dose animal studies to predict the possible response in humans at exposure levels far below those administered to animals;
- The assumption that chemicals considered to be carcinogens do not have thresholds (i.e., for all doses greater than zero, some risk is assumed to be present); and
- The fact that epidemiological studies (i.e., human exposure studies) are limited and are not generally considered in a quantitative manner in deriving toxicity values.
- Chemical-specific uncertainties in toxicity criteria are provided below for major cancer risk drivers with soil gas and/or shallow groundwater estimated excess lifetime cancer risks above 10^{-6} (i.e., chloroform) as well as for chemicals with noncancer toxicity criteria obtained from PPRTV appendices (bromochloromethane, 2-chlorotoluene, dibromomethane, dichlorodifluoromethane, n-propylbenzene, and 1,1,2-trichloroethane), followed by a discussion regarding soil gas and groundwater analytes for which surrogate criteria were used.

Chloroform

The IUR for chloroform is obtained from IRIS based primarily on a mouse gavage study (USEPA 2020c). The tumor type considered in the derivation of IUR was hepatocellular carcinoma, and USEPA used a linearized multistage procedure to extrapolate metabolism-dependent carcinogenic responses from mice to humans. The IUR was derived by taking a geometric mean of the slope factor and assuming 100% for low doses of chloroform in air. Adequate numbers of animals were treated and observed, and the risks estimates derived are generally supported by male rat kidney tumor data from other studies. Therefore, the uncertainty associated with the IUR for chloroform is expected to be low. In summary, the uncertainty associated with the IUR for chloroform is not expected to have a significant impact on the overall risk evaluation.

Bromochloromethane

The inhalation chronic RfC for bromochloromethane is a screening toxicity value taken from an appendix of a PPRTV assessment based on an inhalation subchronic study of rats (USEPA 2009b). Chronic inhalation toxicity testing of bromochloromethane has not been conducted. The critical effect considered in the derivation of the inhalation chronic RfC is increased relative liver weight in rats. USEPA applied a large composite uncertainty factor of 10,000 to the lowest-observed-adverse-effect level (LOAEL) to account for interspecies extrapolation, intraspecies differences for extrapolation to sensitive humans, database uncertainty (the key study is very old and incompletely reported; there are no developmental or reproductive toxicity data), the use of a LOAEL as the point of departure and using data from a subchronic study to assess chronic exposures. USEPA concluded that due to lack of chronic toxicity testing and large uncertainties associated with the subchronic studies, derivation of a provisional chronic RfC for bromochloromethane is not feasible, and there are considerably more uncertainties associated with the appendix screening chronic RfC. Bromochloromethane was not detected in soil gas (Appendix D) or shallow groundwater (Table 5-1); therefore, it did not contribute to any risks. As indicated in Table 4-6, the maximum SQL of bromochloromethane was well below 0.1 x RBTC. In summary, the uncertainty associated with the inhalation chronic RfC for bromochloromethane is not expected to have a significant impact on the overall risk evaluation.

2-Chlorotoluene

The inhalation subchronic RfC for 2-chlorotoluene is a screening toxicity value taken from an appendix of a PPRTV assessment based primarily on a rat developmental study (USEPA 2010a). The critical effects considered in the derivation of the subchronic RfC were slight ataxia (coordination issues), decreased body-weight gains and food consumption, and increased water consumption. USEPA applied a composite uncertainty factor of 300 to the no-observed-adverse-effect level (NOAEL) to account for animal to human extrapolation, intraspecies differences for potentially susceptible individuals, and database uncertainty (no acceptable two-generation reproduction or neurotoxicity studies). USEPA concluded that insufficient data were available to derive provisional toxicity values for 2-chlorotoluene, and there is considerably more uncertainty associated with the appendix screening subchronic RfC. Additionally, a screening chronic RfC was not derived due to the short duration of developmental studies (14−23 days) and lack of longer-term studies to detect more sensitive respiratory or systemic effects. The inhalation chronic RfC for chlorobenzene was used as a surrogate for 2-chlorotoluene. As indicated in Appendix G, 2-chlorotoluene was not a driver for noncancer HI for any receptor population in the OU-2 BHRA Area. Therefore, the uncertainty associated with the inhalation subchronic RfC for 2-chlorotoluene is not expected to have a significant impact on the overall risk evaluation.

Dibromomethane

The inhalation chronic and subchronic RfC values for dibromomethane are screening toxicity values taken from an appendix of a PPRTV assessment based on an unpublished subchronic inhalation study in rats and dogs (USEPA 2009c). This study is the only adequate evaluation on the inhalation toxicity of dibromomethane; no chronic inhalation toxicity studies were located. The critical effect considered in the derivation of the RfCs is increased blood carboxyhemoglobin levels in rats, which was the only effect observed in the study. Benchmark dose modeling was conducted to derive a lower bound benchmark human equivalent concentration used as a point of departure. To derive the screening subchronic RfC, USEPA applied a composite uncertainty factor of 300 to the point of departure to account for interspecies extrapolation, protection of sensitive human subpopulations, and database deficiencies (no developmental or reproductive toxicity studies); for the screening chronic RfC, an additional uncertainty factor of 10 was also applied to account for using a subchronic study to approximate chronic exposures. USEPA concluded that insufficient data were available to derive provisional toxicity values for dibromomethane, and there is considerably more uncertainty associated with the appendix screening RfC values. Dibromomethane was not detected in soil gas (Appendix D) or shallow groundwater (Table 5-1); therefore, it did not contribute to any risks. As indicated in Table 4-6, the maximum SQL of dibromomethane was well below 0.1 x RBTC. In summary, the uncertainty associated with the inhalation chronic RfC for dibromomethane is not expected to have a significant impact on the overall risk evaluation.

Dichlorodifluoromethane

The inhalation chronic RfC for dichlorodifluoromethane is a screening toxicity value taken from an appendix of a PPRTV assessment based on a six-week intermittent inhalation study in guinea pigs, rabbits, dogs, and monkeys (USEPA 2010b). No chronic inhalation studies have been conducted. There are a few existing subchronic human inhalation studies, but they all have significant limitations. The only chronic inhalation toxicity studies available are two experiments in rats and mice, designed as cancer bioassays, and there are no dose-response data available for non-tumor related effects in animals following chronic inhalation exposure. The critical effect considered in the derivation of the inhalation chronic RfC is reduced body-weight gain. USEPA applied a composite uncertainty factor of 10,000 to the LOAEL to account for interspecies extrapolation, intraspecies differences for potentially susceptible individuals, extrapolation from a LOAEL to a NOAEL, using data from a subchronic study to assess chronic exposures, and database inadequacies (i.e., limited reproductive and developmental toxicity studies via the inhalation route). USEPA concluded that insufficient data were available to derive a provisional chronic toxicity value for dichlorodifluoromethane, and there is considerably more uncertainty associated with the appendix screening chronic RfC. As indicated in Appendix G, dichlorodifluoromethane was not a driver for noncancer HI for any receptor population in the OU-2 BHRA Area. Therefore, the uncertainty associated with the inhalation chronic RfC for dichlorodifluoromethane is not expected to have a significant impact on the overall risk evaluation.

n-Propylbenzene

The inhalation chronic and subchronic RfC values for n-propylbenzene are screening toxicity values taken from an appendix of a PPRTV assessment based on using ethylbenzene as a surrogate (USEPA 2009d). The ototoxicity of ethylbenzene in a subchronic study of rats was shown to be qualitatively similar to that shown by n-propylbenzene following short-term oral exposure; therefore, the resulting assumption is that inhalation exposures of the two compounds would likely have similar results. The chronic RfC for ethylbenzene from IRIS is based on developmental toxicity studies in rats and rabbits, and because of this, the same value is recommended as a screening subchronic RfC. In deriving the screening chronic and subchronic RfCs, USEPA applied a composite uncertainty factor of 300 to the NOAEL to account for intra- and interspecies extrapolation and database deficiencies (lack of multigenerational reproductive and chronic studies). USEPA concluded that insufficient data were available to derive provisional toxicity values for n-propylbenzene, and there is considerably more uncertainty associated with the appendix screening RfC values. As indicated in Appendix G, n-propylbenzene was not a driver for noncancer HI for any receptor population in the OU-2 BHRA Area. Therefore, the uncertainty associated with the inhalation chronic and subchronic RfCs for n-propylbenzene is not expected to have a significant impact on the overall risk evaluation.

1,1,2-Trichloroethane

The inhalation chronic and subchronic RfC values for 1,1,2-trichloroethane are screening toxicity values taken from an appendix of a PPRTV assessment based on a subchronic inhalation study with rats. The inhalation chronic RfC for 1,1,2-trichloroethane is a screening toxicity value taken from an appendix of a PPRTV assessment based on an inhalation subchronic study of rats (USEPA 2009b). Chronic inhalation toxicity testing of 1,1,2-trichloroethane has not been conducted. The critical effect considered in the derivation of the inhalation chronic RfC is increased relative liver weight in rats. USEPA applied a large composite uncertainty factor of 10,000 to the LOAEL to account for interspecies extrapolation, intraspecies differences for extrapolation to sensitive humans, database uncertainty (the key study is very old and incompletely reported; there are no developmental or reproductive toxicity data), the use of a LOAEL as the point of departure and using data from a subchronic study to assess chronic exposures. USEPA concluded that due to lack of chronic toxicity testing and large uncertainties associated with the subchronic studies, derivation of a provisional chronic RfC for 1,1,2-trichloroethane is not feasible, and there are considerably more uncertainties associated with the appendix screening chronic RfC. 1,1,2-Trichloroethane was not detected in soil gas (Appendix D) or shallow groundwater (Table 5-1); therefore, it did not contribute to any risks. As indicated in Table 4-6, the maximum SQL of 1,1,2-trichloroethane was well below 0.1 x RBTC. In summary, the uncertainty associated with the inhalation chronic RfC for 1,1,2-trichloroethane is not expected to have a significant impact on the overall risk evaluation.

Surrogate Criteria

As identified in Table 5-8, 68 of the 87 VOCs analyzed for the soil gas and shallow groundwater samples included in BHRA data sets have toxicity values and 19 VOCs used surrogate toxicity criteria (i.e., inhalation RfC). Of these chemicals, 11 surrogates are those identified by NDEP (2017a). Freon 113 (1,1,2-trichloro-1,2,2-trifluoroethane) was specified as a surrogate for Freon 114 (1,2-dichloro-1,1,2,2-tetrafluoroethane) in *NDEP Response to Revised Technical Memorandum: Screening-Level Indoor Air Health Assessment for the 2008 Tronox Parcels A/B Soil Gas Investigation* (NDEP 2010d). The surrogates used for the seven remaining analytes are as follows:

Analyte	**Surrogate**
tert-Amyl methyl ether	Methyl tert butyl ether
4-Chlorotoluene	Chlorobenzene
2,2-Dichloropropane	1,2-Dichloropropane
1,1-Dichloropropene	1,3-Dichloropropene
Ethyl tert-butyl ether	Methyl tert butyl ether
n-Octane	n-Nonane
1,2,3-Trichlorobenzene	1,2,4-Trichlorobenzene

Among the 19 analytes using surrogate RfCs, 17 analytes were detected in the soil gas and/or shallow groundwater BHRA data sets. Depending on how similar the surrogate is to the analyte, the use of surrogate RfCs for evaluating soil gas and groundwater VOCs may introduce uncertainties and either overestimate or underestimate the potential for noncancer health effects. However, recognizing the very low noncancer HQs estimated for these VOCs (less than 0.002), use of surrogate RfCs is not expected to have a significant impact on the noncancer hazard evaluation or conclusions.

6.2.4 Risk Characterization

Because the risk characterization combines the site characterization, selection of chemicals quantitatively evaluated, exposure assumptions and toxicity assessment, the uncertainties and conservativeness discussed above are carried over into the risk characterization. In addition, risks cannot be quantitatively characterized for chemicals for which toxicity criteria have not been established. In this BHRA, potential health risks were quantified for current and future residents and workers in the OU-2 BHRA Area associated with inhalation of soil gas and shallow groundwater vapor migrating to indoor, outdoor, and trench air. Given the highly conservative nature of the exposure parameters used to characterize these pathways in this BHRA, especially for the RME scenario, it is highly unlikely that the same receptor would be exposed at that level over the entire duration of exposure. These conservative estimates of exposure were then combined with even more conservative estimates of toxicity values to estimate the magnitude (noncancer) or likelihood (cancer) of potential effects. Because of all the conservative assumptions build into each component of the risk assessment to address uncertainty, this methodology is believed to not underestimate the true risk but likely overestimate the true risk by a considerable degree, and the true risk could be as low as zero.

One source of uncertainty that is unique to risk characterization is the assumption that the total risk associated with exposure to multiple chemicals is equal to the sum of the individual risks for each chemical (i.e., the risks are additive). Other possible interactions include synergism, where the total risk is higher than the sum of the individual risks, and antagonism, where the total risk is lower than the sum of the individual risks. Relatively few data are available regarding potential chemical interactions following environmental exposure to chemical mixtures. Some studies have been carried out in rodents that were given simultaneous doses of multiple chemicals. The results of these studies indicated that no interactive effects were observed for mixtures of chemicals that affect different target organs (i.e., each chemical acted independently), whereas antagonism was observed for mixtures of chemicals that affect the same target organ, but by different mechanisms (Risk Commission 1997). While there is no data on chemical interactions in humans exposed to chemical mixtures at the dose levels typically observed in environmental exposures, animal studies suggest that synergistic effects will not occur at levels of exposure below their individual effect levels (Seed et al. 1995). As exposure levels approach the individual effect levels, a variety of interactions may occur, including additive, synergistic, and antagonistic interactions (Seed et al. 1995).

USEPA guidance for risk assessment of chemical mixtures (USEPA 1986) recommends assuming an additive effect following exposure to multiple chemicals. Subsequent recommendations by other parties, such as the National Research Council (NRC 1988) and the Presidential/Congressional Commission on Risk Assessment and Risk Management (Risk Commission 1997), have also advocated a default assumption of additivity. In this BHRA, risk assessments of chemical mixtures summed cancer risks regardless of tumor type, and summed HQs regardless of toxic endpoint or mode of action. Given the available experimental data, this approach likely overestimates potential risks associated with simultaneous exposure to multiple chemicals.

For four soil gas and shallow groundwater VOCs (dibromochloromethane, cis-1,2-dichloroethene, trans-1,2-dichloroethene, and trichlorofluoromethane, all of which are noncarcinogens), inhalation chronic RfCs are not available. Also, an inhalation subchronic RfC is not available for dibromochloromethane. In the absence of toxicity values, these VOCs were not evaluated quantitatively for the corresponding noncancer effects in the BHRA. The impacts of these VOCs on the overall risk estimates were evaluated using the RfCs developed by Cal/EPA (2019), which are derived based on route-to-route extrapolation from oral reference dose (RfD) values developed by the IRIS assuming an inhalation rate of 20 m^3 per day and a body weight of 70 kilograms. Use of the Cal/EPA RfCs would result in very low noncancer HQs estimated for these VOCs (less than 0.001). Therefore, the exclusion of these VOCs from quantitative risk assessment is not expected to have a significant impact on the risk estimates or overall conclusions of the BHRA.

Depths to groundwater in a very limited area near monitoring wells PC-161 and PC-162 were identified to be shallower than 10 feet bgs. Potential exposures through direct contact with groundwater may occur during construction excavation activities in this area. Due to limited numbers of monitoring wells with depth to groundwater shallower than 10 feet bgs in the OU-2 BHRA Area and the relatively low concentrations detected at these two wells, the health risks associated with this pathway were not quantitatively evaluated in the BHRA. The groundwater data collected between 2015 and 2020 from these two wells were evaluated using a semi-quantitative approach.

As shown in Table I-1 in Appendix I, to semi-quantitatively evaluate the potential exposure through groundwater direct contact for the construction workers during excavation activities at areas near monitoring wells PC-161 and PC-162, the maximum detected concentrations for all chemicals analyzed at these two wells were compared to groundwater screening levels developed for the construction workers. The groundwater screening levels for the construction workers were calculated based on maximum contaminant levels (MCLs), maximum contaminant level goals (MCLGs) (40 CFR Part 141), BCLs or RSLs for tap water for each detected chemical at these two wells and the ratio of the intake factors for the drinking water pathway and incidental groundwater ingestion pathway for the construction worker (see additional details in Tables I-1 and I-2). As discussed in Section 5.2, for the construction workers, exposure assumptions recommended by USEPA (2021a) were used, except that a utility trench scenario was evaluated assuming that the construction workers could be in a 10-foot construction trench when conducting excavation activities for 4 hours per day, 5 days per year for one year given the area with depth to groundwater shallower than 10 feet is fairly limited in the OU-2 BHRA Area. The rate of incidental ingestion of groundwater for a construction worker in a utility trench was assumed to be 0.02 L/day per recommendation of the NDEP (NDEP 2017b) to use the assumptions for construction trench scenario from Virginia Department of Environmental Quality (VDEQ) [VDEQ 2020]) (see Table I-2). As shown in Table I-1, the maximum detected concentrations for chemicals detected at PC-161 and PC-162 are well below their respective construction worker groundwater screening levels. Health risks through dermal contact are normally much lower than health risks through ingestion. Therefore, based on the screening results of this analysis, significant health risks are not expected to occur through the groundwater direct contact pathway for the construction workers in this area.

In addition, there are four soil gas[33] and 14 shallow groundwater sample locations[34] located just north of Sunset Road (Figure 4-1). These locations are located within a commercial area and therefore were evaluated under the commercial/industrial scenarios in the risk analysis of this BHRA. These sample locations are located just across Sunset Road which borders the Pittman neighborhood to the north. Due to the proximity of these locations to the residential area, a sensitivity analysis was conducted to conservatively evaluate samples collected at these locations under the residential slab-on-grade building scenario to assess uncertainties associated with evaluating these locations under the commercial/industrial scenario in the risk analysis. Under a residential slab-on-grade building scenario (instead of an indoor commercial/industrial worker scenario), estimated total excess lifetime cancer risks for soil gas at these locations ranged from 6×10^{-7} to 2×10^{-5} and 2×10^{-7} to 8×10^{-6} for 5 feet bgs and 10-15 feet bgs, respectively. Noncancer HI estimates ranged from 0.008 to 0.1 and 0.01 to 0.2 for soil gas at 5 feet bgs and 10-15 feet bgs, respectively. Shallow groundwater cancer risks ranged from 3×10^{-8} to 4×10^{-5} and noncancer HI ranged from 0.0004 to 0.06. When conservatively applying an indoor air residential slab-on-grade scenario for these commercial locations near the residential area, though the estimated cancer risk and non-cancer HI results would be higher than the ones for the indoor commercial/industrial worker scenario, the cancer risk estimates were still within the NDEP acceptable cancer risk range of 10^{-6} to 10^{-4}, and noncancer HI estimates were well below the NDEP target HI of greater than one at these locations. Therefore, evaluating these sample locations under the commercial/industrial scenario is not expected to change the conclusions of this BHRA.

In summary, assumptions used in each step of risk assessment contribute to the overall uncertainty in the BHRA results. However, given that the largest sources of uncertainty generally cause overestimates of exposure or risk, the results presented in this BHRA are considered to represent conservative estimates of the carcinogenic and noncarcinogenic risks, if any, posed by VOCs in soil gas and shallow groundwater in the OU-2 BHRA Area through the vapor intrusion pathway.

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[33] RISG-2, RISG-30, RISG-55, and RISG-56 for soil gas.

[34] PC-24, PC-50, PC-124, PC-125, PC-126, PC-127, PC-128, PC-129, PC-130, PC-131, PC-132, PC-153, PC-153R, PC-194

7. DATA QUALITY ASSESSMENT

Data quality assessment is an analysis that is performed after the risk assessment is completed to determine whether enough data has been collected to support the risk-based decisions that are recommended by the risk assessment. The results of data quality assessment for soil gas and groundwater data are discussed below.

7.1 Soil Gas Data

For soil gas, the evaluations of the residential slab-on-grade building, residential trailer, indoor commercial/industrial worker, and construction worker scenarios were based on the maximum total excess lifetime cancer risk estimates, while the evaluation of the outdoor commercial/industrial worker scenario was based on excess lifetime cancer risk estimates using the 95% UCLs of model-predicted VOC concentrations migrating from soil gas.

7.1.1 Exposure Scenario using Maximum Detected Concentrations

For the residential (for both slab-on-grade and trailer scenarios), indoor commercial/industrial worker, and construction worker scenarios, the evaluation of the risk of vapor intrusion was based on maximum risks at soil gas sample locations for each scenario, rather than on a measure of mean concentrations. For the purposes of the data quality assessment, the risk evaluation was conceptualized as a statistical test of the proportion of the soil gas sample results that are associated with an unacceptable risk of vapor intrusion. The soil gas data quality assessment for the residential, indoor commercial/industrial worker, and construction worker scenarios are summarized in Table 7-1.

As summarized in Table 5-13, the maximum excess lifetime cancer risk estimates for each exposed population are all below the upper limit of the target cancer risk range of 1×10^{-6} to 1×10^{-4}, and the noncancer HI does not exceed the noncancer threshold of greater than 1. Because the estimated risks and hazards at all sample locations did not exceed their respective thresholds, the proportion of samples with unacceptable risk is 0 out of the total number of samples for the scenario, or 0%. The total number of 5 feet bgs and 10-15 feet bgs soil gas samples evaluated in this BHRA for the residential slab-on-grade building, residential trailer, indoor commercial/industrial worker, and construction worker scenarios are summarized in Table 7-1.

In a hypothesis testing framework, a binomial test of proportions was used to evaluate the possibility that there is a greater-than-zero proportion of samples with unacceptable risk. The null hypothesis is that the proportion of samples with an unacceptable risk is 0 (p1=0). The alternative hypothesis is that the proportion is greater than p2, which is p1 plus an appropriate effect size (i.e., population proportion) that the test should be able to detect.

For the purposes of evaluating if a sufficient number of samples were collected to support the risk assessment, the number of samples required was determined using the Exact – Generic binomial test in the software program G*Power version 3.1.9 (Faul et al. 2009). In the HRA, a null hypothesis with a proportion of 0 indicates that the false rejection error rate (α) is 0 and independent of the sample size and other parameters. Thus, the number of samples required depends on the false acceptance rate (β), p1, and p2. The number of samples required for β at 15%, 20% to 25% was tested for all scenarios in Table 7-1.

As a starting point, an effect size of one over the sample size was considered, which would be equivalent to one sample having unacceptable risk. When employing this hypothesis test, the null hypothesis would be rejected if one or more samples with unacceptable risk were observed. As shown in Table 7-1, the number of samples required are larger than corresponding sample sizes for the residential slab-on-grade building, indoor commercial/industrial worker, and construction worker scenarios with an effect size of one over the sample size and β equal to or smaller than 25%, and the residential trailer scenario with an effect size of one over the sample size and β equal to or smaller than 20%. For the above scenarios, the null hypothesis that no soil gas samples would have unacceptable risk is rejected, meaning no sample having unacceptable risk within the current sample size cannot guarantee that all samples would have unacceptable risk. For the residential trailer scenario with an effect size of one over the sample size and β equal to 25%, the number of samples required are the same as the number of samples. For this scenario, the null hypothesis that no soil gas samples would have unacceptable risk is not rejected. Therefore, the current sample size is sufficient to guarantee that no sample location over the entire OU-2 BHRA Area would have an unacceptable risk.

For the scenarios where the null hypothesis is rejected with an effect size of one sample over the total number of samples, an effect size of two over the sample size was considered, which would be equivalent to two samples having unacceptable risk. When employing this hypothesis test, the null hypothesis would be rejected if two or more samples with unacceptable risk were observed. The test using an effect size of two cannot be conducted for the residential trailer scenario because there is a limited sample size of two. As shown in Table 7-1, the number of samples required are smaller than the corresponding sample size with an effect size of two samples over the sample size and β equal to or smaller than 25% for the residential slab-on-grade building, indoor commercial/industrial worker, and construction worker scenarios, meaning the null hypothesis that no soil gas samples would have unacceptable risk is not rejected, and the alternative hypothesis that two or more than two samples having unacceptable risk is rejected. Therefore, the current sample size is sufficient to guarantee that no more than one sample location over the entire OU-2 BHRA Area would have an unacceptable risk.

7.1.2 Exposure Scenario using 95% UCL

For the outdoor commercial/industrial worker scenario, the evaluation of the cancer risk or HI was based on the 95% UCL of the soil gas concentrations from commercial area soil gas samples, which is a measure of mean concentrations. For the purposes of the data quality assessment, the risk evaluation was based on a statistical test of comparing the estimated excess lifetime cancer risk (or HI) based on 95% UCLs of soil gas results with the target cancer risk (or target HI). The soil gas data quality assessment for the outdoor commercial/industrial worker scenario is summarized in Table 7-2.

In a hypothesis testing framework, a t-test can be used to evaluate the possibility that the mean of total cancer risk or HI is greater than or smaller than the target cancer risk or the target HI. The null hypothesis is that the mean of the total cancer risk or the HI is the same as the cancer risk or the target HI based on the 95% UCL of sample results ($Mean_0$). The alternative hypothesis is that the mean of the total cancer risk or the HI is greater than the target cancer risk or the target HI ($Mean_1$) if $Mean_1$ is greater than $Mean_0$, or the mean of the total cancer risk or the HI is smaller than the target cancer risk or the target HI ($Mean_1$) if $Mean_1$ is smaller than $Mean_0$.

The target cancer risk for an outdoor worker is set as 1 × 10^{-6}, the lower end of the target cancer risk range of 1 × 10^{-6} to 1 × 10^{-4}. The target HI for an outdoor worker is 1. As shown in Tables G-3 and G-4, the total cancer risks and HIs are all significantly lower than the corresponding target cancer risk and HI. Chloroform was detected at all samples and was the only major cancer risk driver and HI driver for outdoor worker scenarios based on Tables G-3 and G-4. The number of 5 feet bgs and 10-15 feet bgs soil gas samples for the outdoor worker scenario are 35 and 23, respectively, which are summarized in Table 7-2. The sample size of the chemical as the cancer risk or HI driver for the outdoor worker scenario was tested to evaluate if a sufficient number of samples were collected using the t tests – "Means: difference from constant (one sample case) test" in the software program G*Power version 3.1.9 (Faul et al. 2009).

In the BHRA, the number of samples required to support the risk assessment depends on the false rejection error rate (α), false acceptance rate (β), mean of sample risk ($Mean_0$), mean of target risk/HI ($Mean_1$), and standard deviation of risk/HQ (SD) in a scenario. A value of 5% was used for both α and β. $Mean_0$ is defined as the total risk or HI based on the 95% UCL of sample results for each corresponding scenario. SD is the standard deviation of total risk/HQ, which is simplified to be the standard deviation of risk/HQ based on the 95%UCL of the risk driver. In the G*Power program, the target risk ($Mean_1$) is set to 1.49 × 10^{-4} which is rounded to 1 × 10^{-4} for cancer risk, and the target HI ($Mean_0$) is set to 1.49 which is rounded to 1 for noncancer HI.

As shown in Table 7-2, the number of soil gas samples required to support risk assessment for each depth interval evaluated for the outdoor worker scenario are smaller than the corresponding sample size. With α and β equal to 5%, the null hypothesis that the mean of the total cancer risk or the noncancer HI is the same as total risk or HI is not rejected, and the alternative hypothesis is rejected. Since the cancer risk and noncancer HIs based on the 95% UCL of sample results were below the target thresholds, the mean of the cancer risk or the noncancer HI are also expected to be below the target thresholds. Based on this analysis, the number of soil gas samples collected is sufficient for the purpose of risk characterization.

7.2 Groundwater Data

7.2.1 Exposure Scenario using Maximum Detected Concentrations

For the residential (for both slab-on-grade and trailer scenarios), indoor commercial/industrial worker, and construction worker scenarios, the evaluation of the risk of vapor intrusion was based on maximum risks at groundwater sample locations for each scenario, rather than on a measure of mean concentrations. For the purposes of the data quality assessment, the risk evaluation was conceptualized as a statistical test of the proportion of the groundwater sample results that are associated with an unacceptable risk of vapor intrusion. The groundwater data quality assessment for the residential, indoor commercial/industrial worker, and construction worker scenarios are summarized in Table 7-3.

As summarized in Table 5-17, the maximum excess lifetime cancer risk estimates for each exposed population are all below the upper limit of the target cancer risk range of 1×10^{-6} to 1×10^{-4}, and the noncancer hazard does not exceed the noncancer threshold of greater than 1. Because the estimated risks and hazards at all sample locations did not exceed their respective thresholds, the proportion of samples with unacceptable risk is 0 out of the total number of samples for the scenario, or 0%. The total number of samples are summarized in Table 7-3. The number of shallow groundwater samples are 69, 4, 241, and 310 for the slab-on-grade residential, trailer residential, indoor worker, and construction worker, respectively.

In a hypothesis testing framework, a binomial test of proportions was used to evaluate the possibility that there is a greater-than-zero proportion of samples with unacceptable risk. The null hypothesis is that the proportion of samples with an unacceptable risk is 0 (p1=0). The alternative hypothesis is that the proportion is greater than p2, which is p1 plus an appropriate effect size (i.e., population proportion) that the test should be able to detect.

For the purposes of evaluating if a sufficient number of samples were collected to support the risk assessment, the number of samples required was determined using the Exact – Generic binomial test in the software program G*Power version 3.1.9 (Faul et al. 2009). In the HRA, a null hypothesis with a proportion of 0 indicates that the false rejection error rate (α) is 0 and independent of the sample size and other parameters. Thus, the number of samples required depends on the false acceptance rate (β), p1, and p2. The number of samples required for β at 15%, 20% to 25% was tested for all scenarios in Table 7-3.

As a starting point, an effect size of one over the sample size was considered, which would be equivalent to one sample having unacceptable risk. When employing this hypothesis test, the null hypothesis would be rejected if one or more samples with unacceptable risk were observed. As shown in Table 7-3, the number of samples required are larger than corresponding sample sizes for the slab-on-grade residential, indoor worker, and construction worker scenarios with an effect size of one over the sample size and β equal to or smaller than 25%, and the trailer residential scenario with an effect size of one over the sample size and β equal to or smaller than 20%. For the above scenarios, the null hypothesis that no groundwater samples would have unacceptable risk is rejected, meaning no sample having unacceptable risk within the current sample size cannot guarantee that all samples would have unacceptable risk. For the trailer residential scenario with an effect size of one over the sample size and β equal to 25%, the number of samples required are the same as the number of samples. For this scenario, the null hypothesis that no groundwater samples would have unacceptable risk is not rejected, meaning no sample having unacceptable risk within the current sample size can guarantee that no sample would have unacceptable risk.

For the scenarios where the null hypothesis is rejected with an effect size of one sample over the total number of samples, an effect size of two over the sample size was considered, which would be equivalent to two samples having unacceptable risk. When employing this hypothesis test, the null hypothesis would be rejected if two or more samples with unacceptable risk were observed. The test using an effect size of two cannot be conducted for the trailer residential scenario because there is a limited sample size of two. As shown in Table 7-3, the number of samples required are smaller than the corresponding sample size with an effect size of two samples over the sample size and β equal to or smaller than 25% for the slab-on-grade residential, indoor worker, and construction worker scenarios, meaning the null hypothesis that no groundwater samples would have unacceptable risk is not rejected, and the alternative hypothesis that two or more than two samples having unacceptable risk is rejected. Therefore, the current sample size is sufficient to guarantee that no more than one sample location over the entire OU-2 BHRA Area would have an unacceptable risk.

7.2.2 Exposed Scenario using 95% UCL

For the outdoor commercial/industrial worker scenario, the evaluation of the cancer risk or HI was based on the 95% UCL of the groundwater concentrations from commercial area groundwater samples, which is a measure of mean concentrations. For the purposes of the data quality assessment, the risk evaluation was based on a statistical test of comparing the estimated excess lifetime cancer risk (or HI) based on 95% UCLs of groundwater results with the target cancer risk (or target noncancer HI). The groundwater data quality assessment for the outdoor commercial/industrial worker scenario is summarized in Table 7-4.

In a hypothesis testing framework, a t-test can be used to evaluate the possibility that the mean of total cancer risk or HI is greater than or smaller than the target cancer risk or the target noncancer HI. The null hypothesis is that the mean of the total cancer risk or the HI is the same as the cancer risk or the target noncancer HI based on the 95% UCL of sample results ($Mean_0$). The alternative hypothesis is that the mean of the total cancer risk or the noncancer HI is greater than the target cancer risk or the target noncancer HI ($Mean_1$) if $Mean_1$ is greater than $Mean_0$, or the mean of the total cancer risk or the noncancer HI is smaller than the target cancer risk or the target HI ($Mean_1$) if $Mean_1$ is smaller than $Mean_0$.

The target cancer risk for an outdoor worker is set as 1×10^{-6}, the lower end of the target cancer risk range of 1×10^{-6} to 1×10^{-4}. The target HI for an outdoor worker is 1. As shown in Table G-12, the total cancer risks and HIs are all significantly lower than the corresponding target cancer risk and target HI. Chloroform was detected at all samples and was the only major cancer risk driver and noncancer HI driver for outdoor worker scenarios based on Table G-12. The number of groundwater samples for the outdoor worker scenario is 241, which is summarized in Table 7-4. The sample size of the chemical as the cancer risk or noncancer HI driver for the outdoor worker scenario was tested to evaluate if a sufficient number of samples were collected using the t tests – "Means: difference from constant (one sample case) test" in the software program G*Power version 3.1.9 (Faul et al. 2009).

In the BHRA, the number of samples required to support the risk assessment depends on the false rejection error rate (α), false acceptance rate (β), mean of sample risk ($Mean_0$), mean of target risk/HI ($Mean_1$), and standard deviation of risk/HQ (SD) in a scenario. A value of 5% was used for both α and β. $Mean_0$ is defined as the total risk or HI based on the 95% UCL of sample results for each corresponding scenario. SD is the standard deviation of total risk/HQ, which is simplified to be the standard deviation of risk/HQ based on the 95% UCL of the risk driver. In the G*Power program, the target risk ($Mean_1$) is set to 1.49×10^{-4} which is rounded to 1×10^{-4} for cancer risk, and the target HI ($Mean_0$) is set to 1.49 which is rounded to 1 for noncancer risk.

As shown in Table 7-4, the number of groundwater samples required to support risk assessment for the outdoor worker scenario are smaller than the corresponding sample size. With α and β equal to 5%, the null hypothesis that the mean of the total cancer risk or the noncancer HI is the same as total risk or HI is not rejected, and the alternative hypothesis is rejected. Since the cancer risk and noncancer HIs based on the 95% UCL of sample results were below the target thresholds, the mean of the cancer risk or the noncancer HI are also expected to be below the target thresholds. Based on this analysis, the number of groundwater samples collected is sufficient for the purpose of risk characterization.

8. SUMMARY AND CONCLUSIONS

The BHRA was conducted to evaluate potential health risks to current and future residents and workers from exposures to residual levels of VOCs released from soil gas and groundwater to indoor, outdoor, and trench air in the OU-2 BHRA Area, which was previously defined to be the NERT Off-Site Study Area component of OU-2 located west of Pabco Road. This BHRA report has been prepared according to the methodology described in the BHRA Work Plan for OU-1 and OU-2 Soil Gas and Groundwater, Revision 1 (Ramboll 2018a), submitted to the NDEP on December 18, 2018 and approved by NDEP on January 24, 2019.[35]

Consistent with agency guidance from USEPA (2015), soil gas data collected within the OU-2 BHRA Area since 2008 were used to evaluate potential exposure for current and future residents and workers via inhalation of vapors migrating from the subsurface to indoor air, outdoor air, and trench air. The soil gas data used in this BHRA were specifically collected to evaluate the vapor intrusion pathway. Soil gas data is the preferred line of evidence for assessing vapor intrusion risks as opposed to groundwater or soil data primarily due to higher uncertainties associated with vapor intrusion modeling based on groundwater or soil data (i.e., uncertainty in predicting contaminant partitioning from groundwater or soil moisture to soil gas and in predicting transport through the capillary fringe). Therefore, this BHRA considers the soil gas data as the primary line of evidence for evaluation of the vapor intrusion pathway; the groundwater data were evaluated to provide a secondary line of evidence and to check consistency between soil gas and groundwater results.

Analytical results of soil gas and shallow groundwater samples collected within the OU-2 BHRA Area were assessed through the data processing and DUE steps (see Section 4.1), and data representative of current conditions were selected for purposes of the BHRA. The VOCs selected for evaluation, the CSM and the estimated excess lifetime cancer risks and chronic HIs are summarized as follows:

- All VOCs detected in one or more soil gas or shallow groundwater samples in the BHRA data sets were evaluated in the risk assessment. As summarized in Table 5-1, a total of 71 VOCs were detected in soil gas and a total of 23 VOCs were detected in shallow groundwater.
- Based on the CSM for the OU-2 BHRA Area, potential exposure to soil gas and shallow groundwater was evaluated for residents, indoor commercial/industrial workers, outdoor commercial/industrial workers, and construction workers via inhalation of vapors migrating from soil gas and shallow groundwater to indoor air, outdoor air, and trench air. In addition, a trailer scenario was evaluated for residents living in residential trailers in a limited area in the OU-2 BHRA Area. To be conservative, construction workers were assumed to be exposed to vapors migrating from soil gas/shallow groundwater while standing in a 10-foot trench in the unsaturated zone, placing them closer to the potential sources.
- Excess lifetime cancer risks and noncancer HIs associated with inhalation of vapors migrating from soil gas and shallow groundwater were estimated for detected VOCs

[35] A separate BHRA report is being prepared for OU-1 soil gas and groundwater.

in soil gas and shallow groundwater for each sample for indoor air and trench air scenarios, and based on the 95% UCLs on the mean concentrations over the entire OU-2 BHRA Area (or the maximum outdoor air concentrations predicted over the entire OU-2 BHRA Area if 95% UCLs could not be calculated due to limited detections or higher than the maximum outdoor concentrations) for outdoor air scenarios. The risk results based on the soil gas data evaluation are presented in Table 5-13 and summarized below.

- For the residential slab-on-grade scenario, the estimated excess lifetime cancer risk ranged from 6×10^{-8} to 2×10^{-5} and 2×10^{-7} to 2×10^{-5} for soil gas at 5 feet bgs and 10-15 feet bgs, respectively. As shown on Figures 5-2 and 5-3, the highest risk estimates for both depth intervals correspond to sample location RISG-1. For the residential trailer scenario, the estimated excess lifetime cancer risks ranged from 5×10^{-7} to 1×10^{-5} and 3×10^{-7} to 7×10^{-6} for soil gas at 5 feet bgs and 10-15 feet bgs, respectively. As shown on Figures 5-2 and 5-3, the highest risk estimates at both depth intervals correspond to sample location RISG-77. All of these excess lifetime cancer risk estimates are within the NDEP acceptable risk range of 10^{-6} to 10^{-4}. The cancer risk driver for the soil gas samples was chloroform, contributing to over 97% of the total cancer risk for the location with the highest estimated cancer risks for residents.
- As shown in Figures 5-2 and 5-3, soil gas sample locations with cancer risks above 10^{-6} and less than 10^{-4} for residential indoor air scenarios were located over the area of higher chloroform concentrations in groundwater in the residential area in the OU-2 BHRA Area.
- For indoor commercial/industrial workers, the estimated excess lifetime cancer risks ranged from 5×10^{-9} to 3×10^{-6} and 4×10^{-9} to 2×10^{-6} for soil gas at 5 feet bgs and 10-15 feet bgs, respectively. As shown on Figures 5-4 and 5-5, the highest risk estimates correspond to sample location RISG-6. However, all of these excess lifetime cancer risk estimates were within the NDEP acceptable risk range of 10^{-6} to 10^{-4}. The cancer risk driver for the soil gas samples was chloroform, contributing to over 99% of the total cancer risk at the location with the highest estimated cancer risk for indoor commercial/industrial workers. As shown on Figures 5-4 and 5-5, soil gas sample locations with cancer risks above 10^{-6} for commercial/industrial indoor air scenarios were located over the area of higher chloroform concentrations in groundwater in the commercial/industrial area in the OU-2 BHRA Area.
- The estimated excess lifetime cancer risks for outdoor commercial/industrial workers and construction workers exposed to soil gas at 5 feet bgs and at 10-15 feet bgs were below the lower end of the NDEP acceptable risk range of 10^{-6} to 10^{-4}.
- The estimated total noncancer HIs for all the soil gas scenarios were below the NDEP target HI of greater than one.

As discussed above, this BHRA considers the soil gas data as the primary line of evidence for evaluation of the vapor intrusion pathway; the groundwater data were evaluated to provide a secondary line of evidence and to check consistency between soil gas and groundwater results. Groundwater results for VOCs from shallow monitoring wells (with top of well screens less than 60 feet bgs) collected from 2015 to 2020 within the OU-2 BHRA Area were included in this BHRA analysis. Similar to soil gas, the estimated excess lifetime cancer risks for vapor intrusion from shallow groundwater fell within the NDEP acceptable risk range of 10^{-6} to 10^{-4}, and chloroform was the primary chemical contributor to the estimated total cancer risk. All estimated total noncancer HIs for all the groundwater scenarios were below the NDEP target HI of greater than one. Because of all the conservative assumptions built into each component of the risk assessment, the results presented in this BHRA are considered to represent conservative estimates of the carcinogenic and noncarcinogenic risks, if any, posed by VOCs in soil gas and shallow groundwater in the OU-2 BHRA Area through the vapor intrusion pathway.

The spatial distribution of locations with cancer risk above 10^{-6} for shallow groundwater are also generally consistent with those for soil gas in the OU-2 BHRA Area. The soil gas location with the highest cancer risk estimates (i.e. RISG-1 in the residential area) is co-located with the shallow groundwater well with the highest residential cancer risk estimate (i.e. PC-67). The soil gas location with the highest cancer risk estimates for indoor commercial/industrial workers (i.e. RISG-6 in the commercial area) is also co-located with a shallow groundwater well that is among the wells with the highest cancer risk estimate (i.e. PC-122). The results and conclusions of the groundwater risk evaluation are generally consistent with the results and conclusions of the soil gas risk evaluations for the OU-2 BHRA Area, supporting the OU-2 CSM developed in the RI Report for OU-1 and OU-2 (Ramboll 2021a) which identified that chloroform in groundwater is the main source of chloroform detected in soil gas in this area. The highest cancer risk estimates occur at locations where the highest chloroform concentrations were detected in groundwater within the OU-2 BHRA Area and are located generally downgradient of the upgradient sources (i.e. TIMET, OU-1, and OSSM).

Exposure via domestic use of groundwater was not evaluated because groundwater is not currently used as a domestic water supply and is not anticipated to be used as a domestic water supply given the high concentrations of total dissolved solids (TDS) in shallow groundwater in the OU-2 BHRA area. Incidental ingestion of groundwater and dermal contact with groundwater during short-term construction activities is possible in very limited areas near PC-161 and PC-162 where depth to groundwater is less than 10 feet bgs. Due to the limited number of monitoring wells and the low concentrations detected at these wells, significant health risks during short-term construction activities are not expected to occur through the groundwater direct contact pathway in this area. This potential pathway is discussed as part of the uncertainty analysis of this BHRA.

In summary, potential exposure to VOCs in soil gas and shallow groundwater in the OU-2 BHRA Area through the vapor intrusion pathway does not pose unacceptable carcinogenic and noncarcinogenic human health risks to residents, indoor and outdoor commercial/industrial workers, and construction workers under the conditions and assumptions evaluated. Therefore, additional assessment is not warranted based on the risk characterization results for soil gas and shallow groundwater in the OU-2 BHRA Area as multiple lines of evidence.

9. REFERENCES

American Petroleum Institute (API). 2012. BioVapor A 1-D Vapor Intrusion Model with Oxygen-Limited Aerobic Biodegradation.

http://www.api.org/oil-and-natural-gas/environment/clean-water/ground-water/vapor-intrusion/biovapor

BRC. 2009. BRC Standard Operating Procedure (SOP) 40. Data Review Validation. Revision 4. May 7. NDEP approved May 11, 2009.

Berman, D.W., and K.S. Crump. 2003. Final draft: Technical Support Document for a Protocol to Assess Asbestos-Related Risk, October.

Cal/EPA. 2019. Human and Ecological Risk Office (HERO) Human Health Risk assessment (HHRA) Note Number 10, Issue: Toxicity Criteria. February.

Code of Federal Regulations (CFR). Title 40, Environmental Protection Agency. Part 300, National Oil and Hazardous Substances Pollution Contingency Plan. (40 CFR § 300).

ENSR Corporation (ENSR). 2005. Conceptual Site Model (CSM). Kerr-McGee Facility, Henderson, Nevada. February. NDEP requested response to comments during the next monthly meeting October 22, 2005.

ENSR. 2007. Phase A Source Area Investigation Results Report, Tronox LLC Facility, Henderson, Nevada, September. NDEP approved the Report November 30, 2007 and Appendix G – Data Validation Summary Report (DVSR) December 17, 2007.

ENSR. 2008a. Phase B Source Area Investigation Work Plan, Soil Gas Survey, Tronox LLC Facility, Henderson, Nevada, March. NDEP approved March 26, 2008.

ENSR. 2008b. Revised Draft Data Validation Summary Report, Phase B Source Area Investigation Soil Gas Survey, Tronox LLC Facility, Henderson, Nevada, October. NDEP approved October 20, 2008.

ENSR. 2008c. Quality Assurance Project Plan, Tronox LLC Facility, Henderson, Nevada. Revision 3. April. NDEP approved April 16, 2008.

ENVIRON International Corporation (ENVIRON). 2014a. Remedial Investigation and Feasibility Study Work Plan, Revision 2, Nevada Environmental Response Trust Site, Henderson Nevada, June 19, 2014. NDEP approved July 2, 2014.

ENVIRON. 2014b. Baseline Health Risk Assessment Work Plan, Revision 0, Nevada Environmental Response Trust Site, Henderson, Nevada. February 28. NDEP approved May 20, 2014.

ENVIRON. 2014c. Field Sampling Plan, Revision 1; Nevada Environmental Response Trust Site; Henderson, Nevada. July 18. Approved by NDEP on August 1, 2014.

ENVIRON. 2014d. Quality Assurance Project Plan, Revision 1; Nevada Environmental Response Trust Site; Henderson, Nevada. July 18. Approved by NDEP on August 1, 2014.

Faul, F. 2009. Statistical power analyses using G*Power 3.1: Tests for correlation and regression analyses. Behavior Research Methods, 41, 1149-1160.

Interstate Technology & Regulatory Council (ITRC). 2007. Technical and Regulatory Guidance, Vapor Intrusion Pathway: A Practical Guideline. January.

National Oceanic and Atmospheric Administration (NOAA). 2020. Climate Data Online: Las Vegas Weather Station #USW00023169. Data from January 1980 to December 2019. https://www.ncdc.noaa.gov/cdo-web/. Accessed December 8, 2020.

Nevada Division of Environmental Protection (NDEP). 1994. Phase II Letter of Understanding between NDEP and the Henderson Industrial Site Steering Committee (HISSC). August 15.

NDEP. 2008a. NDEP Response to: Technical Memorandum Data Review for 2007 Tronox Parcels A/B Investigation. Dated February 11, 2008. April 8.

NDEP. 2008b. Guidance on the Development of Summary Statistics Tables, BMI Complex and Common Areas Projects, Henderson, Nevada. December 10.

NDEP. 2010a. NDEP Response to: Health Risk Assessment Work Plan, Phase B Investigation, Tronox LLC, Henderson, Nevada, Dated: March 9, 2010. March 16.

NDEP. 2010b. Supplemental Guidance for Assessing Data Usability for Environmental Investigations at the BMI Complex and Common Areas Projects, Henderson, Nevada. September 1.

NDEP. 2012. Revised Guidance on Qualifying Data due to Blank Contamination for the BMI Complex and Common Areas, BMI Plant Site and Common Areas Projects, Henderson, Nevada. January 5.

NDEP. 2017a. User's Guide and Background Technical Document for NDEP Basic Comparison Levels (BCLs) for Human Health for the BMI Complex and Common Areas. December 2008, Revision 14, July 2017.

NDEP. 2017b. Response to: Soil Gas Investigation and Health Risk Assessment for Parcels C, D, F, G, and H, Revision 1. January 12.

NDEP. 2018a. Email communication with Weiquan Dong at NDEP, re: NFA Status of Sale Parcels I and J. May 15.

New York State Department of Health. 2006. Final Guidance for Evaluating Soil Vapor Intrusion in the State of New York. October.

Northgate and Exponent. 2010a. Health Risk Assessment Work Plan, Tronox Facility, Henderson, Nevada, March 9. NDEP approved March 16, 2010.

Northgate and Exponent. 2010b. Site-Wide Soil Gas Human Health Risk Assessment, Tronox LLC, Henderson, Nevada, November 22 (not reviewed by NDEP).

Ramboll Environ US Corporation (Ramboll Environ). 2016a. Technical Memorandum, Remedial Investigation Data Evaluation. Nevada Environmental Response Trust, Henderson, Nevada, May 2. NDEP approved August 23, 2016.

Ramboll Environ. 2016b. 2016 Groundwater Monitoring Optimization Plan. April 29, 2016. NDEP approved June 24, 2016.

Ramboll Environ. 2016c. Annual Remedial Performance Report for Chromium and Perchlorate, Nevada Environmental Response Trust Site, Henderson, Nevada. Dated October 31, 2016. NDEP approved on December 6, 2016.

Ramboll Environ. 2017a. Work Plan Addendum: Phase 3 Remedial Investigation, Revision 1. October 27. NDEP approved November 8, 2017.

Ramboll Environ. 2017b. Phase 1 Remedial Investigation Data Validation Summary Report and Electronic Data Deliverable for Soil Gas Data, Nevada Environmental Response Trust, Henderson, Nevada. November 3. NDEP approved January 25, 2018.

Ramboll Environ. 2017c. Quality Assurance Project Plan, Revision 2, Nevada Environmental Response Trust, Henderson, Nevada. October 26. NDEP approved on November 8.

Ramboll Environ. 2017d. Annual Remedial Performance Report for Chromium and Perchlorate, Nevada Environmental Response Trust Site, Henderson, Nevada. Dated December 8. NDEP approved on February 6, 2018.

Ramboll Environ. 2017e. Data Validation Summary Report for July through December 2016 Semi-Annual Remedial Performance Sampling, Revision 1, Nevada Environmental Response Trust (NERT), Henderson, Nevada. June 26. NDEP approved on August 17, 2017.

Ramboll Environ. 2017f. Remedial Performance and Groundwater Sampling and Analysis Plan, Revision 1. March 27. NDEP approved on April 30, 2017.

Ramboll US Corporation. (Ramboll). 2018a. Baseline Health Risk Assessment Work Plan for OU-1 and OU-2 Soil Gas and Groundwater, Revision 1, Nevada Environmental Response Trust Site, Henderson, Nevada. December 19. NDEP approved January 24, 2019.

Ramboll 2018b. Phase 2 Remedial Investigation Modification No. 11. May 23. NDEP approved June 21, 2018.

Ramboll. 2018c. Data Validation Summary Report Revision 1, January through March and May 2015 Groundwater Remedial Investigation Sampling, Nevada Environmental Response Trust Site, Henderson, Nevada. June 22. NDEP approved August 14, 2018.

Ramboll. 2018d. Data Validation Summary Report, Revision 1, January through June 2016, Annual Remedial Performance Sampling, Nevada Environmental Response Trust Henderson, Nevada. June 20. NDEP approved July 10, 2018.

Ramboll. 2018e. Annual Remedial Performance Report for Chromium and Perchlorate, Nevada Environmental Response Trust Site, Henderson, Nevada. November 9. NDEP approved January 18, 2019.

Ramboll. 2019a. Phase 3 RI Modification No. 9: Proposed Soil Gas Sampling in OU-1 and OU-2; Nevada Environmental Response Trust Site; Henderson, Nevada. October 7. Approved by NDEP on October 14, 2019.

Ramboll. 2019b. Data Validation Summary Report, Revision 1, Soil and Groundwater Remedial Investigation Phase 2, February through June 2017, Nevada Environmental Response Trust Site, Henderson, Nevada. June 26. NDEP approved July 10, 2019.

Ramboll. 2019c. Data Validation Summary Report, Revision 1, Soil and Groundwater Remedial Investigation Phase 2, July through November 2017, Nevada Environmental Response Trust Site, Henderson, Nevada. May 31. NDEP approved June 3, 2019.

Ramboll. 2019d. Phase 3 Remedial investigation Data Validation Summary Report for December 2017 through November 2018 Data, Nevada Environmental Response Trust Site, Henderson, Nevada. September 26. NDEP approved October 28, 2019.

Ramboll. 2019e. Data Validation Summary Report and Electronic Data Deliverable, Annual Remedial Performance Sampling, January through June 2019, Nevada Environmental Response Trust Site, Henderson, Nevada. December 31. NDEP approved on April 30, 2020.

Ramboll. 2019f. Quality Assurance Project Plan, Revision 3. Nevada Environmental Response Trust Site, Henderson, Nevada. April 8. NDEP approved on April 17, 2019.

Ramboll. 2019g. Quality Assurance Project Plan, Revision 4. Nevada Environmental Response Trust Site, Henderson, Nevada. December 30. NDEP approved on March 16, 2020.

Ramboll. 2020a. Technical Memorandum, Soil Gas Sampling Results for OU-1 and OU-2. Nevada Environmental Response Trust Site, Henderson, Nevada. March 31. NDEP commented on January 28, 2021.

Ramboll. 2020b. Data Validation Summary Report, Remedial Investigation Sampling Phase 2, March 2018 through March 2019, Revision 1, Nevada Environmental Response Trust, Henderson, Nevada. February 14. NDEP approved on April 9, 2020.

Ramboll. 2020c. Annual Remedial Performance Report for Chromium and Perchlorate, Revision 1, Nevada Environmental Response Trust Site, Henderson, Nevada. March 9. NDEP approved on April 30, 2020.

Ramboll. 2020d. Quality Assurance Project Plan, Revision 4. Nevada Environmental Response Trust Site, Henderson, Nevada. March 12. NDEP approved March 16, 2020.

Ramboll. 2020e. Remedial Performance and Groundwater Sampling and Analysis Plan, Revision 1. March 9. NDEP approved April 30, 2020.

Ramboll US Consulting, Inc. (Ramboll). 2021a. Remedial Investigation Report for OU-1 and OU-2. Nevada Environmental Response Trust, Henderson, Nevada. July 9. Under NDEP review.

Ramboll. 2021b. Data Validation Summary Report, Remedial Investigation Sampling Phase 3, February 2019 through January 2020, Nevada Environmental Response Trust, Henderson, Nevada. January 13. NDEP approved on January 27, 2021.

Ramboll. 2021c. Annual Groundwater Monitoring and GWETS Performance Report, July 2019 - June 2020; Nevada Environmental Response Trust Site; Henderson, Nevada. February 26. NDEP Approved on May 6, 2021

United States Environmental Protection Agency (USEPA). National Primary Drinking Water Regulations. Code of Federal Regulations. 40 CRF Part 141.

USEPA. 1992a. Guidance for Data Usability in Risk Assessment. Part A. Office of Emergency and Remedial Response, Washington D.C. Publication 9285.7-09A. PB92-963356. April.

USEPA. 1992b. Guidance for Data Usability in Risk Assessment. Part B. Office of Emergency and Remedial Response, Washington D.C. Publication 9285.7-09B. PB92-963362. May.

USEPA. 1999. Contract Laboratory Program, National Functional Guidelines for Organic Data Review. Office of Solid Waste and Emergency Response. October.

USEPA. 2001. Office of Solid Waste and Emergency Response. Contract Laboratory Program, National Functional Guidelines for Low Concentration Data Review. June.

USEPA. 2004a. Office of Solid Waste and Emergency Response. Contract Laboratory Program, National Functional Guidelines for Inorganic Data Review. October.

USEPA. 2004b. Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment) Final. Office of Emergency and Remedial Response, Washington, DC. EPA/540/R/99/005. July.

USEPA. 2004c. User's Guide for Evaluating Subsurface Vapor Intrusion into Buildings. February.

USEPA. 2005a. Test Methods for Evaluation Solid Waste Physical/Chemical Methods (SW-846), Third Edition, July.

USEPA. 2005b. Office of Emergency and Remedial Response. Contract Laboratory Program Statement of Work for Chlorinated Dibenzo-p-dioxin and Chlorinated Dibenzofuran: Multi-media, Multi-concentration. January.

USEPA. 2008. Office of Solid Waste and Emergency Response. Contract Laboratory Program, National Functional Guidelines for Organic Data Review. June.

USEPA. 2009a. Office of Solid Waste and Emergency Response. Guidance for Labeling Externally Validated Laboratory Analytical Data for Superfund Use. January 2009.

USEPA. 2009b. Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual (Part F, Supplemental Guidance for Inhalation Risk Assessment) Final. EPA-540-R-070-002. January.

USEPA. 2015. OSWER Technical Guide for Assessing and Mitigating the Vapor Intrusion Pathway from Subsurface Vapor Sources to Indoor Air. EPA9200.2-154. June.

USEPA. 2017. EPA Spreadsheet modeling subsurface vapor intrusion. Version 6.0. September.

USEPA. 2021a. Regional Screening Levels User's Guide. May.

USEPA. 2021b. Regional Screening Levels. May.

USEPA. 2021c. Provisional Peer Reviewed Toxicity Values for Superfund (PPRTV). Available online at https://hhpprtv.ornl.gov/. Accessed on March 5, 2021.

USEPA. 2021d. Regional Screening Levels - Subchronic Toxicity Values. May.

Virginia Department of Environmental Quality (VDEQ). 2020. Virginia Unified Risk Assessment Model - VURAM User's Guide. June.