Final

Human Health and Ecological Risk Assessment Work Plan

Remedial Investigation/Feasibility Study
Red Devil Mine, Alaska

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Prepared for:

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List of Abbreviations and Acronyms

–	not available or not applicable
ADAF	age-dependent adjustments factors
ADEC	Alaska Department of Environmental Conservation
ADF&G	Alaska Department of Fish and Game
AF	adherence factor
ALM	Adult Lead Model
As_2S_3	orpiment
AsS	realgar
AT	averaging time
ATV	All-terrain vehicle
B.C.	British Columbia, Canada
BLM	U. S. Department of the Interior Bureau of Land Management
BMD	benchmark dose
Br	plant-soil bioconcentration factor
BW	body weight
Cal EPA	California Environmental Protection Agency
cm	centimeter
cm^2/day	square centimeters per day
C_n	chemical concentration in food item *n*
COCs	compounds of concern
COPC	contaminants of potential concern
cPAHs	carcinogenic polycyclic aromatic hydrocarbons
C_s	chemical concentration in soil/sediment
CSM	conceptual site model
DROs	diesel range organics
DW	dry weight
E & E	Ecology and Environment, Inc.
EC	exposure concentration
Ecology	Washington [State] Department of Ecology
ED	exposure duration
EE_{diet}	estimated exposure from diet
$EE_{soil/sed}$	estimated exposure from incidental soil/sediment ingestion
EE_{total}	total exposure
EF	exposure frequency
EPA	U.S. Environmental Protection Agency
EPC	exposure point concentration
ERA	Ecological Risk Assessment
ERM	effects range median

FCM	food chain multiplier
FeS_2	Pyrite
FI	fraction ingested
F_n	fraction of diet represented by food item *n*
FS	Feasibility Study
FW	fresh weight
HEAST	[EPA Superfund] Health Effects Assessment Summary Tables
HgS	cinnabar
HHRA	Human Health Risk Assessment
HI	hazard index
HQ	hazard quotient
IEUBK	Integrated Exposure Uptake Biokinetic
IR	ingestion rate of receptor
IRIS	Integrated Risk Information System
IR_s	soil/sediment ingestion rate of receptor
IUR	inhalation unit risk
kg	kilogram[s]
L/day	liters per day
LADI	lifetime average daily intake
LEL	low effect level
LOAEL	lowest observed adverse effect level
m	meter
MCLs	maximum contaminant levels
mg	milligram(s)
mg/day	milligrams per day
mg/kg	milligrams per kilogram
mg/kg-day	milligrams per kilogram per day
NDs	nondetects
NOAEL	no observed adverse effect level
Ont.	Ontario, Canada
PAETA	probable apparent effect threshold approach
PEF	particulate emission factor
PEL	probable effect level
QA	quality assurance
QAPP	Quality Assurance Project Plan
QC	quality control
RA	Risk Assessment
RAWP	Risk Assessment Work Plan
RBCLs	risk-based cleanup levels
RBSCs	risk-based screening concentrations
RDM	Red Devil Mine
RfC	reference concentration
RfD	reference dose
RI	Remedial Investigation
RME	reasonable maximum exposure
ROS	regression on order statistics
RSLs	Regional Screening Levels

SA	skin surface area
Sb_2S_3	stibnite
SFs	slope factors
SQAL	sediment quality advisory level
SLERA	screening level ecological risk assessment
SSL	soil screening level
SUF	site use factor
SVOCs	semivolatile organic compounds
TAH	total aromatic hydrocarbon
TAqH	total aqueous hydrocarbon
TAL	target analyte list
TBD	to be determined
TEF	toxicity equivalency factor
TEL	threshold effect level
TRV	toxicity reference value
UCL	upper confidence limit
USGS	U.S. Geological Survey
WA	Washington State
µg/dL	micrograms per deciliter
$\mu g/m^3$	micrograms per cubic meter
YKHC	Yukon-Kuskokwim Health Corporation

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1 Introduction

The Red Devil Mine (RDM) site is an abandoned cinnabar mining and mercury ore processing site located on public lands managed by the U.S. Department of the Interior Bureau of Land Management (BLM) in the State of Alaska. The site is in a remote area of Alaska, approximately 250 air miles west of Anchorage, and 75 air miles northeast of the village of Aniak. The site is located on the southwest bank of the Kuskokwim River, approximately 2 miles southeast from the village of Red Devil.

The RDM has an intricate history of mining operations, contamination studies, and focused cleanup actions. For this Remedial Investigation/Feasibility Study (RI/FS), the RDM site is defined as the area where mining operations were conducted, where mine-related waste sources exist, and where mine-related contamination of media (soil, surface water, sediment, and groundwater) is known to exist or potentially exist. Accordingly, the site includes the following general areas:

- The Main Processing area;
- The Red Devil Creek, extending from a reservoir south of the site to the creek's confluence with the Kuskokwim River, including the tailings delta at the mouth of the creek;
- The underground mine workings; and
- The area west of the main mine processing area where historical surface exploration and mining occurred, inclusive of the "Dolly Sluice" area and its related waste delta on the banks of the Kuskokwim River.

Figures 1-1 through 1-3 of the RI/FS Work Plan show the site location and the main historical and current features of the site area.

1.1 Risk Assessment Overview

This Risk Assessment Work Plan (RAWP) provides methods for conducting a human health risk assessment (HHRA) and ecological risk assessment (ERA) for the RDM site. Data collected during previous investigations, as well as data collected in 2010 and during the upcoming field event described in the RI/FS Work Plan, will be used in the Risk Assessment (RA), provided these data meet the quality assurance (QA)/quality control (QC) criteria outlined by Ecology and Environment, Inc. (E & E), in the Quality Assurance Project Plan (QAPP), Appendix C of the RI/FS Work Plan, and the data usability criteria described in Chapter 2 of this RAWP.

The RA report will provide a summary of methods, including deviations (if any) from the work plan, quantitative estimates of risk to human health and ecological receptors, and uncertainties associated with the risk assessment process.

1.2 Document Structure

The main body of this RAWP consists of the following chapters:

Chapter 2, Data Evaluation: Provides the methods for evaluation of site data for usability in risk assessment.

Chapter 3, Human Health Risk Assessment Methodology: Presents the proposed methodology for the identification of human health contaminants of potential concern (COPCs), exposure assessment, toxicity assessment, and risk characterization.

Chapter 4, Ecological Risk Assessment Methodology: Presents the proposed methodology for the ecological exposure assessment.

Chapter 5, Data Gap Analysis: Presents the known data gaps for the risk assessment and potential approaches for addressing data gaps following development of the risk assessment.

Chapter 6, Development of Risk-Based Cleanup Levels: Presents the proposed methodology for determining preliminary cleanup levels based on the results of the HHRA and ERA.

2 Data Evaluation

Regional studies, contaminant investigations, and sampling programs associated with cleanup activities have been conducted at and near the RDM site over the past 40 years. A review of historical data usability is presented in the RI/FS Work Plan and will not be described in detail in the RAWP.

A summary of the history of environmental sampling and monitoring at the RDM site is provided in Section 3.1 of the RI/FS Work Plan. Five major removal/cleanup actions were performed at the RDM site between 1999 and 2006. These actions have included offsite disposal of hazardous waste and materials and onsite consolidation of mine structure debris. To date, all mine structures have been demolished, and three debris burial areas (monofills) have been constructed. The major removal/cleanup actions that have been conducted at the RDM site are summarized in Section 3.2 of the RI/FS Work Plan.

2.1 Data Usability

Section 3.4 of the RI/FS Work Plan assesses the usability of data generated from previous investigations and studies at the RDM site. Only the sampling methods that give chemical-specific data will be included in the risk assessment. Data from field-screening tests will not be included. Historical data of sufficient quality for use in the RA is presented in Table 3-7 of the RI/FS Work Plan. These reports include the following:

- U.S. Geological Survey (USGS) Mercury Studies (Bailey and Gray 1997; Bailey et al. 2002);
- Wilder/HLA Limited Waste Removal Action (1999), subsurface soil data only;
- Wilder/HLA Source Area Removal and Investigation (2001) – fixed subsurface soil data only;
- MACTEC Historic Source Area Investigation (2005); and
- E & E Groundwater Monitoring Data (2010a).

The rules for data treatment described below will be implemented once a complete project dataset is compiled.

2.2 Data Usability Criteria

The RA highlights chemicals associated with historical operations that are thought or known to have been released to the environment. A review of existing data and a list of target analytes are provided in Chapter 3 of the RI/FS Work Plan.

Relevant data that meet the established quality criteria outlined in Chapter 4 of the QAPP, Appendix C of the RI/FS Work Plan, will be considered for use in the RA. Data used in the RA will meet the data usability criteria outlined by Alaska Department of Environmental Conservation (ADEC) (2010). Data will also be evaluated according to *Guidance for Data Usability for Risk Assessment* (U.S. Environmental Protection Agency [EPA] 1992b), which provides minimum data requirements to ensure that data will be appropriate for risk assessment use. The EPA guidance addresses the following issues relevant to assessing data quality for risk assessment:

- **Data sources**: Consider the type of data collected (for example, field screening data and fixed laboratory data) and determine whether data meet the QA/QC objectives outlined in the project Field Sampling Plan.
- **Consistency of data collection methods:** Review sample collection methods for appropriateness relative to the target analytes, media, and laboratory analytical methods; review field logs to identify sample collection quality issues; and identify differences in sample collection methods, if any, for different field investigations.
- **Analytical methods and detection limits:** Evaluate methods for appropriateness for the target analytes and media and determine whether detection limits are low enough for risk-based evaluation.
- **Data quality indicators:** Review data validation reports for data quality issues.

2.2.1 Data Treatment

Data determined to be acceptable for use in the RA may be treated or modified according to the rules provided in Chapter 4 of the QAPP. Treatment may relate to detected or non-detected analytes, data qualifiers, and/or duplicate sample results. Data reduction and handling of field duplicate samples will be consistent with ADEC requirements (ADEC 2010).

2.2.2 Qualified Data

Problems are sometimes identified in laboratory analytical results. In such cases, detected analytes may be assigned a data qualifier. It is common to identify problems with analytical data associated with the chemical concentration, the chemical identity, interference from other analytes, and/or matrix interferences (EPA 1989).

The analytical results will be validated by an experienced E & E chemist. The data will be validated in accordance with the *National Functional Guidelines for Inorganic Superfund Data Review* (EPA 2010c) and *National Functional Guidelines for Superfund Organic Methods Data Review* (EPA 2008c) in conjunction with the QA/QC requirements specified in each specific analytical method and any project-specific QC defined in the QAPP.

3 Human Health Risk Assessment Methodology

3.1 Overview

This chapter outlines the methodology for the HHRA and consists of methods for determining COPCs (Section 3.2), assessing exposure (Section 3.3) and toxicity (Section 3.4), characterizing risk (Section 3.5), and analyzing uncertainty (Section 3.6).

COPC determination identifies which compounds will be quantitatively and qualitatively evaluated in the HHRA. The exposure assessment describes how exposures to receptors will be quantified for each anticipated exposure pathway, while the toxicity assessment explains how the toxicity of carcinogenic and noncarcinogenic COPCs is estimated. The information from the exposure and toxicity assessments is then combined to generate quantitative estimates of risk.

The RA report will provide a detailed discussion of the uncertainty associated with each step of the RA and will indicate how each issue may impact the overall risk estimates. The RA will draw on federal and state guidance, in addition to information presented in peer-reviewed publications, including but not limited to the following documents:

- *Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual* (Part A), Interim Final (EPA 1989);
- *Risk Assessment Guidance for Superfund Volume I, Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment)* (EPA 2004);
- *Risk Assessment Guidance for Superfund Volume I, Human Health Evaluation Manual (Part F, Supplemental Guidance for Inhalation Risk Assessment)* (EPA 2009c);
- *Human Health Evaluation Manual, Supplemental Guidance, "Standard Default Exposure Factors,"* Interim Final (OSWER Directive 9285.6-02; EPA 1991);
- *Exposure Factors Handbook* (EPA 1997a);
- *Child-Specific Exposure Factors Handbook* (EPA 2008b);
- *ProUCL Version 4.1.00 User Guide* (EPA 2007f, 2010e) ;
- *ProUCL Version 4.1.00 Technical Guide* (EPA 2007h, 2010d);
- *Framework for Metals Risk Assessment* (EPA 2007i);
- *Risk Assessment Procedures Manual* (ADEC 2000, 2010); and
- *Risk Management Criteria for Metals at BLM Sites* (BLM 2004).

3.2 Selection of Contaminants of Potential Concern

Identified COPCs will be quantitatively evaluated for risk. Several parameters will be considered in the selection of COPCs, including the following:

1. Screening values based on toxicological characteristics of each chemical, and
2. Evaluation of essential nutrients.

These parameters are consistent with the EPA document *Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual (Part A)* (EPA 1989) and the ADEC *Risk Assessment Procedures Manual* (2010), and are discussed in further detail throughout this section.

The following compounds were previously identified as target analytes in at least one medium at the site:

- Inorganic compounds including, but not limited to, mercury, antimony, lead, nickel, and arsenic;
- Methyl mercury;
- Petroleum hydrocarbons including diesel range organics (DROs);
- Benzene, toluene, ethylbenzene, and xylenes; and
- Semivolatile organic compounds (SVOCs).

A streamlined RA was conducted at the RDM site in 2001 (Ford 2001). The evaluation focused on potential exposure to antimony, arsenic, lead, and mercury. Due to the limited evaluation in the streamlined risk assessment and the thorough investigation planned in the RI/FS Work Plan, a screening level assessment was not conducted in this work plan. A full screening of COPCs and estimation of risk will be completed in the HHRA.

3.2.1 Screening Values

The first step in selecting COPCs is to compare the maximum site concentrations in each medium (soil, sediment, groundwater, and surface water) to risk-based screening concentrations (RBSCs). Screening values typically are selected from a variety of sources for media that could be primary sources of exposure. As noted in the preliminary conceptual site model (CSM) (discussed below in Section 3.3.1), human receptors that may have contact with exposure media at the RDM site include future onsite residents, recreational or subsistence users, and industrial or mine workers. Exposure media include soil, sediment, surface water, groundwater, and biota. For exposure assessment, tailings will be treated as soil or sediment based on their location and potential for exposure.

Soil and tailings RBSCs will include EPA Regional Screening Levels (RSLs) for residential soils (EPA 2010f, or most recent), one-tenth of the direct contact and inhalation Alaska Method 2 soil cleanup level for the Under 40 inch zone (18 AAC 75.341; values provided in Appendix B of the *Cumulative Risk Guidance* [2008b]) and the BLM’s Risk Management Criteria for Metals at BLM sites for the resident scenario (BLM 2004).

There are no readily available screening criteria from the EPA or ADEC for human exposure to sediments. Soil criteria (e.g., RSLs and one-tenth Method 2 values) will be used as sediment RBSCs. BLM (2004) provides screening criteria for people exposed to sediment while camping. These values, in addition to those listed for soil, will be used for sediment.

Groundwater RBSCs include one-tenth Alaska groundwater cleanup levels (18 AAC 75.345, Table C), EPA RSLs for tap water, and federal maximum contaminant levels (MCLs) (EPA 2009b). COPCs exceeding any of the applicable screening criteria will be included in the assessment for quantitative determination of risk. Chemicals without screening criteria will also be retained as COPCs.

Groundwater RBSCs will be conservatively applied to surface water to determine surface water RBSCs. Water quality standards for surface water (18 AAC 70) and ambient water quality criteria (EPA 2009a) will also be considered RBSCs for identification of COPCs. Bioaccumulative compounds detected in sediment and surface water will be retained as COPCs regardless of their comparison to screening criteria. ADEC defines bioaccumulative compounds as those that have a bioconcentration factor equal to or greater than 1,000 for organic compounds or are identified by the EPA (2000a) as bioaccumulative inorganic compounds (ADEC 2005).

If the maximum site concentration does not exceed any of the RBSCs for each medium, the compound will be eliminated as a COPC. If the site concentration exceeds the RBSC, or no screening level is available from any of the sources listed in this section, the compound will be retained for further evaluation.

3.2.2 Essential Nutrients

The EPA (1989) recommends removing chemicals from further consideration if they are considered “essential nutrients,” present at low concentrations (i.e., only slightly elevated above naturally occurring levels), and toxic only at very high doses. The essential nutrients that will be eliminated from the list of COPCs include magnesium, calcium, sodium, and potassium. These chemicals are toxic only at very high doses, and are expected to be present at concentrations that would not be due to chemical sources at the RDM site. In addition, no screening criteria are available from the sources identified in Section 3.2.1.

3.3 Exposure Assessment

The purpose of the exposure assessment will be to quantify potential exposures of human populations that could result from contact with COPCs from the RDM site. Each complete exposure pathway contains four necessary components:

- A contaminant source and a mechanism of COPC release;
- An environmental medium and mechanism of COPC transport within the medium;
- A potential point of human contact with the affected environmental media, also called the *exposure point*; and
- An exposure route.

The exposure assessment will characterize the exposure setting; identify receptors that may be exposed; identify direct and indirect pathways by which exposures could occur (i.e., pathways for direct ingestion of COPCs from soil and indirect uptake from ingestion of harvested food items); and describe how the rate, frequency, and duration of these exposures will be estimated. The exposure assessment will have the following subsection components:

- A preliminary CSM,
- Exposure Scenarios, and
- A quantification of Exposure.

3.3.1 Preliminary Conceptual Site Model

The preliminary CSM for the RDM site is presented in Figure 3-1 and discussed in this section. The RDM site is on BLM land on the southwest bank of the Kuskokwim River approximately 2 miles southeast from the village of Red Devil. Public access is not restricted, but the mine is in a remote part of Alaska and only has occasional visitors. Access to the site is by boat/barge on the Kuskokwim River, by means of an airstrip at Red Devil Village, and dirt roads and woodland trails via all-terrain vehicles (ATVs) during summer months. Contaminants from mine waste, groundwater, or air emissions may enter the surface water or sediment through surface water runoff, erosion from soils, or direct placement of waste and tailings in surface water bodies (Red Devil Creek and the Kuskokwim River). Contaminants may enter groundwater through infiltration or leaching from source areas. Contaminants may also be directly released to soils, erode from sources, or be deposited from air emissions during previous mine operations. Volatile chemicals in soil (i.e., mercury) may volatilize into the air; other contaminants may be entrained in fugitive dust. Contaminants may bioaccumulate from soils, surface water, or sediment into plants, animals, and fish.

Currently, no one lives permanently or temporarily at the site. Residents of Red Devil Village and nearby communities currently use the site for recreational and subsistence activities. Future use of the site is unknown but may include the site remaining as an occasional recreational or subsistence area. The land is scheduled to be transferred in the future to a local native corporation. The land could be used for additional mining activities or as a residential area.

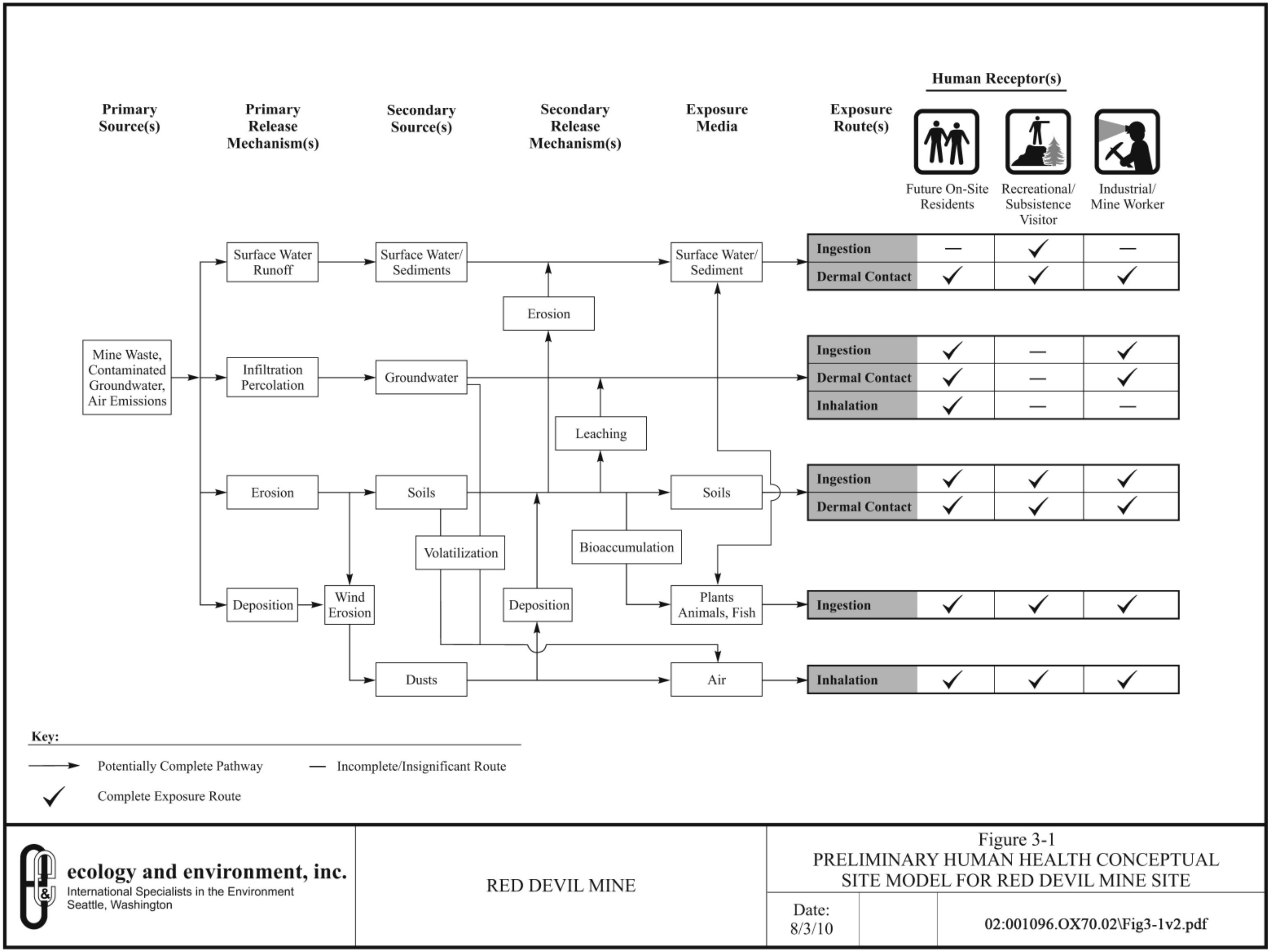
Based on the known and anticipated activities at the RDM site, the following receptors were selected to represent current or potential future use of the site:

- Future onsite resident (adult and child),
- Recreational or Subsistence User (adult and child), and
- Industrial/Mine Worker (adult only).

Each scenario is discussed in further detail in this subsection.

3.3.1.1 Future Onsite Adult and Child Resident

The future adult and child residential scenario represents potential exposures to a person who lives at the site and takes a vacation for two weeks per year from the site. It is assumed that the adults would live and work at the site and the children would live at the site and go to school at the site. It is assumed that the drinking water supply would be from groundwater. Residents may be exposed to COPCs in groundwater through ingestion and dermal contact. In addition, people may be exposed to volatile COPCs (i.e., mercury) in groundwater during showering. Indirect exposure through consumption of native foods such as fish, game, and plants through subsistence activities is included in this scenario; however, only a percentage of native food consumed would be gathered from the site. Adults and children may come in contact with surface water by wading or playing in Red Devil Creek. The adult and child resident scenario will include the following exposure pathways:



Exposure Media	Exposure Route(s)	Future On-Site Residents	Recreational/ Subsistence Visitor	Industrial/ Mine Worker
Surface Water/ Sediment	**Ingestion**	—	✓	—
	Dermal Contact	✓	✓	✓
Groundwater	**Ingestion**	✓	—	✓
	Dermal Contact	✓	—	✓
	Inhalation	✓	—	—
Soils	**Ingestion**	✓	✓	✓
	Dermal Contact	✓	✓	✓
Plants Animals, Fish	**Ingestion**	✓	✓	✓
Air	**Inhalation**	✓	✓	✓

Figure 3-1 Preliminary Human Health Conceptual Site Model for Red Devil Mine Site

- Dermal (skin) contact with surface water and sediments,
- Ingestion of and dermal contact with groundwater,
- Incidental ingestion of and dermal contact with soil,
- Ingestion of native foods,
- Inhalation of dust or volatile chemicals, and
- Inhalation of volatile chemicals in groundwater.

3.3.1.2 Recreational Visitor or Subsistence User

Recreational visitors and subsistence users would visit the site a portion of the year during harvest time and presumably camp in the area. It is assumed that recreational or subsistence users would potentially access the site via ATVs. It is assumed that they would be exposed during the period they were on site and they would obtain drinking water from the creek. It is also assumed that the recreational or subsistence user would consume local plants and hunt game or catch fish from the site. However, only a percentage of total native food consumed by the recreational user or subsistence user would be gathered from the site. Therefore, it is assumed that the recreational or subsistence user could be exposed to contaminants at the RDM site through the following pathways:

- Ingestion of and dermal contact with surface water,
- Dermal contact with sediments,
- Incidental ingestion of and dermal contact with soil,
- Ingestion of native foods, and
- Inhalation of dust or volatile chemicals.

3.3.1.3 Industrial/Mine Worker

If the RDM site is redeveloped in the future as a mine, it is assumed that industrial or mine workers would work at the site and live in nearby Red Devil Village. It is assumed that the drinking water supply would be from groundwater during work times. It is also assumed the workers would fish, hunt, and gather edible plant material; therefore, indirect exposure through consumption of native foods such as fish, game, and plants is included in this scenario; however, only a percentage of food will be assumed to be gathered from the site. The worker scenario will include the following exposure pathways:

- Dermal (skin) contact with surface water and sediments,
- Ingestion of and dermal contact with groundwater,
- Incidental ingestion of and dermal contact with soil,
- Ingestion of native foods, and
- Inhalation of dust or volatile chemicals.

3.3.2 Quantification of Exposure

In the exposure quantification portion of the HHRA, estimates will be made of the magnitude, frequency, and duration of exposure for each complete pathway identified above. For discussion, this portion can be divided into two sequential tasks:

- Estimating exposure concentrations (ECs), and
- Calculating the amount of COPCs potentially taken into the body.

3.3.2.1 Estimation of Exposure Concentration

The concentrations of COPCs to which human receptors will be exposed over time will be estimated according to EPA guidance (EPA 2006b, 2010d). The EPA (1992a) indicates that a 95 percent upper confidence limit (UCL) on the mean of COPC concentrations should be used as the exposure point concentration (EPC). Inherent in this approach is the assumption that receptors that contact an environmental medium containing a COPC do so randomly. Thus, an estimate of average concentration (or in this case the upper bound on the average) is the concentration to which a receptor might be exposed.

To determine the 95 percent UCL, the EPA's ProUCL program, version 4.1.00 (EPA 2010d) or most recent version will be used. ProUCL 4.1 includes goodness-of-fit tests (e.g., normal, lognormal, and gamma) for data sets with and without nondetects (NDs). For data sets with NDs, ProUCL 4.1 can create additional columns to store extrapolated values for NDs obtained using regression on order statistics (ROS) methods, including normal ROS, gamma ROS, and lognormal ROS (robust ROS) methods. ProUCL 4.1 also has parametric (e.g., maximum likelihood estimate, t-statistic, gamma distribution), nonparametric (e.g., skewness-adjusted CLT, Kaplan-Meier), and computer intensive bootstrap (e.g., percentile, bias-corrected accelerated) methods to compute UCLs for uncensored data sets and also for data sets with ND observations.

In some cases, fate and transport modeling may be used in conjunction with the statistical analysis of the environmental data to arrive at the EPC value. Determination of concentrations in local food resources (plants, fish, and wildlife) is discussed in Section 3.3.3.

Operable or exposure units can be designated based on different uses of subareas within the site or the uneven distribution of contamination across the site. Currently, it is assumed the site will be handled as one operable unit but this issue will be evaluated and discussed with the EPA and ADEC prior to development of the HHRA.

3.3.2.2 Calculation of Intake

Potential exposures to the receptors described in the above scenarios are quantified using intakes, which are expressed by the amount of COPCs (in milligrams [mg]) internalized per unit body weight (in kilograms [kg]) per unit time (in days). That is, estimated intakes are provided in units of milligrams per kilogram per day (mg/kg-day). When evaluating carcinogenic COPCs, the intake is referred to as the lifetime average daily intake (LADI), because the intake is averaged over a lifetime.

The generic equation and variables for calculating chemical intakes are described below (ADEC 2010).

$$I = \frac{C \times CR \times EF \times ED}{BW \times AT}$$

Where:

I = Intake; the amount of chemical at the exchange boundary (mg/kg body weight/day).
C = EPC in specific media (e.g., milligrams per liter of water).
CR = Contact rate; the amount of contaminated medium contacted per unit time or event (e.g., liters/day).
EF = Exposure frequency, which describes how often exposure occurs (days/year).
ED = Exposure duration, which describes how long exposure occurs (years).
BW = Body weight; the average body weight over the exposure period (kg).
AT = Averaging time; the period over which exposure is averaged (days).

Exposure to carcinogenic compounds will be evaluated based on exposure to a combined child and adult receptor. Intake will be calculated using age adjustments to account for the total exposure duration. Specifically, intake will be calculated as shown in the following general intake equation:

$$I = \frac{C}{AT} \times \left(\frac{EDc \times EFc \times CRc}{BWc} + \frac{(EDa - EDc) \times EFa \times CRa}{BWa} \right)$$

Where:

$CR_{a \text{ or } c}$ = Contact rate for adult or child (varies).
$EF_{a \text{ or } c}$ = Exposure frequency for adult or child (days/year).
$ED_{a \text{ or } c}$ = Exposure duration for adult or child (years).
$BW_{a \text{ or } c}$ = Body weight for adult or child (kg).

These generic equations will be modified to account for scenario-specific exposures to COPCs. For the inhalation route of exposure, the intake is depicted as an EC (EPA 2009c). For dermal exposure to COPCs in water, the dermally absorbed dose will be determined using equations and chemical-specific parameters from EPA's Dermal Assessment Guidance (2004). Intake equations and proposed values for exposure parameters are presented in Tables 3-1 through 3-9 (at the end of this chapter) and discussed in this section. Note that some exposure factors for the residential and recreational visitor/subsistence user are not currently available. Additional information regarding site usage will be gathered (see Section 3.3.2.5) and additional exposure parameters for these scenarios will be proposed in a technical memorandum to be provided prior to development of the risk assessment.

The intakes calculated for each scenario are intended to represent the reasonable maximum exposure (RME) conditions. An RME scenario is a combination of high-end and average exposure values and is used to represent the highest exposure that is reasonably expected to occur. The RME scenario is a conservative exposure scenario that is plausible yet well above the average exposure level.

For soil ingestion and dust inhalation of arsenic, soil intakes will be multiplied by a relative bioavailability to quantify the level of arsenic that reaches systemic circulation. See Section 3.3.2.6 for additional information on arsenic bioavailability.

3.3.2.3 Exposure to Mutagenic Compounds

Recent EPA guidance (EPA 2005k) provides a protocol on how to evaluate exposure to carcinogenic compounds having a mutagenic mode of action. EPA age-dependent adjustments factors (ADAFs) of cancer potency are based on the assumption that cancer risks generally are higher from early-life exposures than from similar exposures later in life. The EPA (2005k) recommends the following age adjustment:

1. For exposures before 2 years of age (i.e., spanning a 2-year time interval from the first day of birth until a child's 2nd birthday), a 10-fold adjustment.

2. For exposures between 2 and <16 years of age (i.e., spanning a 14-year time interval from a child's 2nd birthday until his or her 16th birthday), a 3-fold adjustment.

3. For exposures after 16 years of age, no adjustment.

The EPA is recommending the ADAFs described above only for mutagenic carcinogens, because the data for non-mutagenic carcinogens were considered to be too limited and the modes of action too diverse to use non-mutagenic carcinogens as a category for which a general default adjustment factor approach can be applied. The California Environmental Protection Agency (Cal EPA) considers this approach insufficiently health-protective and has issued a draft proposal to apply the default cancer potency factor age adjustments described above to all carcinogens unless data are available that allow for development of chemical-specific cancer potency factor age adjustments (Cal EPA 2008). The Cal EPA proposal is in the public review draft stage and has not been finalized. ADEC's risk assessment guidelines recommend the application of ADAFs only for those compounds that display a mutagenic mode of action for carcinogenicity (ADEC 2010). Therefore, for these HHRA ADAFs will only be used for evaluating COPCs that are considered mutagens by the EPA (2005a). The only potential mutagenic COPCs at this site are carcinogenic polycyclic aromatic hydrocarbons (cPAHs). As previously noted, exposure to carcinogenic compounds will be evaluated based on exposure to a combined child and adult receptor.

Many default or exposure factors, specifically wild food ingestion rates, are not available for the age ranges identified for analysis (EPA 2008b). Therefore an age adjusted exposure factor will be used, consistent with the approach applied in development of the EPA RSLs (EPA 2010f). Specifically, intake from compounds having a mutagenic mode of action (i.e., cPAHs) will be evaluated based on dose estimates adjusted upward to account for potential greater susceptibility of children from 0 to 2 years of age, 2 to 6, and 6 to 16 as compared with older children and adults in the following manner. The generic intake equation will be adjusted in the following manner:

$$I = \frac{C \times EF}{AT} \times \left(\frac{ED_{0-2} \times CR_{child} \times 10}{BW_{child}} \right) \times \left(\frac{ED_{2-6} \times CR_{child} \times 3}{BW_{child}} \right) \times \left(\frac{ED_{6-16} \times CR_{adult} \times 3}{BW_{adult}} \right) \times \left(\frac{ED_{16-30} \times CR_{adult} \times 3}{BW_{adult}} \right)$$

As described in Section 3.3.2.2, this generic equation will be modified to account for exposure through the ingestion, inhalation, and dermal routes of exposure.

3.3.2.4 Exposure Factors

In addition to intake rates, exposure factors for body weight (BW), exposure frequency (EF), exposure duration (ED), and averaging time (AT) are included in the intake equation. Values used for BW, EF, ED, and AT vary among scenarios. For exposure pathways related to skin exposure, an additional variable for skin surface area (SA) may be included in the intake equation. As previously noted, some exposure factors for the residential and recreational visitor/subsistence user are not currently available. Exposure factors for these scenarios will be proposed in a technical memorandum to be provided prior to development of the risk assessment.

Body Weight

A value of 70 kilograms (kg) (154 pounds) will be used for all adults and is based on an average of male and female adult BWs. The average BW for all children is 15 kg (33 pounds) for a child up to age 6. These values are consistent with EPA and ADEC guidance (EPA 1989, 2002b; ADEC 2010).

Exposure Frequency and Time

The EF describes how often someone may have contact with affected media over a one-year period. EPA (1989, 1991) recommends an assumption that the future resident (adults and children) may be exposed through a specific exposure pathway for 350 days per year (days/year). The assumption is that people spend at least two weeks at a location other than the exposure scenario location each year (i.e., a two-week vacation). Due to snow cover during winter months, the ADEC recommends the EF for soil exposure be adjusted to 270 days/year for sites in the under-40-inch precipitation region, which includes the RDM site (ADEC 2010). This revised EF is used for soil and sediment contact (ingestion and dermal) for the adult and child future onsite resident.

An EF of 250 days/year will be used for the mine worker, consistent with EPA and ADEC recommendations (ADEC 2010; EPA 2002b) for an industrial scenario. This value assumes workers are onsite an average of five days per week for 50 weeks (assuming two weeks of vacation). Alternatively, mining operations in remote Alaska may use a two weeks on and two weeks off work schedule. The ED of 250 days recommended by the EPA and ADEC provides a conservative estimate under this scenario, as well. This ED will be used for both soil and groundwater exposure, since people will only be exposed to site-related contaminants in either media while at the site.

For exposure to surface water, the event frequency for the residential and mine worker scenarios were determined based on best professional judgment assuming that people would only wade in the water no more than half the days during the summer months (mid-May through mid-September). This results in approximately 60 days per year for the residential scenario and 40 days per year for the mine worker scenario. It is assumed that true exposure would be less than this.

The EF for the recreational and subsistence user for exposure to all media will be determined following results from the local survey information, if available (see Section 3.3.2.5).

For the inhalation route of exposure, the exposure time (i.e., time per day exposed to contaminants in air) is also included with the EF. For inhalation of volatiles in soil, the exposure time is equal to 24 hours per day for residents and 8 hours per day for workers, consistent with the EPA's recommendations (EPA 2009c). For inhalation of volatile COPCs in groundwater during showering, an exposure time of 45 minutes per showering event (0.75 hours) will be used for both the adult and child residential scenarios. The EPA 95th percentile exposure time for showering for children is 44 minutes and for adults is 45 minutes (EPA 2009c). Therefore, 45 minutes is an appropriate estimate for both scenarios.

Exposure Duration

The ED is the length of time in years in which someone may be exposed through a specific exposure pathway. The ED reflects the time period during which people may be exposed. An ED of six years will be assumed for all child scenarios (EPA 1989, 2002b; ADEC 2010) representing a child up to 6 years of age. Exposures occurring beyond age 6 will be accounted for in the adult exposure scenarios.

The default ED for the adults is 30 years for future onsite residents (EPA 2002b; ADEC 2010). The Alaska Department of Fish and Game (ADF&G) completed a subsistence survey in Red Devil Village and Alaska Department of Health and Social Services is planning to conduct a survey in spring 2011. These surveys plan to include questions regarding how long a respondent lived at the current location in Red Devil Village and from where they moved (community in Alaska or state in the United States or other country) prior to the current location. It is assumed that the residential patterns of a new community established near the RDM site would be similar to the pattern seen in residents of Red Devil Village. Therefore, the results of the subsistence survey will be used to estimate the adult residential and recreational/subsistence user ED. This value will be used if it is found to be greater than the default residential ED of 30 years; otherwise the default residential ED will be used.

The default ED for a commercial/industrial worker is 25 years (ADEC 2010), but time in mining occupations is substantially less than that. The median occupational tenure for mining activities is 8.6 years (EPA 1997a). For consistency with EPA and ADEC guidance, an ED of 25 years will conservatively be used for a mine worker.

For carcinogens, the residential and recreational/subsistence user scenarios will be calculated as an aggregate of child and adult exposure; the first six years of the ED will be determined based on the child intake and the remaining time at an adult intake, as described in Section 3.3.2.2.

Averaging Time

The AT is number of days over which an exposure is averaged. The AT varies, depending on whether the COPC in the affected media is a carcinogen or noncarcinogen. A longer AT is used for carcinogenic COPCs to account for the long latency period before exposure effects are seen. The EPA (1989) recommends an AT of 70 years × 365 days/year, or 25,550 days, for exposure to carcinogenic COPCs for the residential scenarios. For noncarcinogenic COPCs, the EPA (1989) recommends using an AT equal to the ED.

These values will be used in the risk assessment. For the ingestion and dermal routes of exposure, the averaging time is displayed in days. For the inhalation route of exposure, the averaging time is displayed in hours (EPA 2009c).

Surface Area of Skin

COPCs are absorbed by the skin through contact with soil and water. Dermal (skin) absorption of COPCs in soil may occur during outdoor activities. COPCs in groundwater may be absorbed by the skin during activities such as bathing or showering. COPCs in surface water may be absorbed through limited contact with surface water during recreational activities (e.g., washing hands or limited play in the creek).

Exposure to COPCs is affected by the surface area of skin coming into contact with the contaminated soil/sediment and the adherence of the soil to the skin. For skin contact with soil, EPA (2004) and ADEC (2010) recommend using a skin surface area of 5,700 square centimeters (cm^2) for an adult wearing a short-sleeved shirt, shorts, and shoes, with exposed skin surface limited to the head, hands, lower legs, and forearms. The recommended skin surface area for children is 2,800 cm^2, for exposed head, hands, lower legs, and forearms (EPA 2004; ADEC 2010). These values will be used for the residential, recreational, and subsistence user scenarios. The SA of 3,300 cm^2 (ADEC 2010; EPA 2004) for an industrial worker will be used for the industrial/mine worker scenario.

Soil-to-skin adherence factor (AF) assumptions are based on values provided by ADEC (2010) and in EPA’s Dermal Assessment Guidance (2004) and are consistent with residential and industrial scenarios, as appropriate.

For dermal absorption of COPCs in groundwater during showering or bathing activities, a surface area of 18,000 cm^2 will be used for adults and 6,600 cm^2 for children, consistent with the RME recommendations presented by the EPA (2004).

Dermal absorption of COPCs in surface water could occur while people wade or play in the water. This exposure would be limited to short times during the summer months. It is assumed that adults and children would have their hands, arms, feet, and legs exposed to surface water, resulting in a skin surface area of 5,672 cm^2 for adults (based on an average between men and women) (EPA 2004) and 4,150 cm^2 for children (EPA 2008b).

3.3.2.5 Intake Rates

The consumption rate is the amount of an environmental exposure medium (e.g., soil, air, surface water, or food) ingested or inhaled over a period of time or per event. Default consumption rates of soil, water, and food are provided by the EPA (1989, 1997a, and 2000d) and ADEC (2010) for use in assessing each exposure pathway for adults and children. Site-specific values will be determined, as needed, based on best professional judgment and surveys with residents of the village of Red Devil and local communities.

Soil Intake Rate

People are assumed to have contact with COPCs through the incidental ingestion of soil. The soil ingestion rate represents the amount of outdoor soil and indoor dust ingested through hand-to-mouth contact. The ADEC (2010) recommends an incidental soil ingestion rate of

100 milligrams per day (mg/day) for adults and 200 mg/day for children. These values are conservative and slightly higher than the EPA values of 100 mg/day for children (soil and dust ingestion) (EPA 2009c) and 50 mg/day for adults (EPA 1997a). The ADEC (2010) recommendation for outdoor workers is 100 mg/day, consistent with EPA recommendations (EPA 2002b). The ADEC values will be used for all scenarios.

Groundwater and Surface Water Intake Rate

People may have contact with COPCs through the ingestion of groundwater or surface water used as a drinking water source. Under the residential scenario, people may use groundwater as the primary drinking water source. The recommended drinking water ingestion rate for an adult resident is 2 liters per day (L/day) (ADEC 2010) and for a child resident is 1 L/day (EPA 2008b). It is also assumed that groundwater would be used for drinking water in an industrial setting while people are working at the site. ADEC (2010) recommends an ingestion rate of 2 L/day under this scenario, as well.

Surface water ingestion rates for adults and children are consistent with the drinking water ingestion rates used for groundwater exposure. These rates were determined to be conservative and based on the assumption that surface water would be used as the primary drinking water while at the RDM site to engage in recreational or subsistence activities.

Food Intake Rate

Plants harvested within the assessment area may take up COPCs from soil into their leaves and roots. In addition, wildlife may take up COPCs through ingestion of soil and consumption of local vegetation and animals. People who consume local vegetation and wildlife, therefore, may indirectly take up COPCs from the RDM site. Human intake of COPCs through food ingestion is determined by the types of food ingested, the amount of each type of food ingested per day, the concentration of COPCs in the food, and the percentage of the diet constituting food within the assessment area.

There is limited subsistence harvest or consumption data available for the village of Red Devil. Although harvest data can provide information on site use patterns, it does not often provide quantitative evaluation of consumption patterns. In 1986, ADF&G conducted household interviews in Red Devil to determine resource use patterns (Brelsford et al. 1987). Although this report provides information on some harvest patterns, it does not provide sufficient detail to determine quantitative ingestion rates, and it is more than 20 years old. Only big game data is available for Red Devil Village in the ADF&G Community Subsistence Information System (ADF&G 2010).

Ballew et al. (2004) conducted a 12-month recall consumption survey in 13 villages throughout Alaska. The regional health corporation serving the village of Red Devil is Yukon–Kuskokwim Health Corporation (YKHC) (Alaska Community Database 2010). Four villages from the YKHC region are represented in the Ballew et al. report, although the names of the specific villages are not provided. The following subsistence foods were identified in the top 50 foods reported by the participants in the YKHC region:

- King salmon
- Moose muscle and organs
- Chum salmon
- Caribou muscle and organs

- Whitefish
- Silver salmon
- Crowberries
- Lowbush salmonberries
- Moose fat and marrow
- Pike
- Seal oil
- Herring
- Tomcod
- Caribou fat and marrow
- Blackfish
- Blueberries
- Goose

For each of the subsistence foods, information on the percentage of that food in the diet and median and maximum amounts (in pounds per year) eaten is provided. This information could be used to determine rough estimates of annual consumption rates of a variety of subsistence foods, although the data would not be specific to the village of Red Devil or provide information on how much subsistence food is harvested from or near the RDM site.

ADF&G's Subsistence Division conducted a comprehensive subsistence survey in the village of Red Devil in April 2010, surveying 11 of 13 households. The survey was used to gather information on subsistence harvest patterns in the village of Red Devil over the past year and covered a wide range of subsistence resources, including fish, large game, and plants. This information will be used to determine the resources used by local residents and subsistence users and the value of fraction ingested (FI) from the RDM site for the future residential, recreational/subsistence user, and mine worker scenarios. These parameters will be developed in consultation with the ADEC and EPA and presented in a technical memorandum prior to development of the HHRA. As requested by the ADEC, conservative estimates of risk will also be calculated based on an FI=1 (all food consumed harvested from the site).

The Alaska Department of Health and Social Services will be conducting a consumption dietary survey in Red Devil Village and other communities near the site in the spring of 2011 as part of the Donlin Mine health impact assessment. The methodology for this survey will be similar to the surveys conducted in Ballew et al. (2004). Consumption information will be collected through recall consumption surveys on an individual basis. Information on body weight, age and gender will be collected and could be used to determine dose estimates. If available, the results from this survey will be used to determine intake rates used in the HHRA. Intake rates used in the HHRA will take into account any suppression effect (i.e., reduction of current intake rates) due to fear of potential contamination in food resources or current restrictions on hunting or gathering of food resources. Food intake rates for all receptors (residential, recreational/subsistence user, and mine worker scenarios) will be developed in consultation with the ADEC and EPA prior to development of the HHRA.

Use of the ADF&G and Alaska Department of Health and Social Services survey to determine the FI and food intake rates will be further discussed with the ADEC and EPA. Exposure factors for the residential and recreational visitor/subsistence user will be proposed in a technical memorandum to be provided prior to development of the risk assessment.

3.3.2.6 Arsenic Bioavailability

Using total soil arsenic concentrations to quantify daily chemical intake typically results in carcinogenic risk results greater than 10^{-6} for soils in naturally occurring background settings (Rodriguez et al. 2003).

These results are skewed high, because the amount of arsenic than can be extracted from soil in the laboratory is greater than the amount that actually would be taken up by an organism. One method of reducing uncertainty and obtaining more reasonable risk estimates is to quantify that amount of arsenic in soils that is bioavailable. Bioavailability is the fraction of a contaminant that is absorbed by an organism via a specific exposure route.

The bioavailability of absorbed inorganic arsenic depends on the matrix in which it is contained. Arsenic taken into the body through drinking water is in a water-soluble form, and it is generally assumed that its absorption from the gastrointestinal tract is nearly complete. Arsenic in soils, however, may be incompletely absorbed because some of the arsenic may be present in water-insoluble forms or may interact with other constituents in the soil. The EPA’s Hazard Identification and Review Committee selected an oral relative bioavailability (soil vs. water) of 25 percent (EPA 2001a).

An in vitro method that simulated the physiological conditions of the digestive process was applied to samples taken from an abandoned mining site, providing information on the levels of metals that can be ingested and assimilated by humans. In that study, the arsenic bioavailability in the stomach ranged from 0.1 percent to 25.3 percent, based on total arsenic concentration (Navarro et al. 2006).

EPA Region 10 recommends use of 60 percent relative bioavailability of total arsenic if contamination is primarily a result of impacts by the mineral industry activities of extraction or beneficiation such as mining, milling, tailings disposal, and other similar activities, and if there are also no associated smelting activities (EPA 2000d). The default value of 60% was obtained from the EPA Region 10 animal study (EPA 1996c). EPA Region 10 indicates there is a high level of uncertainty associated with this default assumption of relative bioavailability because there are no acceptable *in vivo* studies comparing the uptake of arsenic in these matrices with the uptake of soluble arsenic from orally ingested water and therefore, there are no quantitative data on which to develop a default value (EPA 2000d).

Speciation of arsenic tailing, waste rock, and soil will be evaluated through a literature review. Arsenic bioavailability values will be evaluated and an appropriate value will be proposed for use in the HHRA. For soil ingestion and dust inhalation exposures, soil intakes will be multiplied by a relative bioavailability to quantify the level of arsenic that reaches systemic circulation.

Dr. John Drexler at the University of Colorado in Boulder has been working cooperatively with EPA Region 8 for a number of years to develop an *in vitro* method that can be used to obtain relative bioavailability data for lead, arsenic, and potentially other metals in soils. Soil samples from areas of high, medium, and low arsenic concentration will be analyzed using a Relative Bioavailability Leaching Procedure for arsenic (Drexler 2003).

Although this data will not be used directly in the risk assessment, it will be provided as part of the uncertainty analysis in determining the impacts of site-specific bioavailability.

3.3.3 Estimation of COPC Concentrations in Media

As discussed above, concentrations of COPCs to which human receptors will be exposed over time will be estimated per EPA guidance (EPA 1992a) using the 95 percent UCL as the EPC. EPCs will be used for those media for which there will be sampling data (soil, sediment, surface water, and groundwater). Estimated media concentrations will be used for exposure pathway calculations and estimating COPC concentrations in food items. Uptake of COPCs from various media by plants and animals may cause exposures to ecological receptors and humans who consume local plants and animal products. The following subsections describe how COPC concentrations will be obtained for food items such as native vegetation, game, and fish. For more information on estimating EPCs for biota, see Section 4.4.2.1. Target food sources for evaluation in the HHRA will be determined following review of the ADF&G harvest survey report of Red Devil Village and in consultation with the ADEC and EPA.

Determination of concentrations of COPCs in air is also discussed in this section.

3.3.3.1 COPC Concentrations in Native Vegetation

Total mercury and methylmercury have been measured in several terrestrial plant species from the RDM site including willow, white spruce, black spruce, and blueberries (Bailey et al. 2002; Bailey and Gray 1997). A summary of the plant data are provided in Table 4-4. Additional sampling of alder, blueberry, white spruce, and pond plants is scheduled for summer 2011. The samples will be analyzed for target analyte list (TAL) metals. A subset of samples will be analyzed for methylmercury and inorganic arsenic. Plant samples will be co-located with soil samples collected in 2010 (see Attachment A). Where possible, these data will be used in lieu of modeled plant chemical concentrations, depending on data usability criteria and subsistence foods used at the site. Alternatively, soil and vegetation data from Bailey and Gray (1997) and Bailey et al. (2002) may be used to estimate site-specific, soil-to-plant uptake factors for total mercury and methylmercury (see Section 4.4.2.1 under *Exposure Point Concentrations, Terrestrial Plants* for details).

For other site-related chemicals, chemical concentrations in terrestrial plants will be modeled using uptake factors and equations from the EPA (2005i), Bechtel Jacobs (1998a), and Baes et al. (1984) (see Table 4-5).

3.3.3.2 COPC Concentrations in Wild Game

No data on levels of site-related chemicals in wild game or subsistence resources are available for the site. In lieu of actual measured concentrations, E & E will use the approach developed by Baes et al. (1984) and recommended by EPA (2007j, 2005l) to estimate metal concentrations in beef cattle from metal concentrations in their diet. The general equation is:

$$C_M = F_f \text{ x } 50 \text{ x } C_D$$

Where:

C_M = Metal concentration in beef tissue (mg/kg dry).
F_f = Ingestion-to-beef transfer coefficient (days/kg) (from Baes et al. 1984).
50 = Constant; beef cattle consume 50 kg/day of wet feed.
C_D = Diet metal concentration (mg/kg dry) calculated or measured as per Section 3.3.3.1, assuming that game animals are herbivorous.

3.3.3.3 COPC Concentrations in Fish

In 2010, the BLM conducted a study of Kuskokwim River, Red Devil Creek, and other tributaries to the Kuskokwim River near the RDM site. Forage fish were collected and analyzed for site-related chemicals. If it is determined that people are catching and consuming game fish from Red Devil Creek and/or the Kuskokwim River near the mouth of the creek, then the BLM data will be used to estimate concentrations of chemicals in game fish using a food chain multiplier (FCM) approach, as described in Section 4.4.2.1. In brief, the concentration of a chemical in game fish will be estimated from the sculpin concentration times an FCM. For methylmercury, an FCM of three will be assumed to account for biomagnification (i.e., the game fish concentration of methylmercury will be set equal to three times the concentration in sculpin). This approach is supported by the fact that the biomagnification of methylmercury typically is three-fold with each trophic transfer (McGeer et al. 2004). For inorganic mercury and other metals, an FCM of one will be assumed. This approach is defensible because biomagnification of metals (other than methylmercury) in aquatic organisms is rare. In fact, an inverse relationship has been shown for the trophic transfer of metals (except methylmercury) via the diet—that is, concentrations decrease from one trophic level to the next (McGeer et al. 2004). Hence, use of an FCM of one for inorganic mercury and other metals is conservative. This modeling approach can be extended to multiple trophic transfers if need be. For example, if game fish are determined to be two trophic levels above the sculpin, then the sculpin methylmercury concentration will be multiplied by 9 (3 x 3) to estimate the methylmercury concentration in the game fish.

3.3.3.4 COPC Concentrations in Air

To estimate the concentration of particulates in dust at the RDM site, EC for particulates will be calculated using a particulate emission factor (PEF). The PEF relates the concentration of contaminant in soil to the concentration of dust particles in the air generated from a “fugitive” or open source. PEFs for the residential and worker scenarios will be calculated using the equations and parameters identified in the *Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites* (EPA 2002b). The airborne dust concentrations during ATV use for the recreational and subsistence users will be estimated using equation E-18 of the *Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites* (EPA 2002b). This equation is designed to calculate a PEF associated with construction traffic over unpaved roads but can be modified to reflect ATV usage of an unpaved road or trail.

To estimate the concentration of volatile compounds in the air at the RDM site, the air concentration will be determined based on the soil concentration and the volatilization factor. The Foster and Chrostowski model (1986) will be used to estimate the concentration of volatile compounds in the air during showering.

3.4 Toxicity Assessment

The objectives of the toxicity assessment are to compile information on the nature of the adverse health effects of COPCs and to provide an estimate of the dose-response relationship for each COPC selected (i.e., determine the relationship between the extent of exposure and the likelihood and/or severity of adverse effects).

For the risk assessment, COPCs will be divided into two groups: agents known or suspected to be human carcinogens (carcinogens) and noncarcinogens. As used here, the term "carcinogen" denotes any chemical for which there is sufficient evidence that exposure may result in continuing uncontrolled cell division (cancer) in humans and/or laboratory animals. The risks posed by these two groups are assessed differently because noncarcinogenic chemicals generally exhibit a threshold dose below which no adverse effects occur, whereas for carcinogens the simplifying assumption has been made that carcinogenic responses are linearly related to dosage even in the unobservable area of the dose-response curve. That is, it is assumed for carcinogens that each incremental increase in dosage produces an incremental increase in the risk for cancer.

3.4.1 Quantitative Indices of Toxicity

The EPA consensus toxicity indices (e.g., subchronic and chronic reference doses [RfDs] and carcinogenic slope factors [SFs]) will be identified for use in the assessment. Toxicity values will be obtained using the following hierarchy (EPA 2003a; ADEC 2010):

- The Integrated Risk Information System (IRIS) (EPA 2010a) and cited references;
- The Provisional Peer Reviewed Toxicity Values (EPA 2010b) and cited references developed for the EPA Office of Solid Waste and Emergency Response Office of Superfund Remediation and Technology Innovation programs;
- The Agency for Toxic Substances and Disease Registry Minimal Risk Levels (addressing noncancer effects only);
- The EPA Superfund Health Effects Assessment Summary Tables (HEAST) (EPA 1997b) database and cited references; and
- Other criteria as needed.

Noncarcinogenic and carcinogenic indices will be tabulated separately. For noncarcinogenic effects, tabulations will include chemical route-specific reference doses (RfDs) (oral and dermal), reference concentrations (RfCs) (inhalation), critical effects, RfD/RfC basis/source, and uncertainty/modifying factors. Tables will be developed in a similar fashion, by chemical and exposure, for carcinogenic effects; the values in the tables will include SFs (oral and dermal), inhalation unit risk (IUR) (inhalation), mutagen potential, weight or evidence or cancer guideline description, and SF basis/source.

In addition, toxicological summaries will be prepared for all COPCs that are found to contribute substantially to overall risk or hazard. These summaries will qualitatively discuss toxicokinetics and key adverse effects that could result from exposure to site contaminants; the summaries will be provided in the appendix of the risk assessment report.

3.4.2 Route-to-Route Extrapolation of Reference Doses and Slope Factors

Once a substance has been absorbed via the oral or dermal routes, its distribution, metabolism, and elimination patterns (biokinetics) are usually similar regardless of the exposure route. For this reason, and because dermal route RfDs and SFs are usually not available, oral route RfDs and SFs are commonly used to evaluate exposures to substances by both the oral and dermal routes. In such cases, the dermal intake will be adjusted to account for differences in a chemical's absorption between the oral and dermal routes of exposure.

Although inhalation route biokinetics differ more from oral route kinetics than do the dermal route kinetics, oral RfDs and SFs may also be used to evaluate inhalation exposures if inhalation route RfCs and IURs are not available, and vice versa. Toxicological indices will not be extrapolated from one route to another if the critical effect for either route is at the point of contact.

3.4.3 Assessment of Carcinogenic PAHs

If cPAHs are identified as COPCs at the site, they will be assessed using a toxicity equivalency factor (TEF) approach consistent with the EPA's *Provisional Guidance for Quantitative Risk Assessment of Polycyclic Aromatic Hydrocarbons* (EPA 1993b). The TEF is the relative toxicity of a chemical compared to a reference chemical. For this assessment, the TEF will be applied to results for each sample during calculation of the EPCs.

Carcinogenic PAHs include benzo(a)anthracene; benzo(b)fluoranthene; benzo(k)fluoranthene; benzo(a)pyrene; chrysene; dibenzo(a,h,)anthracene; and indeno(1,2,3-cd)pyrene. To evaluate the toxicity of cPAHs, benzo(a)pyrene is used as a reference chemical. The total toxicity of cPAHs will be calculated as a sum of the individual cPAH compounds multiplied by the respective TEF.

3.4.4 Assessment of Lead

Lead has previously been identified as a COPC at the RDM site. Although the toxic effects from lead exposure are well known, there are no verified or consensus toxicity values available for lead in IRIS, HEAST, or other sources. The absence of authoritative toxicity values reflects the scientific community's inability to agree on a threshold dose for lead's noncarcinogenic effects or to satisfactorily estimate its carcinogenic potency, despite a large body of scientific literature on its toxicological effects.

Due to the lack of toxicity values, if lead is determined to be a COPC at the RDM site, exposure to lead will be assessed using physiologically-based toxicokinetic models for children and adults. The exposure estimates derived using these models will then be compared with accepted limits.

Models have been adopted to assess blood lead dose-response relationships in adults and children in lead-contaminated areas. Young children are the segment of the population at greatest risk from lead exposure because in comparison to adults their intake of lead from the gastrointestinal tract is greater (50 percent for children versus 5 percent for adults) and their developing organ systems are more sensitive to the toxic effects of lead.

The lead Integrated Exposure Uptake Biokinetic (IEUBK) model is recommended (EPA 2007g) to assess potential impacts to children from exposure to lead.

The IEUBK model predicts blood lead levels in young children resulting from multiple pathways of exposure, including intake via air, soil, drinking water, and diet. Default parameters exist in the model for intake of lead via the listed pathways. Site-specific data can also be input into the model to derive site-specific results. The IEUBK dietary intake parameter does include consumption of fish or other locally harvested food as a default parameter; therefore, if lead is identified as a COPC and can be taken up into locally harvested food, this consumption will be included as an “alternate” dietary source of lead. The Adult Lead Model (ALM) (EPA 2003b, 2005j) is used to evaluate adult lead risks in non-residential scenarios. The ALM assesses the risks to a developing fetus from potential lead exposures of pregnant women or women of child-bearing age in the workplace. The target fetal blood lead level used in this assessment is 10 micrograms per deciliter (µg/dL). The ALM can be used to calculate preliminary remediation goals, or screening levels, for lead in soil, or can be used to calculate predicted blood-lead concentrations in adult women workers and the fetuses of those workers. This model will be used to evaluate the potential risks of exposure to lead at the RDM site.

The ALM was designed to evaluate exposure to the most sensitive subpopulations, fetuses. The ALM is essentially an equation that estimates an average blood lead level based on additional exposure (above baseline levels) to lead in soil and air. The model applies a biokinetic slope factor to exposure estimates to derive an estimate of blood lead concentrations related to exposure levels. Ingestion exposure is the primary pathway evaluated in the model. A separate input in the equation for inhalation of lead from dust in the air may be necessary for the recreational and subsistence user scenario because of the airborne dust derived from ATV use. The default equation in the ALM is based on soil ingestion only, but the methodology can be modified to include separate variables that represent exposure to lead in various types of dust (EPA 2003b). If lead is identified as a COPC, the equation may be modified to take into account additional ingestion of lead in locally caught food.

3.5 Risk Characterization

Risk characterization, the final component of the risk assessment process, integrates the findings of the first two components (exposure and toxicity) by quantitative estimation of human health risks. For each scenario evaluated, incremental lifetime cancer probabilities will be estimated for an RME exposure scenario.

3.5.1 Assessment of Carcinogens

Any exposure to a carcinogen theoretically entails some finite risk of cancer. However, depending on the potency of a specific carcinogen and the level of exposure, such a risk could be practically negligible.

Scientists have developed several mathematical models to estimate low-dose carcinogenic risks from observed high-dose risks. Consistent with current theories of carcinogenesis, the EPA has selected the linearized multistage model based on prudent public health policy (EPA 1986). As a further conservatism, the EPA uses the upper 95 percent UCL on the dose-response relationship from animal studies to estimate a low-dose SF. By employing these procedures, the regulatory agencies are likely to overestimate the actual SF for humans.

Using the SF (oral and dermal), lifetime excess cancer risks can be estimated by:

$$Risk = \sum LADI_i \times SF_i$$

Where:

$LADI_i$ = Exposure route-specific lifetime average daily intake (mg/kg-day).
SF_i = Route-specific (oral and dermal) slope factor $(\text{mg/kg-day})^{-1}$.

Using the IUR (inhalation), the risk is determined by multiplying the EC by the IUR (EPA 2009c) as shown below:

$$Risk = \sum EC_i \times IUR_i$$

Where:

EC_i = Exposure concentration (micrograms per cubic meter [$\mu g/m^3$]).
IUR_i = Inhalation unit risk $(\mu g/m^3)^{-1}$.

Assuming risk additivity, the carcinogenic risks for the oral, dermal, and inhalation routes of exposure are summed. For carcinogens, the residential and recreational/subsistence user scenarios will be calculated as an aggregate of child and adult exposure; the first six years of the ED will be determined based on the child intake and the remaining time at an adult intake. See Section 3.3.2.3 regarding evaluating exposure to mutagenic compounds.

3.5.2 Assessment of Noncarcinogens

In accordance with EPA guidelines (1989), a hazard quotient (HQ) for noncarcinogenic risks is derived for each chemical and exposure route and, based on the assumption of dose additivity, the individual HQs are summed over all contaminants to determine the hazard index (HI).

Risks associated with non-cancer effects (e.g., organ damage, immunological effects, birth defects, and skin irritation) are usually assessed by comparing the estimated average exposure to an acceptable daily dose, RfD or RfC.

There a two standard approaches for determining RfDs and RfCs. In one approach, the RfD is selected by identifying the lowest reliable no observed adverse effect level (NOAEL) or lowest observed adverse effect level (LOAEL) in the scientific literature, then applying a uncertainty factor (usually ranging from 10 to 1,000) to allow for differences between the study conditions and the human exposure situation to which the RfD is to be applied. NOAELs and LOAELs can be derived from either human epidemiological studies or animal studies; however, they are usually based on laboratory experiments on animals in which relatively high doses are used. Consequently, uncertainty or safety factors are applied when deriving RfDs to compensate for data limitations inherent in the underlying experiments and for the lack of precision created by extrapolating from high doses in animals to lower doses in humans.

In 1995, the EPA's Risk Assessment Forum published guidance on the benchmark dose (BMD) approach in the assessment of noncancer health risk. The BMD approach provides a more quantitative alternative in the dose-response assessment than the NOAEL/LOAEL process for noncancer health effects (EPA 2000c). The use of BMD methods involves fitting mathematical models to dose-response data and using the different results to select a BMD that is associated with a predetermined benchmark response. As an example, the BMD method was used to derive the oral reference dose for methyl mercury (EPA 2001b).

Non-cancer hazards are usually assessed by calculating an HQ, which is the ratio of the estimated exposure to the RfD (oral and dermal), as follows:

$$HQ = \frac{CDIi}{RfDi}$$

Where:

CDI_i = Chronic Daily Intake (mg/kg-day).
RfD_i = Reference Dose (mg/kg-day).

Likewise, inhalation hazard is assessed by comparing the EC to the RfC, as follows:

$$HQ = \frac{ECi}{RfCi}$$

Where:

EC_i = Exposure concentration ($\mu g/m^3$).
RfC_i = Reference concentration ($\mu g/m^3$).

The HI calculated for a single mode of action is a measure of how close the estimated exposure comes to the RfD. If the HI is less than 1, adverse effects would not be expected. If the HI is greater than 1, adverse effects are possible, but not necessarily certain. If the HI exceeds 1, toxicology staff will review and segregate major chemical-specific effects identified in the derivation of the RfD by mechanisms of action and target organ. Upon segregation, HIs will be recalculated for specific effects or target organs to further define potential risks.

3.5.3 Assessment of Background Contribution to Risk

Consistent with EPA policy (EPA 2002a), COPCs at the site will include compounds that exceed risk-based concentrations, including chemicals that are below background levels. The risk characterization section of the HHRA will include an analysis of contribution from elevated background concentrations. Cancer risks and HQs will be calculated with and without consideration of the contribution of background concentrations. Risk characterization will include determining risks and hazards for each receptor based on site-determined EPCs (see Sections 3.3.2.1 and 3.3.3) for each COPC as determined in Section 3.2.

Site risks and hazards will also be calculated for each receptor subtracting out the contribution of background based on the background concentrations as determined in this section.

As recommended in the background guidance document for CERCLA sites (EPA 2002a, 2010d), two-sample hypothesis tests (e.g., Student's t-test, the Wilcoxon Mann-Whitney test, the quantile test, or Gehan's test) will be used to compare site and background concentrations in each media. The hypothesis-testing approaches can be used on both uncensored (without NDs) and left-censored (with NDs) data sets. Once the sample populations (site and background) have been compared, outliers identified (if applicable), and the background samples confirmed, appropriate background threshold values at the site will be computed using EPA's ProUCL version 4.1 software package and will be consistent with EPA guidance (EPA 2010d).

Eleven upland background surface soil samples and 10 Red Devil Creek alluvium background surface soil samples were collected during the 2010 field season. Sample location maps and results for mercury, antimony, and arsenic are provided in the *2010 Limited Field Sampling Report, RI/FS. Red Devil Mine, Alaska* (E & E 2010b). In addition, the BLM collected slimy sculpin, small Dolly Varden, and small salmonids from Red Devil Creek and several reference creeks. Hence, a background comparison is possible for soil and fish (Varner, M. 2011A summary of the Red Devil Creek fish samples is provided in Section 4.4.2.1 (see Exposure Point Concentrations, Forage Fish). If sufficient samples are not available to determine an acceptable background level, as is potentially the case for groundwater and surface water, only a qualitative discussion of contribution of risk will be made.

3.6 Uncertainty Analysis

Uncertainty is inherent in every step of the risk assessment process and will be discussed in relation to its impact on the risk assessment results. For example, the intake of each COPC for each receptor will be uncertain because assumptions must be made for exposure factors such as contact rate, frequency, and duration. Similarly, the uncertainty underlying a toxicity estimate for a particular COPC may be great or small, depending on the confidence EPA provides in the toxicity database or critical study on which the toxicity estimate is based. The risk assessment report will include an evaluation of the uncertainty associated with each step of the risk assessment process. Uncertainty will, in general, be determined qualitatively unless otherwise noted.

Table 3-1 Calculation of COPC Intake from Soil and Sediment Ingestion

A. Intake Equation[1]:

$$Intake\,(mg/kg/day) = \frac{C_s \; x \; IR \; x \; CF \; x \; EF \; x \; ED}{BW \; x \; AT}$$

B. Variables and Assumptions:

Exposure Case

Variables	**Future Residential**	**Recreational/ Subsistence User**	**Mine Worker**	**Units**	**Description/Source**
C_s	Chemical-specific			mg/kg	Concentration of COPC in soil/ sediment; 95% UCL or maximum value
IR_a	100	100	100	mg/day	Adult soil ingestion rate (ADEC 2010; EPA 2002b)
IR_c	200	200	–	mg/day	Child soil ingestion rate (ADEC 2010)
CF	$1x10^{-6}$	$1x10^{-6}$	$1x10^{-6}$	kg/mg	Unit correction factor
EF_a	270	TBD	250	day/year	Adult residential user exposure frequency (ADEC 2010; EPA 2002b)
EF_c	270	TBD	–	day/year	Child residential exposure frequency (ADEC 2010)
ED_a	30	30	25	years	Adult exposure duration (ADEC 2010; EPA 1997a, 2002b)
ED_c	6	6	–	years	Child exposure duration (ADEC 2010, EPA 2002b)
BW_a	70	70	70	kg	Adult body weight (ADEC 2010; EPA 1989, 2002b)
BW_c	15	15	–	kg	Child body weight (ADEC 2010; EPA 2002b)
AT_c	25,550			days	Averaging time–carcinogens (EPA 1989)
AT_{nc}	ED x 365			days	Averaging time–noncarcinogens (EPA 1989)

Key:
ADEC = Alaska Department of Environmental Conservation
COPC = contaminant of potential concern
EPA = U.S. Environmental Protection Agency
kg = kilogram
mg = milligram
TBD = to be determined
UCL = upper confidence limit

years

Table 3-2 Calculation of COPC Intake from Dermal Soil and Sediment Contact

A. Intake Equation[1]:

$$Intake\,(mg/kg/day) = \frac{C_s \; x \, SA \, x \, AF \; x \, ABS \; x \, CF \; x \, EF \; x \, ED}{BW \; x \, AT}$$

B. Variables and Assumptions:

	Exposure Case				
Variables	**Future Residential**	**Recreational/ Subsistence User**	**Mine Worker**	**Citation**	**Description/Source**
C_s	Chemical-specific			mg/kg	Concentration of COPC in soil; 95% UCL or maximum value
SA_a	5,700	5,700	3,300	cm^2	Adult exposed body surface area (ADEC 2010; EPA 2004)
SA_c	2,800	2,800	–	cm^2	Child exposed body surface area (ADEC 2010)
CF	0.001			kg/mg	Conversion factor
AF_a	0.07	0.07	0.2	mg/cm^2	Adult skin adherence factor (ADEC 2010; EPA 2004)
AF_c	0.2	0.2	–	mg/cm^2	Child skin adherence factor (ADEC 2010; EPA 2004)
ABS	Chemical-specific			unitless	Skin absorption; values to be obtained from EPA 2004
EF_a	270	TBD	250	day/year	Adult exposure frequency (ADEC 2010; EPA 2002b)
EF_c	270	TBD	–	day/year	Child exposure frequency (ADEC 2010; EPA 2002b)
ED_a	30	30	25	years	Adult exposure duration (ADEC 2010; EPA 1997a, 2002b)
ED_c	6	6	–	years	Child exposure duration (ADEC 2010; EPA 2002b)
BW_a	70	70	70	kg	Adult body weight (ADEC 2010; EPA 1989, 2002b)
BW_c	15	15	–	kg	Child body weight (ADEC 2010; EPA 2002b)
AT_c	25,550			days	Averaging time–carcinogens (EPA 1989)
AT_{nc}	ED x 365			days	Averaging time–noncarcinogens (EPA 1989)

Key:
ABS = absorption
ADEC = Alaska Department of Environmental Conservation
cm = centimeter
COPC = contaminant of potential concern
CT = average or central tendency case
EPA = U.S. Environmental Protection Agency
kg = kilogram
mg = milligram
TBD = to be determined
UCL = upper confidence limit

Note:

[1] For carcinogens, intake for the residential and recreational/subsistence user scenarios will be calculated as an aggregate of child and adult exposure, as described in Section 3.3.2.2.

Table 3-3 Calculation of COPC Intake from Groundwater Ingestion

A. Intake Equation[1]**:**

$$Intake\,(mg/kg/day) = \frac{C_w \; x \; IR \; x \; EF \; x \; ED}{BW \; x \; AT}$$

B. Variables and Assumptions:

	Exposure Case				
Variables	**Future Residential**	**Recreational/ Subsistence User**	**Mine Worker**	**Units**	**Description/Source**
C_w	Chemical-specific			mg/L	Concentration of COPC in water; 95% UCL or maximum value
IR_a	2	–	2	liters/day	Adult drinking water ingestion rate (ADEC 2010)
IR_c	1	–	–	liters/day	Child drinking water ingestion rate (EPA 2008b)
EF_a	350	–	250	day/year	Adult exposure frequency (ADEC 2010; EPA 2002b)
EF_c	350	–	–	day/year	Child exposure frequency (ADEC 2010)
ED_a	30	–	25	years	Adult exposure duration (ADEC 2010 ; EPA 2002b)
ED_c	6	–	–	years	Child exposure duration (ADEC 2010; EPA 1989, 2002b)
BW_a	70	–	70	kg	Adult body weight (ADEC 2010; EPA 2002b)
BW_c	15	–	–	kg	Child body weight (ADEC 2010; EPA 2002b)
AT_c	25,550			days	Averaging time–carcinogens (EPA 1989)
AT_{nc}	ED x 365			days	Averaging time–noncarcinogens (EPA 1989)

Key:

ADEC	=	Alaska Department of Environmental Conservation
COPC	=	contaminant of potential concern
EPA	=	U.S. Environmental Protection Agency
kg	=	kilogram
mg	=	milligram
TBD	=	to be determined
UCL	=	upper confidence limit

Note:

[1] For carcinogens, intake for the residential and recreational/subsistence user scenarios will be calculated as an aggregate of child and adult exposure, as described in Section 3.3.2.2.

Table 3-4 Calculation of COPC Intake from Dermal Groundwater Contact

A. Intake Equation[1]:

$$DAD(mg/kg/day) = \frac{DAevent\ x\ EV\ x\ ED\ x\ EF\ x\ SA}{BW\ x\ AT}$$

B. Variables and Assumptions:

	Exposure Case				
Variables	**Future Residential**	**Recreational/ Subsistence User**	**Mine Worker**	**Units**	**Description/Source**
DA_{event}	Chemical and event specific			mg/cm2-event	Absorbed dose per event; calculated based on Equations 3.2 and 3.3 from EPA 2004
SA_a	18,000	–	18,000	cm^2	Adult exposed body surface area (EPA 2004)
SA_c	6,600	–	–	cm^2	Child exposed body surface area (EPA 2004)
EV_a	1	–	1	events/day	Adult event frequency (EPA 2004)
EV_c	1	–	–	events/day	Child event frequency (EPA 2004)
EF_a	350	–	250	day/year	Adult exposure frequency (ADEC 2010; EPA 2002b)
EF_c	350	–	–	day/year	Child exposure frequency (ADEC 2010)
ED_a	30	–	25	years	Adult exposure duration (ADEC 2010 ; EPA 2002b)
ED_c	6	–	–	years	Child exposure duration (ADEC 2010; EPA 1989, 2002b)
BW_a	70	–	70	kg	Adult body weight (ADEC 2010; EPA 2002b)
BW_c	15	–	–	kg	Child body weight (ADEC 2010; EPA 2002b)
AT_c	25,550			days	Averaging time–carcinogens (EPA 1989)
AT_{nc}	ED x 365			days	Averaging time–noncarcinogens (EPA 1989)

Key:
Cm = centimeter
COPC = contaminant of potential concern
EPA = U.S. Environmental Protection Agency
kg = kilogram
mg = milligram
TBD = to be determined
UCL = upper confidence limit

Note:

[1] For carcinogens, intake for the residential and recreational/subsistence user scenarios will be calculated as an aggregate of child and adult exposure, as described in Section 3.3.2.2.

Table 3-5 Calculation of COPC Intake from Surface Water Ingestion

A. Intake Equation[1]:

$$Intake\,(mg/kg/day) = \frac{C_w \; x \, IR \; x \, EF \; x \, ED}{BW \; x \, AT}$$

B. Variables and Assumptions:

	Exposure Case				
Variables	**Future Residential**	**Recreational/ Subsistence User**	**Mine Worker**	**Units**	**Description/Source**
C_w	Chemical-specific			mg/L	Concentration of COPC in water; 95% UCL or maximum value
IR_a	–	2	–	L/day	Adult drinking water ingestion rate (ADEC 2010)
IR_c	–	1	–	L/day	Child drinking water ingestion rate (EPA 2008b)
EF_a	–	TBD	–	day/year	Adult exposure frequency
EF_c	–	TBD	–	day/year	Child exposure frequency
ED_a	–	30	–	years	Adult exposure duration (ADEC 2010 ; EPA 2002b)
ED_c	–	6	–	years	Child exposure duration (ADEC 2010; EPA 1989, 2002b)
BW_a	–	70	–	kg	Adult body weight (ADEC 2010; EPA 2002b)
BW_c	–	15	–	kg	Child body weight (ADEC 2010; EPA 2002b)
AT_c	25,550			days	Averaging time–carcinogens (EPA 1989)
AT_{nc}	ED x 365			days	Averaging time–noncarcinogens (EPA 1989)

Key:
ADEC = Alaska Department of Environmental Conservation
COPC = contaminant of potential concern
EPA = U.S. Environmental Protection Agency
L = liter(s)
mg = milligram
TBD = to be determined
UCL = upper confidence limit

Note:

[1] For carcinogens, intake for the residential and recreational/subsistence user scenarios will be calculated as an aggregate of child and adult exposure, as described in Section 3.3.2.2.

Table 3-6 Calculation of COPC Intake from Dermal Surface Water Contact

A. Intake Equation[1]:

$$DAD(mg/kg/day) = \frac{DAevent\ x\ EV\ x\ ED\ x\ EF\ x\ SA}{BW\ x\ AT}$$

B. Variables and Assumptions:

	Exposure Case				
Variables	**Future Residential**	**Recreational/ Subsistence User**	**Mine Worker**	**Units**	**Description/Source**
DA_{event}	Chemical and event specific			mg/cm^2-event	Absorbed dose per event
SA_a	5,672	5,672	5,672	cm^2	Adult exposed body surface area (EPA 2004)
SAc	4,150	4,150	–	cm^2	Child exposed body surface area (EPA 2008b)
EV_a	1	1	1	Events/day	Adult event frequency (EPA 2004)
EV_c	1	1	–	Events/day	Child event frequency (EPA 2004)
EF_a	60	TBD	40	day/year	Adult exposure frequency (site-specific)
EF_c	60	TBD	–	day/year	Child exposure frequency (site-specific)
ED_a	30	30	25	years	Adult exposure duration (ADEC 2010 ; EPA 2002b)
ED_c	6	6	–	years	Child exposure duration (ADEC 2010; EPA 1989, 2002b)
BW_a	70	70	70	kg	Adult body weight (ADEC 2010; EPA 2002b)
BW_c	15	15	–	kg	Child body weight (ADEC 2010; EPA 2002b)
AT_c	25,550			days	Averaging time–carcinogens (EPA 1989)
AT_{nc}	ED x 365			days	Averaging time–noncarcinogens (EPA 1989)

Key:

Cm	=	centimeter
COPC	=	contaminant of potential concern
EPA	=	U.S. Environmental Protection Agency
kg	=	kilogram
mg	=	milligram
TBD	=	to be determined
UCL	=	upper confidence limit

Note:

[1] For carcinogens, intake for the residential and recreational/subsistence user scenarios will be calculated as an aggregate of child and adult exposure, as described in Section 3.3.2.2.

Table 3-7 Calculation of COPC Intake from Soil Inhalation Exposure

A. Intake Equation[1]:

$$EC\,(ug/m^3) = \frac{C_a \; x \; ET \; x \, EF \; x \, ED}{AT}$$

B. Variables and Assumptions:

	Exposure Case				
Variable	**Future Residential**	**Recreational/ Subsistence User**	**Mine Worker**	**Units**	**Description/Citation**
C_a	Chemical-specific			ug/m3	Concentration of COPC in air; modeled concentration
ET_a	24	TBD	8	hours/day	Adult exposure time (EPA 2009c)
ET_c	24	TBD	–	hours/day	Child exposure time (EPA 2009c)
EF_a	270	TBD	250	day/year	Adult residential user exposure frequency (ADEC 2009; EPA 2002b)
EF_c	270	TBD	–	day/year	Child residential exposure frequency (ADEC 2010)
ED_a	30	30	25	years	Adult exposure duration (ADEC 2010; EPA 1997a, 2002b)
ED_c	6	6	–	years	Child exposure duration (ADEC 2010; EPA 2002b)
AT_c	25,550 x 24			hours	Averaging time–carcinogens (EPA 2009c)
AT_{nc}	ED x 365 x 24			hours	Averaging time–noncarcinogens (EPA 2009c)

Key:

COPC = contaminant of potential concern
EPA = U.S. Environmental Protection Agency
m = meter
ug = microgram
TBD = to be determined
UCL = upper confidence limit

Note:

[1] For carcinogens, intake for the residential and recreational/subsistence user scenarios will be calculated as an aggregate of child and adult exposure, as described in Section 3.3.2.2.

Table 3-8 Calculation of COPC Intake from Groundwater Inhalation Exposure

A. Intake Equation[1]**:**

$$EC\,(ug/m^3) = \frac{C_a\ x\ ET\ x\ EF\ x\ ED}{AT}$$

B. Variables and Assumptions:

Variable	Exposure Case: Future Residential	Exposure Case: Recreational/ Subsistence User	Exposure Case: Mine Worker	Units	Description/Citation
C_a	Chemical-specific			ug/m3	Concentration of COPC in air; modeled concentration
ET_a	0.75	–	–	hours/day	Adult exposure time (EPA 2009c)
ET_c	0.75	–	–	hours/day	Child exposure time (EPA 2009c)
EF_a	350	–	–	day/year	Adult exposure frequency (ADEC 2010; EPA 2002b)
EF_c	350	–	–	day/year	Child exposure frequency (ADEC 2010)
ED_a	30	–	–	years	Adult exposure duration (ADEC 2010; EPA 1997a, 2002b)
ED_c	6	–	–	years	Child exposure duration (ADEC 2010; EPA 2002b)
AT_c	25,550 x 24			hours	Averaging time–carcinogens (EPA 2009c)
AT_{nc}	ED x 365 x 24			hours	Averaging time–noncarcinogens (EPA 2009c)

Key:
COPC = contaminant of potential concern
EPA = U.S. Environmental Protection Agency
m = meter
ug = microgram
TBD = to be determined
UCL = upper confidence limit

Note:

[1] For carcinogens, intake for the residential and recreational/subsistence user scenarios will be calculated as an aggregate of child and adult exposure, as described in Section 3.3.2.2.

Table 3-9 Calculation of COPC Intake from Subsistence Food Ingestion

A. Intake Equation[1]:

$$Intake\,(mg/kg/day) = \frac{Cf \; x \, IR \, x \, FI \; x \, EF \; x \, ED}{BW \; x \, AT}$$

B: Variables and Assumptions:

	Exposure Case				
Variables	**Future Residential**	**Recreational/ Subsistence User**	**Mine Worker**	**Units**	**Description/Source**
Cf	Chemical-specific			mg/kg	Modeled concentration of COPC in subsistence foods
IR_a	TBD	TBD	TBD	kg/day	Adult ingestion rate of subsistence foods (local survey)
IR_c	TBD	TBD	–	kg/day	Child ingestion rate of subsistence foods (local survey)
FI	TBD	TBD	TBD	unitless	Fraction ingested from RDM site
EF_a	365	TBD	250	day/year	Adult residential user exposure frequency (ADEC 2010; EPA 2002b)
EF_c	365	TBD	–	day/year	Child residential exposure frequency (ADEC 2010)
ED_a	30	30	25	years	Adult exposure duration (ADEC 2010; EPA 1997a, 2002b)
ED_c	6	6	–	years	Child exposure duration (ADEC 2010; EPA 2002b)
BW_a	70	70	70	kg	Adult body weight (ADEC 2010; EPA 1989, 2002b)
BW_c	15	15	–	kg	Child body weight (ADEC 2010; EPA 2002b)
AT_c	25,550			days	Averaging time–carcinogens (EPA 1989)
AT_{nc}	ED x 365			days	Averaging time–noncarcinogens (EPA 1989)

Key:

ADEC = Alaska Department of Environmental Conservation
COPC = contaminant of potential concern
EPA = U.S. Environmental Protection Agency
kg = kilogram
mg = milligram
TBD = to be determined from interviews with area residents and/or BLM personnel

Note:

[1] For carcinogens, intake for the residential and recreational/subsistence user scenarios will be calculated as an aggregate of child and adult exposure, as described in Section 3.3.2.2.

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4 Ecological Risk Assessment Methodology

4.1 Overview

E & E will prepare an ERA for the RDM site. The purpose of the ERA is to determine whether residual contamination from previous mining activities poses a risk to ecological receptors at the site, including threatened and endangered species, if any. The results of the ERA will be used to determine whether remedial measures may be necessary to protect the natural environment and to aid in selection of appropriate remedial goals if needed.

The methodology used in the ERA will be generally consistent with the EPA, BLM, and State of Alaska ERA guidance, including but not limited to:

- *Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessments* (EPA 1997c);
- *Guidelines for Ecological Risk Assessment* (EPA 1998);
- *Wildlife Exposure Factors Handbook* (EPA 1993a);
- *Risk Management Criteria for Metals at BLM Sites* (BLM 2004);
- *State of Alaska Risk Assessment Procedures Manual* (ADEC 2010); and
- *User's Guide for Selection and Application of Default Assessment Endpoints and Indicator Species in Alaskan Ecosystems* (ADEC 1999).

In addition to the state and federal guidance documents mentioned above, E & E may use publications from Oak Ridge National Laboratory and recent articles from peer-reviewed literature, as appropriate.

The ERA will include an ecological characterization; problem formulation; assessment of risks to community-level receptor groups (terrestrial vegetation, soil invertebrates, benthos, fish, and aquatic invertebrates); wildlife risk evaluation; and discussion of uncertainty. These components are discussed below. In addition, this work plan identifies data gaps related to assessment of ecological risk that E & E recommends be filled during the field investigation phase of the project.

4.2 Ecological Characterization

E & E will prepare an ecological description of the RDM site based on information contained in previous site reports, general information on Alaska ecoregions, and observations made by E & E personnel during site visits. Vegetative communities, wildlife species, and surface-water drainage features will be described. The U. S. Fish and Wildlife Service and ADF&G will be contacted for current information on threatened and endangered species in the site vicinity.

4.3 Preliminary Problem Formulation

Problem formulation is the first step in the risk assessment process. It identifies the goals, breadth, and focus of the assessment (EPA 1997c, 1998). The problem formulation step identifies site-related contaminants (stressors), potential ecological receptors, and potential exposure pathways. A conceptual model is then developed to summarize the relationship between stressors and receptors. Lastly, assessment endpoints and measures (previously called measurement endpoints) are developed to guide the remaining steps of the risk assessment process. A preliminary problem formulation and CSM for the RDM site is presented in this section. The CSM may be refined during subsequent phases of the ERA process.

4.3.1 Contaminant Sources and Migration Pathways

The RDM was Alaska's largest mercury mine, producing 1.2 million kilograms (kg) (2.73 million pounds) of mercury between 1933 and 1971 (Bailey et al. 2002). Cinnabar (HgS) and stibnite (Sb_2S_3) are the principal metallic minerals at the site, with minor amounts of realgar (AsS), orpiment (As_2S_3), and pyrite (FeS_2). High-grade ore contained as much as 30 percent mercury by weight, but most ore contained 2 to 5 percent. Several hundred meters of trenches, where surface mining took place, are present on the site. In addition, tailings and calcine piles are located on the site and several of these lie near a small creek, Red Devil Creek, which drains the mine area into the Kuskokwim River. During a site investigation by the U. S. Geological Survey (Bailey et al. 2002), abundant cinnabar, lesser amounts of stibnite, and a few beads of liquid mercury were visible in Red Devil Creek. Additional information on the RDM site and previous site investigations is provided in the RI/FS Work Plan.

Contaminated soil, crushed ore, tailings, and other mine wastes from RDM have been exposed at the surface for decades. Mercury and other metals in these wastes were subject to transport by water and wind to Red Devil Creek, the Kuskokwim River, groundwater beneath the site, and surrounding terrestrial areas. In addition, liquid mercury at the site was subject to volatilization to the atmosphere. Approximately 10 years ago, the BLM conducted remedial work to address these problems. However, the success of the remedial work and current site conditions are not fully known.

4.3.2 Contaminants of Potential Concern

Based on the minerals present at the site (see Section 4.3.1) and previous site assessment work (Ford 2001), mercury, methylmercury, antimony, and arsenic are considered the primary contaminants of potential concern (COPCs) at the site. In addition, lead and diesel range organics (DROs) may be present at elevated levels in soil at the locations of some historical mining structures (BLM 2001). However, the streamlined risk evaluation conducted by the BLM (Ford 2001) was limited only to those analytes suspected of being elevated in environmental media at the site—arsenic, antimony, mercury, lead, and DROs. No information is provided in BLM (2001) for other metals and organic compounds. Therefore, a formal screening level ecological risk assessment (SLERA) will be conducted for the site using remedial investigation (RI) sample data collected in 2010 and 2011. Target analyte list (TAL) inorganic compounds, petroleum related chemicals, semivolatile organic compounds, and polychlorinated biphenyls will be evaluated in the SLERA.

As discussed with the EPA and ADEC during the comment resolution meeting for the RAWP, the SLERA will be provided to the agencies for review and comment after all RI sample data are available (late 2011), but before the baseline ecological risk assessment is initiated. Table 4-1 lists screening benchmarks for metals for soil, sediment, and surface water that will be used in the SLERA to identify COPCs. Screening benchmarks for organic contaminants detected at the site will be taken from applicable EPA and ADEC guidance documents.

4.3.3 Potential Ecological Receptors

The following ecological receptor groups have the potential to be affected by site-related contaminants at the RDM site:

- Terrestrial plants and invertebrates;
- Mammals and birds that use the mine site, Red Devil Creek, and Kuskokwim River near the site to satisfy their food and habitat needs; and
- Aquatic biota (e.g., benthos, fish) in Red Devil Creek and Kuskokwim River near the site.

4.3.4 Preliminary Ecological Conceptual Site Model

Figure 4-1 provides a preliminary ecological CSM for the site featuring the ecological receptor groups identified in the previous section. Terrestrial plants are exposed to site-related chemicals primarily by direct contact with contaminated soil. Soil invertebrates may be exposed to site-related contaminants through direct contact with contaminated soil, ingestion of contaminated soil, and through the food chain. Birds and mammals may be exposed to site-related chemicals through incidental ingestion of soil and/or sediment, consumption of food, and drinking. Dermal exposure of wildlife to site-related chemicals is expected to be negligible compared with other exposure routes due to the protection provided by their external coverings (heavy fur and feathers). Inhalation is also expected to be a minor route of exposure for wildlife compared with ingestion of water, sediment, and prey. Inhalation could potentially be an important exposure route if hexavalent chromium were present in site soils at high levels, but this situation is highly unlikely given what is known about the site. Aquatic biota in Red Devil Creek and the Kuskokwim River may be exposed to site-related chemicals through direct contact with and ingestion of contaminated sediment and surface water and through the food chain.

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Table 4-1 Ecological Risk-Based Screening Values for Soil, Sediment, and Surface Water, Red Devil Mine Site, Alaska

	Soil (mg/kg)							Freshwater Sediment (mg/kg)					Surface Water (µg/L)		
	EPA Eco-SSL							MacDonald et al. (2000)		MacDonald et al. (1999)					
Compound	Plant	Soil Invert.	Bird	Mammal	Plant (Alloway 1990)	Plant (Efroymson et al. 1997)	Minimum	TEL	PEL	Value	Type	Minimum	EPA (2009a) Chronic Criterion	ADEC (2008a, 2009) Chronic Standard	Minimum
Metals															
Aluminum	–	–	–	–	–	–	–	–	–	58,000	ERM, *Hyalella*	58,000	–	87	87
Antimony	–	78	–	0.27	–	–	0.27	–	–	2.9	PAETA, WA	2.9	–	–	–
Arsenic	18	–	43	46	–	–	18	5.9	17	–	–	9.8	150	150	150
Barium	–	330	–	2000	–	–	330	–	–	–	–	–	–	–	–
Beryllium	–	40	–	21	–	–	21	–	–	–	–	–	–	–	–
Cadmium	32	140	0.77	0.36	–	–	0.36	0.60	3.5	–	–	1	0.25	0.25	0.25
Chromium (total)	–	–	–	–	75	–	75	37.3	90	–	–	43.4	–	–	–
Chromium (III)	–	–	26	34	75	–	26	–	–	–	–	–	74	74	74
Chromium (VI)	–	–	–	130	–	1	1	–	–	–	–	–	11	11	11
Cobalt	13	–	120	230	–	–	13	–	–	50	Criterion, Ont.	50	–	–	–
Copper	70	80	28	49	–	–	28	35.7	197	–	–	31.6	9	9	9
Iron	–	–	–	–	–	–	–	–	–	21,200	LEL, B.C.	21,200	–	1,000	1,000
Lead	120	1,700	11	56	–	–	11	35.0	91.3	–	–	35.8	2.5	2.5	2.5
Manganese	220	450	4300	4000	–	–	220	–	–	460	LEL, B.C.	460	–	–	–
Mercury	–	–	–	–	0.3	0.3	0.3	0.17	0.48	–	–	0.18	0.77	0.77	0.77
Methyl Mercury	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Nickel	38	280	210	130	–	–	38	18.0	36.0	–	–	22.7	52	52	52
Selenium	0.52	4.1	1.2	0.63	–	–	0.52	–	–	5	Criterion, B.C.	5	5	5	5
Silver	560	–	4.2	14	–	–	4.2	–	–	3.9	PAETA, WA	3.9	3.2	3.2	3.2
Thallium	–	–	–	–	1	1	1	–	–	–	–	–	–	–	–
Vanadium	–	–	7.8	280	50	–	7.8	–	–	–	–	–	–	–	–
Zinc	160	120	46	79	–	–	46	123	315	–	–	121	120	118	118
Organic Chemicals[a]															
TAqH	–	–	–	–	–	–	–	–	–	–	–	–	–	15	–
TAH	–	–	–	–	–	–	–	–	–	–	–	–	–	10	–

Table 4-1 Ecological Risk-Based Screening Values for Soil, Sediment, and Surface Water, Red Devil Mine Site, Alaska

	Soil (mg/kg)							Freshwater Sediment (mg/kg)					Surface Water (µg/L)		
	EPA Eco-SSL							MacDonald et al. (2000)		MacDonald et al. (1999)					
Compound	Plant	Soil Invert.	Bird	Mammal	Plant (Alloway 1990)	Plant (Efroymson et al. 1997)	Minimum	TEL	PEL	Value	Type	Minimum	EPA (2009a) Chronic Criterion	ADEC (2008a, 2009) Chronic Standard	Minimum

Key:
– = not available or not applicable.
B.C. = British Columbia, Canada.
ADEC = Alaska Department of Environmental Conservation.
Ecology = Washington State Department of Ecology.
EPA = [U.S.] Environmental Protection Agency.
ERM = effects range median.
LEL = low effect level.
mg/kg = milligrams per kilogram.
Ont. = Ontario, Canada.
SSL = soil screening level.
PAETA = probable apparent effect threshold approach.
PEL = probable effect level.
TAH. = total aromatic hydrocarbons.
TAqH = total aqueous hydrocarbons.
TEL = threshold effect level.
WA = Washington State.
µg/L = micrograms per liter.

Note:
[a] = Benchmarks for other organic chemicals detected in RI samples will be taken from applicable EPA and ADEC guidance.

4.3.5 Assessment Endpoints and Measures

In an ERA, assessment endpoints are expressions of the ecological resources that are to be protected (EPA 1997c). An assessment endpoint consists of an ecological entity and a characteristic of the entity that is important to protect. According to EPA (1998), assessment endpoints do not represent a desired achievement or goal, and should not contain words such as protect or restore, or indicate a direction for change such as loss or increase. Assessment endpoints are distinguished from management goals by their neutrality (EPA 1998).

Measurements used to evaluate risks to the assessment endpoints are termed “measures” and may include measures of effect (e.g., results of toxicity tests), measures of exposure (e.g., chemical concentrations in soil), and/or measures of ecosystem and receptor characteristics (e.g., habitat characteristics) (EPA 1998). Based on the site ecology, COPCs, and preliminary conceptual model, the ecological resources potentially at risk at the RDM site include terrestrial vegetation, invertebrates, mammals, birds, and aquatic biota (fish, benthos, and other aquatic organisms).

The ADEC (1999) recommends default assessment endpoints, indicator species, and assessment methods (i.e., measures) for interior Alaska, the ecoregion in which the RDM site is located. These default assessment endpoints, indicator species, and measures are summarized in Table 4-2. The ADEC recommends 24 default assessment endpoints for the interior Alaska ecoregion (1999). Based on E & E’s current understanding of the RDM site ecology, only 17 of these assessment endpoints are likely to be relevant. The rationale for excluding certain assessment endpoints is provided in the last column of Table 4-2. E & E anticipates using the default assessment methods recommended by the ADEC (1999) to evaluate the 17 assessment endpoints considered relevant to the RDM site (see Table 4-2), with the following substitutions and additions: (1) the Green-winged Teal will be substituted for the Mallard as a representative semi-aquatic avian herbivore; (2) the Spruce Grouse will be substituted for the Dark-eyed Junco as a representative avian herbivore; (3) the beaver will be substituted for the Northern bog lemming as a representative semi-aquatic mammalian herbivore; (4) BLM data on the abundance and diversity of benthic invertebrates in Red Devil Creek and other tributaries to the Kuskokwim River will be used to help evaluate the relative health of the benthic-invertebrate community in Red Devil Creek; and (5) the degree of re-vegetation of areas previously disturbed by mining will be used to qualitatively assess the long-term impacts, or lack thereof, to terrestrial vegetation resulting from elevated metals concentrations in soil.

Table 4-2 Default Assessment Endpoints, Indicator Species, and Measures for the Interior Alaska Ecoregion from ADEC (1999) Along with Risk Questions and Measurement Endpoints for the Baseline ERA for the Red Devil Mine Site.

Assessment Endpoint	Risk Question	Primary Indicator Species	Recommended Measurement Endpoints for Baseline ERA[a]	Typical Tier I Assessment Method	Primary (bold) and Other Exposure Media	Include in ERA for RDM Site?
Primary Producers						
Terrestrial plant species abundance, diversity, and primary production.	Are levels of contaminants in surface soil from the site great enough to affect terrestrial plant survival, growth, or reproduction?	All plants that obtain nutrients primarily from soil.	1. Chemical concentrations in soils. 2. Results of soil phytotoxicity tests with site soil samples.	Compare soil chemical concentration with phytotoxicity benchmarks.	Surface soil	Yes
Freshwater plant species abundance, diversity, and primary production.	None.	All plants that obtain nutrients primarily from freshwater.	None.	Compare surface water chemical concentration with chronic, freshwater quality criteria.	Fresh water	No, no wetlands are present onsite and the small Red Devil Creek does not provide suitable habitat for floating or rooted aquatic plants, nor does the Kuskokwim River near the site. Will be verified during upcoming RI/FS field work.
Freshwater semi-aquatic plant species abundance, diversity, and primary production.	None.	All plants that obtain nutrients primarily from freshwater sediment.	None.	Compare sediment chemical concentration with sediment quality benchmark.	Freshwater sediment, fresh water	No, no wetlands are present on site and Red Devil Creek does not provide suitable habitat for floating or rooted aquatic plants, nor does the Kuskokwim River near the site. Will be verified during RI/FS field work.
Herbivores and Detritivores						
Freshwater aquatic invertebrate community abundance and diversity.	Are levels of contaminants in surface water from Red Devil Creek great enough to affect survival, growth, or reproduction of freshwater aquatic invertebrates?	All freshwater aquatic invertebrates.	1. Chemical concentrations in surface water. 2. Results form surface water bioassays with a laboratory-reared aquatic invertebrate such as *Ceriodaphnia dubia*.	Compare surface water chemical concentration with chronic, freshwater quality criteria	Fresh water	Yes

Table 4-2 Default Assessment Endpoints, Indicator Species, and Measures for the Interior Alaska Ecoregion from ADEC (1999) Along with Risk Questions and Measurement Endpoints for the Baseline ERA for the Red Devil Mine Site.

Assessment Endpoint	Risk Question	Primary Indicator Species	Recommended Measurement Endpoints for Baseline ERA[a]	Typical Tier I Assessment Method	Primary (bold) and Other Exposure Media	Include in ERA for RDM Site?
Freshwater benthic invertebrate community abundance and diversity.	Are levels of contaminants in sediment from Red Devil Creek great enough to affect survival, growth, or reproduction of benthic invertebrates?	All freshwater benthic invertebrates.	1. Chemical concentrations in sediment. 2. Results from benthic macroinvertebrate surveys in Red Devil Creek and nearby reference creeks.	Compare sediment chemical concentration with sediment quality benchmark.	Freshwater sediment	Yes
Soil invertebrate community abundance and diversity.	Are levels of contaminants in site soils great enough to affect survival, growth, or reproduction of soil invertebrates?	All terrestrial invertebrates.	1. Chemical concentrations in soil. 2. Results from soil toxicity tests with a laboratory-reared soil invertebrate such as the earthworm *Eisenia foetida*.	Compare soil chemical concentration with available toxicity benchmarks for earthworms or other soil invertebrates.	Surface soil	Yes
Freshwater fish detritivore abundance and diversity.	Are levels of contaminants in surface water from Red Devil Creek great enough to affect survival, growth, or reproduction of freshwater fish?	All freshwater fish.	1. Chemical concentrations in surface water. 2. Results frm surface water bioassays with a laboratory-reared fish species such as the fathead minnow (*Pimphales promelas*).	Compare surface water chemical concentration with chronic, freshwater quality criteria.	Fresh water	Yes
Freshwater semi-aquatic avian herbivore abundance and diversity.	Does the daily dose of chemicals received by herbivorous waterfowl from consumption of semi-aquatic plants and other media in the settling ponds at the RDM site exceed TRVs for survival, growth or reproduction of birds?	Green-winged teal[b]	1. Chemical concentrations in settling pond sediment. 2. Chemical concentrations in settling pond surface water. 3. Chemical concentrations in semi-aquatic plants growing in the settling ponds.	Modeled chemical dose from ingestion of semi-aquatic plants, water, and sediment compared with TRV.	Freshwater sediment, fresh water	Yes. According to ADEC, signs of waterfowl use of the settling ponds near the main processing area have been reported.

Table 4-2 Default Assessment Endpoints, Indicator Species, and Measures for the Interior Alaska Ecoregion from ADEC (1999) Along with Risk Questions and Measurement Endpoints for the Baseline ERA for the Red Devil Mine Site.

Assessment Endpoint	Risk Question	Primary Indicator Species	Recommended Measurement Endpoints for Baseline ERA[a]	Typical Tier I Assessment Method	Primary (bold) and Other Exposure Media	Include in ERA for RDM Site?
Terrestrial avian herbivore abundance and diversity.	Does the daily dose of chemicals received by herbivorous birds from consumption of terrestrial plants and other media at the site exceed TRVs for survival, growth or reproduction of birds?	Spruce grouse[b]	1. Chemical concentrations in soil. 2. Chemical concentrations in surface water. 3. Chemical concentrations in conifer needles.	Modeled chemical dose from ingestion of terrestrial plants, water, and soil compared with TRV.	Surface soil, fresh water	Yes. Spruce grouse are known to use the site and are hunted by residents of Red Devil Village.
Freshwater mammalian, semi-aquatic mammalian, herbivore abundance, and diversity.	Does the daily dose of chemicals received by herbivorous mammals from consumption of semi-aquatic and terrestrial plants and other media at the site exceed TRVs for survival, growth or reproduction of mammals?	Beaver[b]	1. Chemical concentrations in soil. 2. Chemical concentrations in surface water. 3. Chemical concentrations in green alder bark.	Modeled chemical dose from ingestion of plants, water, and sediment compared with TRV.	Freshwater sediment, fresh water	Yes. Historic use of Red Devil Creek by beavers is evident.
Terrestrial mammalian herbivore abundance and diversity.	Does the daily dose of chemicals received by herbivorous mammals from consumption of terrestrial plants and other media at the site exceed TRVs for survival, growth or reproduction of mammals?	Tundra vole.	1. Chemical concentrations in soil. 2. Chemical concentrations in surface water. 3. Chemical concentrations in a representative herbaceous plant (blueberry stems and leaves).	Modeled chemical dose from ingestion of terrestrial plants, water, and soil compared with TRV.	Surface soil, fresh water	Yes
Secondary Consumers						
Freshwater avian invertivore abundance and diversity.	None.	American dipper.	None.	Modeled chemical dose from ingestion of benthic invertebrates and sediment compared with TRV.	Fresh water	No, redundant with Common Snipe exposure scenario (see below).

Table 4-2 Default Assessment Endpoints, Indicator Species, and Measures for the Interior Alaska Ecoregion from ADEC (1999) Along with Risk Questions and Measurement Endpoints for the Baseline ERA for the Red Devil Mine Site.

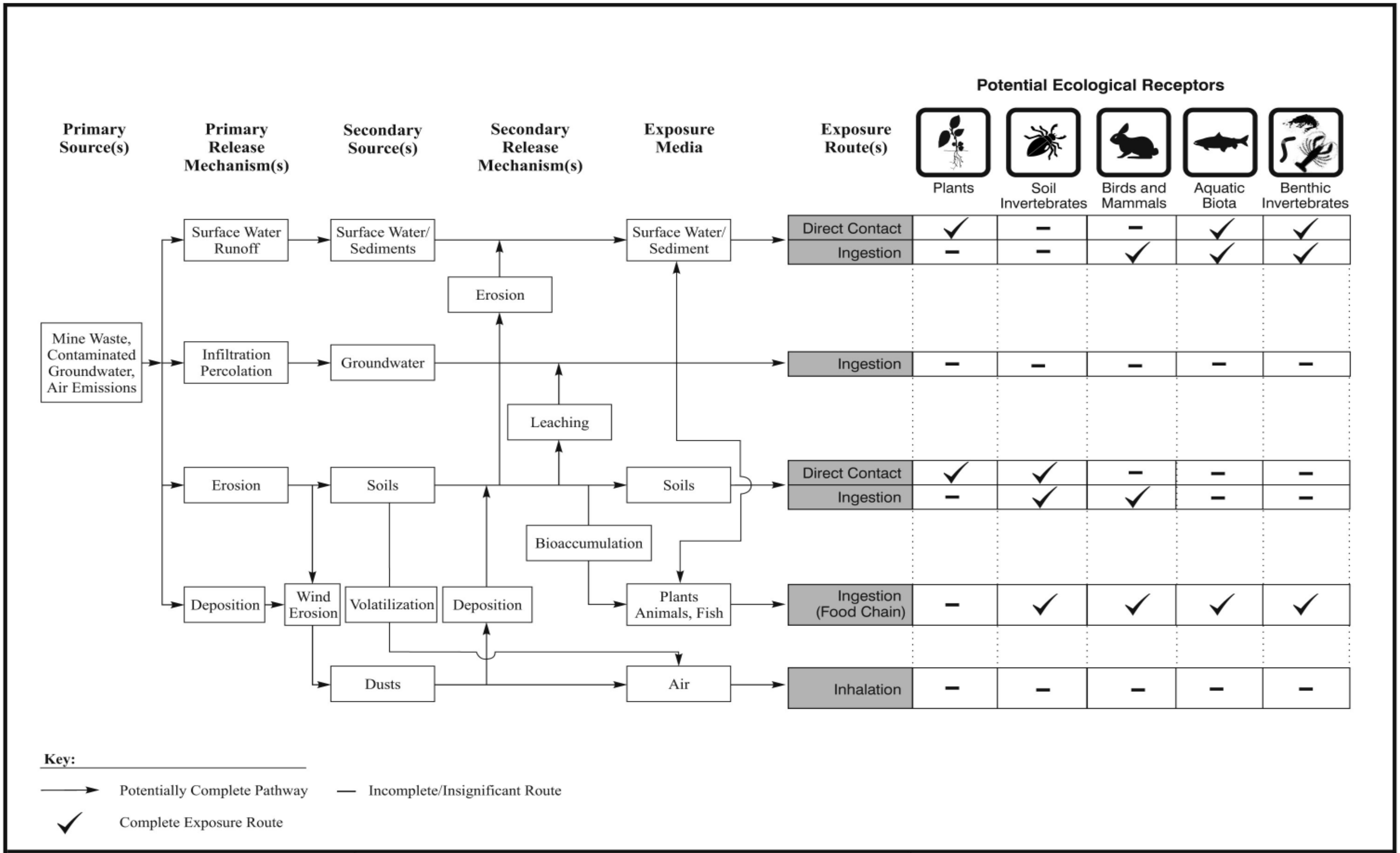
Assessment Endpoint	Risk Question	Primary Indicator Species	Recommended Measurement Endpoints for Baseline ERA[a]	Typical Tier I Assessment Method	Primary (bold) and Other Exposure Media	Include in ERA for RDM Site?
Semi-aquatic avian invertivore abundance and diversity.	Does the daily dose of chemicals received by semi-aquatic birds from consumption of benthic invertebrates and other media from Red Devil Creek exceed TRVs for survival, growth or reproduction of birds?	Common snipe.	1. Chemical concentrations in sediment. 2. Chemical concentrations in surface water. 3. Chemical concentrations in benthic invertebrates.	Modeled chemical dose from ingestion of benthic invertebrates, surface water, and sediment compared with TRV.	Freshwater sediment	Yes
Terrestrial avian invertivore abundance and diversity.	Does the daily dose of chemicals received by invertivorous birds from consumption of terrestrial invertebrates and other media from the site exceed TRVs for survival, growth or reproduction of birds?	American robin.	1. Chemical concentrations in soil. 2. Chemical concentrations in surface water. 3. Chemical concentrations in terrestrial invertebrates.	Modeled chemical dose from ingestion of soil invertebrates, surface water, and soil compared with TRV.	Surface soil	Yes
Freshwater fish invertivore abundance and diversity.	Are levels of contaminants in surface water from Red Devil Creek great enough to affect survival, growth, or reproduction of freshwater fish?	All freshwater fish.	1. Chemical concentrations in surface water. 2. Results form surface water bioassays with a laboratory-reared fish species such as the fathead minnow (*Pimphales promelas*).	Compare surface water chemical concentration with chronic, freshwater quality criteria.	Fresh water	Yes
All terrestrial invertebrates.	None.	All terrestrial invertebrates.	None.	Compare soil chemical concentration with available toxicity benchmarks for earthworms or other soil invertebrates.	Surface soil	No, redundant with soil invertebrate assessment endpoint and measure (see above). Also, terrestrial invertebrates (spiders, bark beetles, etc.) are likely to have limited exposure to chemicals in soil.

Table 4-2 Default Assessment Endpoints, Indicator Species, and Measures for the Interior Alaska Ecoregion from ADEC (1999) Along with Risk Questions and Measurement Endpoints for the Baseline ERA for the Red Devil Mine Site.

Assessment Endpoint	**Risk Question**	**Primary Indicator Species**	**Recommended Measurement Endpoints for Baseline ERA**[a]	**Typical Tier I Assessment Method**	**Primary (bold) and Other Exposure Media**	**Include in ERA for RDM Site?**
Freshwater amphibian invertivore abundance and diversity.	Are levels of contaminants in surface water from Red Devil Creek great enough to affect survival, growth, or reproduction of amphibians?	Wood frog.	**1. Chemical concentrations in surface water.**	Compare surface water chemical concentration with chronic, freshwater quality criteria	Fresh water, sediment	Yes
Terrestrial mammalian invertivore abundance and diversity.	Does the daily dose of chemicals received by invertivorous mammals from consumption of terrestrial invertebrates and other media from the site exceed TRVs for survival, growth, or reproduction of mammals?	Masked shrew.	**1. Chemical concentrations in soil.** **2. Chemical concentrations in surface water.** 3. Chemical concentrations in terrestrial invertebrates.	Modeled chemical dose from ingestion of soil invertebrates, surface water, and soil compared with TRV.	Surface soil	Yes
Tertiary Consumers						
Freshwater avian piscivore abundance and diversity.	Does the daily dose of chemicals received by piscivorous birds from consumption of fish and other media from Red Devil Creek exceed TRVs for survival, growth, or reproduction of birds?	Belted kingfisher.	**1. Chemical concentrations in sediment.** **2. Chemical concentrations in surface water.** **3. Chemical concentrations in fish.**	Modeled chemical dose from ingestion of fish and water compared with TRV.	Fresh water	Yes
Terrestrial avian carnivore abundance and diversity.	Does the daily dose of chemicals received by carnivorous birds from consumption of small mammals and other media from the site exceed TRVs for survival, growth or reproduction of birds?	Northern shrike.	**1. Chemical concentrations in soil.** **2. Chemical concentrations in surface water.** 3. Chemical concentrations in small mammals.	Modeled chemical dose from ingestion of prey compared with TRV.	Surface soil	Yes
Terrestrial mammalian carnivore abundance and diversity.	Does the daily dose of chemicals received by carnivorous mammals from consumption of prey and other media from the site exceed TRVs for survival, growth, or reproduction of mammals?	Least weasel.	**1. Chemical concentrations in soil.** **2. Chemical concentrations in surface water.** 3. Chemical concentrations in small mammals.	Modeled chemical dose from ingestion of prey, surface water, and soil compared with TRV.	Surface soil	Yes

Table 4-2 Default Assessment Endpoints, Indicator Species, and Measures for the Interior Alaska Ecoregion from ADEC (1999) Along with Risk Questions and Measurement Endpoints for the Baseline ERA for the Red Devil Mine Site.

Assessment Endpoint	Risk Question	Primary Indicator Species	Recommended Measurement Endpoints for Baseline ERA[a]	Typical Tier I Assessment Method	Primary (bold) and Other Exposure Media	Include in ERA for RDM Site?
Freshwater mammalian carnivore abundance and diversity.	Does the daily dose of chemicals received by piscivorous mammals from consumption of fish and other media from Red Devil Creek exceed TRVs for survival, growth or reproduction of mammals?	Mink.	**1. Chemical concentrations in sediment.** **2. Chemical concentrations in surface water.** **3. Chemical concentrations in fish.**	Modeled chemical dose from ingestion of fish and sediment compared with TRV.	Fresh water, sediment, surface soil	Yes
Freshwater mammalian piscivore abundance and diversity.	None.	River otter.	None.	Modeled chemical dose from ingestion of fish and water compared with TRV.	Fresh water	No, redundant with mink scenario (see above).
Freshwater fish piscivore abundance and diversity.	Are levels of contaminants in surface water from Red Devil Creek great enough to affect survival, growth, or reproduction of freshwater fish?	All freshwater fish.	**1. Chemical concentrations in surface water.** 2. Results form surface water bioassays with a laboratory-reared fish species such as the fathead minnow (*Pimphales promelas*).	Compare surface water chemical concentration with chronic, freshwater quality criteria.	Fresh water	Yes



Exposure Media	Exposure Route(s)	Plants	Soil Invertebrates	Birds and Mammals	Aquatic Biota	Benthic Invertebrates
Surface Water/ Sediment	Direct Contact	✓	–	–	✓	✓
	Ingestion	–	–	✓	✓	✓
Groundwater	Ingestion	–	–	–	–	–
Soils	Direct Contact	✓	✓	–	–	–
	Ingestion	–	✓	✓	–	–
Plants Animals, Fish	Ingestion (Food Chain)	–	✓	✓	✓	✓
Air	Inhalation	–	–	–	–	–

Key:

→ Potentially Complete Pathway

– Incomplete/Insignificant Route

✓ Complete Exposure Route

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RED DEVIL MINE

Figure 4-1
PRELIMINARY ECOLOGICAL CONCEPTUAL SITE MODEL FOR RED DEVIL MINE SITE

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Figure 4-1 Preliminary Ecological Conceptual Site Model for Red Devil Mine Site

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4.4 ERA Methodology

4.4.1 Community-Level Receptors

Terrestrial vegetation, soil invertebrates, benthic invertebrates, fish, aquatic invertebrates, and amphibians typically are evaluated at the community level (EPA 1997c, 1998). Given the large number of species that occur within each of these communities at any given site, it is prohibitive in terms of cost and time to evaluate each individual species. Instead, measures are selected that allow inferences to be made about all species in the community. As described in Table 4-2 above, potential risks to terrestrial plants and soil invertebrates will be assessed by comparing soil chemical concentrations with available soil benchmarks for plants and soil fauna, respectively. The benchmarks will be taken from the EPA (2005a–h, 2006a, 2007a–e), Efroymson et al. (1997), and/or Alloway (1990). Potential risks to benthic invertebrates will be assessed by comparing sediment chemical concentrations with sediment quality benchmarks from MacDonald et al. (1999, 2000) and also by comparing benthic macroinvertebrate diversity and abundance in Red Devil Creek with nearby reference creeks. Potential risks to fish (all trophic levels), aquatic invertebrates, and amphibians will be evaluated by comparing surface water chemical concentrations with chronic water quality criteria from EPA (2009a) and ADEC (2008a). Table 4-1 lists the soil, sediment, and surface water benchmarks and criteria for metals proposed for use at the RDM site. Screening benchmarks for other groups of detected chemicals will be taken from applicable EPA and ADEC guidance.

4.4.2 Wildlife

4.4.2.1 Exposure Assessment

This section identifies specific wildlife exposure scenarios that will be evaluated in the assessment and discusses how wildlife exposure to chemicals in the environment will be quantified.

Wildlife Exposure Scenarios and Pathways

As shown in Table 4-2, 11 wildlife species from different trophic levels (guilds) will be included in the ERA for the RDM site. These species are:

Herbivores:

- Spruce grouse (*Dendragapus canadensis*)
- Tundra vole (*Microtus oeconomus*)
- Beaver (*Castor canadensis*)
- Green-winged teal (*Anus crecca*)

Invertivores

- Common snipe (*Gallinago gallinag*)
- American robin (*Turdus migratorius*)
- Masked shrew (*Sorex cinereus*)

Carnivores

- Northern shrike (*Lanius excubitor*)
- Least weasel (*Mustela nivalis*)

Piscivores:

- Belted kingfisher (*Ceryle alcyon*)
- Mink (*Mustela vison*)

For these 11 species, E & E will estimate exposure from diet, incidental ingestion of soil and/or sediment, and drinking. Direct contact with contaminated media will not be quantitatively evaluated because it is a minor route of exposure for wildlife due to the protection provided by their external coverings (fur and feathers).

Wildlife Exposure Calculations

Chemical exposure for wildlife will be calculated as the sum of exposures from diet, incidental soil/sediment ingestion, and drinking. Dietary exposure will be calculated as shown in the following equation:

$$EE_{diet} = ([(C_1 \text{ x } F_1) + (C_2 \text{ x } F_2) + ... (C_n \text{ x } F_n)] \text{ x SUF x ED x IR})/BW$$

Where:

EE_{diet} = Estimated exposure from diet (milligrams per kilogram [mg/kg] per day)
C_n = Chemical concentration in food item *n* (mg/kg, wet weight)
F_n = Fraction of diet represented by food item *n*
SUF = Site use factor (unitless)
ED = Exposure duration (unitless)
IR = Ingestion rate of receptor (kg, wet weight/day)
BW = Body weight of receptor (kg)

The SUF indicates the portion of an animal's home range represented by the site. If the home range is larger than the site, the SUF equals the site area divided by the home range area. If the site area is greater than or equal to the home range, the SUF equals 1. ED is the percentage of the year spent in the site area by the receptor species. Home-range size, IR, diet composition, and BW for the nine wildlife species being evaluated, will be taken from the EPA (1993a), Dunning (1993), Kaufman (1996), or other credible references (see Table 4-3).

Wildlife exposure to chemicals through incidental soil/sediment ingestion will be estimated in a manner similar to that used for dietary exposure, as shown in the following equation:

$$EE_{soil/sed} = (C_s \text{ x } IR_s \text{ x SUF x ED})/BW$$

Where:

$EE_{soil/sed}$ = Estimated exposure from incidental soil/sediment ingestion (mg/kg-day)
C_s = Chemical concentration in soil/sediment (mg/kg, dry weight)
IR_s = Soil/sediment ingestion rate of receptor (kg, dry weight/day)
SUF, ED, and BW are as defined above.

Soil/sediment ingestion rates will be taken from the literature (Beyer et al. 1994, 2008; Sample et al. 1997; Sample and Suter 1994) or based on professional judgment (if a literature value cannot be found) (see Table 4-3).

Table 4-3 Exposure Parameters for Wildlife Receptor Species, Red Devil Mine Ecological Risk Assessment

Species	Diet Composition	Body Weight (kg)	Food Ingestion (kg/d) Dry	Soil/Sed. Ingestion (kg/d) Dry	Home Range	Exposure Duration (unitless)	Surface Water Ingestion (L/day)
Herbivores and Detritivores							
Spruce Grouse[1]	100% conifer foliage	0.53	0.06	0.0056	3.93	1.0	0.038
Tundra vole[2]	100% herbaceous plants	0.047	0.0085	0.0002	0.1087 ha	1.0	0.0063
Green-winged Teal[2]	100% aquatic herbaceous plants	0.32	0.053	0.0010	243 ha	0.34	0.027
Beaver[3]	100% tree bark	24.5	0.186	0.0037	n.a.	1.0	1.76
Secondary Consumers							
Common Snipe[2]	100% aquatic invertebrates	0.116	0.015	0.0016	0.1 to 48 ha	0.3	0.014
American Robin[4]	100% soil invertebrates	0.077	0.0186	0.00019	0.42 ha	0.3	0.011
Masked Shrew[2]	100% soil invertebrates	0.0064	0.0021	0.00011	0.22 ha	1.0	0.0011
Piscivores and Carnivores							
Belted Kingfisher[5]	100% fish	0.148	0.024	negligible	2.2 km	0.3	0.016
Northern Shrike[6]	100% small mammals and birds	0.0656	0.0139	negligible	n.a.	0.3	0.0095
Least Weasel[7]	100% small mammals	0.039	0.0048	negligible	n.a.	1.0	0.0053
Mink[5]	100% fish	1.0	0.044	negligible	1.9 to 2.6 km	1.0	0.099

Notes:

[1] Exponent (2007) for Willow Ptarmigan.

[2] Exponent (2007).

[3] Body weight from www.Alaskan-Adventures.com (accessed 6-7-11). Food and water ingestion rates calculated from body weight using allometric relationships from Sample et al. (1996). Soil ingestion rate assumed to be 2% of food ingestion rate.

[5] Sample and Suter (1994).

[6] Dunning (1993) for body weight. Food and water ingestion rates calculated from body weight using allometric relationship for passerine birds from Sample et al. (1996). Soil ingestion typically is negligible for predatory wildlife.

[7] EPA (1993a) for body weight. Food and water ingestion rates calculated from body weight using allometric relationship for placental mammals from Sample et al. (1996). Soil ingestion typically is negligible for predatory wildlife.

Key:

ha = hectares
kg = kilograms
kg/d = kilograms per day
km = kilometers
n.a. = not available

Wildlife exposure to chemicals through drinking will be estimated in a manner similar to that used for dietary exposure, as shown in the following equation:

$$EE_{drinking} = (C_w \text{ x } IR_w \text{ x } SUF \text{ x } ED)/BW$$

Where:

$EE_{drinking}$ = Estimated exposure from drinking surface water (mg/kg-day)
C_w = Chemical concentration in surface water (mg/L)
IR_s = Surface water ingestion rate (L/day)
SUF, ED, and BW are as defined above.

Surface water ingestion rates will be taken from the literature or calculated using allometric relationships from Sample et al. (1996). The values are provided in Table 4-3.

The total exposure for a receptor will be calculated as the sum of the exposure from diet, incidental soil/sediment ingestion, and drinking as represented by the following equation:

$$EE_{total} = EE_{diet} + EE_{soil/sed} + EE_{drinking}$$

Where:

EE_{total} = Total exposure (mg/kg-day)
EE_{diet} = Estimated exposure from diet (mg/kg-day)
$EE_{soil/sed}$ = Estimated exposure from incidental soil/sediment ingestion (mg/kg-day)
$EE_{drinking}$ = Estimated exposure from surface water consumption (mg/kg-day)

Exposure Point Concentrations

Soil: Surface soil (0 to 2 feet below ground surface) data from the 2010 and 2011 RI sampling event and historical surface soil data (if deemed useable) will be used to estimate EPCs for soil. ProUCL software version 4.1 (EPA 2010d) will be used to calculate the UCL on the arithmetic average concentration for each COPC (see Section 3.3.2.1 for additional discussion of calculating the EPC). The surface soil EPCs may be used for up to four purposes: (1) to estimate exposure from incidental soil ingestion; (2) to model chemical concentrations in terrestrial vegetation, the preferred food of the Spruce grouse, beaver, and tundra vole; (3) to model chemical concentrations in soil invertebrates, the preferred prey of the American robin and masked shrew; and (4) to model chemical concentrations in small mammals, a preferred prey of the least weasel and Northern shrike.

Sediment: Surface sediment (0 to 6 inches below the sediment-water interface) data from the 2010 and 2011 RI sampling event and historical surface sediment data (if deemed useable) will be used to estimate EPCs for sediment. ProUCL version 4.1 will be used to calculate the UCL on the average concentration for each COPC. The sediment EPCs may be used for two purposes: (1) to estimate exposure from incidental sediment ingestion; and (2) to model chemical concentrations in benthic invertebrates, the preferred prey of the Common Snipe.

Surface Water: Surface water samples were collected from multiple locations in Red Devil Creek for the RI/FS in the summer of 2010. These data will be used to estimate exposure point concentrations in surface water for use in the wildlife risk evaluation. If possible, based on the number of detects and data distribution, ProUCL software version 4.1 will be used to calculate a UCL on the average concentration for chemicals in surface water. If not, the maximum detected concentration will be used as the EPC.

Terrestrial Plants: Green alder bark, white spruce needles, blueberry fruit, and blueberry stems and leaves will be collected from the site and background area in summer 2011 to support the exposure assessment for the beaver, Spruce grouse, and tundra vole. The samples will be analyzed for TAL metals, methylmercury, and arsenic speciation. A technical memorandum describing the plant sampling approach and how the resulting data will be used in the ERA is attached to this RAWP. A draft version of the memorandum was reviewed by the EPA and ADEC in June 2011 and revisions were made based on agency comments. Total mercury and methylmercury were measured historically in several terrestrial plant species from the RDM site (Bailey and Gray 1997; Bailey et al. 2002), but because the data are greater than 10 years old, they will not be used quantitatively in the ERA.

Soil Invertebrates: No data on levels of site-related chemicals in soil invertebrates are available for the site. Therefore, chemical concentrations in soil invertebrates will be modeled using uptake factors and equations from the EPA (2005i), Sample at al. (1998b), and/or other sources (see Table 4-4). The modeled concentrations will be used to estimate dietary exposure for the American robin and masked shrew.

Small Mammals: No data on levels of site-related chemicals in small mammals are available for the site. Therefore, chemical concentrations in small mammals will be modeled using uptake factors and equations from the EPA (2005i), Sample et al. (1998a), and/or other sources (see Table 4-4). The modeled concentrations will be used to estimate dietary exposure for the least weasel and Northern shrike.

Benthic Invertebrates: In 2010, the BLM conducted a study of the Kuskokwim River, Red Devil Creek, and other tributaries to the Kuskokwim River near the RDM site. As part of this study, benthic invertebrate samples were collected for chemical analysis. Six composite samples of mayflies were collected from Red Devil Creek and analyzed for methylmercury (Varner, M. 2011). Methylmercury in the Red Devil Creek samples ranged from 23 to 131 µg/kg wet weight. Methylmercury in benthic invertebrate samples from nearby reference creeks was 2 to 10 times lower than in Red Devil Creek. These data will be used to estimate dietary exposure to methylmercury for the Common snipe. For metals not analyzed by the BLM, levels in benthic invertebrates will be modeled using the bioaccumulation factors and equations from Bechtel Jacobs (1998b) and/or other sources (see Table 4-6).

Table 4-4 Uptake Equations for Metals into Plants, Soil Invertebrates, and Small Mammals (from EPA 2005i with modifications)

	Soil to Plants		Soil to Earthworms		Soil or Diet to Small Mammals	
Analyte	**Equation**	**Source**	**Equation**	**Source**	**Equation**	**Source**
Antimony	$\ln(C_p) = 0.938 * \ln(C_s) – 3.233$	a	$C_e = C_s$	g	$C_m = 0.00 1 * 50 * Cd$	f
Arsenic	$C_p = 0.03752 * C_s$	b	$\ln(C_e) = 0.706 * \ln(C_s) – 1.421$	e	$\ln(C_m) = 0.8188 * \ln(C_s) – 4.8471$	d
Barium	$C_p = 0.156 * C_s$	b	$C_e = 0.091 * C_s$	c	$C_m = 0.00015 * 50 * Cd$	f
Beryllium	$\ln(C_p) = 0.7345 * \ln(C_s) – 0.536 1$	h	$C_e = 0.045 * C_s$	c	$C_m = 0.00 1 * 50 * Cd$	f
Cadmium	$\ln(C_p) = 0.546 * \ln(C_s) – 0.475$	b	$\ln(C_e) = 0.795 * \ln(C_s) + 2.114$	e	$\ln(C_m) = 0.4723 * \ln(C_s) – 1.2571$	d
Chromium	$C_p = 0.04 1 * C_s$	b	$C_e = 0.306 * C_s$	e	$\ln(C_m) = 0.7338 * \ln(C_s) – 1.4599$	d
Cobalt	$C_p = 0.0075 * C_s$	b	$C_e = 0.122 * C_s$	c	$\ln(C_m) = 1.307 * \ln(C_s) – 4.4669$	d
Copper	$\ln(C_p) = 0.394 * \ln(C_s) + 0.668$	b	$C_e = 0.5 15 * C_s$	e	$\ln(C_m) = 0.1444 * \ln(C_s) + 2.042$	d
Lead	$\ln(C_p) = 0.561 * \ln(C_s) – 1.328$	b	$\ln(C_e) = 0.807 * \ln(C_s) – 0.218$	e	$\ln(C_m) = 0.4422 * \ln(C_s)+0.0761$	d
Manganese	$C_p = 0.079 * C_s$	b	$\ln(C_e) = 0.682 * \ln(C_s) – 0.809$	e	$C_m = 0.0205 * C_s$	d
Mercury	$\ln(C_p) = 0.544 * \ln(C_s) – 0.996$	b	$\ln(C_e) = 0.118 * \ln(C_s) – 0.684$	c	$C_m = 0.25 * 50 * Cd$	f
Methylmercury	USGS plant data	h	USGS plant data * FCM (3)	i	USGS plant data * FCM (3)	i
Nickel	$\ln(C_p) = 0.748 * \ln(C_s) – 2.223$	b	$C_e = 1.059 * C_s$	e	$\ln(C_m) = 0.4658 * \ln(C_s) – 0.2462$	d
Selenium	$\ln(C_p) = 1.104 * \ln(C_s) – 0.677$	b	$\ln(C_e) = 0.733 * \ln(C_s) – 0.075$	e	$\ln(C_m) = 0.3764 * \ln(C_s) – 0.4158$	d
Silver	$C_p = 0.014 * C_s$	b	$C_e = 2.045 * C_s$	c	$C_m = 0.004 * C_s$	d
Vanadium	$C_p = 0.00485 * C_s$	b	$C_e = 0.042 * C_s$	c	$C_m = 0.0123 * C_s$	d
Zinc	$\ln(C_p) = 0.554 * \ln(C_s) + 1.575$	b	$\ln(C_e) = 0.328 * \ln(C_s) + 4.449$	e	$\ln(C_m) = 0.0706 * \ln(C_s) + 4.3632$	d

Notes:

a. Regression from measured data (EPA 2005i).
b. Bechtel Jacobs 1998a.
c. Sample et al. 1998b.
d. Sample et al. 1998a.
e. Sample et al. 1999.
f. Baes et al. 1984 for beef cattle.
g. Regression from measured data (EPA 2005i).
h. Bailey et al. (2002) and Bailey and Gray (1997).
i. Professional judgment based on McGeer et al. (2004)

Key:

C_s = Concentration in soil (mg/kg)
C p = Concentration in plant tissue (mg/kg dry weight)
C_e = Concentration in earthworm (mg/kg dry weight)
C_m = Concentration in small mammal tissue (mg/kg dry weight)
Cd = Concentration in diet (mg/kg dry weight) where small mammal diet is assumed to be 100% earthworms
FMC = food chain multiplier
n.a. = not available

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Forage Fish: In 2010, the BLM conducted a study of the Kuskokwim River, Red Devil Creek, and other tributaries to the Kuskokwim River near the RDM site. Forage fish and game fish were collected and analyzed for site-related chemicals. Between June and October 2010, the BLM collected 24 slimy sculpin (*Cottus cognatus*, 3 to 4 inches total length), 11 juvenile Dolly Varden (*Salvelinus mama Walbaum*, less than 6 inches total length), 1 juvenile Chinook salmon (*Oncorhynchus tshawytscha*, 8 cm total length), and 2 small unidentified salmonids (8 to 11 cm total length) from Red Devil Creek (Varner, M. 2011). A summary of the Red Devil Creek fish data for antimony, arsenic, mercury, and methylmercury for samples collected in August 2010 is provided in Table 4-5. Based on E & E's preliminary review of the BLM 2010 fish database, the levels of antimony, arsenic, mercury, and methylmercury in fish from Red Devil Creek are at least an order of magnitude greater than in nearby creeks. Because the slimy sculpin has a small home range, those collected from Red Devil Creek likely have spent most of their life in the creek or in the Kuskokwim River near the creek's mouth. The Dolly Varden and Chinook are more mobile and therefore attributing contaminants in these species to the RDM site is problematic because the fish only use Red Devil Creek seasonally. E & E proposes to use the BLM data for sculpin to estimate EPCs for the Kingfisher and mink (see Table 4-6). A complete summary of the BLM fish data for Red Devil Creek and nearby reference creeks will be provided in the risk assessment report.

Table 4-5 Summary of August 2010 Red Devil Creek Fish Data for Selected Metals

Parameter	Units	Species, Sample Size, and Concentration Range					
		Sculpin	n	Dolly Varden	n	Chinook	n
Antimony	mg/kg wet	6.5 - 38	12	2.2 - 68	8	1.7	1
Arsenic	mg/kg wet	6.8 - 24	12	2.2 - 35	8	7.0	1
Mercury	mg/kg wet	0.68 - 3.7	12	0.30 - 1.6	8	0.45	1
Methylmercury	mg/kg wet	0.16	1	0.19	1	0.20	1

Source: Varner, M. 2011

Predatory Fish: If it is determined that mink are consuming larger predatory fish from Red Devil Creek, then E & E will use the sculpin data to estimate metals concentrations in the predatory fish. For methylmercury, a food-chain multiplier (FMC) of three will be assumed to account for biomagnification (i.e., the predatory fish concentration of methylmercury will be set equal to three times the concentration in sculpin) (see Table 4-6). This approach is supported by the fact that biomagnification of methylmercury typically is three-fold with each trophic transfer (McGeer et al. 2004). For inorganic mercury and other metals, an FMC of one will be assumed. This approach is defensible because biomagnification of metals (other than methylmercury) in aquatic organisms is rare. In fact, an inverse relationship has been shown for trophic transfer of metals (except methylmercury) via the diet—that is, concentrations decrease from one trophic level to the next (McGeer et al. 2004). Hence, use of an FCM of one for inorganic mercury and other metals is conservative. This modeling approach can be extended to multiple trophic transfers if need be.

For example, if predatory fish from Red Devil Creek are two trophic levels above the sculpin, then the sculpin methylmercury concentration will be multiplied by 9 (3 x 3) to estimate the methylmercury concentration in the predatory fish. However, it should be noted that the BLM observed no large predatory fish in Red Devil Creek during their sampling work there in 2010, probably due to the creek's small size. Hence, is seems unlikely that using the sculpin data to model metals concentrations in larger predatory fish will be necessary for the ERA.

Table 4-6 Data Sources and Modeling Approaches for Aquatic Biota.

Analyte	Sediment to Benthic Invertebrate[a]	Forage Fish Concentration[b]	Predatory Game Fish Concentration[c]
Antimony	n.a.	Sculpin Concentration	Sculpin Concentration x FCM (1)
Arsenic	$\log C_b = 0.754 * C_s – 0.292$	Sculpin Concentration	Sculpin Concentration x FCM (1)
Barium	n.a.	Sculpin Concentration	Sculpin Concentration x FCM (1)
Beryllium	n.a.	Sculpin Concentration	Sculpin Concentration x FCM (1)
Boron	n.a.	Sculpin Concentration	Sculpin Concentration x FCM (1)
Cadmium	$\log C_b = 0.692 * C_s + 0.0395$	Sculpin Concentration	Sculpin Concentration x FCM (1)
Chromium	$\log C_b = 0.365 * C_s + 0.2092$	Sculpin Concentration	Sculpin Concentration x FCM (1)
Copper	$\log C_b = 0.278 * C_s + 1.089$	Sculpin Concentration	Sculpin Concentration x FCM (1)
Lead	$\log C_b = 0.801 * C_s – 0.776$	Sculpin Concentration	Sculpin Concentration x FCM (1)
Manganese	n.a.	Sculpin Concentration	Sculpin Concentration x FCM (1)
Mercury	$\log C_b = 0.327 * C_s – 0.67$	Sculpin Concentration	Sculpin Concentration x FCM (1)
Methylmercury	Mayfly Concentration	Sculpin Concentration	Sculpin Concentration x FCM (3)
Molybdenum	n.a.	Sculpin Concentration	Sculpin Concentration x FCM (1)
Nickel	$\log C_b = -0.425 * C_s + 1.48$	Sculpin Concentration	Sculpin Concentration x FCM (1)
Selenium	n.a.	Sculpin Concentration	Sculpin Concentration x FCM (1)
Strontium	n.a.	Sculpin Concentration	Sculpin Concentration x FCM (1)
Vanadium	n.a.	Sculpin Concentration	Sculpin Concentration x FCM (1)
Zinc	$\log C_b = 0.208 * C_s + 1.80$	Sculpin Concentration	Sculpin Concentration x FCM (1)

Notes:

[a] BLM benthic invertebrate samples from Red Devil Creek will be used for mercury and methylmercury. Six composite mayfly samples were collected in 2010. For other metals, biota-sediment accumulation factors and equations from Bechtel Jacobs (1998b) will be used to estimate metals concentrations in benthic invertebrates.

[b] The BLM collected 24 sculpin (3-4 inches total length) samples from Red Devil Creek in 2010.

[c] Metal concentration in predatory fish based on forage fish (sculpin) concentration times food chain multiplier (FCM) (3 for methylmercury and 1 for inorganic mercury and other metals).

Key:

BLM = Bureau of Land Management.
C_b = Concentration in benthic invertebrate (mg/kg dry).
C_s = Concentration in sediment (mg/kg dry).
FCM = Food chain multiplier.
n.a. = Not available.

4.4.2.2 Toxicity Assessment

Mammalian and avian NOAELs and LOAELs for COPCs at the site will be taken from the EPA (2005a-h, 2006a, 2007a-e, 2008a), Sample et al. (1996), and/or the scientific literature. Priority will be given to NOAELs and LOAELs from the EPA because the values from these sources are based on a recent, comprehensive review of the available literature. The NOAELs and LOAELs proposed for use in the Red Devil Mine ERA are listed in Table 4-7.

4.4.2.3 Risk Characterization

The potential risks posed by site-related chemicals will be determined by calculating a hazard quotient (HQ) for each contaminant for each endpoint species. The HQ will be calculated by dividing the total exposure (EE_{total}) by the appropriate toxicity reference value (TRV), as shown in the following equation:

$$HQ = EE_{total}/TRV$$

HQs for each receptor will be calculated based on both the NOAEL and the LOAEL. For a given receptor and chemical, an HQ_{NOAEL} greater than 1 indicates that the estimated exposure exceeds the highest dose at which no adverse effect was observed. An HQ_{LOAEL} greater than 1 suggests that a chronic adverse effect is possible to an individual receptor, assuming that the estimated exposure for that receptor is accurate.

4.4.3 Uncertainty Evaluation

The final analysis in the ERA will be a discussion of uncertainties and possible effects these uncertainties have on interpretation and reliability of the risk results. For example, because most soil benchmarks for effects on plants and soil invertebrates were developed from studies done with temperate-zone species in agricultural soils, there is uncertainty associated with using them to predict possible adverse effects to species at mine sites in Alaska. Little is also known about the concentrations of site-related chemicals in terrestrial plants, soil invertebrates, and small mammals at the site. A review of previous site investigations found only mercury and methylmercury data for terrestrial plants, but no data for other metals in plants and no data for soil invertebrates and small mammals. To address this data gap for terrestrial plants, plant samples will be collected from the site and a background area, and analyzed for TAL metals, methylmercury, and arsenic speciation (see Section 4.4.2.1 and the attached technical memorandum for details). Modeling will be used to address this data gap for soil invertebrates and small mammals, but the available models (see Table 4-5) are conservative in nature and are likely to overestimate the actual concentrations of metals in these organism groups at the site. The degree of possible risk overestimation for wildlife will be described. Another notable source of uncertainty that will be discussed is the bioavailable fraction of total metals in soil and sediment. Lastly, the uncertainty evaluation will compare site with background risks to place the site risks in context.

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Table 4-7 Toxicity Reference Values for Birds and Mammals

Analyte	Wildlife Class	NOAEL (mg/kg-day)	Critical Effect	LOAEL (mg/kg-day)	Critical Effect	Reference and Comments
Antimony	Birds	n.a.	n.a.	n.a.	n.a.	n.a.
	Mammals	0.059	Reproduction	0.59	Reproduction	EPA (2005h). Highest bounded NOAEL (0.059 mg/kg-day) for growth or reproduction below lowest bounded LOAEL (0.59 mg/kg-day) for growth or reproduction from 20 laboratory toxicity studies.
Arsenic	Birds	2.24	Reproduction	3.55	Growth	EPA (2005a). Lowest NOAEL for growth, reproduction, or survival from nine laboratory toxicity studies. Lowest LOAEL for growth, reproduction, or survival greater than selected NOAEL.
	Mammals	1.04	Growth	1.66	Growth	EPA (2005a). Highest bounded NOAEL for growth, reproduction, or survival less than lowest bounded LOAEL for growth, reproduction, or survival from 62 laboratory toxicity studies.
Barium	Birds	20.8	Survival	41.7	Survival	Sample et al. (1996).
	Mammals	51.8	Reproduction, Growth, and Survival	121	Growth and Survival	EPA (2005b). Geometric mean NOAEL for growth, reproduction, and survival from 12 laboratory toxicity studies. Lowest bounded LOAEL for reproduction, growth, or survival greater than geometric mean NOAEL.
Beryllium	Birds	n.a.	n.a.	n.a.	n.a.	n.a.
	Mammals	0.532	Survival	n.a.	n.a.	EPA (2005c). Lowest NOAEL for growth, reproduction, or survival from four laboratory toxicity studies.
Cadmium	Birds	1.47	Reproduction, Growth, and Survival	2.37	Reproduction	EPA (2005d). Geometric mean NOAEL for growth, reproduction, and survival from 49 laboratory toxicity studies. Lowest bounded LOAEL for growth, reproduction, or survival greater than geometric mean NOAEL.
	Mammals	0.77	Growth	1	Growth	EPA (2005d). Highest bounded NOAEL (0.77 mg/kg-d) for reproduction, growth, or survival less than the lowest bounded LOAEL (1.0 mg/kg-d) from 141 laboratory toxicity studies.
Chromium	Birds	2.66	Reproduction, Growth, and Survival	2.78	Survival	EPA (2008a). Geometric mean NOAEL for growth, reproduction, and survival from 17 laboratory toxicity studies. Lowest bounded LOAEL for reproduction, growth, or survival greater than geometric mean NOAEL.
	Mammals	9.24	Reproduction and Growth	n.a.	n.a.	EPA (2008a). Geometric mean NOAEL for reproduction and growth from 10 studies with trivalent chromium.
Cobalt	Birds	7.61	Growth	7.8	Growth	EPA (2005e). Geometric mean NOAEL for growth from 10 toxicity studies. Lowest bounded LOAEL for growth or reproduction greater than geometric mean NOAEL.
	Mammals	7.33	Reproduction and Growth	10.9	Reproduction	EPA (2005e). Geometric mean NOAEL for reproduction and growth based on 21 laboratory toxicity studies. Lowest bounded LOAEL for growth or reproduction greater than geometric mean NOAEL.

Table 4-7 Toxicity Reference Values for Birds and Mammals

Analyte	Wildlife Class	NOAEL (mg/kg-day)	Critical Effect	LOAEL (mg/kg-day)	Critical Effect	Reference and Comments
Copper	Birds	4.05	Reproduction	4.68	Growth	EPA (2007a). Highest bounded NOAEL for reproduction, growth, or survival (4.05 mg/kg-day) lower than the lowest bounded LOAEL for reproduction, growth, or survival (4.68 mg/kg-day).
	Mammals	5.6	Reproduction	6.79	Growth	EPA (2007a). Highest bounded NOAEL for reproduction, growth, or survival (5.6 mg/kg-day) lower than the lowest bounded LOAEL for reproduction, growth, or survival (6.79 mg/kg-day).
Lead	Birds	1.63	Reproduction	1.94	Reproduction	EPA (2005f). Highest bounded NOAEL (1.63 mg/kg-day) for growth, reproduction, or survival lower than the lowest bounded LOAEL (1.94 mg/kg-day) for growth, reproduction, or survival based on 57 laboratory toxicity studies.
	Mammals	4.7	Growth	5	Growth	EPA (2005f). Highest bounded NOAEL (4.7 mg/kg-day) for growth, reproduction, or survival lower than the lowest bounded LOAEL (5 mg/kg-day) for growth, reproduction, or survival based on 220 laboratory toxicity studies.
Manganese	Birds	179	Reproduction and Growth	348	Growth	EPA (2007b). Geometric mean NOAEL for reproduction and growth. Lowest bounded LOAEL for reproduction or growth greater than geometric mean NOAEL.
	Mammals	51.5	Reproduction and Growth	65	Growth	EPA (2007b). Geometric mean NOAEL for reproduction and growth. Lowest bounded LOAEL for reproduction or growth greater than geometric mean NOAEL.
Mercury	Birds	0.45	Reproduction	0.9	Reproduction	Sample et al. (1996).
	Mammals	13.2	Reproduction and Survival	n.a.	n.a.	Sample et al. (1996).
Methylmercury	Birds	0.068	Reproduction	0.37	Reproduction	CH2MHILL (2000).
	Mammals	0.032	Reproduction	0.16	Reproduction	CH2MHILL (2000).
Nickel	Birds	6.71	Growth and Survival	11.5	Growth	EPA (2007c). Geometric mean NOAEL for reproduction and growth. Lowest bounded LOAEL for reproduction or growth greater than geometric mean NOAEL.
	Mammals	1.7	Reproduction	2.71	Reproduction	EPA (2007c). Highest bounded NOAEL for reproduction, growth, or survival below lowest bounded LOAEL for reproduction, growth, or survival.
Selenium	Birds	0.291	Survival	0.368	Reproduction	EPA (2007d). Highest bounded NOAEL for reproduction, growth, or survival below lowest bounded LOAEL for reproduction, growth, or survival.
	Mammals	0.143	Growth	0.145	Reproduction	EPA (2007d). Highest bounded NOAEL for reproduction, growth, or survival below lowest bounded LOAEL for reproduction, growth, or survival.
Silver	Birds	2.02	Growth	20.2	Growth	EPA (2006a). Lowest LOAEL for reproduction or growth divided by 10.
	Mammals	6.02	Growth	60.2	Growth	EPA (2006a). Lowest LOAEL for reproduction or growth divided by 10.
Thallium	Birds	n.a.	n.a.	n.a.	n.a.	n.a.
	Mammals	0.0074	Reproduction	0.074	Reproduction	Sample et al. (1996).

Table 4-7 Toxicity Reference Values for Birds and Mammals

Analyte	Wildlife Class	NOAEL (mg/kg-day)	Critical Effect	LOAEL (mg/kg-day)	Critical Effect	Reference and Comments
Vanadium	Birds	0.344	Growth	0.413	Reproduction	EPA (2005g). Highest bounded NOAEL (0.344 mg/kg-day) for growth, reproduction, or survival less than lowest bounded LOAEL (0.413 mg/kg-day) for reproduction, growth, or survival based on 94 laboratory toxicity studies.
	Mammals	4.16	Reproduction and Growth	5.11	Growth	EPA (2005g). Highest bounded NOAEL (4.16 mg/kg-day) for growth or reproduction less than lowest bounded LOAEL (5.11 mg/kg-day) for growth, reproduction, or survival based on 94 laboratory toxicity studies.
Zinc	Birds	66.1	Reproduction and Growth	66.5	Reproduction	EPA (2007e). Geometric mean NOAEL for reproduction and growth. Lowest bounded LOAEL for reproduction or growth greater than geometric mean NOAEL.
	Mammals	75.4	Reproduction and Growth	75.9	Reproduction	EPA (2007e). Geometric mean NOAEL for reproduction and growth. Lowest bounded LOAEL for reproduction or growth greater than geometric mean NOAEL.

Key:
LOAEL = lowest observed adverse effect level
mg/kg-day = milligrams per kilogram per day
n.a. = not available
NOAEL = no observed adverse effect level

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5 Data Gap Analysis

The difficulty associated with conducting site investigations in remote areas of Interior Alaska and the need to complete the RI/FS for the Red Devil Mine site in a timely manner resulted in some data gaps going unaddressed by the RI sampling as well as deviations from some risk assessment process guidelines. Notable shortcomings within the RAWP and larger RI/FS Work Plan affecting the HHRA and ERA processes for the site are identified below.

5.1 Human Health Risk Assessment Process

Site harvest and consumption data has not yet been collected or reported (see Section 3.3.2.5). The ADF&G and Alaska Department of Health and Social Services survey will be used to determine the FI and food intake rates used in the HHRA. Exposure factors for the residential and recreational visitor/subsistence user will be proposed in a technical memorandum to be provided prior to development of the risk assessment and are not included in this work plan.

The survey data mentioned above will also identify subsistence resources used by the local communities. Local fish and vegetation (i.e., blueberries) will be collected at the site and be used to determine COPC concentrations in these food items. COPC concentration in wild game will be modeled based on plant and soil data. No wild game tissue will be analyzed. If potential risks from consumption of wild game are at an unacceptable level at the site and are too uncertain to allow a confident risk management decision to be made, then additional field sampling to better define these site risks will be investigated and may be implemented in 2012.

5.2 Ecological Risk Assessment Process

5.2.1 Delayed Screening Level Ecological Risk Assessment

For the reasons given below, a SLERA was not completed for the site using existing site data as part of RI/FS Work Plan development.

- A risk evaluation conducted previously by the BLM (2001) clearly indicated that potential risks may exist at the site for several ecological receptor groups due to arsenic, antimony, mercury, and perhaps lead and DRO. Hence, it was known based on BLM (2001) that additional ERA work was needed to better define site risks from these chemicals.

- Previous site investigations analyzed environmental media only for the chemicals suspected of being present at elevated levels at the site; namely arsenic, antimony, mercury, lead, and DRO. No historical data are available for other metals and organic chemicals. Hence, it was not possible to determine from data that existed prior to this RI if the COPC list identified by the BLM (2001) was complete.

- Samples being collected for this RI are being analyzed for a wide range of analytes, including TAL metals, methylmercury, arsenic speciation, SVOCs, and polychlorinated biphenyls s. As a result, it was decided that it was necessary to use the RI sample data to conduct a definitive SLERA for the site. A SLERA completed using only historical sample data would need to be redone using RI sample data to be certain that no COPCs were overlooked.

In their comments on the draft version of this RAWP, the EPA commented on the need to complete a SLERA for agency review to allow for the necessary scientific-management decisions to be made before the baseline ERA for the site is initiated. To satisfy this request, it was agreed that a SLERA will be conducted using RI sample data and provided to the agencies for review and comment. The primary objective of the SLERA will be to identify COPCs to carry forward into the baseline ERA.

5.2.2 Addressing Unresolved Data Gaps

Several data gaps will remain following the RI field investigation. In particular, no data are being collected on the following: (1) chemical concentrations in soil invertebrates; (2) chemical concentrations in small mammals; (3) direct measures of soil toxicity to terrestrial plants; (4) direct measures of sediment toxicity to benthic invertebrates; and (5) direct measures of surface water toxicity to fish and other aquatic life. Hence, it is possible that potential risks to several ecological receptor groups will be too uncertain to allow a confident risk management decision to be made. If so, then additional field sampling to better define ecological risks at the site may be implemented in 2012. Such sampling may include collection of soil invertebrates and/or small mammals for chemical analysis and/or collection of sediment, soil, and/or surface water for bioassays with laboratory-reared organisms to provide direct evidence of toxicity, or lack thereof, of environmental media at the site.

6 Development of Risk-Based Cleanup Levels

6.1 Human Health Risk-Based Cleanup Levels

Preliminary alternative risk-based cleanup levels (RBCLs) will be developed in the HHRA for compounds of concern (COCs) (those COPCs that exceed risk-based standards). RBCLs will be developed for each scenario and COC that exceeds a target cancer risk of 1 in 100,000 (10^{-5}) and an HI of 1.0. Developing RBCLs for each scenario will provide a range of RBCLs based on future land use and will assist in risk management decisions at the site, including determination of remedial action objectives.

RBCLs will be developed using the exposure equations and parameters identified in the HHRA and back-calculating a target concentration in each individual media. Alternative RBCLs will be adjusted to ensure the cumulative risk and hazard at the site do not exceed a target excess cancer risk of 1 in 100,000 (10^{-5}) or an HI of 1.0.

If lead is determined to be a COC in soil at the site, RBCLs will be determined using the IEUBK model and ALM using a target blood lead level of 10 ug/dL or ADEC's lead cleanup levels (400 mg/kg for residential land use and 800 mg/kg for commercial and industrial land use).

Generally, cleanup levels are not set at concentrations below natural background levels (EPA 2010d). If RBCLs exceed background levels, preliminary cleanup levels will default to background concentrations as determined in Section 3.5.3.

6.2 Ecological Risk-Based Cleanup Levels

The ERA will provide details on which chemicals in each media contribute to risk. Ultimately, this information may be used to derive ecological RBCLs for soil, sediment, and/or surface water to protect wildlife and/or other assessment endpoints. The RBCLs will be calculated using the same screening values, equations, and input parameters used in the ERA, but by running the exposure and risk characterization equations in reverse. For example, if it is determined that a small mammal (shrew) or songbird (robin) is the receptor most at risk, a soil RBCL based on one or more target risk levels (e.g., HQ_{NOAEL} and/or $HQ_{LOAEL} = 1$) may be calculated for the chemical that poses the risk. Ecological RBCLs will be compared with site-specific background levels and the greater of the two values will be used to guide remedial decisions.

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Attachment A Revised Vegetation Sampling Approach

TECHNICAL MEMORANDUM

Revised Vegetation Sampling Approach for the Red Devil Mine Site, Alaska
Prepared by Ecology and Environment, Inc. for the Bureau of Land Management
21 June 2011

Ecology and Environment, Inc. (E&E) has prepared this technical memorandum at the request of the U.S. Department of the Interior Bureau of Land Management (BLM), Anchorage Field Office, Anchorage, Alaska to address comments provided by the U.S. Environmental Protection Agency (EPA) and Alaska Department of Environmental Conservation (ADEC) on the Remedial Investigation/Feasibility Study (RI/FS) Work Plan for the Red Devil Mine Site, Alaska (E & E 2011). Specifically, this memorandum outlines an approach for sampling of edible berries and other plant tissues from the site. The resulting data will be used in the site-specific human health and ecological risk assessments. Using measured rather than modeled plant chemical concentrations in the risk assessments is expected to reduce uncertainty in estimating exposure from consumption of plants from the site. The proposed approach is discussed under seven main headings: (1) Target Species and Tissues; (2) Sample Collection and Handling; (3) Numbers of Samples; (4) Sampling Locations; (5) Target Analytes and Analytical Methods; (6) Schedule; and (7) Other Risk Assessment Considerations.

1. Target Species and Tissues

E & E proposes collecting tissues of green alder (*Alnus crispa*), white spruce (*Picea glauca*) and blueberry (*Vaccinium uliginosum*) to support the human health and ecological risk assessments for the Red Devil Mine site (see Table 1). These species were collected previously from the site by Bailey and Gray (1997) and thus are expected to be present in collectable quantities during the 2011 field season.

Table 1. Target Plant Species for Metals Analysis, Red Devil Mine Site, Alaska.

Target Species	Target Tissue	Risk Assessment Use
Green alder (*Alnus crispa*)	Bark	Beaver scenario
White spruce (*Picea glauca*)	Needles	Herbivorous bird (Spruce grouse) scenario.
Blueberry (*Vaccinium uliginosum*)	Fruit	Human health risk assessment.
	Leaves and stems	Herbivorous mammal (vole) scenario.

Harvest and consumption surveys of the area are being conducted and/or analyzed by Alaska Department of Fish and Game and the Department of Health and Social Services, although results are not presently available. The only consumption or harvest data currently available for the area is from Ballew et al. (2004). Ballew et al. (2004) conducted a 12-month recall consumption survey in 13 villages throughout Alaska. The regional health corporation serving the village of Red Devil is Yukon-Kuskokwim Health Corporation (YKHC) (Alaska Community Database 2010). Four villages from the YKHC region are represented in the Ballew et al. report, although the names of the specific villages are not provided. Crowberries, lowbush salmonberries, and blueberries were identified as local plants or berries in the top 50 foods reported by the participants as being consumed in the YKHC region. Based on discussions with Larry Beck of BLM (Beck 2011) and Gail Vanderpool at the Red Devil B&B and Hotel (Vanderpool 2011), blueberries are readily available in the sunny and open slope areas and are most plentiful in August. Crowberries had been seen by BLM personnel growing on the slope uphill from the Dolly Shaft in or around the blueberry bushes some year ago but not since. Other types of berries have not been identified near the site (Beck 2011). For these reasons, blueberries (fruit) were targeted for collection and use in the human health risk assessment.

The target plant species and tissues recommended for collection (see Table 1) are intended to provide data for estimating exposure for common herbivorous wildlife species that use the site, including the beaver, Spruce grouse, and vole. The beaver feeds extensive on the bark of trees such as alder, birch, willow, and popular. The Spruce grouse feeds extensively on needles of coniferous trees such as spruce and pine. Voles consume many different types of herbaceous plants.

2. Sample Collection and Handling

Samples will be collected by gloved hand with the aid of a stainless steel blade or scissors if necessary and placed into food-grade plastic bags with zip closures. New gloves will be used for each sample and sampling equipment will be decontaminated between samples. Composite samples will be collected; that is, plant tissues from multiple (two to five) individual plants will be combined into a single sample until the minimum required sample mass (50 to 100 grams fresh weight) is reached. The minimum required sample mass will be verified with the contract laboratory. One composite duplicate sample each of green alder bark, White spruce needles, blueberry fruit, and blueberry stems and leaves will be collected. The field duplicate sample will be taken from the sample plants that the routine sample is collected from.

The plant tissue samples will be stored and shipped on ice (approximately 4°C). Samples will be analyzed unwashed. Loosely adhering external contamination, if present, will be shaken off in the field. If the plant samples cannot be analyzed immediately after receipt by the laboratory, they will be stored frozen.

If collection of new surface soils samples becomes necessary (see Section 4), E & E will follow the soil sample collection methods presented in Appendix A (Field Sampling Plan [FSP]) of the RI/FS Work Plan for the site (E & E 2011). The target depth range for new surface soil samples will be 0 to 6 inches beneath any surface vegetation and/or leaf-litter layer.

3. Numbers of Samples

For each target plant species and tissue type, eight background and eight site composite samples will be collected. This sample size will be adequate to detect a 50% increase over background with a statistical power and confidence of 90%, assuming a coefficient of variation (CV) of 50% (see Table 2). The CV for total mercury in plant tissues collected previously from the site were: White spruce needles, 49%; blueberry leaves, 41%; blueberry stems 42%, and blueberry fruit 41% (Bailey and Gray 1997). A sample size of eight also should be adequately large to allow calculation of an upper confidence level (UCL) on the average concentration using ProUCL software.

Table 2. Relationship between Measures of Statistical Performance and Sample Size.

Coefficient of Variation (%)	Power (%)	Confidence Level (%)	Number of samples required to identify differences of 30%, 50%, and 100% over background		
			30%	50%	100%
10	90	90	2	1	0
20	90	90	4	2	1
30	90	90	8	4	1
40	90	90	14	6	2
50	90	90	20	**8**	3
60	90	90	28	11	4
70	90	90	38	15	5
80	90	90	49	19	6

Table 2. Relationship between Measures of Statistical Performance and Sample Size.

Coefficient of Variation (%)	Power (%)	Confidence Level (%)	Number of samples required to identify differences of 30%, 50%, and 100% over background		
			30%	50%	100%
90	90	90	61	23	7
Notes:					
1. Based on EPA (1989, 1992).					
2. One tailed t-test, site versus background.					
3. Shaded cell is target sample size.					

The power analysis described in this section assumes a normal data distribution. E & E reviewed the total mercury data for alder leaves; White spruce needles; and blueberry leaves, stems, and fruit provided in Bailey and Gray (1997). When log transformed, these data sets are normally distributed.

Table 3 summarizes lists the number of samples that will be collected from the site and background area.

Table 3. Number of Plant Samples for Metals Analysis, Red Devil Mine Site, Alaska.

Target Species	Target Tissue	Number of Samples			
		Site	Background	Field Duplicate	Total
Green alder	Bark	8	8	1	17
White spruce	Needles	8	8	1	17
Blueberry	Fruit	8	8	1	17
	Leaves and stems	8	8	1	17
Pond Vegetation	TBD	4	3	1	8
Total →		36	35	5	76

Key:
TBD = to be determined.

4. Sample Locations

As discussed with ADEC, co-located soil and plant sample data are preferred. To address this issue, E & E will revisit the 2010 surface soil sample locations and look for the target plant species within a 3 meter radius of these locations. If the target plant species is sufficiently plentiful, a composite sample will be collected. If the desired number of composite plant samples can be attained with this approach, then no new surface soil samples will be collected. If not, then the target plant species will be collected from where they are available along with a centrally located soil sample. This general approach will be used to collect both background and site plant samples. The site is defined as the main-processing area, Red Devil Creek downstream from the main-processing area, and surface-mining-disturbed area. The background area includes the area were bedrock-derived, upland background soil samples and Red Devil Creek alluvium background soil samples were collected in 2010. The Red Devil Creek background alluvium soil samples were collected along Red Devil Creek upstream from the main processing area. Figures showing plant tissue sampling locations are provided in the revised FSP. Plant sample locations will be documented by collecting Global Positioning System coordinates.

5. Target Analytes and Analytical Methods

All plant tissue samples will be analyzed for target analyte list (TAL) metals. In addition, 50% of the plant samples will be analyzed for methylmercury. Finally, 50% of the blueberry fruit samples will be analyzed for inorganic arsenic, the most toxicologically significant form of arsenic for human exposure. If additional surface soil samples are collected, they will be analyzed for the same parameters as the plant samples.

Based on experience at other sites, E & E will use EPA Method 6020A for most metals, EPA Method 7471 (cold vapor) for total mercury, EPA Method 1630 for methylmercury, and EPA Method 1632 for arsenic speciation in the plant tissue samples. For selenium, EPA Method 7742 (Atomic Absorption, Borohydride Reduction) may be used instead of Method 6020A if there are mercury interference problems (to be determined by the laboratory). A subset of each plant tissue sample will be analyzed for percent moisture by EPA Method 160.3. Metals concentrations in plant tissue samples will be reported on both a wet- and dry-weight basis. This combination of analytical methods has been used to generate plant tissue data for use in risk assessments at other sites in Alaska, such as the Red Dog Mine Site (Exponent 2004). EPA Methods 7471 and 1630 have detection limits well below the levels of total mercury and methylmercury in plants at the Red Devil Mine reported by Bailey and Gray (1997). Unfortunately, there are no data for other metals in plants at the Red Devil Mine to compare with method detection limits. However, given that the above-mentioned methods have been used successfully at other sites to generate plant tissue data for risk assessments, we posit that they are fitting for use at this site. Tables 4 and 5 summarize the number of analyses, analytical methods, and quality assurance objectives.

Table 4. Number of Plant Tissue Chemical Analyses, Red Devil Mine Site, Alaska.

Parameter	Target Species	Target Tissue	Number of Analyses			
			Site	Background	Field Duplicate	Total
TAL Metals[a]	Green alder	Bark	8	8	1	17
	White spruce	Needles	8	8	1	17
	Blueberry	Fruit	8	8	1	17
		Leaves and stems	8	8	1	17
	Pond Vegetation	TBD	4	3	1	8
Percent Moisture	Green alder	Bark	8	8	1	17
	White spruce	Needles	8	8	1	17
	Blueberry	Fruit	8	8	1	17
		Leaves and stems	8	8	1	17
	Pond Vegetation	TBD	4	3	1	8
Methylmercury	Green alder	Bark	4	4	1	9
	White spruce	Needles	4	4	1	9
	Blueberry	Fruit	4	4	1	9
		Leaves and stems	4	4	1	9
	Pond Vegetation	TBD	1	1	1	3
Arsenic Speciation	Blueberry	Fruit	4	4	1	9
		Total	93	91	16	200

Key:

TAL = Target Analyte List

TBD = To be determined.

Note: a = Aluminum, antimony, arsenic, barium, beryllium, cadmium, calcium, chromium, cobalt, copper, iron, lead, magnesium, manganese, mercury, nickel, potassium, selenium, silver, sodium, thallium, vanadium, and zinc.

6. Schedule

Vegetation samples will be collected during summer 2011 concurrent with other field activities at the site, which are scheduled to begin in July. Because early-August is generally the best time for blueberry picking at the site (Beck 2011, Vanderpool 2011), plant sampling will be conducted near the middle or end of the 2011 field work.

Table 5. Analytical Methods and Quality Assurance Objectives for Plant Sample Analysis, Red Devil Mine Site, Alaska.

Parameter	EPA Method	Analytical Accuracy	Total Precision
Arsenic Speciation	1632 modified	75-125%	±25%
Methylmercury	1630 modified	75-125%	±25%
Percent moisture	160.3	na	na
TAL Metals[a]	6020A/7471	75-125%	±25%

Key:

na = Not applicable

TAL = Target Analyte List

Note: a = Aluminum, antimony, arsenic, barium, beryllium, cadmium, calcium, chromium, cobalt, copper, iron, lead, magnesium, manganese, mercury, nickel, potassium, selenium, silver, sodium, thallium, vanadium, and zinc.

7. Other Risk Assessment Considerations

7.1 Substitution of Spruce Grouse for Dark-Eyed Junco

In the process of developing the list of target plant species and tissues, E & E reviewed the dietary preferences of herbivorous wildlife species known or likely to occur on site. This exercise leads us to recommend that the Spruce grouse be substituted for the Dark-eyed junco as a representative herbivorous bird for the environmental risk assessment (ERA). There are several reasons for this recommendation:

1. The Spruce grouse is a year-round resident whereas the Dark-eyed junco is migratory, spending only the summer months at the site. Hence, a herbivorous-bird scenario featuring the Spruce grouse is more conservative than a scenario featuring the Dark-eyed junco.

2. The Spruce grouse is mostly vegetarian, whereas the Dark-eyed junco feeds heavily on invertebrates during the summer breeding season (Kaufman 1996). Hence, the Spruce grouse is a better representative receptor for the herbivorous-bird feeding guild.

3. Spruce grouse are present at the site and are heavily hunted by local residents (Beck 2011); hence, they likely have a greater societal value locally than the Dark-eyed junco.

EPA suggested that E & E consider using the common redpoll (*Cardueis flammea*) instead of the Spruce grouse because the body-weight normalized food ingestion rate of the redpoll is greater than that of the Spruce grouse given its smaller body weight. However, the difference in ingestion rates is balanced by the fact that foliage (the Spruce grouse's preferred food) typically has greater levels of contaminants than seeds (the redpoll's preferred food). Also, the Spruce grouse is expected to have a greater soil ingestion rate than the redpoll given its habit of foraging off the ground. For the Spruce grouse, E & E will use the percent soil in diet given for the wild turkey (9.3%) in Beyer et al. (1994). In contrast, for the redpoll, we likely would assume a value of between 0 and 2% soil in diet. All things considered, the Spruce grouse is not necessarily a less conservative choice for a representative herbivorous avian receptor than the redpoll, and may in fact be the more conservative choice.

7.2 Herbivorous Mammal Receptors

As requested by ADEC, a beaver scenario will be added to the ERA. Because a representative herbivorous mammal—tundra vole—is already included in the ERA, the ERA now includes two herbivorous mammal receptors. As requested by ADEC and EPA, both receptors will be evaluated in the ERA because they feed on different types of vegetation from different habitats. E & E will use metals data for blueberry stems and leaves to estimate exposure from consumption of herbaceous plants by the vole. Tundra voles prefer sedges over other herbaceous plants, but the site does not provide much open marshy habitat for sedge growth. Instead, the site is covered largely with secondary growth deciduous tress (alder, willow, popular, etc.) and conifers, with an understory of mosses, ferns, various grasses, and other herbaceous plants.

7.3 Plant Samples from Settling Ponds

As requested by ADEC, a herbivorous waterfowl scenario will be added to the ERA based on reports of signs of waterfowl use of the settling ponds. To provide site-specific data on levels of metals in plant materials from the settling ponds, E & E proposes to collect one composite sample of aquatic or semi-aquatic vegetation, if present, from each settling pond. A second sample will be collected from one of the settling ponds to provide information on within-pond variability. The target plant species will be decided at the time of sampling. We posit that only a limited number of samples are needed to characterize the settling ponds for the following reasons: (1) the ponds are small; (2) surface sediment in each pond is expected to be similar given the material discharged to the ponds (slurried mill tailings) and (3) the ponds are unlikely to be highly attractive to waterfowl because they contain water only seasonally and/or have trees growing in them. Three background pond plant samples will be collected from the reservoir upgradient from the site. The pond plant samples will be analyzes for TAL metals and methylmercury.

7.4 Other Subsistence Foods

As requested by ADEC, E & E field personnel will note the names and locations of other subsistence plants (e.g., salmonberries, crowberries) at the site. In addition to harvesting plants, residents of Red Devil Village may harvest game animals from the site. The Risk Assessment Work Plan describes a simple model developed by Baes et al. (1984) for estimating metal uptake from soil by grazing animals. As agreed to during the comment-resolution meeting, E & E will add a discussion to the RAWP to support using this model. We agree that EPA has the right to request future sampling of mammal tissues at the site based on the results of the human health risk assessment.

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