

**Revised Closure and Post-Remediation Screening Health Risk
Assessment Report for Parcels C, D, F, G, and H
Nevada Environmental Response Trust Site
Henderson, Nevada**

May 18, 2012

Prepared For:

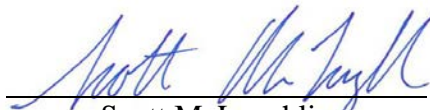
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**Closure and Post-Remediation Screening Health Risk Assessment Report
Parcels C, D, F, G, and H
Nevada Environmental Response Trust Site
Henderson, Nevada**

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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ACRONYM LIST

Acronym	Meaning
ADD	Average daily dose
BCL	Basic comparison level
Bgs	Below ground surface
BEC	Basic Environmental Company
BRC	Basic Remediation Company
CLP	Contact Laboratory Program
COPC	Chemical of potential concern
CSM	Conceptual site model
Cy	Cubic yards
DAF	Dilution attenuation factor
DQI	Data quality indicator
DQO	Data quality objective
DVSR	Data validation summary report
EC	Exposure concentration
ECD	Electron capture detector
ED	Exposure duration
ECAO	Environmental Criteria And Assessment Office
EDA	Exploratory data analysis
EPC	Exposure-point concentration
GC	Gas chromatograph
GISdT [®]	Guided Interactive Statistical Decision Tool
HEAST	Health Effects Assessment Summary Tables
HI	Hazard Index
HRA	Human Health Risk Assessment
ILCR	Incremental Lifetime Cancer Risk
IUPAC	International Union of Pure and Applied Chemicals
LADD	Lifetime average daily dose
LBCL	Leaching Basic Comparison Level
LOU	Letter of Understanding
LVP	Las Vegas Paving
MS	Mass spectrometer
MSD	Matrix spike duplicate
NCEA	National Center for Environmental Assessment
NDEP	Nevada Division of Environmental Protection
OCP	Organochlorine pesticide
PAH	Polynuclear aromatic hydrocarbon
PARCC	Precision, accuracy, representativeness, comparability, and completeness
PCB	Polychlorinated biphenyls
PEF	Particulate emission factor
PPRTV	Provisional peer-reviewed toxicity value
PQL	Practical quantitation limit



Acronym	Meaning
QA/QC	Quality assurance/quality control
QAPP	Quality Assurance Project Plan
RAS	Remedial Alternatives Study
RfC	Reference concentration
RfD	Reference dose
RME	Reasonable maximum exposure
ROD	Record of Decision
RPD	Relative percent difference
RZ-A	Remediation Zone A
SF	Slope factor
SOP	Standard operating procedure
SQL	Sample quantitation limit
SRC	Site-related chemical
SVOC	Semi-volatile organic compound
SWP	Soil-water partitioning
TEF	Toxicity equivalency factor
TEQ	Toxicity equivalency
TPH	Total petroleum hydrocarbon
U	Qualified
UCL	Upper confidence limit
URF	Unit risk factor
U.S. EPA	U.S. Environmental Protection Agency
VOC	Volatile organic compound



EXECUTIVE SUMMARY

On behalf of the Nevada Environmental Response Trust (the Trust), Northgate Environmental Management, Inc. (Northgate) has prepared this Revised Closure and Post-Remediation Human Health Risk Assessment (HRA) Report for Parcels C, D, F, G, and H (Parcels) at the Nevada Environmental Response Trust Site in Henderson, Nevada (the Site). The Parcels represent a subset of the original parcels A through J. It should be recognized that these parcels do not correspond to Clark County assessor parcel designations.

Analytical results for confirmation soil samples indicate that the Parcels have been successfully remediated, consistent with the remediation goals established by the approved Remedial Action Workplan (BEC, 2008a) and the Nevada Division of Environmental Protection (NDEP). It is noted that small portions of proposed scrape areas in Parcels F, G, and H were not excavated due to surface impediments as described in Sections 3.3 through 3.5. These data demonstrate that the Parcels have been remediated to commercial/industrial standards, with the exception of a small area south of the existing South Haul Road Fence line which remains to be remediated by BMI when their haul road is removed as discussed in Section 3.2.

A post-remediation HRA was conducted to evaluate the residual soil and soil-gas chemical concentrations in the Parcels. A screening-level evaluation of soil concentrations was also conducted for the soil to groundwater pathway. Soil data collected as part of the initial and confirmation sampling efforts were evaluated and the usable data were selected for the purposes of this HRA. The methods and findings from the HRA can be summarized as follows:

Soil

- Based on the Conceptual Site Model (CSM) for the Parcels, potential exposure to soil was evaluated for future onsite indoor and outdoor commercial workers and future construction workers via direct contact with soil (i.e., incidental ingestion, dermal contact) and inhalation of dust. Chemicals of potential concern (COPCs) were selected according to a multi-step process, including comparisons to background for metals and radionuclides, a toxicity screen, frequency of detection, and CSM considerations. Based on this process, 14 chemicals were selected as COPCs.
- Non-cancer hazard indices and/or theoretical excess cancer risks associated with direct contact with soil and inhalation of dust were estimated for all of the COPCs except asbestos, based on the maximum detected concentration. The estimated hazard indices and excess cancer risks were equal to or below NDEP's point of departure for non-cancer



effects (hazard index of 1) and cancer risks (1×10^{-6}) for future onsite indoor and outdoor commercial workers and future construction workers under the conditions evaluated.

- With regard to asbestos, a best estimate and an upper-bound estimate were calculated. The estimated risks for death from lung cancer or mesothelioma for asbestos exposures to future onsite outdoor commercial workers and construction workers are less than or equal to 1×10^{-6} , except for upper-bound estimates of exposure to amphibole fibers by future construction workers.
- Additional confirmation samples were collected for polynuclear aromatic hydrocarbons (PAHs) in Parcel F. PAHs were not detected in these samples at detection limits below the NDEP basic comparison levels (BCLs). Therefore, inclusion of these data in the risk assessment calculations will not affect the results of this post-remediation HRA.

The results indicate that exposure to residual chemicals in soil in the Parcels should not result in unacceptable risks for all future onsite receptors evaluated in this HRA.

Soil to Groundwater Leaching

The soil leaching to groundwater pathway is not fully evaluated in this document. As discussed in Section 5.3, several COPCs were detected in samples collected from the Parcels at concentrations that exceed NDEP default leaching-based BCLs (LBCLs). Further analysis to assess the potential for groundwater contamination from leaching will be evaluated in a separate deliverable.

Soil Gas

Soil gas samples collected in the Parcels were evaluated as part of the Site-Wide Soil Gas Risk Assessment (Northgate, 2010b). COPCs in soil gas were selected according to a multi-step process, including a toxicity screen, frequency of detection, and CSM considerations. Based on this process, eight chemicals (benzene, bromodichloromethane, carbon tetrachloride, chloroform, hexachlorobutadiene, naphthalene, tetrachloroethene, and trichloroethene) were selected as COPCs. Excess cancer risks associated with exposure of indoor and outdoor commercial workers to the COPCs in soil gas through inhalation of vapors in indoor and outdoor air, respectively, at the Parcels are at or below 1×10^{-6} , and hazard index values are well below 1. Based on findings reported in the Site-Wide Soil Gas Risk Assessment, inhalation of vapors in indoor air (by future indoor commercial workers) or outdoor air (by future outdoor commercial workers) should not result in unacceptable risk.



Cumulative Cancer Risk and Hazard Index

To evaluate potential health effects associated with COPCs in soil and soil gas, cumulative risks and hazard indices were estimated. The estimates likely overstate risks to a worker as they assume long-term exposure to the maximum concentrations of chemicals in both soil and soil gas. The cumulative cancer risk and hazard index associated with worker exposures to COPCs in soil and soil gas were estimated based on the combined results from this soil HRA and the Site-Wide Soil Gas HRA (Northgate 2010b).

To estimate cumulative risk and hazard index for the indoor commercial worker, it is assumed that the worker is exposed to COPCs in soil (via incidental ingestion) and soil gas (via inhalation of vapors in indoor air of a commercial building) simultaneously. It is also assumed that the outdoor commercial worker is exposed to COPCs in soil (via incidental ingestion, dermal contact, and inhalation of dust) and soil gas (via inhalation of vapors in outdoor air) simultaneously. The cumulative incremental lifetime cancer risks (ILCRs) for an indoor commercial worker (2×10^{-6}) and outdoor commercial worker (1×10^{-6}) associated with potential simultaneous exposure to chemicals in soil and soil gas are at the lower end of the target risk range (10^{-6} to 10^{-4}) generally considered to be protective of human health. The cumulative hazard indices for these receptors are below the threshold value of one.

Cancer risks and hazard indices were not estimated for construction worker exposure to COPCs in soil gas in the Site-Wide Soil Gas HRA (Northgate, 2010b). However, assuming that the risks and hazard indices for a construction worker from exposure to soil gas are similar to those estimated for an outdoor commercial worker, the ILCR for a construction worker from simultaneous exposure to chemicals in soil and soil gas (approximately 2×10^{-7}) would be below the target risk range. The total hazard index for a construction worker (approximately 0.8) would be below one. Based on this evaluation, simultaneous exposure to COPCs in soil and soil gas should not pose an unacceptable risk to future workers.



1.0 INTRODUCTION

On behalf of the Trust, Northgate has prepared this Revised Closure and Post-Remediation Human Health Risk Assessment (HRA) Report for Parcels C, D, F, G, and H (Parcels) at the Site. The original draft of this report was authored by Northgate and Exponent, Inc. (Exponent) and submitted to NDEP on December 10, 2010 on behalf of Tronox, LLC (Tronox). This revised report has been prepared to address NDEP comments on the original draft issued in a letter dated May 19, 2011. These Parcels represent a subset of the original Parcels A through J. It should be recognized that these parcels do not correspond to Clark County assessor parcel designations.

This report presents field activities related to soil remediation and asbestos abatement conducted in the Parcels, a post-remediation risk assessment that was performed to evaluate potential human health risks associated with residual concentrations of chemicals in soil following remediation, and supporting tables, figures, and appendices.

The remedial actions described in this report are based on information contained in the following documents:

- *Removal Action Workplan for Soil, Tronox Parcels “C”, “D”, “F”, “G”, and “H” Sites, Henderson, Nevada (RAW)*, prepared by Basic Environmental Company (BEC), dated July 1, 2008 (BEC, 2008a);
- Nevada Division of Environmental Protection (NDEP) July 2, 2008, approval letter of *Removal Action Workplan for Soil, Tronox Parcels “C”, “D”, “F”, “G”, and “H” Sites, Henderson, Nevada* dated July 1, 2008, with comments, and July 2, 2008, e-mail correspondence between Shannon Harbour of NDEP and Susan Crowley of Tronox regarding NDEP comment clarifications (NDEP, 2008a);
- *Data Validation Summary Report, Tronox Parcels C, D, F, and G Investigation, November 2007, BMI Industrial Complex, Clark County, Nevada*, prepared by ERM-West, Inc., and dated February 2008 (ERM-West, 2008a);
- *Data Validation Summary Report, Tronox Parcel H Investigation, January 2008, BMI Industrial Complex, Clark County, Nevada*, prepared by ERM-West, Inc., and dated April 2008 (ERM-West 2008b);
- *Data Validation Summary Report, Tronox Parcels C, D, F, G and H Supplemental Investigations-June-July 2008, BMI Industrial Complex, Clark County, Nevada*, prepared by ERM-West, Inc., and dated January 2009 (ERM-West, 2009); and



- *Data Validation Summary Report, Parcels “C”, “D”, “F”, “G”, and “H” Soil Confirmation, Tronox LLC, Henderson, Nevada*, prepared by Northgate, dated June 15, 2010 (Northgate, 2010a).

1.1 Scope of Report

The purpose of this report is twofold: 1) to describe the field activities related to implementing the RAW for soil in the Parcels, including the scraping and removal of asbestos- and chemically-impacted soils within the Parcels; and 2) present a post-remediation HRA based on the initial and confirmation Parcel soil data.

The objective of the post-remediation HRA is to evaluate the potential for adverse human health impacts that may occur as a result of exposure to soil in the Parcels that contains residual chemicals. The findings of this report are intended to support the site closure process for the Parcels. Potential exposure to residual chemicals in soil vapor in the Parcels was evaluated as part of the Site-Wide Soil Gas Human Health Risk Assessment (Northgate 2010b), and the soil-gas findings with regard to the Parcels are summarized in this report. Issues related to groundwater beneath the Parcels will be further assessed in a separate deliverable.

The overall goal of this report is to demonstrate that soil within the Parcels has been remediated in a manner consistent with the cleanup strategy presented in the RAW (BEC, 2008a), and that under a future commercial/industrial land-use scenario, there is no significant risk to human health associated with the Parcels.

1.2 Report Organization

This closure and HRA report is organized as follows:

- Section 2.0 describes past uses of the Parcels and results of BEC’s Phase 2 soil sampling.
- Section 3.0 describes Northgate’s field activities related to the scraping and removal of soil in the Parcels, including summaries of soil volumes removed and disposed. The confirmation soil sampling program conducted within the Parcels after completion of removal activities is also discussed.
- Section 4.0 presents the sources of the analytical data used in the post-remediation HRA, and procedures used to evaluate the data.
- Section 5.0 presents the post-remediation HRA and includes the conceptual site model (CSM), selection of chemicals of potential concern (COPCs), exposure assessment, toxicity assessment, and risk characterization.



- Section 6.0 presents an overall summary and conclusions regarding the current conditions at the Parcels.
- Section 7.0 provides references for documents cited in this report.

Supporting tables, figures, and appendices follow the text of this report.



2.0 NEVADA ENVIRONMENTAL RESPONSE TRUST SITE DESCRIPTION AND HISTORY

The approximately 450-acre Site, of which the Parcels constitute approximately 83.4 acres, is located approximately 13 miles southeast of the city of Las Vegas in an unincorporated area of Clark County, Nevada, and lies in Sections 1, 12, and 13 of Township 22 S, Range 62 E, (Figure 1). The Site is located within the Black Mountain Industrial (BMI) complex, which consists of several facilities, owned and/or operated by chemical companies, one of which is owned and operated by Tronox, as a tenant, on property owned by the Trust. The City of Henderson surrounds the BMI complex, which is an unincorporated Clark County “island.”

Early in the Site’s environmental investigation history, the Parcels were identified as areas that were either generally undeveloped and/or not significantly chemically-impacted by previous uses. Parcel boundaries are shown on Figure 2.

The BMI complex was first developed by the U.S. government in 1942 as a magnesium plant for World War II operations. Later, a part of the BMI complex was leased by Western Electrochemical Company (WECCO). WECCO produced manganese dioxide, sodium chlorate, sodium perchlorate, and other perchlorates. WECCO also produced ammonium perchlorate (a powerful oxidizer) for the Navy during the early 1950s, using a plant that was constructed on the Site by the Navy. WECCO merged with American Potash and Chemical Company (AP&CC) in 1956, and continued production of ammonium perchlorate for the Navy. In 1967, AP&CC merged with Kerr-McGee Corporation (Kerr-McGee) and added production of boron chemicals in the early 1970s. The production processes included elemental boron, boron trichloride (a colorless gas used as a reagent in organic synthesis), and boron tribromide (a colorless fuming liquid compound used in a variety of applications). The production of boron tribromide was discontinued in 1994, and the production of sodium chlorate and ammonium perchlorate was discontinued in 1997 and 1998, respectively. Perchlorate was reclaimed at the Site using existing equipment until early 2002.

In 2005, Kerr-McGee Chemical LLC was renamed Tronox LLC. Tronox’s Henderson facility continues to produce electrolytic manganese dioxide, used in the manufacture of alkaline batteries; elemental boron, a component of automotive airbag igniters; and boron trichloride, used in the pharmaceutical and semiconductor industries and in the manufacture of high-strength boron fibers for products that include sporting equipment and aircraft parts. Tronox currently leases the Henderson facility (the Facility) from the Trust, which took title to Site (including the Facility) on February 14, 2011.



During the 1970s, the U.S. Environmental Protection Agency (U.S. EPA), the State of Nevada, and Clark County investigated potential environmental impacts from the BMI companies' operations, including atmospheric emissions, groundwater and surface-water discharges, and soil impacts (Ecology and Environment, 1982). From 1971 to 1976, Kerr-McGee modified its manufacturing process and constructed lined surface impoundments to recycle and evaporate industrial wastewater. In 1976, the facility achieved zero discharge status regarding industrial wastewater management. In 1980, the U.S. EPA requested specific information from the BMI companies regarding their manufacturing and waste management practices by issuing Section 308 letters. In 1993, a Phase I site assessment was completed for the Site and approved by NDEP. In 1994, NDEP issued a Letter of Understanding (LOU) to Kerr-McGee that identified 69 specific areas or items of interest and indicated the level of environmental investigation they wanted Kerr-McGee to conduct. In 1996, Kerr-McGee completed a Phase II site assessment, which included field sampling as described in an NDEP approved Phase II Work Plan.

Tronox continued to undertake environmental investigations as well as removal actions at the Site up until February 14, 2011, on which date the Trust assumed responsibility for removal activities at the Site pursuant to an Interim Consent Agreement. A detailed discussion of the specific areas or items of interest identified in the LOU, and a list of the products made, years of production, and approximate waste volumes for WECCO, AP&CC, and Kerr-McGee/Tronox are found in the *Conceptual Site Model (CSM) Report* (ENSR, 2005).

Background information, including local geology, hydrogeology, and wind direction, is also described in the *Conceptual Site Model (CSM) Report* (ENSR 2005). In general, groundwater is encountered in the fine-grained facies within the uppermost Muddy Creek Formation. The depth to groundwater ranges from about 27 to 80 feet bgs and is generally deepest in the southernmost portion of the Site (where Parcel H is located). The prevailing wind direction for the Site is from the Southwest and the South or West with the Olin property located up-wind (west) and the TIMET property located down-wind (east) from the Site (see Figure 1 for wind-rose). Based on the prevailing wind direction, the nearest down-wind residences are located approximately 1800 feet from Parcel D, which is the northern-most parcel included in this report.

2.1 Historical Uses and Results of Investigations of Parcels C, D, F, G, and H

Northgate compiled information regarding historical usage and investigations of the Parcels from the following sources:

- *Environmental Conditions Assessment, Kerr-McGee Chemical Corporation, Henderson, Nevada Facility*, prepared by Kleinfelder, and dated April 1993 (Kleinfelder, 1993);



- *Removal Action Workplan for Soil, Tronox Parcels “C”, “D”, “F”, “G” and “H” Sites, Henderson, Nevada (RAW)*, prepared by Basic Environmental Company (BEC), and dated July 1, 2008 (BEC, 2008a);
- *Revised Phase B Site Investigation Work Plan for Areas I, II, III and IV*, Text, Tables and Figures, prepared by AECOM, dated December 2008, and containing summaries for 70 LOUs (sites identified in an August 15, 1994 Letter of Understanding); and
- *Phase I Environmental Site Assessment [ESA], Approximately 182 Acres, APNs 178-13-601-002, -002, 178-12-101-002, -003, 178-12-201-005, 178-12-601-005, 178-01-401-001, 178-11-501-007, and Portions of 178-12-401-009 & 178-13-101-002, Henderson, Nevada*, prepared by Converse Consultants (Converse), and dated March 5, 2007 (Converse, 2007).

In addition, Northgate created a map that consists of the Parcel location map overlain with the LOU locations (henceforth: LOUs). The resultant map (Figure 2) was reviewed to determine which LOUs were identified in each of the five Parcels. No LOUs are located in Parcels C, D, and H. LOUs 63 and 65c are located in Parcel F; and LOU 65d is located in Parcel G. Descriptions of these LOUs are included in Sections 2.1.2 and 2.1.3, respectively.

On behalf of BEC, ERM-West conducted soil sampling in Parcels C, D, F, and G in August and September 2007 (data validation summary report [DVSR] dated February 2008 [ERM-West, 2008a]) and in Parcel H during January and March 2008 (DVSR dated April 2008 [ERM-West, 2008b]) in accordance with the *Phase 2 Sampling and Analysis Plan to Conduct Soil Characterization* (BEC, 2007). The initial investigation data summaries and risk tables were presented by BEC and discussed with NDEP and Tronox on May 15, 2008 (NDEP, 2008b). Based on the findings discussed during the meeting, a supplemental investigation was conducted in Parcels C, D, F, G, and H in June and July 2008, in accordance with the *Sampling and Analysis Plan (SAP)*; BEC, 2008b), and results were reported in the DVSR dated January 2009 (ERM-West, 2009). BEC prepared a RAW for the Parcels that proposed remediation polygons in each of the Parcels (BEC, 2008a). The RAW was approved by NDEP on July 2, 2008 (NDEP, 2008a), and served as the basis for Northgate’s 2010 remediation of the Parcels.

Asbestos remediation goals for the Parcels were established by NDEP as four or more long chrysotile fibers and one or more long amphibole fibers (>10 microns [μm] in length and <0.4 μm in width). The Agency for Toxic Substances and Disease Registry (ATSDR) action level of one part per billion was used as a remediation goal for dioxins and furans. For all other chemicals, the NDEP BCLs for the Industrial/Commercial worker, which are based on an ILCR of one in one million (1×10^{-6}) or a non-cancer hazard index of 1, were used as the remediation goals (BEC, 2008a).



2.1.1 Parcel C and D Historical Use and Investigation

Historical use of Parcels C and D has been limited, based on review of historical aerial photographs and reports of past activities. No LOUs are located in Parcels C and D (Figure 3). Parcel C is a 20.4-acre parcel located directly north and adjacent to the former Trade Effluent Ponds. Review of aerial photographs indicates that sometime prior to 1950, multiple ditches lined with French drains were installed across Parcel C, perpendicular to, and leading from, a main French drain that traversed east-west along the northern berm of the ponds located along the southern boundary of Parcel C. The drains were ostensibly used for capturing underflow from the former Trade Effluent Ponds. At some point, these ditches were disturbed and possibly graded over.

Parcel D is a 24.6-acre parcel located directly north of Parcel C, and based on review of historical aerial photographs, the ditches (French drains) described for Parcel C extended into and terminated in the eastern two-thirds of Parcel D. According to the BEC (2008a) RAW, Phase 2 soil sampling performed in Parcels C and D indicated the presence of long amphibole fibers and long chrysotile fibers exceeding remediation goals at four locations (samples TSB-CR-02, TSB-CR-03, and TSB-CJ-03 in Parcel C, and TSB-DR-04 in Parcel D), and dioxins/furans in sample TSB-CR-07 located in Parcel C (Figure 3).

BEC developed Thiessen/Voronoi polygons for Parcels C and D. The single polygon located in Parcel D was an exception to the rule, because it was located in a drainage ditch. BEC based the dimensions of this polygon on the fact that two subsequent soil samples collected east and west of TSB-DR-04 (TSB-DR-04E and TSB-DR-04W) were found to be “clean.” These polygons were the basis for Northgate’s remedial design for Parcels C and D (Figure 3). Northgate’s remedial activities are described in Section 3.2.

2.1.2 Parcel F Historical Use and Investigation

LOUs 63 and 65c are located in Parcel F. Parcel F is a 7.2-acre parcel that was initially leased by W.S. Hatch Company, a trucking operation, from 1980 to 1986. Jack B. Kelley, Inc. (J.B. Kelley) leased Parcel F from 1986 through at least 1993 and also operated a trucking operation (Kleinfelder, 1993). The company hauled commodities such as lime and soda ash. The areas of interest at the J.B. Kelley site included a 10,000-gallon fiberglass diesel underground storage tank (UST), a ceramic-lined 600-gallon waste-oil UST, and truck washing in eight open concrete vaults that formerly served as foundations for peat storage buildings during World War II. Rinsate from truck washing was reportedly discharged to possibly the former vault floors, metal containment tanks, a storm sewer, and/or the ground surface. Additional fluids from truck



maintenance activities, such as oil changes, were reportedly discharged to the storm sewer, which conveyed the wash water and other fluids northward to the Beta Ditch (Kleinfelder, 1993).

Chemicals reported in tanker-truck rinsate consisted of lime, soda ash, barite, magnesium chloride brine, and possibly dilute concentrations of ferric chloride, hydrochloride, sodium hydro sulfide, sodium hydroxide, and titanium tetrachloride. Onsite wash activities ceased in 1991. JB Kelley, Inc. retained consultants to conduct field investigations of the diesel UST and 600-gallon ceramic-lined waste-oil UST. Both tanks were found to have leaked, and were removed in 1991. Contaminated soil in the tank pits was reportedly excavated at the time of tank removal (Kleinfelder, 1993).

According to the Converse (2007) Phase 1 Site Assessment, a Phase I ESA was conducted for Parcel F by Tetra Tech EM, Inc. (Tetra Tech), in October of 2005, on behalf of TIMET. The Tetra Tech ESA reportedly found three Recognized Environmental Conditions (RECs) in Parcel F: an empty steel tank, three 55-gallon drums, and a painted surface on the interior of a building. No additional information was reported by Converse regarding these RECs (Converse, 2007).

LOU 65c was formerly occupied by Nevada Pre-Cast Concrete, which used office space near the J.B. Kelley operations from January 1973 to May 1978. Reportedly, only office activities were conducted by Nevada Pre-Cast Concrete (Kleinfelder, 1993). No waste streams or chemical uses have been associated with LOU 65c.

Soil quality investigations have been performed to characterize Parcel F. According to the BEC (2008a) RAW, Phase 2 soil sampling performed in Parcel F indicated the presence of long amphibole fibers and long chrysotile fibers exceeding remediation goals at eight locations in Parcel F (TSB-FJ-01, TSB-FJ-02, TSB-FR-02, TSB-FJ-03, TSB-FJ-05, TSB-FJ-06, TSB-FJ-07, and TSB-FJ-08). In addition, Aroclor 1254, benzo(a)pyrene, benzo(b)fluoranthene, dibenz(a,h)anthracene at TSB-FR-02, and arsenic at TSB-FJ-02 were detected above BCLs (Figure 4).

BEC developed Thiessen/Voronoi polygons for Parcel F. These polygons were the basis for Northgate's remedial design for Parcel F (Figure 4). Northgate's remedial activities are described in Section 3.3.

2.1.3 Parcel G Historical Use and Investigation

Only one LOU—LOU 65d—is located in Parcel G (5.2-acre parcel). Green Ventures International leased a building (“S3 Changehouse”) from August 1980 to September 1981 for



use as a marketing office by a Green farming operation. Only office activities were conducted by Green Ventures International (Kleinfelder, 1993). No waste streams or chemical uses have been associated with LOU 65d.

Soil quality investigations have been performed to characterize Parcel G. According to the BEC (2008a) RAW, Phase 2 soil sampling performed in Parcel G indicated the presence of long amphibole fibers exceeding the remediation goal at two locations (TSB-GJ-04 and TSB-GJ-09) and benzo(a)pyrene above its BCL at TSB-GJ-06 (Figure 5).

BEC developed Thiessen/Voronoi polygons for Parcel G. These polygons are the basis for Northgate's remedial design for Parcel G (Figure 5). Northgate's remedial activities are described in Section 3.4.

2.1.4 Parcel H Historical Use and Investigation

Review of historical aerial photographs from 1950 through 2006 of Parcel H (26-acre parcel) indicates that the property has remained undeveloped. Soil quality investigations have been performed to characterize Parcel H. According to the BEC (2008a) RAW, Phase 2 soil sampling performed in Parcel H indicated the presence of long amphibole fibers and/or long chrysotile fibers exceeding remediation goals at two locations (TSB-HJ-09 and TSB-HR-06).

BEC developed Thiessen/Voronoi polygons for Parcel H. These polygons were the basis for Northgate's remedial design for Parcel H (Figure 6). Northgate's remedial activities are described in Section 3.5.



3.0 PARCEL REMEDIATION AND CONFIRMATION SAMPLING

3.1 Scope of Work

Northgate conducted field work, under the oversight of NDEP, to remediate the Parcels during the months of March and April 2010. Work was performed in accordance with the RAW (BEC, 2008a). Remediation consisted of scraping the top 1 foot or less from each polygon shown on Figures 3 through 6. After each polygon was scraped to the target depth, confirmation soil samples were collected from each polygon. A total of 21 confirmation soil samples and 16 field quality control (QC) samples were collected from 18 polygons in the five Parcels. Field samples and the associated field QC samples were logged into the laboratories in Sample Delivery Groups (SDGs). The Parcel Soil Confirmation data are contained in nine SDGs.

The analytical data were validated by Laboratory Data Consultants, Inc. (LDC) in accordance with procedures described in the NDEP *Data Verification and Validation Requirements – Supplement, Henderson, Nevada, April 13, 2009*, established for the BMI Plant Sites and Common Areas Projects (NDEP, 2009a). A complete listing of the Parcel Soil Confirmation samples and SDGs is presented in Table 1-2 of the Northgate (2010a) Data Validation Summary Report for the Parcels, which is discussed later in this report.

A total of 11,262 tons of soil were scraped during remediation of the Parcels and transported in covered trucks to Apex Landfill, approximately 37 miles away from the Site. Figures prepared by Las Vegas Paving (LVP) are presented as Appendix A-1. Soil disposal manifests are presented in Appendix A-2. Descriptions of each scrape area are presented for each Parcel in the following sections (3.2 through 3.5). Parcels C and D are presented together because they share boundaries and have similar site-use history.

3.2 Parcels C and D Scrape Cleanup

Five scrape areas were located in Parcels C and D, as shown approximately on Figure 3. A total of 1,807 cubic yards (cy) and 82 cy of soil were removed from Parcels C and D, respectively. More than 50% of the soil removed was in the vicinity of sample TSB-CJ-03 (680 cy). Total scrape depths in Parcel C and D ranged from 0.4 to 1.0 feet below original grade surface as shown in Table 1. Approximately 8,345 square feet south of the existing South Haul Road Fence line remains to be remediated by BMI when their haul road is removed (Parcel C and D Scrape Area Information, Appendix A-1). An Addendum to this report will be submitted to NDEP once BMI has removed the haul road.



3.3 Parcel F Scrape Cleanup

Eight scrape areas were located in Parcel F, as shown approximately on Figure 4 and in Appendix A-1 (Parcel F Scrape Area Information). A total of 3,928 cy of soil was removed from Parcel F. Total scrape depths in Parcel F ranged from 0.2 to 0.9 feet below original grade surface as shown in Table 1. Two small portions of proposed remediation areas in Parcel F were not scraped because of impediments: 1) approximately 1,000 square feet section of the center portion of Fourth Street (along the western boundary of Parcel F) that was covered by asphalt, and 2) approximately 1,955 square feet of railroad track along the southern boundary (Parcel F Scrape Area Information, Appendix A-1). However, excavation was conducted to the edge of the above-described inaccessible areas.

3.4 Parcel G Scrape Cleanup

Three scrape areas were located in Parcel G, as shown approximately on Figure 5 and in Appendix A-1 (Parcel G Scrape Area Information). A total of 1,094 cy of soil was removed from Parcel G. Total scrape depths in Parcel G ranged from 0.3 to 0.4 feet below original grade surface as shown in Table 1. Three small portions of the remediation areas in Parcel G were not scraped because of impediments: 1) approximately 1,880 square feet of a section of the southern third of Fourth Street that was covered by asphalt; 2) approximately 1,955 square feet of railroad track along the southern boundary; and 3) approximately 135 square feet of asphalt located in the northeast corner (Parcel G Scrape Area Information, Appendix A-1). However, excavation was conducted to the edge of the above-described inaccessible areas.

3.5 Parcel H Scrape Cleanup

Two scrape areas were located in Parcel H, as shown approximately on Figure 6 and in Appendix A-1 (Parcel H Scrape Area Information). A total of 617 cy of soil was removed from Parcel H. More than 50% of the soil removed was in the vicinity of sample TSB-CJ-03 (680 cy). Total scrape depths in Parcel H ranged from 0.3 to 0.7 feet below original grade surface as shown in Table 1. Approximately 621 square feet of soil in one remediation area in Parcel H was not scraped because of the presence of a landscaped, asphalt-covered public footpath (Parcel H Scrape Area Information, Appendix A-1). Soil was excavated to the edge of this inaccessible area.

3.6 Confirmation Sampling Rationale

Confirmation soil samples were collected in a manner consistent with the RAW (BEC, 2008a) at the same locations as original samples. The confirmation sampling locations were surveyed by



LVP prior to sample collection. Table 1 presents a summary of information regarding the scrape areas and confirmation sampling. Figures 3 through 6 show the Parcels, scrape areas, and confirmation sample locations and identifications.

3.7 Confirmation Sampling Methodology

Following remediation of soils, Northgate collected confirmation soil samples from each of the five Parcel remediation sites in April 2010. Field activities and sampling procedures were performed under the supervision of a Certified Environmental Manager and in accordance with the Basic Remediation Company (BRC) *Health and Safety Plan, BMI Common Areas, Clark County, Nevada*, dated October 2005 (BRC and MWH, 2005); the BRC *Field Sampling and Standard Operating Procedures (SOP), BMI Common Areas, Clark County, Nevada*, dated August 2007 (BRC, ERM and MWH, 2007); and the BRC SOP-12 Surface Soil Sampling for Asbestos, dated December 2008 (BRC, ERM, MWH, 2008).

As discussed previously, polygon size and shape were determined based on BEC’s Phase 2 soil sampling results and locations where contaminants of concern were detected above remediation goals, triggering remediation (BEC, 2008a). At each remediation polygon, the trigger sample point was surveyed and marked by LVP before and after the parcel was scraped and graded. Samples to be analyzed for asbestos were collected using the methodology outlined in SOP-12 (BRC, ERM, MWH, 2008), all such samples are considered to be surface soil samples. The samples were collected from an area measuring 50 feet by 50 feet and subdivided into four quadrants as required by SOP-12. Once the confirmation sample point was marked and cleared, soil samples were collected for laboratory analysis.

The number and type of confirmation samples that were analyzed are summarized below.

Location	Asbestos	Dioxin	SVOC	PCB	Arsenic
Parcels C and D	4	1			
Parcel F	8		1	1	1
Parcel G	2		1		
Parcel H	2				

Confirmation sample results indicated that all analytes were detected below their respective NDEP BCLs and met the NDEP target goals of four or fewer long chrysotile fibers and less than one long amphibole fiber.

Use of the confirmation sampling results and the original 2007 and 2008 characterization data in the post-remediation risk assessment are discussed in the following sections.



4.0 DATA SUMMARY AND DATA USABILITY EVALUATION ASSESSMENT

This section summarizes the sources of analytical data and procedures used to evaluate the data, and presents data summaries used in the Parcels post-remediation HRA.

4.1 Investigation and Data Sources

As discussed in Section 2.1, analytical data obtained from BEC's 2007 and 2008 and Northgate's 2010 sampling events are used in the Parcels post-remediation HRA. The data set for the Parcels consists of 31 sample locations in Parcels C and D, 23 sample locations in Parcel F, 13 sample locations in Parcel G, and 24 sample locations in Parcel H.

4.2 Data Usability

The primary objective of the data usability evaluation is to identify appropriate data for use in the Parcels post-remediation HRA. Evaluation of the analytical data for the Parcels, in terms of usability for this assessment, was conducted in accordance with the criteria presented in the *Guidance for Data Usability in Risk Assessment (Parts A and B)* (U.S. EPA, 1992b,c) and the *NDEP Supplemental Guidance for Assessing Data Usability for Environmental Investigations at the BMI Facility in Henderson, NV* (NDEP, 2010a). These criteria include:

- Reports to risk assessors
- Documentation
- Data sources
- Analytical methods and detection limits
- Data review
- Data quality indicators (DQIs): precision, accuracy, representativeness, comparability, and completeness (PARCC).

Criterion I –Reports to Risk Assessors

The usability analysis of the site characterization data requires the availability of specific report components for review. The required information is available from the following documentation associated with the Parcels data and data collection efforts:

- The site description is provided in Section 2 of this report. The *Sampling and Analysis Plan (SAP) to Conduct Supplemental Soil Characterization for Tronox Parcels C, D, F, G, and H, Henderson, Nevada* (BEC, 2008b), and the *Removal Action Work (RAW) Plan for Soil, Tronox Parcels C, D, F, G, and H Sites,*



Henderson Nevada, July 2008 (BEC, 2008a) identifies the sample locations and remediation areas. Figures 3 through 6 of this report also provide soil sample locations by parcel.

- Data are presented in Appendix B for the following DVSRs:
 - DVSR Tronox Parcels C, D, F, and G Investigation November 2007, dated February 2008 (ERM-West, 2008a)
 - DVSR Tronox Parcel H Investigation January 2008, dated April 2008 (ERM-West, 2008b)
 - DVSR Tronox Parcels C, D, F, G and H Supplemental Investigations June/July 2008, dated January 2009 (ERM-West, 2009)
 - DVSR Tronox Parcels C, D, F, G, and H Soil Confirmation April 2010, dated June 15, 2010 (Northgate, 2010a), with final response to comments, dated July 21, 2010 (Northgate, 2010c).
- The laboratory provided a quality assurance/quality control (QA/QC) narrative with each analytical data package, and the data review provides a narrative of qualified analytical results. A description of the analytical methods and detection limits is included. These narratives are included as part of each DVSR.
- Method-specific QC results are provided in each laboratory report, along with associated raw data. The laboratory reports and QC results are included as part of each DVSR.
- Data flags used by the laboratory were defined adequately and are discussed further below. The DVSRs and accompanying lab reports were considered complete for HRA purposes.
- Laboratory reports include the name and address of the laboratory, unique identification of the test report, client and project name, and dates of sample receipt and analysis. Each analytical report describes the analytical method used, and provides results on a sample-by-sample basis, along with sample-specific quantitation limits (SQLs), and provides results of appropriate QC samples, such as method blanks, laboratory control spike samples, surrogate recoveries, internal standard recoveries, matrix spike samples, second column confirmation, interference checks, and serial dilutions. All laboratory reports contained data equivalent to a Contract Laboratory Program (CLP) deliverable, inclusive of CLP QC summary forms where applicable, and the supporting raw data. Reported sample analysis results were imported into the project database.

Criterion II – Documentation Review

The objective of the documentation review is to ensure that each analytical result can be traced to a sample location, and that the procedures used to collect the environmental samples are appropriate. As discussed in the SAP and RAW, all sample collection and handling procedures were consistent



with NDEP-approved *BRC Field Sampling and Standard Operating Procedures* (BRC 2007) and the *Tronox Quality Assurance Project Plan* (QAPP; AECOM/Northgate 2009). Chain-of-custody (COC) forms prepared in the field were reviewed and compared to the analytical data results provided by the laboratory to ensure completeness of the data set. Based on the documentation review, all samples analyzed by the laboratory were correlated to the correct geographic locations and are shown in Figures 3 through 6 of this report. Summary data tables are provided in Appendix C of this report. All reviewed reports provide adequate information regarding sample results related to location and sampling procedures.

Criterion III – Data Sources

The review of data sources is performed to ensure that the analytical techniques are appropriate to identify the COPCs, appropriate analytical methods have been used, and adequate sample coverage of source areas has been obtained. All analytical sample data results for soil were provided. The data collection activities were developed to characterize a broad spectrum of chemicals potentially present on the Parcels, including asbestos, volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), metals, radionuclides, dioxin/furans, polychlorinated biphenyls (PCBs), PAHs, organochlorine pesticides (OCPs), and petroleum hydrocarbons. Based on the sample locations (taken at both random and judgmental locations), the conceptual site model for each parcel, and the sample results, the data for the analytical suites were deemed representative to evaluate site conditions.

Criterion IV – Analytical Methods and Detection Limits

In addition to the appropriateness of the analytical techniques evaluated as part of Criterion III, it is necessary to evaluate whether the detection limits are low enough to allow adequate characterization of risks. At a minimum, this data usability criterion can be met through the determination that routine U.S. EPA reference analytical methods were used in analyzing samples collected from the property. Each of the identified U.S. EPA methods was approved by NDEP as part of the SAP (BEC 2007; BEC, 2008b) and the QAPP (BRC 2008b). The range of detection limits achieved in the field samples was compared to NDEP BCLs. With the exceptions of benzo(a)pyrene and dibenz(a,h)anthracene, which are PAHs, all had non-detectable results, with method detection limits below NDEP BCLs.

With regard to the PAH analysis, it appears that the NDEP-approved DVSRs associated with the initial sampling events in 2007 and 2008 were all reported to the practical quantitation limit (PQL) rather than the SQL. This resulted in reported detection limits that were greater than the BCLs for benzo(a)pyrene and dibenz(a,h)anthracene. However, based on review of the



laboratory data packages, and as discussed with the laboratory, the procedure for evaluating PAH results consisted of the following steps. First, the laboratory reviewed the chromatograms. If a PAH was detected above the PQL, then the value was reported. If the PAH was detected above the SQL, but below the PQL, then the value was reported and flagged as a J value. If there was no indication that the PAH was detected, it was reported as a non-detect value at the PQL. These procedures are consistent with the approved DVSR for the 2007 and 2008 sampling program. As discussed further in Section 5.2, this has little impact on the overall evaluation, because very few soil borings had detections of PAHs.

Criterion V – Data Review

The data review portion of the data usability process involves review of the quality of the analytical data received from the laboratory by a professional knowledgeable in HRA data application. The data set was reviewed by Renee Kalmes, MSPH, CIH, and Greg Brorby, DABT. All soil data were subject to data validation using EPA guidelines (U.S. EPA, 1999; 2001; 2004a; 2005a, b; 2008; 2009a), the BMI Plant Site Specific Supplemental Guidance on Data Validation from NDEP (NDEP, 2009a), and BRC SOP 40 and Data Review/Validation (BRC, 2009). These federal EPA guidelines, which were prepared for CLP data, were adapted to reflect the analytical methods and measurement quality objectives established for the individual sampling events and the guidance provided by NDEP.

Four separate DVSRs were prepared for the Parcel data (ERM-West, 2008a,b; ERM-West, 2009; Northgate, 2010a). Any analytical errors and/or limitations in the data have been addressed, and explanations for data qualification are provided in the respective data tables. The results of LDC's data review of these issues are presented in the DVSRs and are summarized below.

Although certain laboratory limits, such as percent recovery and relative percent difference (RPD) between sample and duplicate, were exceeded for certain compounds or analyses, as identified by the laboratory (and confirmed during LDC's review of the data), there does not appear to be a widespread effect on the quality of the analytical results. Furthermore, based on a review of the laboratory narratives (provided in the laboratory reports in each DVSR), the laboratory does not believe that the observed exceedances of laboratory criteria are cause for concern. As discussed below, when quality criteria were not met for some analytical results, various data qualifiers were added to indicate limitations and/or bias in the data. The definitions for the data qualifiers, or data validation flags, used during validation are those defined in the DVSRs. Sample results were rejected based on findings of serious deficiencies in the ability to properly collect or analyze the sample and meet QC criteria. Depending on the specific DVSR,



91% to 99.8% of the data obtained during the field investigations were found to be valid and were not rejected.

It was noted during the review of the 2010 soil confirmation results that some of the reported values for PAHs at sample location TSB-FR-02 in Parcel F were rejected due to exceedances of internal calibration limits. For purposes of the HRA, we have excluded the original PAH data for this location, because this area has been remediated. However, because insufficient post-remediation data were available, another confirmation sample (and field duplicate) was collected on November 30, 2010 to ensure that the cleanup goals for PAHs were met for the remediation polygon associated with this sample location. The results for these additional samples are provided in Appendix G; however, they are not included in any of the tabular summaries or in the risk assessment calculations. As shown in the appendix, PAHs were not detected in either of these samples at detection limits below the BCLs. These results confirm that this area of Parcel F has been remediated and inclusion of these samples would not affect the conclusions of the post-remediation HRA presented herein.

Analytical results for other qualifiers, and their potential usability in the HRA, were also reviewed. Specifically, all *J*-qualified data were identified (Appendix B, Table B-1, Summary of *J*-qualified Parcel Data) and evaluated. Data were qualified as *J* for one the following reasons:

- Calibration violations, indicating a low bias (4 instances)
- MS/MSD recovery outside of control limits (140 instances), almost exclusively metals
- Surrogate recovery outside of control limits (4 samples)
- Holding-time exceedance (77 samples), primarily OCPs
- Laboratory control sample (LCS) recovery outside of control limits (14 samples), all calcium.

Table B-1 provides the reported soil concentration for each of the *J*-qualified samples. In all instances, the reported soil concentration is significantly below its respective BCL or the chemicals were not health-based, site-related chemicals of interest in the Parcels (i.e., zirconium, chlorite, sodium). Therefore, use of the *J*-qualified data in the HRA is not expected to have a substantial impact on the overall conclusions of the report, and all *J*-qualified data were retained for purposes of the post-remediation HRA.



Criterion VI – Data Quality Indicators

Data quality indicators (DQIs) are used to verify that sampling and analytical systems used in support of project activities are in control and that the quality of the data generated for this project is appropriate for making decisions affecting future activities. The DQIs address the field and analytical data quality aspects, as they affect uncertainties in the data collected for site characterization and risk assessment. The DQIs include completeness, comparability, representativeness, precision, and accuracy. The project QAPP provides the definitions and specific criteria for assessing DQIs using field and laboratory QC samples and is the basis for determining the overall quality of the data set. Data validation activities included the evaluation of these parameters, and all data not meeting the established criteria were qualified during the validation process.

“Completeness” is measured by the total number of acceptable data points and total number of samples collected by source area and exposure area. Field completeness is defined as the percentage of samples actually collected versus those intended to be collected. This field completeness calculation is based on the total sample locations scheduled compared to the COC requests sent to the laboratories. The field completeness goals stated in the QAPPs are 90%. A comparison of samples reported in the database indicates actual field completeness of 100% for all sampling events. All COC requests were faithfully executed by the laboratories, with minor exceptions detailed in the data validation memoranda. Laboratory completeness is defined as the percentage of valid data points versus the total expected from the laboratory analyses. Actual laboratory completeness was 100% on the basis of sample analysis (i.e., all requested analyses were performed and reported by the laboratories), and depending on the specific DVSR, 91.41% to 99.8% completeness based on valid data, with 0.2% to 8.59% of the data qualified as rejected (*R*). The data eliminated from the HRA dataset are presented in Appendix B, Table B-2, Summary of Reject Parcel Data. Data were qualified as “R/rejected” during the validation process. The Parcel site characterization dataset approved by NDEP (NDEP, 2008a) and results from confirmation soil samples (Northgate, 2010c) were used to support the HRA.

“Comparability” is a qualitative characteristic expressing the confidence with which one data set can be combined with another for purposes of estimating exposure. Comparability is a qualitative expression of the measure of confidence that two or more data sets may contribute to a common analysis. In general, comparability of data was maximized by using standard methods for sampling and analysis, reporting data, and data validation over the 2007/2008 and 2010 sampling programs. With the exception of the reporting issue for PAHs (PQL rather than the



SQL), the reporting requirements were the same for all the investigations. Similar sampling methods and testing methods were used throughout the program.

“Representativeness” is the degree to which data accurately and precisely represent a characteristic of the population at a sampling point or an environmental condition. There is no standard method or formula for evaluating representativeness, which is a qualitative term.

“Representativeness” is achieved through selection of sampling locations that are appropriate relative to the objective of the specific sampling task, and by collection of an adequate number of samples from relevant types of locations. As noted, the initial sampling was conducted in accordance with the NDEP-approved *Phase 2 Sampling and Analysis Plan to Conduct Soil Characterization* (BEC, 2007). The investigation involved collection of random soil matrix samples placed within a grid across the Parcels. The random sample locations were supplemented with judgment-based sampling locations targeting specific site features and LOUs. The placement of the sample locations was deemed representative to evaluate the soil conditions in the context of the CSM.

“Precision” is a measure of the degree of agreement between replicate measurements of the same source or sample. Precision is expressed by RPD between replicate measurements. Replicate measurements can be made on the same sample or on two samples from the same source. Field precision for the parcel samples was assessed by evaluating the field duplicate results. As discussed under *Criterion V – Data Review*, matrix spike versus matrix spike duplicates (MS/MSD) were evaluated focusing on the samples that were *J*-qualified. In all instances, the reported soil concentration is significantly below its respective BCL. Therefore, use of the *J*-qualified data in the post-remediation HRA is not expected to have a substantial impact on the overall conclusions of the report, and all *J*-qualified data were retained for purposes of the HRA.

Field duplicate precision was evaluated in accordance with the *Statistical Analysis Recommendations for Field Duplicates and Field Splits* (NDEP, 2008c), where the primary sample and field duplicate are independent samples. RPD exceedances were qualified as estimated (UJ/J) due to concentration uncertainty. A summary of qualified field duplicates is presented in the associated DVSR tables (Appendix B). All field duplicate precision data were determined to be usable for purposes of the HRA.

“Accuracy” measures the level of bias that an analytical method or measurement exhibits. Several QC parameters are used to evaluate the accuracy of reported analytical results:

- Holding times;
- Method blanks;



- Surrogate spike recovery; and
- LCS percent recovery.

As discussed under *Criterion V – Data Review*, holding-time exceedances and calibration exceedances were evaluated focusing on the samples that were *J*-qualified. In all instances, the reported soil concentration is significantly below its respective BCL, or the chemicals are not site-related chemicals of interest. Therefore, use of the *J*-qualified data in the post-remediation HRA is not expected to have a substantial impact on the overall conclusions of the report, and all *J*-qualified data were retained for purposes of the HRA.

Data Usability Conclusions

Evaluation of the analytical data for the Parcels, in terms of usability for the risk assessment, was conducted in accordance with U.S. EPA and NDEP guidance. Some data points were found to be qualified, and all *J*-qualified data were evaluated individually. Based on the evaluation, all data usability requirements were met, and with the exception of the rejected data discussed above, all Parcel data were deemed to be usable for risk assessment purposes.

4.3 Data Used in Post-Remediation Health Risk Assessment

A complete set of validated data for the Parcels is provided in Tables C-1 through C-10 of Appendix C. Data not considered in the post-remediation HRA due to soil removal and soil scraping activities are highlighted in each table. All confirmation data obtained in 2010 following the soil removal activities are included in these tables, with the exception of the recently collected confirmation data for PAHs described above that is provided in Appendix G.

Based on the post-remediation data, summaries for the Parcels are provided in Table 2 for organics and general chemistry, and in Table 3 for inorganics and radionuclides. The data summaries present the number of samples, frequency of detection, minimum concentration detected, maximum concentration detected, location of maximum detect, minimum non-detect limit, maximum non-detect limit, determined counts of detections above NDEP worker BCLs, and determined counts of non-detects above NDEP worker BCLs (NDEP, 2010b). The NDEP worker BCLs shown in the table are the lower of the indoor and outdoor worker values.¹ As

¹ Worker BCLs are based on combining human health toxicity values with a standard exposure factor to estimate contaminate concentrations in environmental media that are considered by NDEP to be protective of human exposure (including sensitive sub-groups) over a lifetime. Worker BCLs do not address intrusion of VOCs into indoor air, particulate emission during construction/excavation activities, and groundwater contact from soil-leached chemicals.



discussed further in Section 5.2, NDEP BCLs are used as part of the toxicity screen for determining COPCs.

Table 4 presents the soil data summary results for asbestos. There are a total of 72 post-remediation surface soil (0- to 0.5-feet bgs) samples. Results are reported in terms of the number of long fibers (i.e., $>10\ \mu\text{m}$ long and $<0.4\ \mu\text{m}$ wide) observed in the sample. As shown in the table, no long amphibole fibers were observed in any of the samples. A total of 34 long chrysotile fibers were observed in 20 locations; a maximum of four long chrysotile fibers were observed in any one sample.



5.0 POST-REMEDATION HEALTH RISK ASSESSMENT

This section presents the post-remediation HRA and includes the following items:

- Exposure Scenarios and Conceptual Site Model
- Selection of Chemicals of Potential Concern
- Exposure Assessment
- Toxicity Assessment
- Risk Characterization.

The post-remediation HRA follows the basic procedures outlined in the U.S. Environmental Protection Agency's (U.S. EPA's) *Risk Assessment Guidance for Superfund: Volume I—Human Health Evaluation Manual* (U.S. EPA, 1989). Other guidance documents consulted in formulating the risk assessment include:

- Guidelines for Exposure Assessment (U.S. EPA 1992a)
- Exposure Factors Handbook (U.S. EPA 1997)
- Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment) (U.S. EPA 2004a)
- Soil Screening Guidance: Technical Background Document (U.S. EPA 1996)
- Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites (U.S. EPA 2002a)
- Soil Screening Guidance for Radionuclides (U.S. EPA 2000)
- Technical Support Document for a Protocol to Assess Asbestos-Related Risk, Final Draft (U.S. EPA 2003a)
- Nevada Administrative Code Chapter NAC 445A. Adopted Permanent Regulation of the Nevada State Environmental Commission. LCB File No. R119-96 (NDEP 1996)
- Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual (Part F, Supplemental Guidance for Inhalation Risk Assessment) (U.S. EPA 2009b).



5.1 Exposure Scenarios and Conceptual Site Model

The exposure scenarios considered in the post-remediation HRA depend on the relevant exposure pathways and receptor populations for the Parcels. The CSM is a tool used in risk assessment to describe relationships between chemicals and potentially exposed human receptor populations, thereby delineating the relationships between the suspected sources of chemicals identified at the Site, the mechanisms by which the chemicals might be released and transported in the environment, and the means by which receptors could come in contact with the chemicals. The CSM provides a basis for defining data quality objectives (DQOs), guiding site characterization, and developing exposure scenarios.

5.1.1 Sources and Release Mechanisms

A list of potential site-related chemicals (SRCs) was agreed upon with NDEP, based on review of historical Site operations and practices, as well as those at the neighboring facilities. Not all the SRCs are related to Parcel operations, but were included because they may be related to neighboring facilities. The Parcel SRCs include:

- Volatile organic chemicals (VOCs)
- Semivolatile organic chemicals (SVOCs)
- Organochlorine pesticides (OCPs)
- Polychlorinated biphenyls (PCBs)
- Dioxins/furans
- Asbestos
- Metals
- Perchlorate
- Cyanide
- Radionuclides

As discussed in the relevant Parcel SAPs (BEC 2007; BEC 2008b), the distribution of sampling locations involved collecting random soil matrix samples that were supplemented with judgment-based sampling locations targeting specific site features within the Parcels.

Potential release mechanisms from above-ground source areas, such as spills, leaks, or accidents, could have released SRCs to surface soils. These SRCs may have then leached into subsurface soils and eventually migrated to groundwater.



In addition to the potential primary release mechanisms, secondary release mechanisms may include resuspension of SRCs in surface soils into ambient air. Volatile organics detected in the subsurface also have the ability to migrate upward to ambient air or into buildings.

Although all of these pathways are considered in the CSM, the scope of the Parcel HRA is limited to evaluating direct contact with affected soil and inhalation of dust. Additionally, findings from the Site-wide soil gas HRA (Northgate, 2010b) are included in this assessment.

5.1.2 Potential Receptors and Exposure Pathways

The identification of potentially exposed populations and exposure pathways is supported by the CSM. For a complete exposure pathway to exist, all of the following elements must be present (U.S. EPA, 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 medium
- A route of exposure (e.g., inhalation, ingestion, dermal contact).

As discussed previously, the Parcels are composed of vacant land. In the future, the Parcels are likely to be used for industrial and/or commercial purposes. Accordingly, current and future “onsite receptors” include long-term indoor workers, long-term outdoor workers, and short-term construction workers (U.S. EPA, 2002a). Other potential onsite receptors, such as visitors or trespassers, do not warrant assessment. As discussed by U.S. EPA (2002a), evaluation of exposures to members of the public under a non-residential land-use scenario is not warranted, for two reasons:

1. Public access is generally restricted at industrial sites
2. While the public may have access to commercial sites, onsite workers have a much higher exposure potential, because they spend substantially more time at a site.

Current and future “offsite receptors” are residential and worker receptors located outside the Parcel boundaries who could be exposed to airborne chemicals emitted from the Parcels during short-term construction projects (U.S. EPA, 2002a). Considering the distance from the Parcels to the nearest offsite residents, and based on the relative difference in the onsite construction particulate emission factor (which is on the order of 10^{+6} m³/kg) and the offsite receptor particulate emission factor during construction (which is on the order of 10^{+8} m³/kg), versus other exposure factors that may be higher for the offsite receptors, the onsite construction worker exposure will be



greater than that of the offsite receptor. Accordingly, offsite receptors are not evaluated quantitatively in the HRA. This issue is discussed further in the uncertainty assessment.

5.1.3 Conceptual Site Model

Based on the source and release mechanisms identified in the Parcels, Figure 7 presents the following exposure pathways and receptor populations that are considered in the HRA:

- Indoor commercial workers²
 - Incidental soil ingestion³
 - External exposure from soil⁴
 - Indoor inhalation of VOCs from soil and groundwater^{5, 6}
- Outdoor commercial/industrial workers
 - Incidental soil ingestion²
 - External exposure from soil³
 - Dermal contact with soil
 - Outdoor inhalation of dust^{2, 7}
 - Outdoor inhalation of VOCs from soil and groundwater^{8, 9}
- Construction workers
 - Incidental soil ingestion²
 - External exposure from soil³
 - Dermal contact with soil

² In accordance with U.S. EPA, 2002a, dermal absorption is not considered to be a complete exposure pathway for the indoor worker. Soil ingestion is identified by U.S. EPA (2002a) as a potentially complete exposure pathway for an indoor worker, due to potential for contact through ingestion of soil tracked indoors from outside. Inhalation of indoor dust (particulates) is accommodated via the soil ingestion pathway (U.S. EPA, 2002a, Exhibit 4-1).

³ Includes radionuclide exposures; however, as noted in Section 5.2, radionuclides are not selected as COPCs for the Parcels.

⁴ Only radionuclide exposures; however, as noted in Section 5.2, radionuclides are not selected as COPCs for the Parcels.

⁵ Indoor inhalation of VOCs from soil and groundwater was evaluated as part of a site-wide assessment based on collected soil-vapor measurements, and the results are summarized in this report.

⁶ Radon is not expected to be an issue for the Parcels because future use will remain commercial/industrial. Additionally, as noted in Section 5.2, radionuclides are not selected as COPCs for the Parcels.

⁷ Includes asbestos exposures.

⁸ Pathway was evaluated quantitatively only if estimated indoor air concentrations indicated the need as part of the site-wide soil gas assessment.

⁹ Quantitatively evaluated only if warranted based on indoor exposures.



- Outdoor inhalation of dust^{2,5}
- Outdoor inhalation of VOCs from soil and groundwater^{8,9}

With regard to the pathways that involve direct contact with soil, commercial workers are assumed to come into direct contact with shallow soil, 0–2 feet bgs, and construction workers are assumed to come into direct contact with soil at 0–10 feet bgs, as specified in the approved HRA Work Plan (Northgate, 2010d). It should be noted that incidental ingestion of groundwater or dermal contact with groundwater during short-term construction activities are not considered complete pathways due to groundwater depth being greater than 20 feet bgs.

5.2 Selection of Chemicals of Potential Concern Based on Direct Contact with Soil

All chemicals detected in validated soil samples collected from 0–10 feet bgs were used as the initial list of COPCs¹⁰. However, to ensure that the risk assessment focuses on those chemicals that contribute the most to the overall risk (U.S. EPA, 1989), the following procedures were used to eliminate chemicals for quantitative evaluation in the risk assessment:

- Identification of metals and radionuclides for which Parcel concentrations are at or less than background concentrations
- Identification of chemicals that will not contribute significantly to risk and hazard estimates based on a toxicity screen.

Each of these procedures is discussed in the following sections.

5.2.1 Evaluation of Site Concentrations Relative to Background

Consistent with U.S. EPA guidance (1989, 1992b,c), site data for metals and radionuclides were evaluated relative to background concentrations, to identify those that are not elevated above naturally occurring levels and can, therefore, be eliminated from further quantitative evaluation in the health risk assessment. This evaluation was based on a combination of exploratory data analysis (EDA) and appropriate statistical methods (U.S. EPA, 2002b). When the weight of evidence of the EDA and results of the statistical analyses indicated that a particular chemical is within background levels, then the chemical was not identified as a COPC. For radionuclides, NDEP's *Guidance for Evaluating Radionuclide Data for the BMI Plant Sites and Common Area Projects* (NDEP, 2009b) and *Guidance for Evaluating Secular Equilibrium at the BMI Complex*

¹⁰ Although the direct contact exposure pathway focuses on the upper 10 feet, it should be noted that no chemicals above BCLs or above the deep background data set range were detected in soils analyzed to depths of 30 feet below ground surface in the Parcels.



and Common Areas (NDEP, 2009c) were followed to assess secular equilibrium when performing background comparisons.

For the evaluation of metals, NDEP has requested that the Site soil concentrations from Remediation Zone A (RZ-A) be used as the background data set for comparisons to Site concentrations (NDEP, 2010c). The RZ-A soil samples were collected as part of the Area IV investigation (i.e., a subset of the Phase B Area IV samples) and were analyzed in accordance with the *Revised Phase B Investigation Work Plan, Tronox LLC Facility, Henderson, Nevada, December 2008* (AECOM, 2008) and the *Revised Phase B Quality Assurance Project Plan Tronox LLC Facility, Henderson, Nevada, July 2009* (AECOM and Northgate 2009). A detailed discussion of the RZ-A background data set is contained in the *Revised Technical Leaching Memorandum*, dated November 18, 2010 (Northgate 2010e). Specifically, the RZ-A background dataset consists of total of 31 samples collected from 14 borings. Sixteen samples were collected between 0.5 and 2 feet bgs and 15 samples were collected between 10 and 11.5 feet bgs. Primary samples and field duplicates were treated as independent samples, on the basis of preliminary evaluation indicating that the variance of the duplicates was similar to the variance of the primary samples, in consultation with NDEP guidance (NDEP, 2009a; Paul Black, pers. comm., November 11, 2009).

Soil data collected from locations within the Parcels at starting depths between 0 and 10 feet bgs were included in this evaluation. Samples were generally collected at starting depths of 0 feet bgs (87 samples) or 10 feet bgs (63 samples), although a few samples were collected at 5 feet bgs (9 samples). Field duplicates were again treated as independent samples.

For radionuclides, Parcel soil concentrations were compared to background levels using the existing soils background data presented in the *Background Shallow Soil Summary Report, BMI Complex and Common Area Vicinity* (BRC and TIMET, 2007), which includes both the ENVIRON (2003) data set and the BRC/TIMET data set collected in 2005. Specifically, only the subset of shallow background data identified as being from sediments derived from the McCullough Range were used, based on the recommendation of NDEP (NDEP, 2009d). These samples were collected at 0, 5, and 10 feet bgs. The total number of samples in this data set ranged from 81 to 101, depending on analyte, with approximately 30 to 40 samples for each depth interval (see Table 7).

EDA was performed using summary statistics (*Guidance on the Development of Summary Statistics Tables for the BMI Plant Sites and Common Areas Projects, Henderson, Nevada*; NDEP, 2008e) and normal quantile-quantile (Q-Q) plots and side-by-side box-and-whisker plots



to qualitatively evaluate whether the Parcel and background data are representative of a single population. These plots are included in Appendix D (metals) and E (radionuclides). Normal Q-Q plots provide a visual assessment of how closely a data set follows a normal distribution. Data points that fall on roughly a straight line may be considered to follow a normal distribution. When the highest concentrations fall above the straight line, the data set may follow a lognormal distribution. When both the background and Parcel data are included, the Q-Q plots provide a direct visual comparison of the two distributions. A curve that is higher in the vertical direction indicates a higher distribution of values (U.S. EPA 2002b). No further statistical analysis (normality, outliers) was conducted on the data in the Q-Q plots. Side-by-side box-and-whisker plots provide a visual comparison between the site and background data sets and an easy assessment of whether the bulk of samples from the Parcels are above background. For each data set, the box in the box-and-whisker plot encompasses the central 50% of the results from the 25th to 75th percentiles. Substantial overlap between the boxes for background and site data indicates that the site data may not be significantly different from background. The whiskers demarcate one “step” above the 75th percentile and below the 25th percentile. One “step” is defined as 1.5 times the interquartile range (the difference between the 75th and 25th percentiles). Data points above and below the whiskers are considered potential outliers and are shown on the plots as open circles; an “x” on the plot represents non-detect values.

The computer statistical software program Guided Interactive Statistical Decision Tools (GiSdT[®]; Neptune and Company, 2007) was used to perform all statistical comparisons. Specifically, statistical background comparisons were performed using the Quantile test, Slippage test, *t*-test, and Wilcoxon Rank Sum test with Gehan modification (this suite of tests is sometimes referred to as Gilbert’s Toolbox). The *t*-test is parametric, which assumes that the data are normally distributed. In contrast, the Wilcoxon Rank Sum test, Quantile test, and Slippage test are non-parametric, and thus do not require an assumption of whether the data are normally or lognormally distributed (U.S. EPA, 2002b; NDEP, 2009e). These non-parametric tests are described further below.

- The Wilcoxon Rank Sum test performs a test for a difference between the sums of the ranks for two populations. This is a non-parametric method for assessing differences in the centers of the distributions that relies on the relative rankings of data values. Knowledge of the precise form of the population distributions is not necessary. The Wilcoxon Rank Sum test has less power than the two-sample *t*-test wherein the data are normally distributed, but the assumptions are not as restrictive. The GiSdT[®] version of the Wilcoxon Rank Sum test uses the Mantel approach for ranking the data, which is equivalent to using the Gehan ranking



system. The Gehan ranking system is used to rank non-detects with the rest of the data (NDEP, 2009e).

- The Quantile test addresses tail effects that are not addressed in the Wilcoxon Rank Sum test. The Quantile test looks for differences in the right tails (upper end of the data set), rather than the central tendency like the Wilcoxon Rank Sum test. The Quantile test was performed using a defined quantile = 0.80 (Paul Black, pers. comm., Oct. 7, 2009).
- The Slippage test looks for a shift to the right in the extreme right tail of the background data set versus the extreme right tail of the site data set. This test determines, for each metal and radionuclide, whether the number of site concentrations that are greater than the maximum background concentration is greater than would be expected statistically if the site and background distributions are the same.

Non-detect results were set equal to one-half of the limit of detection for purposes of the parametric test and set equal to the detection limit for purposes of the non-parametric tests. The sample quantitation limit (SQL) was used as the detection limit for both the Parcels and background data sets, per NDEP guidance (NDEP 2008d). An alpha = 0.05 is typically used to evaluate a statistically significant result (U.S. EPA, 2002b). However, as more tests are performed, it is more likely that a statistically significant result will be obtained purely by chance. Given the use of multiple statistical tests, an alpha = 0.025 was selected as a reasonable significance level for determining whether Parcel data are different from background (NDEP, 2009e). Generally, any chemical that resulted in a *p*-value less than 0.025 in one of four tests was retained for further consideration in the COPC selection process. Additionally, because these tests are set up with one-sided hypotheses, not only can the differences between the two samples be detected, but also, a directional determination can be made as well (e.g., site is greater than background).

For radionuclides, if approximate secular equilibrium (discussed further below) is exhibited in an isotope decay chain, then background comparisons were performed to confirm whether all the radionuclides in that decay chain are similar to background. If any radionuclide is greater than background, then all the radionuclides in that decay chain generally would be carried forward in the risk assessment. If they are not greater than background, then they would not be identified as COPCs and would not be evaluated quantitatively in the risk assessment. If secular equilibrium is not exhibited, then background comparisons are performed for each radionuclide separately, and individual radionuclides would be selected as COPCs, depending on the outcome of the background comparisons.



Metals

The summary statistics for the background (RZ-A) and Parcel data are summarized in Table 5, including number of detections, total number of samples, percent detections, minimum detected value, maximum detected value, median, mean, and standard deviation (NDEP, 2008e); Q-Q and box-and-whisker plots are included in Appendix D. Consistent with NDEP guidance, the median, mean, and standard deviation are based on detected values (NDEP, 2008e).

The results for the four statistical tests (p-values) are also included in Table 5, as well as a determination as to whether the Parcel data are greater than background. It is important to note that many of the p-values for multiple tests are close to or equal to one, suggesting that the Parcel data are lower than background. This issue is discussed further below. In addition, there are several chemicals for which there is low frequency of detection (less than 25%) in the site or background data set. Finally, chemicals for which only one p-value was less than 0.025 are noted on Table 5. Based on these results, the chemicals identified as being greater than background in the Parcels include arsenic, beryllium, total chromium, mercury, molybdenum, sodium, and uranium.

All of these chemicals were evaluated further in the COPC selection process (Section 5.2), regardless of whether the elevated concentrations could be related to the CSM for the Parcels. In addition, as also noted in Table 5, there was an insufficient number of detected values in either the background or Parcel data sets, or both, for several metals to reliably determine whether the Parcel data were greater than background. Therefore, these metals (antimony, boron, chromium VI, platinum, selenium, silver, thallium, tin, and tungsten) were also evaluated further in the COPC selection process (Section 5.2).

Radionuclides

Secular equilibrium is defined by the International Union of Pure and Applied Chemicals (IUPAC) as “Radioactive equilibrium where the half-life of the precursor isotope is so long that the change of its activity can be ignored during the period of interest and all activities remain constant” (IUPAC, 1997). In other words, the activity of each radionuclide within an isotope decay chain is essentially the same. The analysis of secular equilibrium was performed according to NDEP’s *Guidance for Evaluating Radionuclide Data for the BMI Plant Sites and Common Areas Projects* (NDEP, 2009b) and *Guidance for Evaluating Secular Equilibrium at the BMI Complex and Common Areas* (NDEP, 2009c). The uranium decay series and thorium decay series were broken down by different depth intervals, per the recommendations from NDEP to use the same chemical-specific depth intervals used for the background comparison (BRC/TIMET,



2007). The uranium decay series includes, in order, U-238, U-234, Th-230, and Ra-226. The thorium decay series includes Th-232, Th-228, and Ra-228. The depth intervals used for the uranium decay series were for data collected between 0 and 6 feet bgs, and between 6 and 10 feet bgs. The Th-232 chain was analyzed for the single depth interval of 0 to 10 feet bgs.

The results of the equivalence test for secular equilibrium of radionuclides in the Parcels are presented in Table 6a. The table includes the p -value, a conclusion about secular equilibrium, the delta used, the sample size, the number of missing data pairs (if any), the mean proportions of radioactivity, lower and upper 95% confidence intervals, and data shifts (the value by which all negative activities are shifted upward toward zero, if this setting was used). The equivalence test analysis was performed using Neptune's EnviroGiSDT statistical analysis tool. The null hypothesis of the test is that the radionuclides within a decay series are not in secular equilibrium. Per NDEP guidance (NDEP, 2009c), the delta value (maximum deviation from equal proportions) was set to 0.10 (based on NDEP evaluations of background data sets), and a decay series was considered to be in secular equilibrium if the p -value was less than the standard significance level of 0.05. As noted in the documentation for the GiSDT software, the upper and lower confidence intervals are included primarily to show which radioisotopes are producing more/less radioactivity than the others, in case secular equilibrium is not shown. As shown in Table 6a, the equivalence test indicates that the thorium decay series is in approximate secular equilibrium in shallow soils between 0 and 10 feet bgs. The uranium decay series also is in approximate secular equilibrium in shallow soils between 0 and 6 feet bgs, but not between 6 and 10 feet bgs, with a delta value of 0.10. This result may be an artifact of the number of samples collected from this depth interval ($n=61$) vs. the number of samples collected between 0 and 6 feet bgs ($n=90$) or for the thorium decay series ($n=156$). As also shown in Table 6a, the confidence limits on the mean proportions of radioactivity for the uranium series for shallow soil between 0 and 6 feet bgs are wider than for shallow soil between 6 and 10 feet bgs, and much wider than for the thorium decay series for shallow soil between 0 and 10 feet bgs. The wider the confidence limits on the mean proportions of radioactivity, the more likely that the null hypothesis will not be rejected, given a fixed value for delta, as illustrated in the example provided in NDEP's (2009c) guidance. Further, NDEP's equivalence testing of the Parcel C/D/F/G data, which appears to have been done for a single depth interval, indicates that the uranium decay series is in approximate secular equilibrium (NDEP, 2009c).

Secular equilibrium was further evaluated using exploratory data analysis. Box-and-whisker plots (box-plots) of the Parcel radionuclide results for the isotopes in the uranium decay series and the thorium decay series are presented in Figure 8. Correlation matrices for these same two decay chains are shown in Table 6b-i. In conjunction with the equivalence testing described above,



these exploratory data analysis methods serve as additional lines of evidence for establishing whether the decay chains are in secular equilibrium (NDEP, 2009c).

The box-plots in Figure 8 show that, in general, the activities of the isotopes in the uranium decay series (Figure 8a) and thorium decay series (Figure 8b) have comparable mean activities, although for both series, the radium isotopes appear to be slightly lower than the uranium and thorium isotopes. In general, the box plots suggest that the two decays series are in approximate secular equilibrium.

As shown in Table 6b-i, the correlation matrices show a positive correlation between the isotopes within each chain, which would be consistent with decay chains in secular equilibrium. The correlations are strongest for the uranium decay chain, where the strongest correlation occurs between U-238 and U-234, and the weakest correlations occur between Ra-226 and the uranium isotopes. For the thorium decay chain, the strongest correlation is between the Th-232 and Th-228, while a weaker correlation is exhibited between Ra-228 and the thorium isotopes. The correlation between Ra-228 and Th-232 is very weak, reflective of the larger scatter in the Ra-228 activities. A similar picture was seen for the decay-chain correlations for the 2005 BRC/TIMET Background data set, which are presented in Table 6b-ii.

Background Comparison

Comparisons between site data and the background data set for the Th-232 decay series were based on combined data between 0 and 10 feet bgs in each data set, as recommended in BRC's Background Soil Summary Report (BRC/TIMET, 2007). For the U-235 and U-238 decay series, the site and background data were subdivided into two depth intervals, as also recommended in the Background Soil Summary Report (BRC/TIMET, 2007). For these radionuclides, site data collected between 0 and 6 feet bgs were compared to background data collected at 0 and 5 feet bgs, and site data collected between 6 and 10 feet bgs were compared to background data collected at 10 feet bgs. The background comparison tests were carried out using Neptune's EnviroGiSDT statistical analysis tool.

The summary statistics for the background and site radionuclide data for the Parcels are summarized in Table 7, including the number of detections, total number of samples, percent detections, minimum detected value, maximum detected value, median, mean, and standard deviation (NDEP, 2008e); Q-Q and box-and-whisker plots are included in Appendix E.

Consistent with NDEP guidance, the median, mean, and standard deviation are based on detected values (NDEP, 2008e). The results for the four statistical tests (p -values) are also included in the



table, as well as a determination as to whether the site data are greater than background. Based on these results, Th-228, U-234, and U-235 are identified as being above background, although this is based only on the results of a single test for Th-228. Given that the radionuclide chains are generally within secular equilibrium and there is no reason to believe that the Parcels have been affected by thorium or uranium isotopes, radionuclides were not evaluated further in the COPC selection process.

5.2.2 Evaluation of Site Concentrations Relative to Toxicity Screen

Table 8 contains a list of all chemicals (64 potential COPCs) that were either positively identified in at least one soil sample as presented in Tables 1 through 3 or, for metals, were determined to be above background (or for which a background determination could not be made) based on evaluation presented in Table 5. Based on the methods in the approved HRA Work Plan (Northgate, 2010d), a combination of frequency of detection (chemical is detected in less than 5% of the samples) and a toxicity screen were used to further reduce the initial list of potential COPCs. No chemical was eliminated based solely on frequency of detection.

The chemical toxicity screen used was based on comparison of the maximum detected concentration to a percentage of the BCL. To illustrate this BCL comparison, Table 8 presents the ratio of the BCL divided by the maximum detected soil concentration. A ratio >10 indicates that the maximum detected concentration is less than 10% of the BCL. A ratio of >100 indicates that the maximum detected concentration is less than 1% of the BCL. The results of the chemical toxicity screen can be summarized as follows:

- With the exception of 4,4'-DDE, alpha-BHC, beta-BHC, benzo(a)pyrene, hexachlorobenzene, Aroclor 1254, perchlorate, arsenic, and dioxin, the detected chemicals have maximum detected concentrations less than 10% of the BCL (or ratios above 10). The majority of detected chemicals have very large ratios, indicating that they would not contribute substantially to overall health risk estimates.
- All persistent, bioaccumulative, and toxic chemicals and Class A carcinogens were retained as COPCs, unless their ratio of BCL to maximum detected concentration was greater than 100 (maximum detected concentration is less than 1% BCL), indicating that they would not contribute significantly to overall health risk estimates. All detected carcinogenic PAHs were retained as COPCs.
- There is no BCL for asbestos; however, one or more long chrysotile fibers (>10 microns $[\mu\text{m}]$ in length and $<0.4 \mu\text{m}$ in width) were detected in 3 of 18 samples analyzed for asbestos. Therefore, long chrysotile fibers were identified as a COPC.



- Dioxin was not retained as a COPC, because the maximum detected concentration of dioxin/furan TEQ (765) is below the NDEP recommended default target goal of 1000 pg/g.
- Arsenic was not retained as a COPC because all but one of the measured concentrations were below NDEP-approved remediation target of 7.2 mg/kg, and the remaining detection, which is for a sample collected at 10 feet bgs, was 8.0 mg/kg, only slightly above the remediation target.
- As shown in Table 8, BCLs are not available for the following detected organic compounds: endrin aldehyde, gamma-chlordane, di-n-octyl phthalate, octachlorostyrene, and 1,2,3-trichlorobenzene. Consistent with NDEP guidance, surrogate BCLs were identified for those compounds for which a representative surrogate could be identified, specifically, endrin (for endrin aldehyde), chlordane (for gamma-chlordane), butyl benzyl phthalate (for di-n-octyl phthalate), and 1,2,4-trichlorobenzene (for 1,2,3-trichlorobenzene). A representative surrogate for octachlorostyrene was not identified. The uncertainty in using surrogate compounds for the toxicity screen and COPC selection and absence of an appropriate surrogate for octachlorostyrene is discussed in Section 5.7.
- BCLs are not available for two metals, platinum and sodium (Table 8). Platinum was detected in only 7 of 157 samples, at a maximum concentration of 2.4 mg/kg in sample TSB-FJ-02-02-0. Surface soil at this location was scraped because of the presence of asbestos; therefore, the soil represented by this sample has been removed. The next highest detected platinum concentration was 0.15 mg/kg. Sodium was detected in all but one of the 157 samples, at a maximum concentration of 2910 mg/kg; however, sodium is an essential nutrient and it was shown to be slightly elevated above background based on only one of four statistical tests (see Table 5). In such cases, U.S. EPA (1989) guidance suggests that essential nutrients do not need to be considered further in the quantitative risk assessment. In contrast to organic compounds, NDEP guidance does not recommend the use of surrogates for metals. The uncertainty in the risk estimates due to the exclusion of these metals as COPCs (due to the absence of BCLs and associated toxicity values) is discussed in Section 5.7.

It should be noted that, in a few instances, the detection limit was higher than the BCL for one or more chemicals. For example, out of 157 samples analyzed for OCPs, the detection limit for one sample exceeded the BCLs for aldrin and dieldrin and the detection limits for two samples exceeded the BCL for toxaphene (see Table 2 and Table C6 in Appendix C). Given that these chemicals were not detected in any sample and the detection limits for nearly all of the samples were below their BCLs, these few instances of elevated detection limits are not expected to affect



the conclusions of this post-remediation HRA. The only other chemicals for which the detection limits exceeded the BCLs were benzo(a)pyrene and dibenz(a,h)anthracene. As discussed in Section 4.2, these values represent PQLs for samples collected in 2007 or 2008, in which the laboratory reviewed the chromatograms and reported the results to the PQL in cases where there was no indication that PAHs were present in the sample.

In summary, based on the background comparison for metals and radionuclides, and the toxicity screen evaluation, the following 14 chemicals are identified as COPCs for the Parcels and are evaluated quantitatively in the post-remediation HRA.

- 4,4'-DDE
- 4,4'-DDT
- Alpha BHC
- Beta BHC
- Benz(a)anthracene
- Benzo(a)pyrene
- Benzo(b)fluoranthene
- Benzo(k)fluoranthene
- Chrysene
- Hexachlorobenzene
- Aroclor 1248
- Aroclor 1254
- Perchlorate
- Asbestos (long chrysotile fibers)

5.3 Evaluation of Chemicals of Potential Concern Based on Potential Leaching to Groundwater

COPCs were also identified based on a screening-level evaluation for the potential for leaching from soil to groundwater in general accordance with NDEP's *Soil to Groundwater Leaching Guidance* (NDEP, 2010d).



Tables 2 and 3 present the number of detections above the LBCLs for organics and inorganics, respectively. Chemicals detected at least once above their respective LBCLs, excepting inorganic chemicals that were shown to be within background, are listed below with a brief discussion of the frequency and magnitude of detections relative to LBCLs.

Chemical	Evaluation
Alpha-BHC	Detected in 7% of the samples. Maximum detected concentration of 0.059 mg/kg is above the LBCL (DAF 20) of 0.0006 mg/kg
Beta-BHC	Detected in 34% of the samples. Maximum detected concentration of 0.18 mg/kg is above the LBCL (DAF 20) of 0.002 mg/kg
Gamma BHC (Lindane)	Detected in only 1 out of 157 samples at a concentration of 0.013 mg/kg, which is essentially equal to the LBCL (DAF 20) of 0.01 mg/kg
Benzo(a)anthracene	Detected in 2 of 146 samples. The maximum detected concentration of 0.096 mg/kg is below the LBCL (DAF 20) of 1.6 mg/kg
Hexachlorobenzene	Detected in 3% of the samples. Maximum detected concentration of 0.37 mg/kg is below the LBCL (DAF 20) of 2 mg/kg
Acetone	Detected in 27% of the samples. The maximum detected concentration of 1.9 mg/kg is below the LBCL (DAF 20) of 16 mg/kg
Methylene chloride	Detected in 14% of the samples. The maximum detected concentration of 0.021 mg/kg is essentially equal to the LBCL (DAF 20) of 0.021 mg/kg
Arsenic	Detected in 100% of the samples. The maximum detected concentration of 8 mg/kg is only slightly above the 7.2 mg/kg NDEP recommended comparison level, and is below the LBCL (DAF 20) of 20 mg/kg
Chromium (total)	Detected in 100% of the samples. The maximum detected concentration of 19 mg/kg is below LBCL (DAF 20) of 40 mg/kg.
Nickel	Detected in 100% of the samples. The maximum detected concentration of 22.6 mg/kg is below the LBCL (DAF 20) of 140 mg/kg.
Thallium	Detected in only 3% of the samples. The maximum detected concentration of 0.45 mg/kg is below the LBCL (DAF20) of 8 mg/kg.

The soil leaching to groundwater pathway is not addressed in this deliverable beyond the screening-level evaluation presented above. Further analysis to assess the potential for



groundwater contamination from leaching will be evaluated in a separate deliverable. It should be noted that perchlorate is not listed above because an LBCL has not been established by the NDEP. However, previous evaluations at the Site have established that perchlorate is highly leachable (Northgate, 2011), and it should be included as a COPC for future evaluations of the leaching pathway.

5.4 Exposure Assessment

The magnitude of exposure for any given receptor is a function of the amount of the constituent in the exposure medium, and the frequency, intensity, and duration of contact with that medium. This section presents the equations and assumptions used to calculate potential exposures for each of the identified COPCs.

5.4.1 Determination of Representative Exposure-Point Concentrations

A representative exposure-point concentration (EPC) is a COPC-specific and medium-specific concentration used in the dose equation for each receptor and each exposure pathway. The methods, rationale, and assumptions employed in deriving the EPCs are discussed below for the relevant environmental media based on the COPCs evaluated in the Parcels.

5.4.1.1 Soil

Soil EPCs were used to estimate direct-contact exposure for future onsite indoor and outdoor commercial workers and construction workers. The soil EPCs were also used to derive airborne particulate concentrations of non-volatile COPCs. For the purposes of this HRA, a screening approach was used that incorporated use of the maximum detected concentration within the 0- to 10-foot bgs interval for each identified COPC, except for asbestos, which is discussed separately below. This assumption likely overestimates potential health risks, because receptors are unlikely to be exposed to the maximum concentration for all COPCs over an extended period of time.

5.4.1.2 Asbestos

Bulk soil concentrations for asbestos were used to estimate exposure-point concentrations in air according to the methodology described in *Technical Guidance for the Calculation of Asbestos-Related Risk in Soils for the BMI Complex and Common Areas* (NDEP, 2009f). This methodology is based on the protocols described in U.S. EPA (2003a), and requires estimation of asbestos concentrations in soil to develop exposure-point concentrations in air.



Asbestos concentrations in surface soils are based on the number of long fibers (i.e., >10 μm long and <0.4 μm wide) observed in a sample, multiplied by the analytical sensitivity of the measurement:

$$C_{soil} = f \times AS$$

where f is the number of long fibers observed (unitless), and AS is the analytical sensitivity (fibers per gram [fibers/g]).¹¹ If more than one asbestos sample is collected, the analytical sensitivity is pooled across the n samples as follows:

$$Pooled\ AS = 1 \times \frac{1}{\sum_{i=1}^n AS_n}$$

Two estimates of the asbestos concentration were calculated (i.e., a best estimate and an upper-bound estimate), as defined in U.S. EPA's draft methodology (U.S. EPA, 2003a) and NDEP (2009f). The best-estimate concentration is similar to a central-tendency estimate, whereas the upper-bound concentration is comparable to a reasonable maximum exposure estimate. The pooled analytical sensitivity is multiplied by the number of long chrysotile or amphibole structures to estimate concentration. For the best estimate, the number of long fibers measured is incorporated into the calculation above. The upper bound of the asbestos bulk soil concentration is calculated as the 95% UCL of the Poisson distribution, where the mean equals the number of long structures detected. This value is calculated as follows (NDEP 2009f):

$$95\% \ UCL = \frac{\chi^2_{0.95} (2 \times (x + 1))}{2}$$

The 95% UCL of the Poisson distribution is then multiplied by the pooled analytical sensitivity to estimate the upper-bound concentration.

5.4.1.3 Outdoor Dust

Long-term exposure to COPCs bound to dust particles was evaluated using U.S. EPA's particulate emission factor (PEF) approach (U.S. EPA, 2002a). The PEF relates concentrations of a chemical in soil to the concentration of dust particles in the air. The Q/C (Site-Specific Dispersion Factor [U.S. EPA, 2002a]) values are based on the Las Vegas, Nevada, area, as presented in Appendix D of U.S. EPA (2002a). The U.S. EPA guidance for dust generated by construction activities (U.S. EPA, 2002a) was used for short-term construction worker

¹¹ The laboratory results are reported as "structures"; however, the term "fibers" is used herein for simplicity.



exposures. Input soil concentrations for the model are the EPCs described above. The remaining model input parameters are summarized in Table 10; the calculations, including all intermediate equations, are included in Appendix F of this report. It should be noted that the PEF for short-term construction workers includes two components, emissions from unpaved roads and emissions from wind erosion, excavation, dozing, grading, and tilling (U.S. EPA, 2002a). These sources of dust emissions are combined into a single PEF for short-term construction workers as follows:

$$PEF_{sc_total} = \frac{1}{\left(\frac{1}{PEF_{sc_road}}\right) + \left(\frac{1}{PEF_{sc}}\right)}$$

where:

PEF_{sc_total} = total subchronic construction-related PEF (m^3/kg)

PEF_{sc_road} = subchronic PEF for unpaved road traffic

PEF_{sc} = subchronic PEF for construction activities.

For onsite workers, the PEF is limited to emissions from wind erosion from surface soil, which is calculated according to the Equation 24 in NDEP's (2009f) asbestos guidance, as shown in Appendix F.

The air concentration term for COPCs bound to dust particles is derived from soil concentrations (mg/kg for chemicals and $fibers/g$ for asbestos) by applying the PEF values described above in the following equations:

Chemicals

$$C_{air} = C_{soil} \times CF_1 \times \left(\frac{1}{PEF}\right)$$

Asbestos

$$C_{air} = C_{soil} \times CF_2 \times \left(\frac{1}{PEF}\right) \times \left(\frac{1}{CF_3}\right)$$



where:

- C_{air} = air concentration ($\mu\text{g}/\text{m}^3$, f/cm^3)
- CF_1 = conversion factor (1000 $\mu\text{g}/\text{mg}$)
- CF_2 = conversion factor (1000 g/kg)
- CF_3 = conversion factor ($10^6 \text{ cm}^3/\text{m}^3$)
- PEF = particulate emission factor (m^3/kg).

For asbestos, the soil bulk concentrations and air concentrations (and subsequent health risks) were calculated using NDEP's "asbestos guidance riskcalcs.xls" spreadsheet. It should be noted that asbestos bulk soil concentrations and corresponding air concentrations were calculated for each Parcel separately. The approximate size of each area is presented in Table 9.

5.4.2 Exposure Calculations

Reasonable maximum exposures to chemicals were calculated for future onsite indoor and outdoor commercial workers and future onsite construction workers, using the exposure pathway-specific dose equations presented below and the exposure input parameters presented in Tables 10 and 11, respectively. The dose calculation spreadsheets for each exposure scenario are included in Appendix F. The methodology used to estimate the average daily dose (ADD) via each of the complete exposure pathways is based on U.S. EPA (1989, 1992a) guidance. For chemical carcinogens, lifetime average daily dose (LADD) estimates are based on chronic lifetime exposure extrapolated over the estimated average 70-year lifetime (U.S. EPA, 1989), to be consistent with cancer slope factors, which are based on chronic lifetime exposures. For noncarcinogens, ADD estimates are averaged over the estimated exposure period.

5.4.2.1 Chemicals

Soil Ingestion:

$$Dose = \frac{C_{\text{soil}} \times SIR \times CF_4 \times EF \times ED \times BIO}{BW \times AT}$$

where:

Dose = ADD for non-carcinogens and LADD for carcinogens (mg/kg-day)



- C_{soil} = chemical concentration in soil (mg/kg)
 SIR = soil ingestion rate for indoor workers (SIR_i), outdoor workers (SIR_o), or construction workers (SIR_{cw}) (mg/day)
 CF_4 = conversion factor (10^{-6} kg/mg)
 EF = exposure frequency for indoor workers (EF_i), outdoor workers (EF_o), or construction workers (EF_{cw}) (days/year)
 ED = exposure duration for commercial workers (ED_w) or construction workers (ED_{cw}) (years)
 BIO = relative bioavailability (unitless)
 BW = body weight (kilograms)
 AT = averaging time (days); equal to the $ED \times 365$ days/year for non-carcinogens (AT_{nc}) and 70 years (average lifetime) $\times 365$ days/year for carcinogens (AT_c)

Dermal Contact:

$$Dose = \frac{C_{soil} \times CF_4 \times SA \times AF \times ABS \times EF \times ED}{BW \times AT}$$

where:

- $Dose$ = ADD for non-carcinogens and LADD for carcinogens (mg/kg-day)
 C_{soil} = chemical concentration in soil (mg/kg)
 CF_4 = conversion factor (10^{-6} kg/mg)
 SA = skin surface area for outdoor workers (SA_o) or construction workers (SA_{cw}) (cm^2 /event)
 AF = soil to skin adherence factor for outdoor workers (AF_o) or construction workers (AF_{cw}) (mg/cm^2)
 ABS = absorption factor (unitless)
 EF = exposure frequency for outdoor workers (EF_o) or construction workers (EF_{cw}) (events/year)
 ED = exposure duration for commercial workers (ED_w) or construction workers (ED_{cw}) (years)
 BW = body weight (kilograms)



AT = averaging time (days); equal to the ED × 365 days/year for non-carcinogens (AT_{nc}) and 70 years (average lifetime) × 365 days/year for carcinogens (AT_c).

Chemical-specific dermal absorption values from U.S. EPA guidance (U.S. EPA, 2004b [Part E RAGS]) are used in the risk assessment.

Inhalation:

The contaminant concentration in air, rather than contaminant intake, is used as the basis for estimating chemical inhalation risks based on guidance described in *Part F, Supplemental Guidance for Inhalation Risk Assessment* (U.S. EPA, 2009b). As presented in the CSM, indoor dust (particulate) is accommodated via the soil ingestion pathway for indoor workers. The inhalation equation for outdoor workers and construction workers is:

$$EC = \frac{C_{soil} \times CF_1 \times ET_o \times EF \times ED}{AT \times PEF}$$

where:

- EC = exposure concentration for evaluating exposure to non-carcinogens (EC_{nc}) or carcinogens (EC_c) (µg/m³)
- C_{soil} = chemical concentration in soil (mg/kg)
- CF₁ = conversion factor (1000 µg/m³)
- ET_o = exposure time outdoors onsite (hr/day)
- EF = exposure frequency for outdoor workers (EF_o) or construction workers (EF_{cw}) (days/yr)
- ED = exposure duration for commercial workers (ED_w) or construction workers (ED_{cw}) (year)
- AT = averaging time (hours); equal to the ED × 365 days/year × 24 hours/day for non-carcinogens (AT_{nc}) and 70 years (average lifetime) × 365 days/year × 24 hours/day for carcinogens (AT_c)
- PEF = particulate emission factor (m³/kg) – see Table 9.

5.4.2.2. Asbestos

Exposure to asbestos fibers in air was evaluated using the methodology described in NDEP (2009f). The NDEP asbestos risk assessment guidance is based on methods for assessing asbestos risk described in U.S. EPA (2003a), and also on associated examples of the



implementation of these methods as described in other documents by the authors of U.S. EPA documents (Berman and Chatfield, 1990; Berman and Crump, 1999a,b, 2001; Berman and Kolk, 2000). The exposure equation for asbestos is analogous to that recommended by U.S. EPA for other inhalation carcinogens. The exposure concentration is a function of the asbestos air concentration, the length of time an individual is exposed, and the averaging time for which carcinogenic effects are evaluated for the unit risk factor. The equation for a time-weighted exposure concentration in air used in performing an asbestos inhalation risk assessment is the same as for chemicals:

$$EC_a = \frac{C_{air} \times ET_o \times EF \times ED}{AT}$$

where:

EC_a = exposure concentration for evaluating exposure to asbestos (f/cm^3)

C_{air} = air concentration of asbestos (f/cm^3)

ET_o = Exposure time outdoors onsite (hours/day)

EF = Exposure frequency for commercial workers (EF_w) or construction workers (EF_{cw}) (days/year)

ED = Exposure duration for commercial workers (ED_w) or construction workers (ED_{cw}) (years)

AT = Averaging time (hours); based on 70 years (average lifetime) (AT_c).

As stated previously, potential exposure to asbestos in soil was evaluated for each Parcel.

5.5 Toxicity Assessment

Cancer oral slope factors (SFs), which are expressed in units of $(mg/kg\text{-day})^{-1}$, or inhalation unit risk factors (URFs), 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 exposure to potentially carcinogenic chemicals. The SF and URF are defined as the 95% UCL of the probability of a carcinogenic response per unit daily intake or concentration of a chemical over 70 years. A higher value implies a more potent carcinogenic potential. Non-cancer oral reference doses (RfDs), which are expressed in units of $mg/kg\text{-day}$, and inhalation reference concentrations (RfCs), which are expressed in units of mg/m^3 , are experimentally derived “no-effect” levels that are used to quantify the extent of toxic effects other than cancer due to exposure to chemicals. The RfD and RfC are intended to represent the dose or concentration of a



chemical that is not expected to cause adverse health effects, assuming daily exposure over a lifetime, even in sensitive individuals, with a substantial margin of safety. With RfDs and RfCs, a lower value implies a more potent toxicant. These criteria are generally developed by U.S. EPA risk assessment work groups and are listed in the U.S. EPA risk assessment guidance documents and databases.

Table 12 presents the toxicity criteria used in this assessment based on the following hierarchy (based on U.S. EPA, 2003b), with the exception of asbestos, which is discussed separately below:

1. IRIS
2. CalEPA – Office of Environmental Health Hazard Assessment (OEHHA) Toxicity Criteria Database
3. U.S. EPA’s Provisional Peer Reviewed Toxicity Values (PPRTVs)
4. National Center for Environmental Assessment (NCEA, or other current U.S. EPA sources)
5. Health Effects Assessment Summary Tables (HEAST)
6. U.S. EPA Criteria Documents (e.g., drinking-water criteria documents, drinking-water Health Advisory summaries, ambient water-quality criteria documents, and air-quality criteria documents)
7. ATSDR toxicological profiles
8. U.S. EPA’s Environmental Criteria and Assessment Office (ECAO)
9. Peer-reviewed scientific literature.

For carcinogens, the U.S. EPA weight-of-evidence classification is identified in the table for each carcinogenic COPC. For carcinogenic PAHs (except naphthalene), provisional U.S. EPA guidance for estimating cancer risks was used (U.S. EPA, 1993). The procedure uses information from the scientific literature to estimate the carcinogenic potency of several PAHs relative to benzo(a)pyrene. These relative potencies are used to modify the SF developed for benzo(a)pyrene for each PAH. Further, U.S. EPA has not derived toxicity criteria to evaluate the potential non-cancer health hazards associated with exposure to the carcinogenic PAHs. Per the HRA Work Plan, a toxicological surrogate (i.e., pyrene) was used to quantify the potential non-carcinogenic effects of the carcinogenic PAHs. This surrogate was selected by NDEP consultants (NDEP, 2006) from a list of six PAHs for which non-cancer oral toxicity criteria have been assigned by the U.S. EPA, based on careful consideration of their relevant toxicity data, target organ(s), dose-response information, and structure-activity relationships. From the



available oral non-cancer toxicity data reported by the U.S. EPA, the most sensitive target organs are the liver, kidney, and blood (hematological effects [IRIS], U.S. EPA, 2010; ATSDR, 1990, 1995; ORNL, 1993). For the carcinogenic PAHs, the non-cancer target organs were found to be the same, and the reported toxicological thresholds for these effects are generally in the range of those reported for the non-cancer PAHs (ATSDR, 1995). Although naphthalene (2-ring structure) has the most stringent oral non-cancer toxicity criterion (0.02 mg/kg day), pyrene (4-ring structure; oral RfD of 0.03 mg/kg-day) was selected to be the best surrogate, due to (1) non-cancer toxicity endpoints that are more consistent with those for carcinogenic PAHs; and (2) the greater number of rings in the pyrene chemical structure (NDEP, 2006).

Asbestos risks were assessed in line with the approaches specified in NDEP's (2009f) *Technical Guidance for the Calculation of Asbestos-Related Risk in Soils for the BMI Complex and Common Areas*. The approach relies on exposure-response coefficients that describe the toxicity of different fiber lengths and types of asbestos. These risk coefficients are adopted from the draft, *Technical Support Documents for a Protocol to Assess Asbestos Related Risk* (U.S. EPA, 2003a). The majority of available information indicates that lung cancer and mesothelioma are the most important risks associated with low levels of asbestos (NDEP, 2009f; U.S. EPA, 2003a). Types and aspect ratios (relative length versus diameter) of asbestos fibers differ, and are known to affect the potency of the material; therefore, deriving conclusions regarding the health effects related to asbestos exposure is complex. In the U.S. EPA draft document (U.S. EPA, 2003a), studies from environments with asbestos dusts of differing characteristics were reviewed to evaluate asbestos-related risks. U.S. EPA developed an optimal exposure index, which best reconciles the published literature. The index assigns equal potency to fibers longer than 10 µm and thinner than 0.4 µm, and assigns no potency to fibers of other dimensions. The optimal exposure index also assigns unique exposure-response coefficients for chrysotile and amphibole fibers for the endpoints of mesothelioma and lung cancer. Optimum dose-response coefficients, based on the body of available data, were assumed for this risk assessment. These coefficients are used to calculate the factor "R," which is defined as the "Estimated Additional Deaths from Lung Cancer or Mesothelioma per 100,000 persons from Constant Lifetime Exposure to 0.0001 TEM f/cc Longer than 10 µm and Thinner than 0.4 µm" (U.S. EPA, 2003a, Table 8-2 combined lung cancer and mesothelioma risk). This factor is calculated as follows (Equation 8-1 of U.S. EPA, 2003a):

$$R = 0.5 \left((0.786(NSM + NSF)) + (0.214(SM + SF)) \right)$$



where:

NSM = risk for population of non-smoking males

NSF = risk for population of non-smoking females

SM = risk for population of smoking males

SF = risk for population of smoking females.

“R” is calculated separately for long chrysotile and long amphibole fibers, reflecting the difference in potency between fiber types. Using the values for NSM, NSF, SM, and SF in Table 8.2 of U.S. EPA (2003a), “R” for chrysotile is 0.5693, and “R” for amphiboles is 63.206. “R” is then used to calculate the URF as follows:

$$\begin{aligned}URF &= \frac{10^{-5}}{0.0001} \times R \\ &= \frac{1}{10} \times R\end{aligned}$$

The numerator, 10^{-5} , and the denominator, 0.0001, reflect that the values in Table 8-2 of U.S. EPA 2003a are based on a risk per 100,000 persons exposed to an asbestos air concentration of 0.0001 f/cc. The resulting URFs are 0.05693 for long chrysotile fibers and 6.3206 for long amphibole fibers. These values were used to estimate risks associated with exposure to asbestos in soil at the Parcels (see Appendix F).

5.6 Risk Characterization

Risk characterization represents the final step in the risk assessment process. In this step, the results of the exposure and toxicity assessments are integrated into quantitative or qualitative estimates of potential health risks. Potential cancer risks and non-cancer adverse health effects are characterized separately. In addition, potential cancer risks associated with exposure to asbestos are characterized separately for the other carcinogenic chemicals. This section also contains a qualitative discussion of the uncertainties associated with this assessment.

5.6.1 Evaluation of Potential Cancer Risks

Carcinogenic risks are estimated as the incremental probability of an individual developing cancer over a lifetime as a result of exposure to a given chemical at a given concentration. Carcinogenic risks for chemicals are evaluated by multiplying the estimated average exposure



rate (i.e., LADD calculated in the exposure assessment) by the chemical's SF or the estimated average exposure concentration (i.e., EC calculated in the exposure assessment) by the chemical's URF. The SF or URF converts estimated LADDs or ECs averaged over a lifetime to incremental risk of an individual developing cancer. According to U.S. EPA (1989), this approach is appropriate for theoretical upper-bound incremental lifetime cancer risks of less than 1×10^{-2} . Lifetime chemical-specific risks and total site risks are estimated as follows:

$$Risk_{oral\ or\ dermal} = LADD \times SF$$

where:

LADD = lifetime average daily dose (mg/kg-d)
 SF = cancer slope factor (mg/kg-d)⁻¹

$$Risk_{inhalation} = EC_c \times URF$$

where:

EC_c = exposure concentration for evaluating exposure to carcinogens (μg/m³)
 URF = unit risk factor (μg/m³)⁻¹

and

$$Total\ Site\ Risk = \sum Chemical\ Risk$$

The estimated excess cancer risks for each chemical and exposure route are summed, regardless of the type of cancer associated with each chemical, to estimate the total excess cancer risk for the exposed individual.

For most chemicals, the NDEP point of departure is a cumulative incremental cancer risk of 1×10^{-6} (NDEP, 2010b). U.S. EPA considers 1×10^{-6} to 1×10^{-4} to be the target range for acceptable risks at sites where remediation is considered (U.S. EPA, 1990). Estimates of lifetime excess cancer risk associated with exposure to chemicals of less than one in one million (1×10^{-6}) are considered to be so low as to warrant no further investigation or analysis (U.S. EPA, 1990). It should be noted that cancer risks in the 1×10^{-6} to 1×10^{-4} range or higher do not necessarily mean that adverse health effects will be observed. Current methodology for estimating the



carcinogenic potential of chemicals is believed to not underestimate the true risk, but could overestimate the true risk by a considerable degree, and the true risk could be as low as zero.

5.6.1.1 Indoor Commercial Worker

The estimated excess cancer risks associated with exposure of an indoor commercial worker to the COPCs in soil through incidental ingestion are summarized in Table 13, and the calculation spreadsheets are presented in Appendix F. For an indoor commercial worker, the excess cancer risk due to exposure to chemicals in soil is 5×10^{-7} . Hexachlorobenzene and Aroclor 1254 are the largest contributors to the overall risk. This value is below the lower end of the generally acceptable risk range, indicating that potential exposure to COPCs in soil by an indoor commercial worker should not pose an unacceptable carcinogenic health risk under the conditions evaluated.

5.6.1.2 Outdoor Commercial Worker

The estimated excess cancer risks associated with exposure of an outdoor commercial worker to the COPCs in soil through incidental ingestion, dermal absorption, and inhalation are summarized in Table 13, and the calculation spreadsheets are presented in Appendix F. For an outdoor commercial worker, the excess cancer risk due to exposure to chemicals in soil is 1×10^{-6} . Incidental soil ingestion and dermal contact with soil for hexachlorobenzene and Aroclor 1254 are the largest contributors to the overall risk; inhalation exposure is inconsequential. This value is at the lower end of the generally acceptable risk range, indicating that potential exposure to COPCs in soil by an outdoor commercial worker should not pose an unacceptable carcinogenic health risk under the conditions evaluated.

5.6.1.3 Construction Worker

The estimated excess cancer risks associated with exposure of a construction worker to the COPCs in soil through incidental ingestion, dermal absorption, and inhalation are summarized in Table 14, and the calculation spreadsheets are presented in Appendix F. For a construction worker, the excess cancer risk due to exposure to chemicals in soil is 2×10^{-7} . Incidental soil ingestion and dermal contact with soil for hexachlorobenzene and Aroclor 1254 are the largest contributors to the overall risk; inhalation exposure is inconsequential. This value is below the lower end of the generally acceptable risk range, indicating that potential exposure to COPCs in soil by an outdoor commercial worker should not pose an unacceptable carcinogenic health risk under the conditions evaluated.



5.6.2 Evaluation of Non-Cancer Health Effects

Non-cancer adverse health effects are evaluated by comparing the estimated average exposure rate (i.e., ADDs or ECs estimated in the exposure assessment) with an exposure level at which no adverse health effects are expected to occur for a long period of exposure (i.e., the RfDs and RfCs). ADDs and RfDs are compared by dividing the ADD by the RfD to obtain the ADD:RfD ratio, as follows:

$$\text{Hazard Quotient}_{\text{oral or dermal}} = \frac{ADD}{RfD}$$

where:

ADD = average daily dose (mg/kg-d)

RfD = reference dose (mg/kg-d)

Similarly, ECs and RfCs are compared by dividing the EC by the RfC to obtain the EC/RfC ratio, as follows:

$$\text{Hazard Quotient}_{\text{inhalation}} = \frac{EC_{nc} \times 10^{-3} \text{ mg}/\mu\text{g}}{RfC}$$

where:

EC_{nc} = exposure concentration for evaluating exposure to noncarcinogens (μg/m³)

RfC = reference concentration (mg/m³).

A hazard quotient less than or equal to 1 indicates that the predicted exposure to that chemical should not result in an adverse noncarcinogenic health effect (U.S. EPA, 1989). If more than one pathway is evaluated, the hazard quotients for each pathway, for all COPCs, are summed to determine whether exposure to a combination of pathways poses a health concern. This sum of the hazard quotients is known as a hazard index.

$$\text{Hazard Index} = \sum \text{Hazard Quotients}$$

The NDEP non-cancer risk management target is a hazard index (HI) value of less than or equal to 1.0 (NDEP, 2010b). It should be noted that HI or HQ values greater than 1 do not necessarily



mean that adverse health effects will be observed, because a substantial margin of safety has been incorporated into many of the RfDs and RfCs.

5.6.2.1 Indoor Commercial Worker

The estimated non-cancer hazard quotients and hazard indices associated with exposure of an indoor commercial worker to the COPCs in soil through incidental ingestion are summarized in Table 13, and the calculation spreadsheets are presented in Appendix F. The total hazard index due to exposure to chemicals in soil is 0.1, indicating that potential exposure of indoor commercial workers to COPCs in soil should not pose a potential noncarcinogenic health risk under the conditions evaluated. Perchlorate is the largest contributor to the overall hazard index.

5.6.2.2 Outdoor Commercial Worker

The estimated non-cancer hazard quotients and hazard indices associated with exposure of an outdoor commercial worker to the COPCs in soil through incidental ingestion, dermal absorption, and inhalation are summarized in Table 13, and the calculation spreadsheets are presented in Appendix F. The total hazard index due to exposure to chemicals in soil is 0.2, indicating that potential exposure of outdoor commercial workers to COPCs in soil should not pose a potential noncarcinogenic health risk under the conditions evaluated. Incidental soil ingestion of perchlorate is the largest contributors to the overall hazard index.

5.6.2.3 Construction Worker

The estimated non-cancer hazard quotients and hazard indices associated with exposure of a construction worker to the COPCs in soil through incidental ingestion, dermal absorption, and inhalation are summarized in Table 14, and the calculation spreadsheets are presented in Appendix F. The total hazard index due to exposure to chemicals in soil is 0.8, indicating that potential exposure of construction workers to COPCs in soil should not pose a potential noncarcinogenic health risk under the conditions evaluated. Incidental soil ingestion of perchlorate is the largest contributors to the overall hazard index.

5.6.3 Asbestos

The equation used to estimate inhalation cancer risk for asbestos is as follows:

$$Risk_{inhalation} = EC_a \times URF$$



where:

$$\begin{aligned} EC_a &= \text{exposure concentration for evaluating exposure to asbestos (f/cm}^3\text{)} \\ \text{URF} &= \text{unit risk factor (f/ cm}^3\text{)}^{-1}. \end{aligned}$$

As noted in NDEP's (2009f) risk assessment guidance, EC_a is a function of the asbestos air concentration, the length of exposure, and the averaging time. These latter two factors are combined into a "unit risk adjustment factor" (URF adjustment factor) in NDEP's "asbestos guidance risk calcs.xls" spreadsheet, which was used in this HRA. The estimated asbestos air concentrations, URFs, URF adjustment factors, and risks for death from lung cancer or mesothelioma for asbestos exposures to outdoor commercial workers and construction workers are summarized in Table 15, and the calculation spreadsheets are presented in Appendix F.

The upper-bound estimated risks for death from lung cancer or mesothelioma for asbestos exposures to outdoor commercial workers are less than 1×10^{-6} for all of the Parcels (up to 2×10^{-8} for chrysotile and 6×10^{-7} for amphiboles [Parcel D]). For construction workers, the best and upper-bound estimates for chrysotile are less than 1×10^{-6} for all of the Parcels (up to 5×10^{-7} and 7×10^{-7} , respectively [Parcel D]). For amphiboles, the best estimate is zero for all Parcels, and the upper-bound estimates range from 1×10^{-5} (Parcels C, F, G and H) to 3×10^{-5} (Parcel D). It should be noted that the upper-bound risk estimates are based on an observed count of zero long amphibole structures in the 72 samples collected from the Parcels. It should also be noted that the unit risk factors used to estimate risks from asbestos exposure were intended to evaluate constant lifetime exposures, not short-term exposure such as construction activities (U.S. EPA, 2003a). Therefore, these results indicate that exposures to asbestos in soil in the Parcels should not result in unacceptable risks for all future onsite receptors.

5.7 Uncertainty Analysis

Uncertainty is inherent in many aspects of the risk assessment process. Uncertainty generally arises from a lack of knowledge, as well as variability of (1) site conditions and future site use; (2) toxicity and dose-response of the COPCs; and/or (3) the extent to which an individual may be exposed (if at all) to the chemicals. This lack of knowledge means that assumptions must be made based on information presented in the scientific literature or on professional judgment. Although some assumptions have significant scientific basis, many do not. The assumptions that introduce the greatest amount of uncertainty, and their effects on the findings of this HRA, are summarized in Table 16, and discussed further below. This discussion is qualitative in nature, reflecting the difficulty in quantifying the uncertainty in specific assumptions. In general,



assumptions were selected in a manner that purposely biases the process toward health protection.

Uncertainty Associated with Site Characterization Data

Samples cannot be collected from every possible location; therefore, there is always some uncertainty associated with the representativeness of site characterization data. The investigation involved collection of random soil matrix samples placed within a grid across the Parcels. The random sample locations were supplemented with judgment-based sampling locations targeting specific site features and LOUs. The placement of the sample locations was deemed representative to evaluate the soil conditions in the context of the CSM. Because most of the sampling locations were targeted, and samples from these locations were analyzed for the full suite of SRC chemicals, the relative uncertainty in the site characterization data is considered to be low.

The maximum concentration obtained in any of the Parcels was used as the exposure-point concentration to evaluate all Parcels, which is a highly conservative assumption because it is very unlikely that receptors will be exposed to the maximum concentrations of all COPCs in each Parcel over an extended period of time.

Uncertainty Associated with Data Usability/Data Evaluation

A subset of the data was qualified with a *J* qualifier and estimated with low bias. These data were evaluated further to assess potential impact on the risk assessment results. Inclusion of these data is not expected to result in an underestimate of the potential risks associated with residual chemicals in soil at the Parcels, because (1) the number of affected data points was very small relative to the entire data set, (2) the maximum detected concentration was used as the EPC in the risk assessment calculations, and (3) most of the chemicals identified with a *J* qualifier were not selected as COPCs, because their concentrations were significantly (greater than 100 times) below the BCLs.

With regard to the PAH analysis, it appears that the NDEP-approved DVSRs associated with the initial sampling events in 2007 and 2008 were all reported to the PQL rather than the SQL. This has little impact on the overall evaluation, because only one soil boring had detections of PAHs, and all confirmation samples were reported as non-detect for PAHs.



Uncertainty Associated with Selection of COPCs

Based on comparison to background, some metals were identified as being above background, and for others, there are insufficient detections in the background and/or site data sets to make a determination. For the majority of these metals, there is no reason to believe they are related to historical Site/Parcel activities, based on the CSM. Although three radionuclides were identified as being above background, there is no reason to believe that the Parcels have been affected by thorium or uranium isotopes; therefore, no radionuclides were identified as COPCs. In addition to the metals, chemicals detected in at least one sample were included in the COPC selection process. Of these 64 chemicals, 14 were identified as COPCs. For those chemicals that were not selected as COPCs, the maximum detected concentration was generally a factor of 10, if not a factor of 100 or more, lower than the NDEP commercial worker BCL; therefore, exclusion of these chemicals from the quantitative risk assessment may slightly underestimate the potential health risks posed by the Parcels, but to such a small degree as to be inconsequential to the overall results of the HRA. Conversely, some metals may have been selected as COPCs, but may actually be within background.

Surrogate BCLs were used for the toxicity screen and COPC selection for endrin aldehyde, gamma-chlordane, di-N-butyl phthalate, and 1,2,3-trichlorobenzene in the absence of NDEP-derived BCLs for these compounds. As shown in Table 8, these compounds were excluded as COPCs based on the toxicity screen. The surrogates identified are considered to be toxicologically representative of these compounds, and given that the ratios of the BCLs to the maximum detected concentrations ranged from 1,798 to 415,882, the detected concentrations of these compounds would not be expected to contribute significantly to the total risk estimates.

Finally, no representative surrogate was identified for octachlorostyrene, platinum, or sodium. Octachlorostyrene was detected in only 2 of 157 samples with a maximum detected concentration of 0.065 mg/kg. Platinum was detected in only 7 of 157 samples at a maximum concentration of 2.4 mg/kg in sample TSB-FJ-02-02-0. Surface soil at this location was removed because of the presence of asbestos; therefore, the soil represented by this sample has been removed. The next highest detected platinum concentration was 0.15 mg/kg. Sodium was detected in all but one of the 157 samples at a maximum concentration of 2910 mg/kg. Sodium is an essential nutrient that was found to be only slightly elevated above background in one statistical test (see Table 5). In such cases, U.S. EPA (1989) guidance suggests that essential nutrients do not need to be considered further in the quantitative risk assessment. Considering the low frequency of detection for octachlorostyrene and platinum, and the fact that sodium is an



essential nutrient, the exclusion of these chemicals as COPCs is not expected to impact the risk estimates or overall conclusions of the HRA.

Uncertainty Associated with Exposure-Point Concentrations

The maximum detected concentration within all the Parcels was used as the EPC for all of the COPCs except asbestos. This assumption likely overestimates potential health risks, because receptors are unlikely to be exposed to the maximum concentration for all COPCs over an extended period of time. With regard to asbestos, two EPCs were calculated—a best estimate and an upper-bound estimate—for each Parcel as a whole. Because no long amphibole fibers were counted in any of the samples, the best estimate is zero. The upper bound of the asbestos bulk soil concentration is calculated as the 95% UCL of the Poisson distribution, where the mean equals the number of long structures detected. This value is then multiplied by the pooled analytical sensitivity to estimate the upper-bound concentration. The 95% UCL of the Poisson distribution for zero fibers counted is three fibers; therefore, for long amphibole fibers, the upper-bound EPC assumes that three long amphibole fibers are present, even though none were actually counted. Therefore, the potential risks associated with exposure to asbestos based on the upper-bound EPCs may be overestimated, particularly for long amphibole fibers.

Uncertainty Associated with Fate-and-Transport Modeling

The fate-and-transport modeling in this HRA is limited to estimating PEFs for construction workers and commercial workers. These values were estimated according to U.S. EPA guidance (2002a) based on a combination of site-specific and default input parameters. For most chemicals, inhalation of dust does not contribute significantly to the overall risk estimates, because exposure via ingestion and dermal contact is much higher; therefore, the uncertainty in this input parameter does not affect the conclusions of the HRA. However, for chemicals such as asbestos, which is evaluated as a carcinogen only through the inhalation route, the potential uncertainty in the PEF contributes substantially to the overall uncertainty in the risk estimate. This is particularly important for the construction worker scenario, because the estimated PEF is large relative to non-construction scenarios. The PEF for construction accounts for several potential sources of dust, including excavating, tilling, and dumping; however, the largest contributor to the overall PEF is driving over unpaved roads. In this case, the majority of the input parameters are based on default values recommended by U.S. EPA (2002a). U.S. EPA provides the basis for most of these values, but not others, including the average weight of the vehicle (8 tonnes) and the number of vehicles that will drive across the area every day (30). The applicability of these and other assumptions to future construction at the Parcels is unknown;



however, it is believed that, in combination, these assumptions are more likely to overestimate than underestimate potential health risks, potentially to a significant degree.

Uncertainty Associated with Exposure Assessment

The exposure assessment in this HRA is based on a reasonable maximum exposure (RME) scenario, which is defined by EPA as the highest exposure that could reasonably be expected to occur for a given exposure pathway at a site (U.S. EPA, 1989). To achieve this goal, the RME scenario uses highly conservative exposure assumptions. For example, this HRA assumes that a future onsite outdoor commercial worker incidentally ingests 100 mg of site soil per day, 225 days per year, for 25 years. These and other upper-bound, default estimates of exposure most likely overestimate the potential health risks associated with the site. It should be noted, however, that the HRA was limited to direct contact with soil and inhalation of dust. The potential health risks associated with chemicals in soil vapor were addressed separately for the Site as a whole, including the Parcels. Finally, it should be noted that potential health risks were not evaluated quantitatively for offsite receptors. However, because (1) offsite receptors would be exposed to lower concentrations than onsite receptors, and (2) the estimated health risks for onsite receptors are below levels of concern, potential health risks to offsite receptors would also be below levels of concern.

Uncertainty Associated with 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 the low concentrations that are generally encountered in the environment. 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 conservatism in the toxicity criteria used in this HRA 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)
- 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.

In aggregate, these assumptions lead to overestimates of risk, such that the actual risk is unlikely to be higher than the estimated risk, but could be considerably lower and, in fact, could be zero.



Chemical-specific uncertainties in toxicity criteria are provided below for chemicals that contribute most to the estimated cancer risks (hexachlorobenzene) and hazard indices (perchlorate) and asbestos, followed by a discussion regarding chemicals for which route-to-route extrapolations were assumed, surrogate criteria were used, or no criteria were available.

Hexachlorobenzene

The oral slope factor and inhalation unit risk factor for HCB are based on a 2-year chronic feeding study in rats (U.S. EPA, 2010). Significantly increased incidences of kidney and liver tumors were observed in treated animals, and the toxicity criteria were ultimately based on increased liver tumors in females. With regard to their confidence in these criteria, U.S. EPA concluded that significant increases in malignant tumors were observed among an adequate number of animals observed for their lifetime. Additionally, U.S. EPA calculated slope factors from a total of 14 different data sets encompassing three species, four studies, and various endpoints. These values fell within a range of approximately one order of magnitude (U.S. EPA, 2010).

Perchlorate

The oral reference dose for perchlorate is based on a 14-day drinking-water study of adult human volunteers (U.S. EPA, 2010). The critical effect from this study is radioactive iodide uptake inhibition in the thyroid. This is not considered to be an adverse effect; therefore, basing the oral RfD on this endpoint is a more conservative approach than traditional hazard assessment. U.S. EPA applied an intraspecies uncertainty factor of 10 to the no-observed-effect level (NOEL) to account for differences in sensitivity within the human population. U.S. EPA concluded that their confidence in the oral RfD is high, because it is based on a no-effect level for a well-characterized precursor effect, accompanied by a 10-fold uncertainty factor for susceptible populations (U.S. EPA 2010).

Asbestos

The potential risk associated with exposure to long chrysotile fibers in soil was assessed based on methodology from U.S. EPA (2003a), as specified in NDEP's (2009f) asbestos risk assessment guidance. This methodology distinguishes between different fiber sizes (greater than 10 μm in length and less than 0.4 μm in width) and types (chrysotile and amphiboles). U.S. EPA (2003a) developed two sets of risk coefficients—one set is "optimized" based on the entirety of the available data, and the other set is "conservative" based on data from a single epidemiology study. Per NDEP (2009f) guidance, the optimized risk coefficients were used in this HRA. In



addition, the risk coefficients are intended to assess long-term average exposure, such as onsite workers. Applying this methodology to short-term workers such as construction workers, as was done in this HRA, may result in additional uncertainty in the risk estimates (U.S. EPA 2003a).

Uncertainty Associated with Risk Characterization

The uncertainties associated with risk characterization are generally the result of combined uncertainties in the site conditions, exposure assumptions, and toxicity criteria. In addition, risks cannot be characterized for chemicals for which toxicity criteria have not been established. In this HRA, potential health risks were quantified for future construction workers and future onsite commercial workers associated with direct contact with soil and inhalation of dust. Given the highly conservative nature of the exposure parameters used to characterize this pathway, 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 acceptable exposure (RfD or RfC) or carcinogenic potency (SF or URF) to estimate the magnitude (non-cancer) or likelihood (cancer) of potential effects. As discussed above (“Uncertainty Associated with Selection of COPCs”), the absence of toxicity criteria for a small number of metals and organic compounds and resulting exclusion from the quantitative evaluation is not expected to impact the risk estimates or conclusions of the HRA.

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 are 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).

EPA guidance for risk assessment of chemical mixtures (U.S. EPA, 1986) recommends assuming an additive effect following exposure to multiple chemicals. Subsequent recommendations by other parties, such as the National Research Council (1988) and the Presidential/Congressional Commission on Risk Assessment and Risk Management (Risk Commission, 1997), have also advocated a default assumption of additivity. As currently practiced, risk assessments of chemical mixtures generally sum cancer risks regardless of tumor type, and sum non-cancer hazard indices 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. It should be noted that asbestos risks were evaluated separately from other chemical risks, consistent with the HRA work plan (Northgate, 2010d). These risk estimates are not additive because of differences in the basis for the carcinogenic toxicity criteria. For chemicals, the SF and URF are defined as the 95% UCL of the probability of a carcinogenic response, whereas the URFs for asbestos are based on the estimated number of additional deaths from lung cancer and mesothelioma.

In summary, these and other assumptions contribute to the overall uncertainty in the results of the HRA. However, given that the largest sources of uncertainty generally result in overestimates of exposure or risk, it is believed that the noncarcinogenic and carcinogenic risks presented in this HRA represent conservative estimates of the risks, if any, posed by residual chemicals at the Parcels.

5.8 Findings from the Site-Wide Soil Gas HRA

In November 2010, a Site-Wide Soil Gas HRA was prepared to evaluate the potential for adverse health impacts that may occur as a result of potential exposure to chemicals in soil gas via inhalation of vapors in indoor or outdoor air (Northgate, 2010b). Soil gas data collected in each of the Parcels was included in the Site-Wide Soil Gas HRA.

Soil gas data collected as part of the Phase B Source Area Investigation Soil Gas Survey were evaluated and considered usable for purposes of the Site-Wide Soil Gas HRA (Northgate, 2010b). COPCs were selected according to a multi-step process, including a toxicity screen, frequency of detection, and CSM considerations. Based on this process, eight chemicals (benzene, bromodichloromethane, carbon tetrachloride, chloroform, hexachlorobutadiene, naphthalene, tetrachloroethene, and trichloroethene) were selected as COPCs in soil gas. Risk



estimates for worker exposure to COPCs in soil gas in all Parcels are at or below 1×10^{-6} and hazard indices are well below 1. The Site-wide Soil Gas HRA results are discussed below.

5.8.1 Summary of Potential Cancer Risk Reported in the Site-Wide Soil Gas HRA

5.8.1.1 Indoor Commercial Worker

The estimated excess cancer risks associated with exposure of an indoor commercial worker to the COPCs in soil gas through inhalation of vapors in indoor air are summarized in Table 6, and the calculation spreadsheets are presented in Appendices F and G, of the Site-wide Soil Gas HRA (Northgate, 2010b). For an indoor commercial worker, the total excess cancer risk due to exposure to chemicals in soil gas in all the Parcels is 1×10^{-6} . With the exception of Parcel C, the excess cancer risk is less than 1×10^{-7} in each parcel. Chloroform is the largest contributor to overall risk from chemicals in soil gas.

5.8.1.2 Outdoor Commercial and Construction Worker

The estimated excess cancer risks associated with exposure of an outdoor commercial worker to the COPCs in soil gas through inhalation of vapors in outdoor air are summarized in Table 7, and the calculation spreadsheets are presented in Appendix H of the Site-wide Soil Gas HRA (Northgate, 2010b). For an outdoor commercial worker, the excess cancer risk due to exposure to chemicals in soil gas is 1×10^{-8} , a level well below the generally acceptable risk range and, therefore, protective of human health.

The excess cancer risks associated with exposure of a construction worker to COPCs in soil gas were not evaluated in the Site-Wide Soil Gas HRA (Northgate 2010b). However, if it is assumed that construction worker exposure to soil gas through inhalation of vapors in outdoor air is similar to that of an outdoor commercial worker, the risks for construction worker exposure to soil gas would also be at levels considered protective of human health.

5.8.2 Summary of Non-Cancer Health Effects

5.8.2.1 Indoor Commercial Worker

The estimated non-cancer hazard quotients and hazard indices associated with exposure of an indoor commercial worker to the COPCs in soil gas through inhalation of indoor vapors are summarized in Table 8, and the calculation spreadsheets presented in Appendix F of the Site-wide Soil Gas HRA (Northgate, 2010b). For an indoor commercial worker, the total hazard



index due to inhalation of chemicals in soil gas is 0.3. Chloroform is the largest contributor to the overall hazard index from chemicals in soil gas.

5.8.2.2 Outdoor Commercial and Construction Worker

The estimated non-cancer hazard quotients and hazard indices associated with exposure of an outdoor commercial worker to the COPCs in soil gas through inhalation of outdoor vapors are summarized in Table 7, and the calculation spreadsheets are presented in Appendix H of the Site-wide Soil Gas HRA (Northgate, 2010b). For an outdoor commercial worker, the total hazard index from inhalation of chemicals in soil gas in the Parcels is 0.00001.

The hazard indices associated with exposure of a construction worker to the COPCs in soil gas were not estimated for the Site-Wide Soil Gas HRA. However, if it is assumed that construction worker exposure to soil gas through inhalation of vapors in outdoor air is similar to that of an outdoor commercial worker, the hazard indices for this receptor would be below the threshold of one.

5.9 Cumulative Risk and Hazard Indices for Soil and Soil Gas

To evaluate potential health effects associated with simultaneous exposure to COPCs in soil and soil gas, cumulative risks and hazard indices were estimated for the indoor and outdoor workers. The cumulative ILCR and hazard index associated with worker exposure to COPCs in soil and soil gas were estimated based on the combined results from this soil HRA and the Site-Wide Soil Gas HRA (Northgate 2010b).

5.9.1.1 Indoor Commercial Worker

The cumulative ILCR for an indoor commercial worker from simultaneous exposure to chemicals in soil (5×10^{-7}) and soil gas (1×10^{-6}) is 2×10^{-6} . This risk estimate, which is at the lower end of the risk range (10^{-6} to 10^{-4}) considered protective of human health, likely overstates risks to a worker, as it assumes long-term exposure to the maximum concentrations of chemicals in both soil and soil gas. Thus, potential simultaneous exposure to COPCs in soil and soil gas by an indoor commercial worker should not pose an unacceptable carcinogenic health risk under the conditions evaluated.

5.9.1.2 Outdoor Commercial and Construction Worker

The cumulative ILCR for an outdoor commercial worker from exposure to chemicals in soil (1×10^{-6}) and soil gas (1×10^{-8}) is 1×10^{-6} . This estimated risk is at the lower limit of the generally acceptable risk range (10^{-6} to 10^{-4}).



As discussed in Section 5.8, cancer risks were not estimated for construction worker exposure to COPCs in soil gas via inhalation of vapors in outdoor air. However, assuming that the risks for a construction worker from exposure to soil gas are similar to those estimated for an outdoor commercial worker, the ILCR for a construction worker from exposure to chemicals in soil (2×10^{-7}) and soil gas (approximately 1×10^{-8}) would be approximately 2×10^{-7} . This result indicates that potential exposure to COPCs in soil and soil gas by an outdoor commercial or construction worker should not pose an unacceptable carcinogenic health risk under the conditions evaluated.

5.9.2 Summary of Non-Cancer Health Effects

5.9.2.1 Indoor Commercial Worker

The total hazard index for an indoor commercial worker from exposure to chemicals in soil (0.1) and soil gas (0.3) is 0.4, indicating that potential exposure of indoor commercial workers to COPCs in soil and soil gas should not result in adverse noncarcinogenic health effects under the conditions evaluated.

5.9.2.2 Outdoor Commercial and Construction Worker

The total hazard index for an outdoor commercial worker from exposure to chemicals in soil (0.2) and soil gas (0.00001) is 0.2. As discussed in Section 5.8, hazard indices were not estimated for construction worker exposure to COPCs in soil gas via inhalation of vapors in outdoor air. However, assuming that the hazard indices for a construction worker from exposure to soil gas are similar to those estimated for an outdoor commercial worker, the total hazard index for a construction worker from exposure to chemicals in soil (0.8) and soil gas (approximately 0.00001) would be approximately 0.8. These results indicate that potential exposures of outdoor commercial and construction workers to COPCs in soil and soil gas should not pose an unacceptable noncarcinogenic health risk under the conditions evaluated.



6.0 SUMMARY AND CONCLUSIONS

Analytical results for confirmation soil samples indicate that Parcels C, D, F, G, and H have been successfully remediated consistent with the remediation goals established by the RAW (BEC, 2008a) and NDEP. It is noted that small portions of proposed scrape areas in Parcels F, G, and H were not excavated due to surficial impediments as described in Sections 3.3 through 3.5. The data demonstrate that the Parcels have been remediated to commercial/industrial standards, with the exception of a small area south of the existing South Haul Road Fence line which remains to be remediated by BMI when their haul road is removed as discussed in Section 3.2.

Post-remediation HRAs were conducted to evaluate potential risks associated with the residual soil and soil-gas chemical concentrations in the Parcels. A screening-level evaluation of soil concentrations was also conducted for the soil to groundwater pathway. Soil data collected as part of the initial and confirmation sampling efforts were evaluated and considered usable for the purposes of this HRA. The methods and findings from the HRA can be summarized as follows:

Soil

- Based on the CSM for the Parcels, potential exposure to soil was evaluated for future onsite indoor and outdoor commercial workers and future construction workers via direct contact with soil (i.e., incidental ingestion, dermal contact) and inhalation of dust. COPCs were selected according to a multi-step process, including comparisons to background for metals and radionuclides, a toxicity screen, frequency of detection, and CSM considerations. Based on this process, 14 chemicals were selected as COPCs.
- Non-cancer hazard indices and/or theoretical excess cancer risks associated with direct contact with soil and inhalation of dust were estimated for all of the COPCs except asbestos, based on the maximum detected concentration. The estimated hazard indices and excess cancer risks were equal to or below NDEP's point of departure for non-cancer effects (hazard index of 1) and cancer risks (1×10^{-6}) for future onsite indoor and outdoor commercial workers and future construction workers under the conditions evaluated.
- With regard to asbestos, a best estimate and an upper-bound estimate were calculated. The estimated risks for death from lung cancer or mesothelioma for asbestos exposures to future onsite outdoor commercial workers and construction workers are less than or equal to 1×10^{-6} , except for upper-bound estimates of exposure to amphibole fibers by future construction workers.
- Additional confirmation samples were collected for PAHs in Parcel F. PAHs were not detected in these samples at detection limits below the BCLs. Therefore, inclusion of



these data in the risk assessment calculations will not affect the results of this post-remediation HRA.

The results indicate that exposure to residual chemicals in the upper 10 feet of soil in the Parcels should not result in unacceptable risks for all future onsite receptors evaluated in this HRA.

Soil to Groundwater Leaching

As noted above, this deliverable does not fully address the soil leaching to groundwater pathway. Section 5.3 identifies COPCs that exceed NDEP LBCLs and that, along with perchlorate, require additional evaluation. Further analysis to assess the potential for groundwater contamination from leaching will be evaluated in a separate deliverable.

Soil Gas

Soil gas samples collected in the Parcels were evaluated as part of the Site-Wide Soil Gas Risk Assessment (Northgate, 2010b). COPCs in soil gas were selected according to a multi-step process, including a toxicity screen, frequency of detection, and CSM considerations. Based on this process, eight chemicals (benzene, bromodichloromethane, carbon tetrachloride, chloroform, hexachlorobutadiene, naphthalene, tetrachloroethene, and trichloroethene) were selected as COPCs. Excess cancer risks associated with exposure of indoor and outdoor commercial workers to the COPCs in soil gas through inhalation of vapors in indoor and outdoor air at the Parcels are at or below 1×10^{-6} , and hazard index values are well below 1. Based on findings reported in the Site-Wide Soil Gas Risk Assessment, inhalation of vapors in indoor and outdoor air should not result in unacceptable risks to future indoor and outdoor commercial workers.

Cumulative Cancer Risk and Hazard Index

To evaluate potential health effects associated with simultaneous exposure to COPCs in soil and soil gas, cumulative risks and hazard indices were estimated. These estimates likely overstate risks to a worker as they assume long-term exposure to the maximum concentrations of chemicals in both soil and soil gas. The cumulative ILCR and hazard index associated with worker exposures to COPCs in soil and soil gas were estimated based on the combined results from this soil HRA and the Site-Wide Soil Gas HRA (Northgate 2010b). To estimate cumulative risk and hazard index for the indoor commercial worker, it is assumed that the worker is exposed to COPCs in soil (via incidental ingestion) and soil gas (via inhalation of vapors in indoor air of a commercial building) simultaneously. It is also assumed that the outdoor commercial worker is exposed to COPCs in soil (via incidental ingestion, dermal contact, and inhalation of dust) and



soil gas (via inhalation of vapors in outdoor air) simultaneously. The cumulative ILCRs for an indoor commercial worker (2×10^{-6}) and outdoor commercial worker (1×10^{-6}) associated with potential simultaneous exposure to chemicals in soil and soil gas are at the lower end of the target risk range (10^{-6} to 10^{-4}) generally considered to be protective of human health. The cumulative hazard indices for these receptors are below the threshold value of one.

Cancer risks and hazard indices were not estimated for construction worker exposure to COPCs in soil gas in the Site-Wide Soil Gas HRA (Northgate, 2010b). However, assuming that the cancer risks and hazard indices for a construction worker from exposure to soil gas are similar to those estimated for an outdoor commercial worker, the ILCR for a construction worker from simultaneous exposure to chemicals in soil and soil gas (approximately 2×10^{-7}) would be below the target risk range. The total hazard index for a construction worker (approximately 0.8) would be below one. Based on this evaluation, simultaneous exposure to COPCs in soil and soil gas should not pose an unacceptable risk to future workers.



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