Formosa Mine Superfund Site

Douglas County, Oregon

FINAL OU1 REMEDIAL INVESTIGATION REPORT

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

Report

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Executive Summary

The Formosa Mine Superfund Site (Site) encompasses the abandoned Formosa and Silver Butte mines and portions of Upper Middle Creek and South Fork Middle Creek. These creeks are severely affected by acid rock drainage (ARD) and associated releases of contaminants of potential concern (COPCs). ARD generating mine materials are present on the surface and within the underground mine. Mine materials contain naturally enriched concentrations of COPCs such as arsenic, cadmium, copper and zinc. COPCs in source materials are associated with pyrite, a sulfide mineral that generates ARD when exposed to oxidizing conditions and percolating water. The ARD process results in dissolution of COPCs from solid mine materials, transport in surface water and groundwater, subsequent contamination of stream sediments and soil, and severe effects to the aquatic ecosystem.

The purpose of the remedial investigation (RI) is to characterize physical characteristics, nature and extent of contamination, fate and transport processes, and risks to human health and ecological receptors in sufficient detail to support the feasibility study (FS). The RI/FS process will identify the best approaches to remediate ARD and associated environmental contamination. This RI was prepared for the US Environmental Protection Agency (EPA) in accordance with the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) and associated regulations and guidance. Cooperating agencies include the US Bureau of Land Management (BLM), Oregon Department of Environmental Quality (ODEQ), and United States Geological Survey.

Introduction

The Site is located in Douglas County, Oregon, within the Coast Range Klamath Mountains at elevations ranging from 3,200 to 3,700 feet (ft) above mean sea level (amsl). Historic underground mining occurred during the 1920's and 1930's. Exploration activities occurred intermittently after historic mining, and modern mining was conducted by Formosa Exploration Inc. (FEI) during 1990 to 1993. Copper was the primary payable metal, and some gold and silver was produced as a byproduct of copper production. Reclamation was conducted by FEI and cooperating agencies during 1993 to 1994, but the reclamation was not successful in mitigating ARD generation. EPA, BLM and ODEQ have conducted ARD management activities at the Site since that time.

Previous work assessing contamination at the Site was conducted prior to and after modern mining; however, the most comprehensive work was conducted during the late 1990's and early 2000's by BLM, ODEQ, and EPA. This work demonstrated adverse effects to the environment caused by ARD generation, and supported listing of the Site on the National Priorities List in 2007. Previous work is compiled and summarized in a

Data Summary Report (CDM 2008). The previous work was used to scope the RI, prevent duplication of efforts, and focus RI investigations.

During the RI, the Site was subdivided into two operable units, Operable Unit 1 (OU1) and Operable Unit 2 (OU2). OUs are management tools used during the CERCLA process. The OUs are described as follows:

- **OU1** includes surface and subsurface mine materials and contaminated soils located outside of the underground mine workings; and
- **OU2** includes all remaining media and site contamination, including surface water, stream sediment, groundwater, underground workings, and adit water drainage.

This RI report is focused on OU1, but also describes data collected to date associated with OU2. The OU1 data are sufficient to support the OU1 FS, which is in progress. The OU2 data are useful to understand adverse effects of OU1 source materials on media included in OU2 such as surface water and groundwater.

Study Area Investigations

Two sampling and analysis plans (SAPs) were developed during the RI, SAP1 (CDM 2009) and SAP2 (CDM 2010). These SAPs define investigation activities that address both OU1 and OU2. During the course of these investigations, EPA and other cooperating agencies decided to focus RI work on OU1 to expedite Site remedial action. Some RI work was conducted that primarily addresses components of OU2 including surface water and groundwater sampling. However, additional RI work is required to fully characterize OU2 in sufficient detail to support a subsequent OU2 FS.

Investigations completed to date included:

- Geochemical characterization and spatial delineation of OU1 mine materials;
- Sampling of seeps, springs, surface water and groundwater; and
- Sampling of potentially affected and background soils.

These data were validated in accordance with EPA protocol. The data are usable for the purpose of the RI with limited exceptions as described in Section 2 of the OU1 RI report.

Physical Characteristics

Physical characteristics were assessed to support FS evaluations in accordance with CERCLA guidance. The OU1 RI evaluated physical characteristics of the following:

- Mining infrastructure, former mining facility locations and characteristics, waste rock dumps (WRDs), underground mine characteristics, adit water drainage, and reclamation;
- Climate, surface water hydrology, and groundwater hydrology; and

- Ecology, land use, and demographics.

Mining was conducted primarily by underground methods, which resulted in construction of a network of underground voids, partial backfill of underground voids with ARD generating mine materials, and placement of ARD generating mine materials on the surface. Reclamation of the mine between 1993 and 1994 included removal of former mineral processing facilities, haulage of low grade ore and tailings into the underground mine, re-grading of waste rock and other mine materials located on the surface, construction of a tailings repository in a former water storage pond (the encapsulation mound), and revegetation. Major site features include:

- **OU1 mine materials** located on the surface, which contain ARD generating source materials and cover an area of approximately 25 acres;
- The **underground mine**, which includes the underground voids and OU2 mine materials present within the voids;
- The **adit water diversion system**, which collects mining influenced water (MIW) from the Formosa 1 adit and Silver Butte 1 adits and diverts the water to an overland flow drainfield;
- **Watersheds and drainages** including Upper Middle Creek and South Fork Middle Creek, which are affected by MIW; and
- **Historic mining features** such as the former crusher, shop, milling, water and tailings storage areas, and the encapsulation mound.

Previous mine reclamation is not effectively mitigating contaminant generation and transport from the former mine into the environment. The Formosa 1 adit discharges MIW on a perennial basis, the encapsulation mound (a capped repository that stores strongly acid generating tailings and ore) is leaking to groundwater at rate estimated to be 17 percent of precipitation, and surface mine materials are generating ARD and contributing to surface water and groundwater contamination.

The Site is located in rugged mountainous terrain near the headwaters of Upper Middle Creek and South Fork Middle Creek, two perennial streams that flow from the mine area downstream to Cow Creek. Precipitation ranges from 15 to 70 inches per year in the general area, and falls primarily in the late fall and winter. Average precipitation for the area is 34.5 inches based on data from a weather station near the Site at an elevation of 3,973 ft amsl. Snow is present on an intermittent basis during winter months, and summers are characterized by mild temperatures and low precipitation. Stream flow varies seasonally in relation to precipitation patterns with highest flows occurring during late fall and winter. Groundwater discharges to surface water from alluvial and fracture-controlled bedrock aquifers in headwaters of Upper Middle Creek and South Fork Middle Creek.

Vegetation in the mine area ranges from mining-denuded areas largely devoid of vegetation to coniferous forest dominated by Douglas fir. The forest is habitat for wildlife including black bear, deer, and a variety of birds. Creeks near the site provide aquatic habitat for chinook salmon, coho salmon and other species. The northern spotted owl, a federally threatened species, has been

reported in the area, and designated critical habitat for the northern spotted owl is present in a portion of the Site. Land uses in the area are primarily logging and recreational. Land ownership includes a mixture of private lands and federal land managed by BLM.

Nature and Extent of Contamination

Evaluation of nature and extent of contamination considered:

- OU1 mine materials and soil;
- Surface water; and
- Groundwater.

OU1 Mine Materials and Soil

The Formosa Mine exploited an ore body called a volcanogenic massive sulfide, which is a natural deposit of rock that is strongly enriched in metals. The mining process exposed these rocks to surface weathering through construction of tunnels and haulage of broken rock to the surface. Mine materials such as waste rock, tailings, and mixtures of waste rock or tailings with other media are source materials for ARD generation. A primary goal of the RI was characterizing and delineating mine materials to facilitate evaluation of remedial alternatives in the FS. Mine material characteristics are summarized as follows:

- Mine materials contain elevated concentrations of metals and other COPCs.
- Mine materials are moderately to strongly ARD generating.
- As a result of the ARD generation process, metals leach from mine materials in concentrations that cause contamination of surface water and groundwater.
- The volume of mine materials in OU1 is estimated to be 317,000 cubic yards.
- It is estimated that OU1 mine materials cause generation of between 4 and 12 million gallons of ARD during an average year.
- The areal distribution of mine materials encompasses 25.7 acres, and the thickness of mine materials is relatively low with an average thickness of about 9 feet.

Potentially affected soils located down-slope from steep piles of mine materials were sampled, and metals concentrations were compared to background samples to evaluate potential COPC dispersion from mine materials into soils. The data indicate that the potentially affected soils have metals concentrations that exceed concentrations measured at the background locations. However, the potentially affected soils are located in areas that could also be affected by natural dispersion of COPCs from massive sulfide outcrops that were present prior to mining. Therefore, it is unknown if the elevated metal concentrations observed in these soils are caused by mining, natural processes, or a combination of these factors.

Two other types of mining-affected soils were identified, seep-affected soils and soils in an area of long term MIW discharge. The seep affected soils were observed in local areas where visual

evidence indicated MIW seeping slowly from the subsurface into the soils. These areas were generally located down-slope from steep mine material piles. A MIW management system called the adit water diversion system has discharged ARD to the surface over an area of approximately 0.6 acres for the last 17 years. Although this system has reduced metals loading directly to Upper Middle Creek, it has caused soil contamination in the discharge area and is likely causing adverse effects to groundwater and potentially to downstream surface water.

Surface Water

Surface water sampling was conducted to assess effects of the MIW discharge on surface water, to examine contaminant transport pathways, and to evaluate the downstream extent of effects to surface water quality. Surface water and stream sediments have not been fully characterized to date, but available data indicate the following:

- Upper Middle Creek
  - Surface water quality is strongly affected by MIW.
  - MIW discharges from groundwater to surface water upstream of a physical feature called Raymond Bear Falls – below this point, MIW is slowly diluted and COPC concentrations gradually decrease.
  - Water quality data indicates that most MIW groundwater discharging to surface water has similar characteristics to the Formosa 1 adit discharge, strongly acidic calcium-sulfate water with high concentrations of iron, copper, zinc, and other trace metals.
- South Fork Middle Creek
  - Surface water quality is also strongly affected by MIW.
  - MIW discharges from groundwater to surface water in the headwaters of South Fork Middle Creek.
  - Water quality data indicates that MIW discharging from groundwater to surface water is strongly acidic calcium-sulfate water with high concentrations of copper, zinc, and other trace metals and relatively lower iron content as compared to the Upper Middle Creek area.
- Russell Creek and West Fork Canyon Creek, north and west of the Site respectively, are not affected by the mine.
- Discernable MIW effects extend 13 miles downstream from the mine to the confluence of Middle Creek with Cow Creek.
- The Site is not causing adverse effects to drinking water quality at private and municipal intakes located downstream of the mine on Cow Creek.

Extensive accumulations of metal precipitates are present in Upper Middle Creek and South Fork Middle Creek downstream of the areas where MIW discharges from groundwater. This process

leads to attenuation of dissolved metal concentrations in surface water and accumulation of COPCs in sediments.

Groundwater

Although groundwater is not yet characterized in adequate detail to support the OU2 FS, RI activities to date have collected valuable data to understand contaminant transport pathways and demonstrate adverse effects of OU1 mine materials on groundwater quality. Alluvial and bedrock groundwater systems are present, and both groundwater systems are transporting COPCs to surface water. The alluvial groundwater system is present within discrete alluvial aquifers that are located within unconsolidated sediments in the base of tributary drainages. The bedrock aquifer is a fracture controlled aquifer hosted by metavolcanic rocks.

MIW discharging from groundwater to surface water in Upper Middle Creek appears to be primarily attributable to contaminant transport in the alluvial groundwater system. Available data suggest that leakage from the adit water diversion system at the Formosa 1 adit is recharging the alluvial aquifer, and contributing to MIW discharges from groundwater to surface water upstream from Raymond Bear Falls. Although the bedrock aquifer may also be affected in this area, data from one bedrock monitoring well suggests these effects may be minor. However, the bedrock aquifer in this area has not been fully characterized.

In contrast, the bedrock aquifer is strongly contaminated east of the encapsulation mound in the headwaters of South Fork Middle Creek. The groundwater is strongly acidic and contains high concentrations of cadmium, copper, zinc and other COPCs. The alluvial groundwater system in the headwaters area of South Fork Middle Creek is also strongly contaminated by MIW, with similar water quality to the bedrock groundwater system.

Fate and Transport

Contaminant fate and transport processes are generally understood at the Site, although this will be further defined as characterization of OU2 proceeds. Dominant contaminant fate and transport processes that are primarily applicable to OU1 include:

- Sulfide mineral oxidation, ARD generation, and dissolution of COPCs from mine materials;
- Surface runoff of MIW from mine materials into Upper Middle Creek, South Fork Middle Creek and tributary drainages;
- Contaminant transport into alluvial and/or bedrock groundwater as rain and snowmelt percolates through the mine materials and infiltrates into groundwater;
- Contaminant transport in the alluvial and bedrock groundwater systems, and subsequent discharge to surface water in Upper Middle Creek and South Fork Middle Creek; and
- Formation of metal precipitates in surface water and subsequent accumulation in stream sediments.

Acidity is the dominant control on the solubility and transport of dissolved COPCs such as cadmium, copper, iron and zinc. As MIW moves through the watershed, the acidity of the water gradually decreases in response to dilution and other processes. This results in removal of dissolved COPCs from surface water through precipitation and adsorption. However, this process also results in accumulation of COPCs in stream sediments. Once sequestered in stream sediments, these COPCs may be transported further downstream as suspended solids.

Risk Assessment

Risk assessments were conducted to understand potential risks to human and ecological receptors. The risk assessments are focused on exposure areas (EAs) associated with OU1 mine materials and potentially affected soils. These exposure areas are defined as follows:

- **EA-1** includes OU1 mine materials within the primary mine disturbance area;
- **EA -2** includes potentially affected soils located down-slope from accumulations of OU1 mine materials; and
- **EA-3** includes soils affected by the adit water diversion system.

The ecological risk assessment also evaluates MIW to understand risks to downstream aquatic organisms caused by ARD generation and subsequent discharge of MIW from OU1 into Upper Middle Creek and South Fork Middle Creek.

Human Health Risk Assessment

A baseline human health risk assessment was conducted to assess potential risks associated with direct contact, incidental ingestion, and inhalation of OU1 mine materials and soils. The risk assessment did not evaluate potential ingestion of MIW from either surface water or groundwater. Current workers, visitors, and possible offsite residents, and future construction workers, workers, visitors and offsite residents were evaluated. Visitors included trespassers, hikers, campers, ATV riders, and hunters.

The human health risk assessment evaluates potential cancer risks and non-cancer risks. Cancer risks are evaluated in terms of the likelihood that a human receptor would develop cancer as a result of exposure to contaminants within the defined exposure areas. Non-cancer risks are expressed in relation to a hazard benchmark.

Estimated cancer risks for all populations both current and future, fall within or below the EPA acceptable risk range of 10^{-4} to 10^{-6} (i.e., a likelihood of developing cancer ranging from 1 in 10,000 to 1 in 1,000,000). Risks in the various exposure areas are defined as follows:

- **EA-1**: estimated cancer risks for current onsite workers are 1E-05 or less (1 in 100,000), adult and child visitors are 4E-06 or less (1 in 250,000), and offsite residents exposed via inhalation to windblown dusts are less than 1E-06 (1 in 1,000,000). Estimated cancer risks for future construction workers are 7E-06 or less (1 in 143,000), onsite workers are 9E-06 or less (1 in 111,000), and visitors (adult and child) are 4E-06 or less (1 in 250,000), and offsite residents are less than 1E-06 (1 in 1,000,000).

- **EA-2**: Estimated cancer risks for current onsite workers are equal to 2E-06 or less (1 in 500,000), and risks for current visitors (adult and child) and offsite residents exposed via inhalation to windblown dusts are below 1E-06 (1 in 1,000,000).
- **EA-3**: Estimated cancer risks for onsite workers are equal to 6E-05 or less (1 in 17,000), for visitors (adult and child) are equal to 2E-05 or less (1 in 50,000), and for offsite residents exposed via inhalation to windblown dust are 2E-06 or less (1 in 500,000).

Non-cancer risks do not exceed a hazard benchmark of 1.0. Therefore, OU1 mine materials and soils do not pose unacceptable risks associated with the evaluated exposures.

Ecological Risk Assessment

The ecological risk assessment focused on risks to terrestrial organisms present in OU1. However, because OU1 mine materials generate MIW that is transported into Upper Middle Creek and South Fork Middle Creek (components of OU2), the ecological risk assessment also considered risks associated with MIW.

Risks to Terrestrial Organisms

The ecological risk assessment identified several COPCs that present risk to terrestrial organisms. Ecological risks are expressed in terms of a hazard quotient (HQ), with HQs of greater than 1 indicating that COPC concentrations exceed the toxicity screening values and present risk to terrestrial organisms. The HQ is defined as the ratio of the COPC concentration to the toxicity screening value. For example, a hazard quotient of 1 indicates that the COPC concentration is the same as the toxicity screening value, and a HQ of 36 indicates that the COPC concentration is 36 times higher than the toxicity screening value.

Risks to terrestrial organisms in OU1 are summarized as follows:

- **EA-1:** OU1 mine materials present risks associated with arsenic, cadmium, copper, lead, mercury, nickel, selenium, and zinc with HQs ranging from 2 to 36 for one or more ecological receptor types.
- **EA-2:** Potentially affected soils down-slope from OU1 mine materials present risks associated with cadmium, copper, manganese, and zinc with HQs ranging from 2 to 11 for one or more ecological receptor types.
- **EA-3:** Soils affected by water discharging from the adit water diversion system present risks associated with arsenic, copper, vanadium, and zinc with HQs ranging from 3 to 23 for one or more ecological receptor types.

Ecological Risks Associated with Mine Influenced Water

Prior to mining, it is thought that a diverse habitat for aquatic organisms was present in the upper reaches of Upper Middle Creek and South Fork Middle Creek. Surface water in Upper Middle Creek and South Fork Middle Creek is not included in OU1, but discharge of MIW from OU1 into Upper Middle Creek and South Fork Middle Creek causes severe adverse affects to aquatic organisms. Therefore, the ecological risk assessment also evaluated risks to aquatic organisms

associated with MIW. Contributing to these surface water-related risks are concentrations of cadmium, copper, and zinc in surface water, in most cases exceeding an HQ of 1.0 by two orders of magnitude (i.e.; hazard quotients of greater than 100). OU1 mine materials are a significant source of COPCs, which contributes to surface water contamination in Upper Middle Creek and South Fork Middle Creek.

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Acronyms

ABA	acid base accounting
ADD	average daily dose
AES10	EPA Region 10 Architectural and Engineering Services
amsl	above mean sea level
AP	acid potential
ARD	acid rock drainage
ATV	all-terrain vehicle
$BaSO_4$	barite
BCY	bank cubic yard
BERA	baseline ecological risk assessment
bgs	below ground surface
BKG1	background decision unit 1
BKG2	background decision unit 2
BLM	U.S. Bureau of Land Management
$CaCO_3$	calcium carbonate
$CaMg(CO_3)_2$	dolomite
$CaAl_2Si_2O_8$	anorthite
$CaSO_4 \cdot 2H_2O$	gypsum
CDM	CDM Federal Programs Corporation
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
cfs	cubic feet per second
CLP	Contract Laboratory Program
cm^2	centimeter squared
cm/sec	centimeter per second
CO_3^{2-}	carbonate
COC	chemical of concern
COI	chemical of interest
COPC	contaminant of potential concern
CRL	Central Regional Laboratory
CRQL	contract required quantitation limit
CSF	cancer slope factor
CSM	conceptual site model
CTE	central tendency exposure
$CuFeS_2$	chalcopyrite
Cu_5FeS_4	bornite
$(Cu, Fe, Zn, Ag)_{12}As_4S_{13}$	tennantite
$(Cu, Fe, Zn, Ag)_{12}Sb_4S_{13}$	tetrahedrite
Cu_2S	chalcocite
DDT	dichlorodipenyltrichloroethane
DO	dissolved oxygen
DOGAMI	Oregon Department of Geology and Mineral Industries

DPT	direct-push technology
DQI	data quality indicator
DQO	data quality objective
DU	decision unit
Dynamac	Dynamac Corp.
EA	exposure area
EC	exposure concentration
EDA	exploratory data analysis
ELCR	excess lifetime cancer risk
EPA	U.S. Environmental Protection Agency
EPC	exposure point concentration
EPM	equivalent porous media
ERA	ecological risk assessment
ESAT	Environmental Services Assistance Team
ESL	ecological screening level
FD	field duplicate
Fe^{2+}	ferrous iron
Fe^{3+}	ferric iron
$FeCr_2O_4$	chromite
FEI	Formosa Exploration Inc.
$Fe(OH)_3$	iron hydroxide
FeOOH	goethite
Fe_2O_3	hematite
FeS_2	pyrite
$Fe^{2+}SO_4 \cdot 7H_2O$	melanterite
$Fe_2(SO_4)_3 \cdot 9H_2O$	coquimbite
$Fe_3(SO_4)_4 \cdot 14H_2O$	roemerite
FF	farm forrest
FPXRF	field portable x-ray fluorescence
FRC	Formosa Resources Corporation
FS	feasibility study
ft	feet
gal	gallons
GIS	Geographic Information System
gpm	gallons per minute
GPS	global positioning system
GWPR	groundwater quality protection requirement
H^+	hydrogen
HC	Hart Crowser Inc.
HCI	hydrochloric acid
HCO_3^-	bicarbonate
HDOH	Hawaii Department of Health
HDPE	high density polyethylene
HHEBRA	human health and ecological baseline risk assessment
HHRA	human health risk assessment

HI	hazard index
HNO_3	nitric acid
$(H_3O)Fe(SO4)2{\cdot}3H_20$	rhomboclase
HQ	hazard quotient
H_2SO_4	sulfuric acid
ICP-AES	inductively coupled plasma – atomic emission spectroscopy
ICP-MS	inductively coupled plasma – mass spectrometry
ID	identification
in	inches
IRAM	interim remedial action measure
IRIS	Integrated Risk Information System
J	estimated qualifier
LADD	lifetime average daily dose
LCS	laboratory control sample
LiDAR	light detection and ranging
µg/L	microgram per liter
$\mu g/m^3$	microgram per cubic meter
µm	micrometer
µS/cm	microSiemens per centimeter
MA	Middle Creek A
MB	Middle Creek B
MC	Middle Creek C
MD	Middle Creek D
ME	Middle Creek E
MEL	Manchester Environmental Laboratories
MF	Middle Creek F
mg/cm^2	milligrams per square centimeter
mg/day	milligrams per day
mg/kg	milligrams per kilogram
mg/kg-day	milligrams chemical per kilogram body weight per day
$(mg/kg\text{-}day)^{-1}$	inverse milligrams chemical per kilogram body weight per day
mg/L	milligrams per liter
mg/m^3	milligrams per cubic meter
$(Mg, Fe)SiO_4$	olivine
$MgSiO_4$	forsterite
MIS	multi-increment sampling
MIW	mining-influenced water
mL	milliliter
mm	millimeter
MS	matrix spike
MS/MSD	matrix spike/matrix spike duplicate
NFG	National Functional Guidelines
NNP	net neutralization potential
NOAA	National Oceanic and Atmospheric Administration
NOAEL	no-observed-adverse-effect level

Norecol	Norecol Inc.
NOV	notice of violation
NP	neutralization potential
NPL	National Priorities List
NRWQC	National Recommended Water Quality Criteria
NWTPH-Dx	Northwest Total Petroleum Hydrocarbons – diesel and extended ranges
OAR	Oregon Administrative Rule
ODEQ	Oregon Department of Environmental Quality
ODFW	Oregon Department of Fish and Wildlife
ORP	oxidation reduction potential
OU	operable unit
PAHs	polycyclic aromatic hydrocarbons
PARCCS	precision, accuracy, representativeness, comparability, completeness, and sensitivity
PbS	galena
PRAO	Preliminary remedial action objective
PPRTVs	Provisional Peer Reviewed Toxicity Values
PVC	polyvinyl chloride
QA	quality assurance
QC	quality control
QSP	quartz sericite pyrite phyllite
QST	quartz sericite tuff
R	rejected qualifier
RAC	Remedial Action Contract
RAGS	Risk Assessment Guidance for Superfund
RCA	Russell Creek A
RCB	Russell Creek B
RCC	Russell Creek C
RCD	Russell Creek D
RCE	Russell Creek E
RfC	reference concentration
RfD	reference dose
RI	remedial investigation
RME	reasonable maxium exposure
ROD	record of decision
RPD	relative percent difference
RSD	relative standard deviation
RSLs	regional screeing levels
S1	Surface 1
S2	Surface 2
S3	Surface 3
SA	site assessment
SAP	sampling and analysis plan
SAP1	2009 SAP

SAP2	2010 SAP
SDG	sample delivery group
SEM-EDS	scanning electron microscope-energy dispersive spectroscopy
SFA	South Fork A
SFB	South Fork B
SIM	selected ion monitoring
SiO_2	quartz
Site	Formosa Mine Superfund Site
SLERA	screeing level ecological risk assessment
SOP	standard operating procedure
SOW	statement of work
SPLP	synthetic precipitation leaching procedure
SSLs	soil screeing levels
su	standard unit
TAL	target analyte list
TDS	total dissolved solids
t/kt $CaCO_3$ eq.	ton per kiloton calcium carbonate equivlent
TOC	total organic carbon
TPH-d	total petroleum hydrocarbon diesel
TR	Timberland Resource
TSS	total suspended solids
U	non-detect qualifier
UCL	upper confidence limit
USCS	Unified Soil Classification System
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
WFA	West Fork A
WFB	West Fork B
WFC	West Fork C
WFD	West Fork D
WFE	West Fork E
WFF	West Fork F
WFG	West Fork G
WRD	waste rock dump
yd^3	cubic yard
ZnS	sphalerite

Section 1
Introduction

1.1 Purpose

CDM Federal Programs Corporation (CDM) was tasked by the U.S. Environmental Protection Agency (EPA) Region 8 to perform a remedial investigation (RI) for the Formosa Mine Site (Site) in Douglas County, Oregon. A portion of this work was conducted under the previous EPA Region 8 Remedial Action Contract (RAC) 2, number EP-W-05-049. Currently, this work is being conducted under the EPA Region 10 Architectural and Engineering Services (AES10) Contract, number 68-S7-03-04. The purpose of this work is to characterize the nature and extent of mining–related contamination associated with operable unit (OU) 1, as well as support the subsequent feasibility study (FS) and remedial action for OU1.

The Site is divided into two OUs:

- ***OU1*** includes all surface and subsurface mine materials and contaminated soils deposited outside of the underground mine workings. These mine materials are defined as OU1 mine materials and include materials that were excavated during construction and operation of the mine, such as waste rock, ore, tailings, construction rock, road surfaces, and natural soils co-mingled with waste rock. Contaminated soils are natural soils that are affected by dispersion of contaminants from mine materials or from mining-influenced water (MIW).
- ***OU2*** includes all remaining media and site contamination areas, including surface water, stream sediment, groundwater, underground workings, and adit water drainage. Mine materials present within the underground workings are defined as OU2 mine materials.

The EPA-led RI activities were initiated in October 2009, before development of OU definitions for the Site. Therefore, sampling was initially focused on characterization of the entire Site. Once the OU definitions were developed, a decision was made by the project technical team to complete the RI/FS process in phases, beginning with RI sampling and characterization for OU1. The phased approach focuses on completion of the RI/FS for OU1 before OU2. This approach was selected because of the perceived complexity associated with characterization and remediation of contamination within OU2, and the relatively simpler requirements for characterization of contamination and assessment of risk for OU1. Moreover, this approach will enable a large portion of contamination at the Site (OU1 mine materials and contaminated soils) to be remediated and evaluation of the effectiveness of the OU1 remediation on site surface water and groundwater quality.

This RI report presents information from both OUs collected to date, but provides a more comprehensive assessment of the nature and extent of contamination for OU1. OU2 related data are presented in this RI report to provide supporting information regarding the extent of contamination in surface water and groundwater as a result of OU1 mine materials. The assessment of OU2 data provides justification for remediation of OU1 materials and supports development of preliminary remedial action objectives (PRAOs) for OU1 materials.

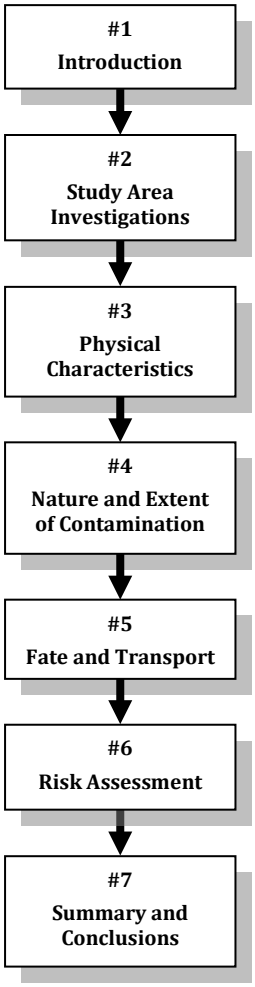
This RI report documents the history of the Site, summarizes previous investigations, describes the physical characteristics of the Site, characterizes the nature and extent of contamination, describes the fate and transport of contaminants, and assesses risk to human health and the environment posed by mining-related contaminants. The subsequent FS report will use data from the RI to perform a systematic analysis of OU1 to determine the need for remediation, candidate remedial technologies and process options, scope of remediation, and cost of remedial action. The FS will also present an analysis of how the risks identified in the RI can be managed using the various proposed remedial approaches.

After the FS is completed, EPA will issue a proposed plan that summarizes the RI and FS and describes EPA's preferred remedy to mitigate risk in OU1. When the proposed plan is issued, there will be a public comment period of at least 30 days, during which EPA will hold a public meeting to introduce the EPA's preferred alternative and allow the public to comment on the proposed plan. Public comments may also be provided to EPA in writing via mail or email. This process is designed to allow the public adequate opportunity to provide formal input to EPA before a final decision is made. EPA will consider all public comments. These comments and EPA's associated responses will be compiled into a responsiveness summary. EPA will then make its final risk management and cleanup decisions and publish those decisions in a record of decision (ROD). The responsiveness summary will be an attachment to the ROD.

1.2 Report Organization

The RI report is organized in a manner that conforms to EPA guidance (EPA 1988) and includes eight sections and appendices as follows:

- Section 1 - Introduction. Provides the purpose and organization of the RI, a brief description of the Site location and layout, and a summary of mining and regulatory activities conducted to date at the Site.
- Section 2 – Study Area Investigations. Provides an overview of Site investigations completed by EPA. Includes discussions of data quality objectives (DQOs), data usability, laboratory methods and analysis, and quality assurance (QA)/quality control (QC).
- Section 3 – Physical Characteristics. Provides a description of the physical characteristics of the Site. Includes discussions of Site features, surface water, geology, groundwater, surface water-groundwater interactions, climate, ecology, and land use and demographics.
- Section 4 – Nature and Extent of Contamination. Describes the nature and extent of contamination in OU1 mine materials, adjacent soil, groundwater, and surface water.



- Section 5 – Fate and Transport. Describes how the contaminants of concern move through the various media at the Site. Includes contaminant release mechanisms, potential routes of migration, sources, and contaminant fate and persistence.
- Section 6 – Risk Assessment. Presents the human health and ecological risk assessments for OU1, with limited assessment of OU2 (e.g., surface water).
- Section 7 – Summary and Conclusions. Summarizes the important technical findings detailed in the previous sections, provides conclusions drawn from that work, and presents the PRAOs based on the preceding sections of the RI report.
- Section 8 – References. Provides a list of reference citations for the RI report.
- Appendix A – Data Summary Report. Provides documentation of site history, summary of previous investigation activities conducted by others, an assessment of QA/QC of previously collected data, summary of previously collected data, and recommendations for data collection activities for the EPA-led RI, FS, and risk assessments.
- Appendix B – Field Data Sheets. Presents documentation of all field-recorded information from the RI sampling events, including equipment calibration logs (B.1), surface soil and waste rock sampling field data sheets (B.2), field portable x-ray fluorescence (FPXRF) sampling field data sheets (B.3), subsurface soil and waste rock sampling field data sheets (boring and trench logs) (B.4), surface water sampling field data sheets (B.5), groundwater purging and sampling field data sheets (B.6), groundwater well development records (B.7), and logbook notes (B.8).
- Appendix C – Laboratory Data Reports and Validation Reports. Presents EPA validation reports for Contract Laboratory Program (CLP) analyses (C.1), EPA data reports and validation reports for Environmental Services Assistance Team (ESAT) analyses (C.2), ACZ laboratory reports, and CDM validation reports for acid-base accounting (ABA) analyses (C.3).
- Appendix D – Boring Logs for Direct-Push Technology Borings and Well Construction Diagrams. Presents computer-generated logs for borings and well construction.
- Appendix E – Mine Material Mineralogical Data. Presents data collected from mineralogical analysis of samples using scanning electron microscopy-energy dispersive spectroscopy [SEM-EDS].
- Appendix F – Remedial Investigation Photographs and Log. Presents all of the photographs for each field event, and provides spreadsheets showing the photograph file name, date, and description.

1.3 Site Description

This section presents an overview of the general site location and description, site contamination, general site features, and fate and transport conceptual model.

Exhibit 1.3-1. Site 3D view, looking from west

1.3.1 Site Location and Description

The general Site location is shown in Figure 1.3-1. An aerial photograph view from the west is presented in Exhibit 1.3-1, which was generated from 3-dimensional (3D) light detection and ranging (LiDAR) data. The Site is an abandoned mine located in southwest Oregon in Douglas County, approximately 25 miles south of Roseburg, Oregon, and 7 miles south of Riddle, Oregon. Specifically, the Site is located within Sections 23, 26, and 27, Township 31 South, Range 6 West Willamette Meridian. Locally, it is situated in the Coast Range Klamath Mountains at elevations between 3,200 and 3,700 feet (ft) above mean sea level (amsl) near Silver Butte Peak (3,973 ft amsl).

The overall Site boundary has not been distinctly defined. The primary mine disturbance area for OU1 is the portion of the Site that has been impacted by deposition of mine materials as a result of mining-related activities. The primary mine disturbance area encompasses approximately 25 acres, as shown on Figures 1.3-1 and 1.3-2.

Surface terrain is characterized by steep mountains, narrow ridges, and deep canyons. The upland area surrounding the primary mine disturbance area of the Site is heavily forested, consisting of predominantly Douglas fir. The Site is situated near the top of a mountain ridge (Silver Butte ridge) that divides several sub-watersheds and drainages. Russell Creek drainage lies to the north of the Site, Upper West Fork Canyon Creek drainage lies to the east, South Fork Middle Creek drainage lies to the south, and Upper Middle Creek drainage lies to the west (Figure 1.3-1).

1.3.2 Site Contamination

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) program was enacted to address abandoned hazardous waste sites that have had a release or pose an imminent threat of release of hazardous substances into the environment (EPA 1988). Hazardous substance releases at the Site are caused by generation of acid rock drainage (ARD), which is an environmental problem caused by weathering of strongly mineralized rock. ARD problems are commonly associated with mining sites because the mining process exposes strongly mineralized rock to the surficial weathering environment as a result of the following Site-specific mining-related activities:

- *Mineral extraction*: underground tunneling, blasting, and excavation to remove ore containing payable metals;

- *Mineral beneficiation*: particle size reduction by crushing and grinding, and separation of payable metals by flotation to create copper and zinc concentrates for smelting; and
- *Mine materials management*: deposition of waste rock, tailings, ore, construction rock, and concentrates, either on the surface or within the underground workings.

At the Formosa Mine, a massive sulfide ore body was mined for primarily copper and zinc and some trace gold and silver. Two periods of mining occurred from 1926 to 1937 and 1990 to 1993. The massive sulfide ore body primarily contains the mineral pyrite (FeS_2), as well as the minerals chalcopyrite ($CuFeS_2$) and sphalerite (ZnS) that were mined for payable copper and zinc. Other trace sulfide minerals are also present in the ore body, along with natural enrichments of trace metals and metalloids. Site contaminants are attributable to the sulfide mineralization and natural enrichments of metals and metalloids in the rock. The process of ARD generation results in mobilization of contaminants into downslope soils, surface water, and groundwater at the Site.

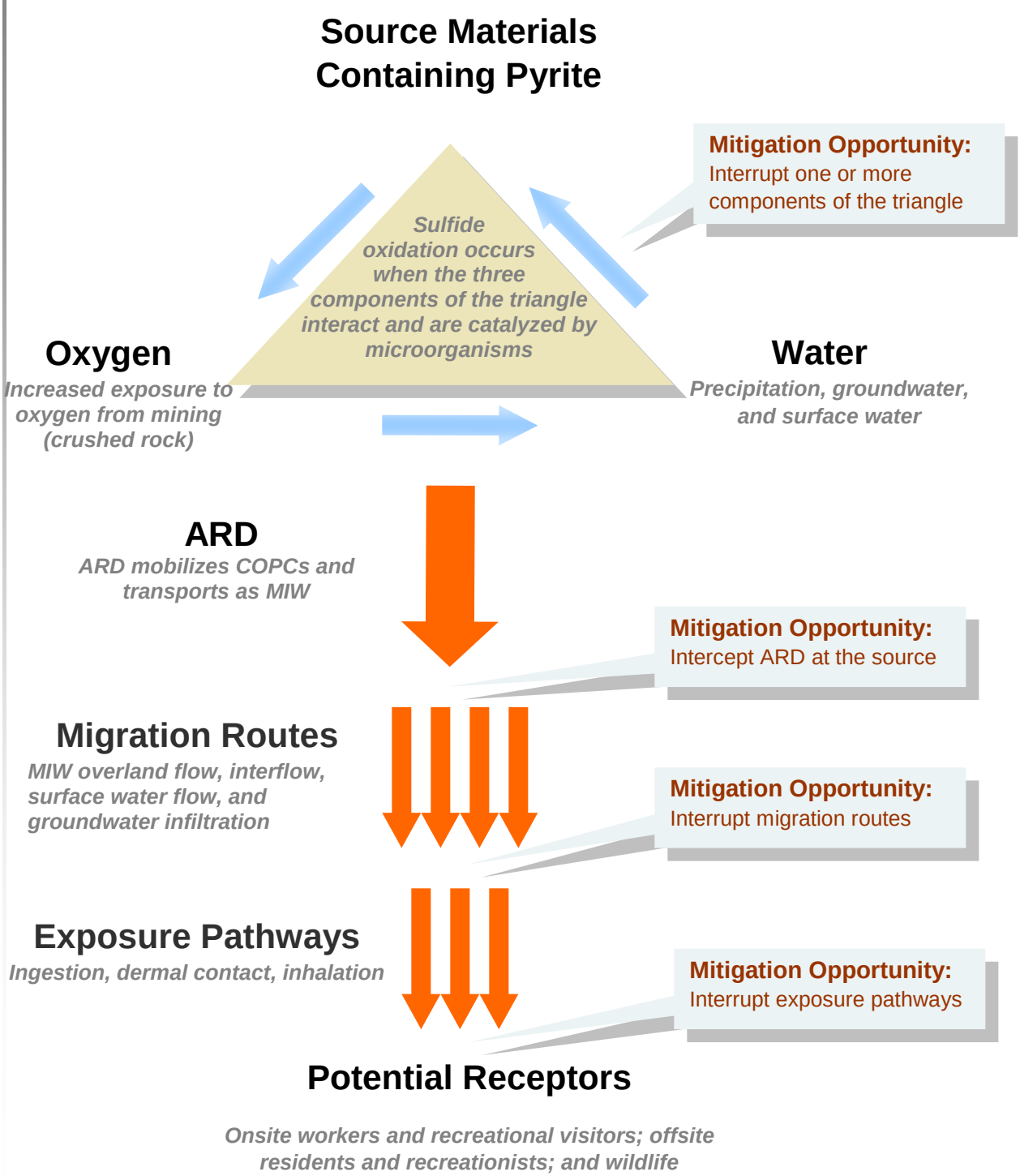
Contaminants of potential concern (COPC) include sulfur present in various forms that generate ARD, dissolved sulfate present in ARD, and several toxic metals and metalloids present in rocks and in ARD, such as aluminum, arsenic, cadmium, copper, lead, manganese, mercury, nickel, selenium, vanadium, and zinc. The term COPCs as used in Sections 1 through 5 of this RI report is intended to generally represent this group of contaminants as a whole. Specific COPCs such as metals and metalloids are identified in Section 6 based on the risk assessments; however, forms of sulfur are not evaluated. Rather, forms of sulfur as COPCs and their relationship to release and transport of metals and metalloids are described in detail in Sections 4 and 5.

The primary cause of ARD generation at the Site is oxidation of the mineral pyrite. Oxidation of pyrite forms sulfuric acid (H_2SO_4), which decreases the pH of water that interacts with the acid generating rocks and increases the solubility of metals and metalloids. Pyrite is widespread in rock exposed by mining at the Site, and acid generation occurs from numerous source materials that are widespread over the primary mine disturbance area. Primary source materials are ARD generating mine materials such as a waste rock, ore, tailings, and co-mingled natural soils and waste rock.

ARD generation from pyrite requires three primary components, oxygen, water, and pyrite, as shown in Exhibit 1.3-2. The pyrite oxidation process is catalyzed by a consortium of microorganisms, which affect the rate of oxidation. In addition to oxygen and water, the overall ARD generation process is controlled by a number of interrelated factors, including concentration of pyrite, grain size and crystal habit of the pyrite, activity of microorganisms, particle size of the rock, and presence of minerals that have the ability to buffer changes in pH caused by pyrite oxidation. At the Site, these interrelated factors result in production of strongly acidic drainage containing concentrations of toxic metals that exceed acceptable standards by several orders of magnitude.

MIW is defined as the water that is generated by processes that result in liberation of mine material contaminants from the solid phase to the dissolved or suspended phase. The term MIW is utilized to describe the sum of all of the processes that create water affected by mining activities that is potentially toxic to the environment regardless of the water pH. For instance, MIW can be acidic or it can be circum-neutral pH with elevated concentrations of COPCs. The use

Exhibit 1.3-2. ARD Generation, Migration, and Mitigation



of the term ARD is intended to describe the primary oxidation process by which contaminants are released from rock sources. MIW is used to describe the migration of ARD once it is generated.

Mine materials that contain secondary products of ARD generation, such as efflorescent iron sulfate minerals, are also primary source materials. Mine materials containing these secondary products are widespread within the primary mine disturbance area as a result of seasonal

fluctuations in precipitation, stream flow, and groundwater levels. The secondary minerals are geochemically unstable once formed, are highly soluble even under neutral pH conditions, and can generate acid upon dissolution when contacted by water. Therefore, these minerals represent a source of secondary acidity that can worsen COPC concentrations and impact to the environment.

1.3.3 General Site Features

The Site has been extensively disturbed by mining and mineral processing operations, and many features associated with mining remain. This section presents a general overview of these features; additional information is provided in Section 3 – Physical Characteristics.

General Site features are shown on Figure 1.3-2. Locations of historic Site features were obtained from maps and drawings from Oregon Department of Geology and Mineral Industries (DOGAMI) and Oregon Department of Environmental Quality (ODEQ) files that document conditions during mining. These maps were digitized and geo-referenced to the state-plane coordinate system to incorporate into the Site geodatabase. The following are the major categories of Site features. These features are presented in the subsections below and discussed in greater detail in Section 3 – Physical Characteristics.

- OU1 mine materials;
- Underground mine;
- Adit water diversion system;
- Watersheds and drainages; and
- Other historic mining features.

1.3.3.1 OU1 Mine Materials

OU1 mine materials are located in several areas throughout the Site. These materials are present in areas where waste rock, ore, tailings, construction rock, and co-mingled waste rock and soils were placed or disturbed during operation of the mine and after closure of the mine. OU1 mine materials also includes surface exposed ARD generating bedrock outcrops. These areas are generally identified as follows:

- Formosa 1 adit waste rock dump (WRD);
- Formosa 2 adit, Formosa 3 adit, and 1090 raise WRDs;
- Silver Butte 1 adit WRD;
- 404 adit WRD;

Exhibit 1.3-3. Encapsulation mound area 3D view, looking from south

- East and west (Exhibit 1.3-4) encapsulation mound WRDs (sloped areas);
- Encapsulation mound (flat top area) (Exhibit 1.3-3), former milling facility area, and former shop facility area;
- Former ore storage and water storage areas (e.g., former million-gallon tank and primary water storage);
- Illegal dump area;
- Surface exposed rock surfaces; and
- Miscellaneous road areas constructed of co-mingled construction rock and soils.

Exhibit 1.3-4. West encapsulation mound WRD

These areas are generally identified on Figure 1.3-2; however, boundaries for the individual areas or WRDs are not delineated. Figure 1.3-2 also shows the extent of OU1 mine materials (e.g., primary mine disturbance area) and the approximate OU1 Site boundary. The extent of OU1 mine materials has been developed based on RI sampling data and is presented and discussed in detail in Section 4. The OU1 boundary includes the extent of mine materials plus an approximate 250-ft horizontal buffer in all directions to capture potentially contaminated areas. The OU1 Site boundary is for illustration purposes of the study area and does not necessarily delineate contaminated or non-contaminated areas.

1.3.3.2 Underground Mine

The Formosa Mine was primarily an underground mine, although early mining and exploration may have included some mining of surface expressions of the massive sulfide ore body. The underground mine has been inaccessible since the portals were closed in 1994 as part of reclamation activities. There were originally five portals to the underground mine workings. Within the main Site area, the Silver Butte 1, Formosa 1, Formosa 2, and Formosa 3 adits and the 1090 raise are reclaimed (e.g., backfilled). On the far southwest portion of the Site and along the ore body strike, the 404 adit and K1G adits are not reclaimed but cannot be entered because of natural collapse of the portal. These mine portal locations are shown on Figure 1.3-2.

Early underground mining into the 1930s was conducted at the Formosa 1 adit level (approximately 3,315 ft amsl elevation) up to the Formosa 3 adit level (approximately 3,510 ft amsl elevation). The underground mine workings area is located to the southeast of the Formosa 3 adit and 1090 raise and follows the dip (60 to 75 degrees southeast) of the ore body to the southeast. Modern mining in the 1990s was focused mostly on following the ore body trend below the Formosa 1 adit level down to approximately 2,890 ft amsl; however modern mining included expansion of the upper historic workings to access intact ore zones that were left by the old miners (DOGAMI 1996). Reclamation of the underground mine workings in 1994 included backfill of the majority of tunnels with various mine materials such as waste rock, tailings, ore,

concentrates, and other co-mingled construction materials. Further information on the extent of underground mine workings is presented in Section 1.4 and Section 3.1.

1.3.3.3 Adit Water Diversion System

The adit water diversion system is intended to capture MIW draining from the Formosa 1 and Silver Butte 1 adits and divert it away from the headwaters of Upper Middle Creek and into a dispersion drainfield. The Silver Butte 1 adit rarely flows, but the Formosa 1 adit (Exhibit 1.3-5) has recorded flows as high as 190 gallons per minute (gpm) (HC 2002). This approach was part of the original reclamation plan implemented by Formosa Exploration Inc. (FEI) in 1994. Over the years, clogging of the pipes by iron precipitate has required ongoing maintenance and reconfiguration of the system.

Exhibit 1.3-5. Current adit water diversion system at Formosa 1 adit

The current adit water diversion system was installed in 2000 and is shown on Figure 1.3-2. The original Formosa 1 system was installed in 1994 at a shallower drain slope than the existing, and the original drainfield was located approximately 120 vertical ft above the existing drainfield. A second configuration was constructed around 1996, which steepened the drain slope and discharged approximately 15-ft downslope and 60-ft north of the original drainfield. Over the years, these changing diversion system configurations have resulted in soil contamination over a wide area as a result of the acidic and metal-bearing MIW discharge (approximately 0.6 acre area, see Figure 4.1-17a).

1.3.3.4 Watersheds and Drainages

Of the four drainages that have headwaters near the Site, only the Upper Middle Creek and the South Fork Middle Creek drainages are known to be contaminated by MIW based on historic data and RI sampling data. Several contaminated groundwater seeps/springs discharge to surface water in areas downslope from mine material and contaminated soil areas that have resulted in widespread contamination to the Middle Creek subwatershed. The area of contaminated surface water identified based on historic data and RI sampling data with concentrations above freshwater aquatic criteria extends for the entire length of South Fork Middle Creek (approximately 5 miles) and for the entire length of Middle Creek (approximately 13 miles).

For Upper Middle Creek, contaminated groundwater seeps (acidic pH, high total dissolved solids [TDS], and high metals concentrations) are observed starting at approximately 200 horizontal ft and 100 vertical ft from the main site road (Road 30-6-35.1; Figure 1.3-2). The causes for these seeps are a result of leaching from the Formosa 1 adit WRD and contaminated road areas, from Formosa 1 adit MIW that may not be currently collected by the adit water diversion system, and potentially contaminated bedrock groundwater.

For South Fork Middle Creek, contaminated groundwater seeps (acidic pH, high TDS, and high metals concentrations) are observed starting at approximately 575 horizontal ft and 320 vertical ft below the top of the encapsulation mound. The causes for these seeps are a result of leaching from the encapsulation mound, east encapsulation mound WRD, and illegal dump area, and contaminated bedrock groundwater.

1.3.3.5 Other Historic Mining Features

Several other historic features are shown on Figure 1.3-2 that were associated with operation of the mine. These include features that are either removed from the Site or buried within the various WRDs.

- Former crusher, shop, and milling facilities;
- Former primary water storage and million-gallon tank;
- Former water and tailings storage pond;
- Former runoff water diversions and water dispersion system;
- Former tailings line from mill;
- Historic roads; and
- Historic crib walls.

Some of these features that have remnants buried beneath mine materials include the milling facility concrete foundation, the water and tailings storage pond, some intact crib walls, dispersed and demolished crib wall materials, and several partially reclaimed road areas. Historic mining features are described in more detail in Section 1.4 Site History and in Section 3.1 Site Features.

1.3.4 Fate and Transport Conceptual Models

Conceptual models of contaminant fate and transport processes have been developed to illustrate processes contributing to ARD generation, contaminant transport, and fate in the environment. The conceptual models build upon the basic processes presented in Exhibit 1.3-2 and provide detailed ARD generation and transport pathways in relation to the important site features. Figures 1.3-3 and 1.3-4 illustrate the conceptual models for the two important areas of the Site, the Formosa 1 adit and Upper Middle Creek, and the encapsulation mound and South Fork Middle Creek, respectively. These conceptual models of contaminant fate and transport are described in detail in Section 5.1, but are introduced in this introductory section to provide the reader with an initial conceptual understanding of important contaminant fate and transport processes at the Site. The contaminant generation, transport, and fate mechanisms shown on Figures 1.3-3 and 1.3-4 have affected all 13 miles of Middle Creek up to the confluence of Cow Creek and all 5 miles of South Fork Middle Creek up to the confluence with Middle Creek.

1.3.4.1 Formosa 1 Adit and Upper Middle Creek

The Formosa 1 adit and Upper Middle Creek fate and transport conceptual model is shown as Figure 1.3-3, and describes the current conceptual understanding of how metals originating in source materials are dissolved, transported, and discharged into Upper Middle Creek. OU1 source

materials include strongly ARD generating mine materials deposited near the adit portals, which produces MIW containing high concentrations of COPCs that transport towards Upper Middle Creek. OU2 source materials include mine materials and exposed rock surfaces that are present within the underground mine. MIW generated by these OU2 source materials are discharged from the Formosa 1 adit, and potentially transported towards Upper Middle Creek via a perched alluvial groundwater system. This MIW subsequently discharges from groundwater to surface water downstream from the Formosa 1 adit, severely affecting the water quality of Upper Middle Creek.

1.3.4.2 Encapsulation Mound and South Fork Middle Creek

The encapsulation mound and South Fork Middle Creek fate and transport conceptual model is shown as Figure 1.3-4, and describes the current conceptual understanding of how metals originating in source materials are dissolved, transported, and discharged into South Fork Middle Creek. Source materials include strongly ARD generating mine materials deposited in various WRDs and the encapsulation mound, which produces MIW containing high concentrations of COPCs that transport toward South Fork Middle Creek. Numerous MIW seeps are present within the South Fork Middle Creek. The observed discharge of ARD from groundwater to surface water within South Fork Middle Creek may be associated with both the alluvial and bedrock groundwater systems. The bedrock aquifer at the encapsulation mound is severely affected by ARD generation, with strongly acidic pH and high metals concentrations.

1.4 Site History

This section describes the history of the Site, starting from the first exploration in the early 1900s until present day.

1.4.1 Early Mining and Exploration

Geologic exploration activities in the area of the Formosa and Silver Butte mines (formerly referred to together as the Silver Peak Mine) were first conducted in 1910. Mineral rights to the Section 26 portion of the mine were obtained in 1912 with the grant of a 120-acre timber patent. In 1920, the Oregon Exploration Company located lode mining claims in Section 23 and over part of the Section 26 timber patent. Development of the underground mine began in the early 1920's and by 1926, the Oregon Exploration Company commenced underground mining and shipping of ore. Litigation ensued over property rights ownership from 1922 until 1929 when all land claim rights were turned over to the Silver Peak Copper Company (later renamed the Silver Butte Mining and Milling Company). Mining discontinued for one year in 1927. Despite the litigation, mining and shipping of ore continued in 1928 through 1931, and again in 1936 through 1937. No further mineral extraction occurred after 1937 until modern mining (Derkey 1982; Formosa Resources Corporation [FRC] 1987; Ramp 1972; Shenon 1933).

During this early period of mining, waste rock was dumped on the hillsides adjacent to the adit portals and roads, as was typical during that era of mining. WRDs from this era of mining are reported to be present beneath the current road and along the angle of repose slopes adjacent to the Formosa 1 and Silver Butte 1 adits (Wilson 2009). All mining was done above the Formosa 1 adit elevation, so that all new workings could be drained of water by gravity through the Formosa 1 adit. As a result, the Site was left with a legacy of ARD that formed in the network of

underground mine workings and then flowed out of the lower adits and into the headwaters of Middle Creek (DOGAMI 1994). Since the 1930s until modern mining, approximately 5 gpm to 20 gpm of ARD flowed out of the Formosa 1 adit and up to 10 gpm flowed out of the Silver Butte adit (DOGAMI 1994, 1996). Documentation of adit water discharge chemistry before modern mining is described in Norecol Inc. (Norecol) (1989) and is discussed further in Section 1.4.3.

During the period 1926 through 1937, the Silver Peak Mine produced 6,620 short tons of ore, which yielded 735,600 pounds of copper, 231,980 ounces of silver, and 490 ounces of gold (Ramp 1972). Zinc was also present in the same ore body as sphalerite (ZnS), although zinc was not considered a marketable metal at the time. Between 1926 and 1931, smelters charged a penalty for high zinc levels present in shipped ore (Derkey 1982; FRC 1987). As a result, ore with very high zinc content was left behind by the miners, and ore was shipped with as low zinc content as possible by blending ores from various parts of the mine (Derkey 1982; FRC 1987).

1.4.2 Modern Exploration

Later development work was conducted in 1952 by the Umpqua Consolidated Mining Company, which involved rehabilitation of some of the underground mine workings (FRC 1987). Various geologic explorations were conducted over the later years. R.E. Derkey completed a doctoral dissertation on the geology of the Silver Peak Mine in 1982, which was the most extensive report published to date (Derkey 1982).

From 1976 to 1979, the mine and adjoining lands were under lease to Chevron Resources Company (FRC 1987). A series of geochemical and geophysical surveys were performed as well as drilling exploration, although Chevron did not pursue mining operations (FRC 1987). In 1984, FRC (formerly Rand Ventures Inc.) had acquired a portion of the mine and adjoining properties. From 1984 through 1989, FRC conducted an extensive geologic exploration program to further define the quantity and location of ore reserves. This work was first conducted on claims that FRC owned and on claims that FRC leased from the Silver Butte Mining and Milling Company.

In May 1987, FRC (incorporated in Canada) established a subsidiary company called FEI based in Roseburg, Oregon to further conduct exploration activities (FRC 1988). In July 1987, the mineral claims owned by FRC and the mineral lease and option to purchase agreement with Silver Butte Mining and Milling Company were assigned to FEI.

1.4.3 Modern Mining

This section presents a summary of the baseline environmental study and modern mining activities after the study was completed.

1.4.3.1 Baseline Environmental Study

Based on the extensive exploration by FRC/FEI, significant ore reserves were determined to be present and the company began to pursue opening an active mining operation at the Silver Peak Mine around 1988. As part of the permitting process, FEI's contractor (Norecol) conducted a baseline environmental study between 1988 and 1989 to document conditions before initiation of modern mining activities (Norecol 1989). The study included gathering climate and hydrology data, rock sampling, surface water sampling, fish and macroinvertebrate sampling, and the installation and sampling of groundwater wells near the current encapsulation mound area (see

Section 3.4 for discussion of groundwater data). Sampling conducted by Norecol documents adverse affects from adit discharges and seeps to Upper Middle Creek and documents conditions in South Fork Middle Creek before modern mining. Conditions in Middle Creek were better than post-modern mining based on fish and macroinvertebrate studies (see Appendix A). Surface water, fish, and macroinvertebrate sampling on South Fork Middle Creek did not show adverse effects at this time, which indicates that degradation to South Fork Middle Creek did not occur until during and/or after modern mining.

Samples were collected from the Formosa 1 adit discharge in October 1988, February and March 1989, and one sample was collected from the Silver Butte 1 adit discharge in February 1989. Although flow measurements were not made, the Formosa 1 adit was flowing directly into Upper Middle Creek during this period. The Formosa 1 adit samples had the following characteristics (Norecol 1989):

- pH ranging from 3.2 standard units (su) to 3.4 su;
- Dissolved cadmium concentrations ranging from 0.025 milligrams per liter (mg/L) to 170 mg/L;
- Dissolved copper from 2.1 mg/L to 19 mg/L;
- Dissolved zinc from 16 mg/L to 37 mg/L; and
- Sulfate from 255 mg/L to 278 mg/L.

The Silver Butte 1 adit sample had a pH of 2.5, dissolved cadmium at 0.54 mg/L, dissolved copper at 83 mg/L, dissolved zinc at 98 mg/L, and sulfate at 1,048 mg/L. In May 1989 samples were also collected at seeps detected in the Upper Middle Creek area below the Formosa 1 adit discharge (termed MA and MB). These seeps had elevated metals concentrations, with the highest concentrations of 0.09 mg/L cadmium, 10.7 mg/L copper, and 18.1 mg/L zinc (Norecol 1989).

Between October 1988 and July 1989, several samples were collected at downstream location M1 and SF1 in Middle Creek and South Fork Middle Creek, respectively. These locations are synonymous with locations M3.0 and SF4.7 from sampling by others (see Appendix A), which are 3.0 miles and 4.7 miles from the Site on the two creeks, respectively. Samples collected at M1 indicated nearly one order of magnitude increases in aluminum, cadmium, copper, iron, manganese, and zinc concentrations from October 1988 to March 1989 sampling events. Concentrations decreased for the May 1989 sampling and decreased further for the July 1989 sampling to near the October 1988 levels (Norecol 1989). The increase in metals loading during winter corresponds to increased loading from the adit discharges, seeps, and runoff. These observations are similar to the trend seen during U.S. Bureau of Land Management (BLM)/ODEQ sampling and CDM's RI sampling, in that metals concentrations increase during winter months as a result of higher flows and flushing of metals from the mine.

1.4.3.2 Modern Mining Activities

In spring of 1990, Oregon DOGAMI approved FEI's conditional use permit. Underground mining was conducted by FEI from early summer 1990 until August 1993. During this modern period of mining, FEI mined copper and zinc ore at a rate of 350 tons to 400 tons per day. About 62,000

tons of ore and 25,000 tons of waste rock were removed from the Silver Peak Mine during this period of mining (DOGAMI 1995).

Ore was crushed, screened, and sent to a flotation mill (Exhibit 1.4-1) located on site to produce zinc and copper concentrates. Copper concentrates were shipped to Japan for smelting. Zinc concentrates were reportedly only created during early production, stockpiled on site, but never shipped to a smelter because of the low volumes produced and low zinc prices (DOGAMI 1995). Waste tailings from the flotation process were stored on site within the 2-acre lined water and tailings storage pond and were also backfilled into the underground mine workings as part of normal operation and later as part of reclamation activities.

Exhibit 1.4-1. Flotation processing at the milling facility

The underground mining process consisted of constructing a spiral decline access that wrapped down and around the ore body. As the decline intersected the ore body, horizontal tunnels were driven along the strike length of the ore body at a given level. Mining started at the bottom at the 880-meter level (2,890 ft amsl) and proceeded upward. The ore was blasted, excavated, and hauled to the surface. The void space in the rock left by excavation of the ore was then backfilled by pumping a tailings and concrete slurry or a pure tailings slurry into the void space. A new cut through the massive sulfide lens was then completed on top of the previous cut using the backfilled tailings and concrete as a floor. At frequent intervals, a sub-horizontal pillar of undisturbed rock was left in place to prevent the underground mine workings from collapsing. Although this prevented a portion of the ore body from being mined, it was necessary to maintain ground support within the mine.

The tailings consisted of finely ground (i.e., less than 400 mesh size) pyrite and gangue minerals such as quartz, barite, and sericite. Trace amounts of chalcopyrite ($CuFeS_2$) (copper-bearing sulfide) and sphalerite (zinc-bearing sulfide) not removed by the flotation process were also likely present. During later years of mining, when zinc processing was no longer profitable, tailings likely contained much higher amounts of finely ground sphalerite (ZnS). FEI's permit required backfilled tailings to be mixed with cement for stabilization before placement; however, it has been reported that cement was not used during backfill of some of the workings (DOGAMI 1995; Wilson 2009). Information on the percentage of cement added to tailings or the time at which tailings were no longer stabilized with cement during backfill is not available. Larger sized waste rock (ore, lean ore, and non-reactive rock) was stored at various locations at the Site.

Onsite inspections in 1993 revealed several violations of FEI's permit conditions (DOGAMI 1990 – 1999). In January and July 1993, DOGAMI issued a Notice of Violation (NOV) to FEI for numerous violations of permit conditions (DOGAMI 1990 – 1999). By August 1993, DOGAMI had issued a Closure Notice for failing to correct the problems identified in the NOV within the 30-day

compliance period (DOGAMI 1993). On August 1, 1993, the mine officially ceased operations and began closure and reclamation activities (DOGAMI 1995).

1.4.4 Mine Reclamation (1993 – 1994)

The majority of reclamation at the Site by FEI was conducted from August 1993 through December 1994. Because of the repeated failure of the adit water diversion system and its required maintenance, reclamation at the Site has continued since the mine shutdown until present day. When mine operations ceased in 1993, the reclamation plan and bond money originally set forth in the 1990 operating permit was determined inadequate for current conditions at the Site (FEI 1995). As a result, the reclamation bond administered by DOGAMI was increased from $500,000 to $980,000 (DOGAMI 1995). Reclamation was conducted as a cooperative effort between DOGAMI, ODEQ, and the BLM. The overall dollars spent by FEI is reported to be over $1,000,000, and the amount spent over the reclamation bond came from Formosa's Japanese investors (DOGAMI 1995).

Several former Site features associated with modern mining activities and reclamation are shown on Figure 1.3-2. Summaries of reclamation activities are described below. Historical information presented here were obtained from a number of references including DOGAMI 1990 – 1999, 1995, and 1996; Heenan 2000, and Northwest Environmental Resources 2003. Some of the information was obtained from these references, as well as from memorandum and letter correspondence between FEI, DOGAMI, ODEQ, and BLM. Specific references to these correspondences are not provided; however, these documents are included as attachments to the Data Summary Report (Appendix A). Maps and drawings obtained from DOGAMI and ODEQ files are also not referenced specifically, but are included in Appendix A. Additional details on Site features and reclamation are provided in Section 3.1.

Removal of crusher facility – The crusher and foundation (Exhibit 1.4-2) were removed from its location next to the Formosa 1 adit. These materials are assumed to have been disposed off site; records do not indicate materials were buried on site. This work was completed by January 1994.

Exhibit 1.4-2. Crusher facility conveyor and crushed ore stockpile near Formosa 1 adit during mining

Removal of stockpiled ore – A large amount of crushed ore was stockpiled in the ore storage area at the time of mine closure. Most of this material was backfilled into the underground mine workings. Records do not indicate the backfilled material was encapsulated. Low-grade ore was also located in the million-gallon tank area; this material was excavated and backfilled into the water and tailings storage pond. Remaining material was regraded, amended with straw and lime, and seeded. This work was completed by January, 1994.

Removal of zinc concentrate dump site - Zinc concentrate was created during early milling operations but never shipped. During mining, the concentrate was stored in a covered shed on the northwest side of the water and tailings storage pond and then later dumped over an embankment on the southeast side of the mill site. The dumped concentrate was then removed during reclamation and placed in the underground mine workings as described below.

Cleanup of diesel fuel spills - Diesel was stored on site and used for all operating equipment. FEI had not used any secondary containment structures or devices for collecting fuel spills during refueling; therefore, fuel was spilled and uncontained in many areas. Approximately 1,200 cubic yards (yd^3) of contaminated soil was excavated from various spill areas and piled on the former million-gallon tank area. The pile was treated using a bioremediation process from approximately 1994 to 1997 to break down the diesel fuel; however, the effectiveness of this process was slow because of the low soil pH. Limestone was added to the pile at various phases to increase pH and increase the degradation reaction rate. Some samples were collected from the bioremediation pile for total petroleum hydrocarbon diesel (TPH-d). Concentrations were reported to have decreased to 200 milligrams per kilogram (mg/kg) TPH-d, although the cleanup target was 100 mg/kg TPH-d. Maximum concentrations of soil originally excavated were on the order of 13,000 mg/kg TPH-d. ODEQ's permit for the diesel-contaminated soil cleanup had expired before the completion of the bioremediation, and in 1996 remaining reclamation bond funds were prioritized for the adit water diversion system. The pile was placed near the former mill site area, amended with biosolids and lime, and seeded after bioremediation.

Removal of sulfide tailings from Upper Middle Creek - During mining operation, finely ground pyrite (FeS_2) and other sulfide tailings materials generated at the crusher and from truck operations had washed from the crusher area and road into the Upper Middle Creek headwaters. Approximately 20 tons of sulfide tailings materials were estimated to have spilled into Upper Middle Creek. The approach to remove the sulfide materials included removal of down timber and brush, raking and washing the stream sediment into a funnel, and then transporting by 4-inch (in) pipe to a collection basin near the sampling location MXR (See Section 2.3.3 for location). In the upper portions of the creek, tailings and mixed soil materials were hand excavated (Exhibit 1.4-3), placed in drums, and removed from the area. The flatter stream gradient and road access at MXR provided conditions needed to build an adequate collection basin.

Exhibit 1.4-3. Hand excavation of tailing and alluvium to a pipe collection system that drains to MXR pond, March 1994

Removal of tailings beyond location MXR was not conducted, although it was assumed at the time that the majority of tailings would have been captured at MXR because of the flatter stream gradient. Materials were then removed from the collection basin and trucked back up to the mine for disposal. The Upper Middle Creek cleanup was a significant effort that took nearly two months

of work to complete. The cleanup process was completed by May 6, 1994 and the pond was decommissioned and backfilled by June 1994.

Backfill of underground mine workings - Crushed ore stockpiled on the surface was placed in the workings below the Formosa 1 level. Zinc concentrate stockpiled at an illegal dump site was removed and backfilled into the 1090 raise. The mine openings above the Formosa 1 adit were filled mostly with tailings. Sulfide tailings materials collected from the Upper Middle Creek cleanup were also backfilled into the underground mine workings. All backfill operations were completed by July 15, 1994.

Exhibit 1.4-4. Closure of an adit portal with rebar and concrete, July 1994

Reclamation of mine portals - Backfill at the Formosa 1 and Silver Butte 1 adit portals (Exhibit 1.4-4) consisted of the following materials (in order of placement): a wooden and burlap bulkhead, crushed limestone backfill, an 8-in acid-resistant concrete cap, and an outer rock cover. Three-in high density polyethylene (HDPE) drainpipes were placed along the entire base of the backfill structures and were fitted with perforated cross drains spaced periodically along the pipelines. On the inside of the wooden bulkhead, vertical riser pipes with an open top were installed. Drainage pipes were constructed of 2-in HDPE that directed adit water out of the adits, beneath the road, and over the embankment into drainfield areas. The drainfield areas were located downslope of the Formosa 1 and Silver Butte 1 adits. The backfill structure was similar for the Formosa 2 and Formosa 3 adits; however, no drainage pipe or bulkheads were installed in these adits and no limestone backfill was placed for the Formosa 3 adit. The fifth portal, the 1090 raise, was backfilled with zinc concentrate, non-reactive waste rock (non-acid generating), a 3-ft bentonite seal, a 6-inch steel reinforced acid-resistant concrete cap, and a soil cover. All mine portal reclamation work was completed by August 4, 1994. The access road constructed to access all of the upper workings was also regraded and revegetated.

Removal of crib wall fill and wood wall structures – Various crib wall structures (Exhibit 1.4-5) were built on the slopes on both sides of the mill site and water and tailings storage pond to increase the available surface area for mine operations. The walls were built of wood and steel rebar and fill material was placed behind the wall. The crib wall fill originated from the water and tailings storage

Exhibit 1.4-5. Crib wall structures on northwest side of Silver Butte ridge

pond excavation. The fill was also mixed with mine waste during placement in the crib walls. During reclamation, the crib walls were removed and the fill was excavated and placed over the mill foundation and used as the encapsulation mound cover, as described further below. Since mine waste was mixed with the crib wall fill, this material may be acid generating. After the fill and wall material was removed, slopes were revegetated by adding straw, paper mulch, tackifier, and seed.

Removal of the mill building and all processing equipment - The process to remove the mill building and equipment began in 1994 and all material was sold or removed from the Site by June 1995; however, the building foundation was left in place. Sulfide materials were washed off of the foundation and crib wall fill was placed over the foundation. Revegetation efforts for the mill site area were apparently similar to that of the encapsulation mound area (described below).

Exhibit 1.4-6. Backfill of low-grade ore over tailings during encapsulation mound construction, May 1994

Backfilling and capping of water and tailings storage pond - During mining, the volume of underground mine workings available for backfilling was consistently smaller than the volume of tailings generated. As a result, a significant amount of tailings were stored in the water storage pond (now referred to as the encapsulation mound). During reclamation, the majority of tailings were hydraulically transported in the underground mine workings; however, some tailings remained in the pond. These remaining tailings were spread on the pond liner to protect the liner from damage during rock backfilling. Seventeen thousand tons of low-grade ore was backfilled onto the remaining tailings (Exhibit 1.4-6), followed by a Bentomat™ cover, and a 5- to 7-ft thick soil/rock cover. This cover was designed as a low-permeability cover system that was intended to prevent infiltration of precipitation into the pond materials, and consists of a layer of bentonite clay sandwiched between two layers of geotextile fabric. Fill placed behind the crib walls was used as the soil/rock cover material. Cover material was mounded with an apex along the long axis of the pond. Samples collected from various crib wall fills indicated that the material did contain some acid generating potential. Approximately 20 tons per acre limestone (one quarter finely ground agricultural limestone and three quarter crushed limestone) were mixed into the top of the soil/rock cover in an attempt to prevent acid generation. After limestone amendment, approximately 42,000 gallons (gal) of biosolids from the Riddle wastewater treatment plant were tilled into the top of the cover, and the area was mulched (straw), seeded, and planted with blackberry cuttings and Douglas fir saplings. Down logs were also placed sporadically on the cover. Wood from the crib walls was also incorporated into the top of the cover. The encapsulation mound cover was completed in August 1994.

Million-gallon tank removal - The million-gallon tank was built in spring 1993 and was used to store process water during milling operations. The foundation for the tank was built on crushed

ore. The tank was subsequently removed and sold during reclamation. Precipitation solids in the tank bottom were pumped into the underground mine workings. Details of reclamation of the crushed ore foundation or attempts at revegetation are unknown.

1.4.5 Adit Water Diversion System Observations and Maintenance (1995 – 1999)

By February 1995, the Formosa 1 adit water diversion pipeline was documented to be plugged and seeps were observed flowing out of the fill rock covers of both the Formosa and Silver Butte adits. The seep water was observed flowing into the ditch and down into Upper Middle Creek. In March 1995, rocks were removed from a section of the Formosa adit pipeline, which had caused the blockage. Water was flowing again in the Formosa adit pipeline; however, adit water was still seeping out of the rock fill located below the adit. Further work was conducted through 1995 such as regrading the road and adding water bars, in an attempt to route seeping adit water from both adits over the road and onto the hillside. (DOGAMI 1990 – 1999; Heenan 2000)

The high iron content of the adit water resulted in formation of iron precipitate scale in the drainage pipes, which soon became a difficult maintenance problem. Because of significant scale buildup very little water was observed flowing through the adit drainage pipes during the winter of 1995/1996. Attempts to clean out the scale proved to be futile and flow eventually ceased in the Formosa adit pipeline. All adit drainage flow was then a combination of subsurface flow and surface flow that ended up in Upper Middle Creek. (DOGAMI 1996)

FEI officially abandoned the Site in April 1996. The amount of money left in the reclamation bond at this time was $40,370 (DOGAMI 1996). The remaining bond money was used for additional monitoring and repair to the Formosa 1 adit water diversion system; which was rebuilt in the fall of 1996. Fill material was removed near the adit portal, three 10-in perforated drainpipes were installed in parallel, coarse rock was backfilled onto the pipes, and a manhole was built to access the drainpipes for cleaning out precipitate (DOGAMI 1990 – 1999; Heenan 2000). A French drain was also installed below the perforated pipe (Heenan 2000). The remaining pipeline down to the drainfield was constructed of 6-in polyvinyl chloride (PVC) with cleanouts spaced at 75-ft intervals (DOGAMI 1990 – 1999). Some rehabilitation work was also conducted on the Silver Butte 1 adit water diversion system during this time (DOGAMI 1990 – 1999).

DOGAMI inspections in 1997 indicated that the Formosa 1 adit water diversion system was functioning, although new scale buildup was occurring, mostly near the drainfield (DOGAMI 1990 – 1999). Regular removal of scale was conducted through the cleanout ports to keep the pipe flowing, but the process was costly and difficult. In November 1997, a new 100-ft section of 6-in pipe was installed at the drainfield and at a steeper gradient than the previous pipeline, with the idea that a faster flow caused by the steeper gradient would reduce scale buildup (DOGAMI 1990 – 1999).

Inspections in March and May 1998 documented a small seep flowing out of the backfill around the Formosa 1 adit and into the ditch down to Upper Middle Creek, and that the collection piping system was clogging with precipitate scale (DOGAMI 1990 – 1999; Heenan 2000). Regular cleanout of scale was continued through 1998, and in September 1998 additional work (trenching and adding new coarse drainage rock) was conducted at the Formosa adit portal to fix

the scaling and collection problems (DOGAMI 1990 – 1999). In 1998, the remaining Formosa bond money had been spent and other options were pursued to obtain funding for continued maintenance on the adit water diversion systems and additional assessment at the Site. Also in 1998, some positive recovery of Upper Middle Creek was noted; however, acidic groundwater was determined to be seeping into Upper Middle Creek causing adverse affects (Heenan 2000). A detailed topographic survey was conducted in 1998 by BLM to identify the location and elevation of the groundwater seeps in relation to the underground mine workings (Heenan 2000).

Because of heavy winter snow during the 1998/1999 winter, access to the Site was apparently not possible until April 1999 (Heenan 2000). At this time, the collection system had become completely plugged with scale, and a large flow of adit seep water was direct discharging into Upper Middle Creek (Heenan 2000). Some surface work was conducted to divert water out of the road ditch and into the adit diversion system (Heenan 2000).

1.4.6 Baseline Remedial Investigation and Interim Remedial Action Measure

Starting in June 1999, BLM in cooperation with ODEQ began an extensive baseline RI at the Site. Through North American Regional Science Council funding, BLM also hired Dynamac Corp. (Dynamac) to conduct a site assessment (SA) in October 1999.

In March 2000, ODEQ declared the Site a State Orphan site, which is a designation in the State of Oregon for sites contaminated by a release of hazardous substances that pose serious threats to human health or the environment and where the parties responsible for the contamination are either unknown - or unable or unwilling - to pay for needed remedial actions. Hart Crowser Inc. (HC) was hired by ODEQ to conduct an investigation at the Site and to design and build the interim remedial action measure (IRAM) adit water diversion and treatment system. A removal assessment report was prepared by HC in September 2000 (HC 2000), and construction of the adit water diversion system portion of the IRAM began in the fall of 2000 and was completed by November. Before start of construction, BLM granted a right of way for ODEQ to proceed with the remedial action on BLM managed property (BLM 2000). The proposed plan for the IRAM included piping adit water approximately 0.6 miles below the mine to an area where level ground is first encountered, and then treatment of the adit water through a series of passive anaerobic treatment ponds to remove metals and sulfate (HC 2000; BLM 2000). The intent of the IRAM was to collect and treat the adit water; however, the dispute over private land ownership prevented a passive treatment system from being built as initially designed (HC 2001a). The IRAM construction completed in 2000 consisted of the following elements:

- Excavation of a 20-ft by 15-ft receiving basin at 5-ft deep, lined with bentonite and a layer of limestone. Both the Formosa and Silver Butte adit flows were directed into the basin.
- Installation of four gravity draining aeration tiers downgradient of the receiving basin, constructed of open top 24-in HDPE pipe, each placed with about 4- to 5-ft drop in elevation. Flow at the last tier transitioned to a 120-ft limestone drain constructed of closed 12-in HDPE pipe.

- Construction of two concrete vaults for collection of precipitate placed in series along the flow path after the limestone drain. The first vault can hold 5,460 gal of water and the second vault can hold 3,870 gal of water.
- Construction of remainder of drainage pipes to the new drainfield using 12-in HDPE. Flow was directed under the road after the second concrete vault and then along the hillside (minimum slope of 10 percent) down to a drainfield further to the south than the previous drainfield.
- Regrading of the encapsulation mound and placement of a geotextile layer and 10-mil thick plastic liner (10 one-thousands of an inch). Silt fence was placed along the eastern edge and stormwater ditches were constructed on both the north and south ends draining to the east.

After approximately 6 months of operation of the system an IRAM report was prepared (HC 2001a). Within a short time, the limestone channel became armored (e.g., coated) with iron precipitates and was no longer effective in raising pH. Over the following years, precipitate formation and plugging of the diversion pipeline remained a problem due to the high iron content of the adit water. The following observations and maintenance actions were obtained from ODEQ time-critical removal incident orders (ODEQ 2003 – 2006):

- In October 2003, it was observed that the adit water diversion pipeline had clogged with precipitate before the first concrete vault, and a section of pipe after the concrete vaults had been severed because of falling rocks. This resulted in about 5 gpm of adit water flowing into Upper Middle Creek. Precipitate was subsequently removed from the plugged pipe sections and vaults, and the broken section of pipe was repaired. The limestone drain section of pipe was also removed and replaced with a new pipe that did not contain limestone.
- In October 2004 and September 2005, repair and maintenance was conducted on the adit water diversion pipeline. Further details on these maintenance visits are unavailable.
- In November 2005, rocks were removed from the adit water diversion pipeline.
- In January 2006, it was observed that runoff from recent rains had breached a surface water runoff control berm, allowing surface water runoff to flow from the road down the hillside causing a 3-ft deep gully to form beneath the adit water diversion pipeline. A support system was subsequently constructed along the eroded section beneath the pipeline, and repairs to the erosion berm and ditches along the road were made.
- In April 2006, it was observed that a pipeline joint had become separated, resulting in discharge of up to 48 gpm of adit water to Upper Middle Creek. The pipeline joint was subsequently repaired, and additional support posts were added to the section of pipeline where the joint had failed.
- In December 2006, maintenance was conducted to repair a section of pipeline and clean out precipitate. Further details on this maintenance visit are unavailable.

Additional maintenance and repairs have since been conducted by EPA's removal program and by BLM. In 2005, citizens petitioned the EPA to consider adding the Site to the National Priorities List (NPL). In 2006, the Site was proposed for listing on the NPL, and in 2007 was officially added to the NPL. After the Site was added to the NPL, the EPA Region 10 Emergency Response Unit took over maintenance on the adit water diversion system. In June 2008, a site-specific sampling plan (EPA 2008a) was developed by EPA to conduct sampling for iron precipitates in piping that was removed and disposed. An emergency response action was conducted in June 2008, which included some piping repairs and replacements, and removal of iron precipitates from piping (EPA 2009a). Samples of iron precipitate were analyzed by toxicity characteristic leaching procedure (EPA Method 1311), and based on the results of the tests, iron precipitates were disposed accordingly (i.e., hazardous or non-hazardous waste). Details on disposal of precipitates are not available.

During a March 2009 Site visit by BLM, CDM, and others, significant plugging of the adit diversion system was observed at the concrete vaults. Adit water was overflowing out of the top of the first concrete vault, onto the main road, and down past where the Middle Creek A (MA) sub-drainage crosses the road. As a result of very high flows, a new drainage channel was cut through the woods to the north of MA, termed Middle Creek C (MC) sub-drainage. Significant erosion and iron staining of the soils in this channel were observed. This channel eventually intersected MA just before the confluence of Middle Creek B (MB) sub-drainage.

Because of this overflow and direct discharge of adit water into Upper Middle Creek, emergency response action was conducted in March 2009 by EPA Region 10. This action involved removal of the iron precipitate obstruction at the concrete vault, repair of pipe, and overall inspection of the diversion system (EPA 2009b). Additional maintenance on the adit water diversion system has been conducted since March 2009 by BLM. This work includes routine cleaning of precipitates, pipe replacement or repair (patching), and structural repairs on the pipe trestle near the MB drainage.

1.4.7 Additional Investigation and Current Site Status

A supplemental RI for the entire Site was conducted by HC after the BLM/ODEQ RI was completed in May 2000. The supplemental RI continued until June 2002 and supplemental RI report was prepared (HC 2002). While RI sampling was being conducted and after installation of the IRAM adit water diversion system, interim data was also reported separately in a data evaluation report (HC 2001b). After the Supplemental RI was completed, HC completed a FS and a human health and ecological baseline risk assessment (HHEBRA). Both the HHEBRA and FS were completed and their associated reports were published in 2004 (HC 2004a and 2004b, respectively).

For the HHEBRA, HC included evaluations of potential receptors and exposure routes for the contaminants present at the Site. For human health, HC investigated exposure to hikers and campers through ingestion and contact with soil, inhalation of soil particulates, and consumption of surface water. HC identified minimal risk to human health, primarily because of the limited exposure by users of the Site.

Ecological risks were evaluated for both aquatic and terrestrial receptors. For aquatic receptors, exposure routes included ingestion and contact with surface water, but potential additional routes also included ingestion and contact with sediment. For terrestrial receptors, primary exposure routes included ingestion and contact with soil, and consumption of surface water. Potentially complete exposure routes included ingestion and contact with sediment, contact with surface water, and inhalation of surface soil particulates. The ecological receptors were of particular importance because of the presence of federally threatened Oregon Coast Coho salmon and Northern Spotted owl species; the Steelhead trout was also a candidate species for listing as federally threatened, and has since been named a species of concern. Results of the HHEBRA indicated that risks to terrestrial ecological receptors, including the Northern Spotted owl, were low because of poor habitat conditions and limited use of resources present in the vicinity of the Site. The HHEBRA identified significant risks to aquatic receptors due to presence of high concentrations of toxic metals and metalloids. Since completion of the HHEBRA and FS by HC, sporadic surface water sampling has been conducted by ODEQ and BLM.

The EPA-led RI was initiated in August 2008. The process began with background data collection, assessment of historic data and information, and development of recommendations for the EPA-led RI/FS and risk assessment. These findings were presented in the Data Summary Report (Appendix A). Although a state-led RI/FS/risk assessment was conducted, the Data Summary Report concluded that additional data collection and assessment was necessary to sufficiently characterize site contamination to conduct remedial action under CERCLA.

Section 2
Study Area Investigations

This section presents the sources for the data used in the RI, how they were collected and analyzed, how they were evaluated for quality, and whether they are usable for the purposes of the RI and, subsequently, the FS. The RI objectives were to characterize the nature and extent of contamination for OU1, evaluate risk to human health and the environment, and provide physical and chemical data necessary to support FS and remedial action decisions.

2.1 Introduction

This section presents the geographic and temporal boundaries of the study area, previous investigations, an overview of the RI sampling activities, and an overview of the process for development of DQOs for the study area investigations.

2.1.1 Study Area Geographic and Temporal Boundaries

As part of the RI process, the boundaries of the study area must be defined. The geographic boundaries of the overall Site study area include the abandoned Formosa and Silver Butte mines and adjacent affected areas. The study area includes underground mine areas, adit discharges, all adjacent Site surface features associated with mining such as WRDs and contaminated roads, downslope areas affected by dispersion of mine materials, groundwater, sediments, and surface water. The primary area disturbed by mining activities is located along the Silver Butte ridge, which is a divide of four subwatersheds: Russell Creek to the north, Upper West Fork Canyon Creek drainage to the east, South Fork Middle Creek to the south, and Upper Middle Creek to the west.

Geographic boundaries of OU1 are shown on Figure 1.3-2. This study area includes source areas of contamination but does not include the downgradient extent of contamination in surface water, sediments, and groundwater. As detailed in Section 1, this RI is focused on OU1, which includes the surface and subsurface mine materials and contaminated soils outside of the underground workings area.

General temporal boundaries of this RI extend from October 2009 through September 2011 and include field events in October 2009, January/February 2010, July 2010, August 2010, and October/ November 2010, January 2011, and September 2011. Only groundwater level data from transducers collected in September 2011 are presented in this RI report. Analytical data from this sampling event and all subsequent sampling events will be presented in the OU2 RI report.

2.1.2 Previous Investigations

Previous investigations include mining exploration and environmental investigations in the mid- to late 1980s; routine site inspections and reports completed during the early 1990s; and environmental investigations completed by ODEQ, U.S. Geological Survey (USGS), and BLM in the late 1990s to early 2000s. These investigations were generally presented in Section 1.4. The Site was added to the EPA's NPL in 2007. Data from investigations before the addition of the Site to EPA's NPL have been evaluated for usability and compiled in the Data Summary Report, which is included as Appendix A. As described in the Data Summary Report, much of the information from these previous investigations was usable in development of field investigation plans and data collection activities to support this RI. However, only a limited amount of these previously collected data are utilized to define nature and extent of contamination for OU1. Some previously collected data are presented herein to support discussions of historic data trends; these data include the following:

- Surface water flow data from historically sampled locations (1999 - 2002);
- Historic adit water, seep, and surface water data (pre-modern mining 1988 - 1989);
- Historic groundwater levels in encapsulation mound area (pre-modern mining 1988 - 1989);
- Select trench and boring data from HC and the EPA Superfund Technical Assessment & Response Team Contract 3 investigations; and
- Historic descriptions of geology and mineralogy.

2.1.3 Overview of Sampling Activities

To complete the RI, two sampling and analysis plans (SAPs) dated September 2009 and July 2010 (CDM 2009a and 2010) were prepared. Both SAPs addressed activities to be conducted for the field programs for the entire Site; however, OU1-related sampling activities were prioritized to provide data for this RI report. Sampling activities originally proposed within each SAP are summarized below:

- The 2009 SAP(SAP1) addressed surface mine materials and soil sampling, monthly/quarterly surface water and groundwater sampling, seep and spring surveys, and installation of flumes and flow rate and water quality instrumentation.
- The 2010 SAP (SAP2) addressed subsurface mine materials and soil sampling, groundwater monitoring well installation, groundwater sampling, hydrogeologic characterization using down-hole geophysical methods, pumping tests, well data loggers, background soil sampling, and soil sampling of areas downslope of mine materials.

SAP1-related activities have been conducted throughout the temporal boundaries of the study. SAP2-related activities have been conducted since July 2010. The surface and subsurface mine material sampling, background soil sampling, and downslope soil sampling for OU1 were completed in November 2010.

While emphasis was placed on completing data collection activities for OU1, groundwater and surface water samples were also collected to support the RI and FS for OU2 and to gain a basic understanding of the affects of OU1 source materials on these media. Activities conducted for OU2 included the following activities:

- Dry season (October 2009) and wet season (January/February 2010) seep and spring surveys;
- One comprehensive surface water sampling event from historic and new locations (October 2009);
- Groundwater sampling from existing functional wells (October 2009 through September 2011);
- Installation of seven shallow groundwater wells (August 2010) and sampling of newly installed wells during the dry and wet seasons (through September 2011); and
- Installation of water level data loggers in all functioning Site wells, which includes the two functioning bedrock groundwater wells and the seven shallow groundwater wells.

Because the RI for OU2 is being phased after remediation of OU1, many sampling activities identified in the initial SAPs were not completed based on EPA direction. The following activities described in SAP1 and SAP2 have not yet been conducted:

- Formosa 1 adit tracer test and tracer resurgence monitoring;
- Installation of flumes and electronic data loggers at the Formosa 1 adit, MXR, and a location in the Upper South Fork Middle Creek;
- Installation and geophysical logging of conventional bedrock wells;
- Installation and geophysical logging of multi-level bedrock monitoring wells;
- Installation of a mine pool monitoring well;
- Single well aquifer pump testing; and
- Installation of six additional planned alluvial wells (MW-6A, MW-14A, MW-17, MW-18, MW-19, and MW-20).

2.1.4 Overview of DQO Process

DQOs were established to determine the usability of historical data, clarify the study objective, define the most appropriate type of data to collect, and determine the most appropriate conditions from which to collect the data. The goal of the DQO process is to "help assure that data of sufficient quality are obtained to support remedial response decisions, reduce overall costs of data sampling and analysis activities, and accelerate project planning and implementation" (EPA 2000).

The DQO process specifies project decisions, the data quality required to support those decisions, specific data types needed, data collection requirements, and analytical techniques necessary to generate the specified data quality. The process also ensures that the resources required to generate the data are justified. The DQO process consists of seven steps and the output from each step influences the choices that will be made later in the process. These steps are:

- Step 1: State the problem;
- Step 2: Identify the goals of the study;
- Step 3: Identify the information inputs;
- Step 4: Define the boundaries of the study;
- Step 5: Develop the analytic approach;
- Step 6: Specify performance or acceptance criteria; and
- Step 7: Develop the plan for obtaining data.

During the first six steps of the process, the planning team develops decision performance criteria (i.e., DQOs) that will be used to develop the data collection design. The final step of the process involves developing the data collection design based on the DQOs.

DQOs presented in both SAPs were specific to the investigation approaches as presented in Section 2.1.3. DQOs were developed according to EPA's seven-step DQO process after the historical data for the Site were screened for usability and the data gaps identified. DQOs were developed for the following media:

- Surface and subsurface mine materials and soils (referred to as waste rock and soils in the SAPs);
- Surface water; and
- Groundwater.

Specific DQOs developed for the Site are described in Section 2.3 in relation to the various investigation activities and media.

2.2 QA/QC Summary

This section discusses QA/QC activities conducted during field events and laboratory analysis to ensure data quality.

2.2.1 Field QA/QC

During the RI, QC samples were collected to evaluate precision and representativeness in the field processes. In most cases, duplicates of samples were collected at a frequency of 10 percent of the total samples by medium and analyses. Equipment rinsate blanks consisted of the final rinse water (deionized water) after it had been in contact with a cleaned sampling tool and were

submitted at a frequency of one rinsate blank per piece of equipment requiring decontamination per day. Field duplicate results and a comparison to the parent samples for surface total metals data, subsurface total metals data, surface and subsurface synthetic precipitation leaching procedure (SPLP) data, surface water data, and groundwater data are presented in Tables 2.2-1a, b, c, d, and e, respectively. Rinsate blank results are presented in Table 2.2-2.

All instruments used in the field were calibrated daily according to manufacturer specifications. Equipment used for field chemistry measurements (Oakton pH and EC meters, YSI meters, and turbidity meters) were calibrated at the beginning of each day of use. Calibration information such as instrument identification number, date, calibration standard used, individual performing the calibration, adjustments made, and final reading for the standard was documented on the equipment calibration logs which are included in Appendix B. If the equipment or instruments could not be properly calibrated, that specific piece of equipment was not used, and an alternate calibrated instrument was used.

2.2.2 Analytical Data QA/QC

Analytical QA/QC includes adherence to analytical holding times and laboratory QC checks such as method blanks, laboratory control samples (LCSs), matrix spikes (MSs), serial dilutions, and laboratory duplicates.

A review of the data set is necessary to determine if the data quality meets the DQOs. Data validation was performed by CDM and EPA Region 10 personnel, according to the current EPA CLP National Functional Guidelines (NFG) for Inorganic Review (EPA 2004a and 2010a). The data validation process provides a system for the evaluation and documentation of factors that may affect the project data, and determines whether or not the data are of sufficient quality to support their intended use. The process includes, but is not limited to, the following assessments:

- Evaluation of data as compared to the precision, accuracy, representativeness, comparability, completeness and sensitivity (PARCCS) parameter criteria specified in the SAP, through the assessments of laboratory and field QC sample results;
- Verification that the analytical procedures and the reported results were consistent with the methods and reporting limits requested;
- Delineation of specific sample handling issues and deviations from the SAP, and the impact on the project DQOs; and
- Extensive quality checking of the database to assure that data integrity was maintained in the process of the data entry.

EPA provided data validation and data validation reports for the CLP laboratories, as well as the ESAT laboratories for EPA Region 10 and Region 5. These validation reports are included in Appendix C. CDM performed data validation on the ABA analyses from ACZ Laboratories, and the validation summaries are also included in Appendix C. Results of the data validation assessments are summarized in the sections that follow, specific to the media and their DQOs. Most data were found to be usable for its intended purpose. A summary of rejected and estimated data, and the

data completeness, defined as the percentage of data that was evaluated to have met the DQOs established in the SAPs and that are usable for the purposes stated, is provided in Table 2.2-3.

Analytical comparability is maintained by consistent usage and adherence to written EPA approved methods. The following laboratories and methods were used throughout all sampling events:

EPA CLP Laboratories, ChemTech and Bonner Analytical:

- Total and dissolved metals analyses on surface water, groundwater, SPLP leachate, mine material, and soil by CLP statement of work (SOW) ILM05.4. Boron, molybdenum, lithium, uranium, and thorium were requested and analyzed in addition to the target analyte list (TAL) metals listed in ILM05.4. In addition and in accordance to the SAP, low level reporting limits were required for cadmium and silver in the surface water and groundwater samples.

Region 10 ESAT Laboratory - Manchester Environmental Laboratories (MEL):

- EPA Method 300.1 – inorganic anions, chloride, fluoride and sulfate by ion chromatography;
- EPA Method 353.2 – nitrate and nitrite;
- Standard Methods 2540C – total dissolved solids;
- Standard Methods 2320B – alkalinity;
- USGS Method I3765 – total suspended solids;
- SW846 Method 6010 – total metals by inductively coupled plasma-atomic emission spectrometry for incremental samples collected by incremental sampling technique; and
- EPA Method 1312 – SPLP extraction; analysis of leachate was performed by the CLP laboratory.

Region 5 ESAT Laboratory:

- Acidity by titration and ammonia

ACZ Environmental Laboratories:

- ABA analyses

Descriptions of these analyses and other tests specific to the characterization sampled media are presented in Section 2.4. The specific results of data validation are summarized in Section 2.3 with respect to each media.

2.3 Sampling Activities

This section presents the sampling activities for the various Site media. Each subsection presents the DQOs specific to each media type, the sampling approaches, deviations from the proposed

approaches in the SAPs, and a data evaluation that includes discussion of data usability, achievement of DQOs, and data completeness.

2.3.1 Surface and Subsurface Mine Materials

This section presents the DQOs for surface and subsurface mine materials, and field activities conducted in 2009 and 2010 in support of these DQOs.

2.3.1.1 DQOs

Surface and subsurface mine materials were collected for lithologic logging, field paste pH and conductivity measurements, as well as collection of selected samples for laboratory analyses. As stated in the SAPs, the principle objectives to be addressed by the collection of these samples were to (CDM 2009a and 2010):

- Determine the nature and extent of surface soil and waste rock contamination present at the Site, and determine if the metals concentrations are greater than the screening criteria for human health (CDM 2009a).
- Determine the potential for mine waste rock and soil in surface disturbance areas on the Site to be ARD-generating, and the potential for these materials to leach contaminants (i.e., metals) into surface waters or into the subsurface(CDM 2009a).
- Determine the areal extent and volume of mine waste rock and soil at the Site that is capable of generating ARD and/or leaching contaminants to surface waters (CDM 2009a).
- Determine the geochemical characteristics and volume of surface and near-surface mine waste materials that are capable of generating ARD and/or leaching contaminants to surface waters or into the subsurface (CDM 2010).
- Determine if soils located downslope from mine waste areas are contaminated with COCs at levels that require additional investigation to support the risk assessments (CDM 2010).

Note that for this RI report, the terms ”mine waste rock and soil” utilized in the original DQOs have been revised to ”mine materials” to provide a more inclusive definition of materials at the Site and to simplify classification of these materials. A detailed definition for mine materials is provided in Section 4.1.

The first three DQOs were presented in SAP1 and the fourth was presented in SAP2 as a revised DQO to define the extent of the mine material contamination as part of the subsurface sampling investigation. The last DQO was presented in SAP2 and was intended to define the extent of contamination in natural soils below WRDs. The sampling and analytic approaches used to achieve this objective apply to both the extent of mine materials at the toe of WRDs and potentially affected soils further downslope; therefore, this DQO is applicable to the sampling approaches defined in this section, as well for Section 2.3.2 Potentially Affected Soils.

A specific DQO or sampling approach for characterization of the contaminated soils at the adit water diversion system drainfield areas was not included in either sampling plan. During the initiation of sampling of surface mine materials in October 2009, the project team determined

that opportunity samples should be collected from this area to provide information on the affects of the adit water discharge on the environment. The same techniques for surface mine materials sampling were applied to sampling soils within the drainfield area.

All DQOs for surface and subsurface mine materials were achieved. The sampling events, methodologies, deviations from the SAP, and a summary of data usability assessment are included in the subsections below.

2.3.1.2 Sampling Approach

Surface and subsurface mine material samples were collected during the October 2009, July 2010, August 2010, and October/ November 2010 field events.

Surface samples were collected during each field event and the surface sample locations were designated with "P" before a sample number. During these events, lithologic logging, paste pH, and conductivity measurements were conducted at 398 surface locations. At 60 of these locations, samples were collected and submitted to analytical laboratories for analyses for total metals, SPLP and subsequent analysis of the leachate for total metals, and ABA. Volumes for SEM-EDS analysis were also collected at 56 of these 60 locations; however, SEM-EDS analysis was only conducted on six samples.

Subsurface samples were collected during the August 2010, and October/ November 2010 field events and all subsurface location samples were designated in the sample identification with "SP" before a sample number. Lithologic logging and paste pH and conductivity measurements were conducted at 184 subsurface "SP" locations. At these locations, a total of 323 field samples were collected, with 47 of the these field samples submitted to analytical laboratories for analyses for total metals, SPLP and subsequent analysis of the leachate for total metals, and ABA.

During the July 2010 and October/ November 2010 field events, FPXRF, paste pH, and conductivity measurements were collected for sieved surface soil samples at 202 "XP" locations. All FPXRF samples were designated in the sample identification with "XP" before a sample number. Samples were collected from 52 of these locations and submitted to a CLP laboratory for total metals analysis, for comparison with the results from the FPXRF. A portion of these "XP" sample locations were collected within mine material areas and a portion of these samples were collected within potentially affected soil areas downslope of mine materials. The FPXRF sampling approach is presented in the following sections; however, note that this approach also applies to potentially affected soil sampling, as presented in Section 2.3.2.

Surface Mine Materials Sampling

Sampling locations for surface mine materials were selected to define geochemical characteristics of exposed mine rock and to delineate surficial source materials that contribute to acid generation and metals leaching. Surface sample locations were spaced at irregular intervals or in a grid pattern, with specific locations selected by the project geochemist, field geologist, or the field team leader based on visual evaluation of lithology, sulfide mineralization, and secondary mineral alteration. Affected areas such as WRDs were generally visually discernable from non-affected areas or native soil areas. Surface samples were collected within visually affected areas, roads, and along margins of visually affected areas. Sufficient samples were collected within these areas to delineate the overall characteristics of the materials present.

Surface sample locations were surveyed in the field with a Global Positioning System (GPS) unit. If GPS could not successfully be used to determine test locations because of heavy forest cover or time of day relative to satellite positions, locations were determined using field surveying methods including a compass, clinometer, and hip chain. Sample locations were marked with flagging tied on rocks or flagging tied on nearby vegetation. If possible, GPS data for each sample location was obtained after collection of the sample at a later more optimal time.

Each surface location was assigned a location identification (ID) with the formula "Pxxx" where P indicated a surface location and the following three characters were digits indicating the order in which the samples were collected (values between 001 and 710). In one instance, a transect of samples were collected along a WRD slope, and these samples were assigned a location ID with the formula "T1-X" (e.g., transect 1). This naming approach was not used for any other transects along WRDs. Several sequences of numbers were skipped when two teams were collecting surface soil samples simultaneously to avoid duplication of location numbers. In one instance, both teams assigned the same location numbers in error and "A" and "B" team designations were added in the field when the error was discovered. Surface mine materials sample locations are shown on Figure 2.3-1 as a general overview of locations. Specific location information is shown on figures presented in Section 4.

Samples of surface materials for paste pH and conductivity measurements were collected in the field with a disposable plastic scoop from a depth of 0 to 6 in below ground surface (bgs). A small amount of material was placed in a disposable plastic cup. Rocks and gravel were removed and distilled water was added to create an approximate 2:1 solid-water volume ratio or less depending on the type of material in the sample. The resultant paste was mixed by swirling. Measurements of pH and conductivity were taken with field meters that had been calibrated before collection of the first sample each day.

Lithologic logging of materials was also conducted at each location. Soil was visually logged according to CDM's Standard Operating Procedure (SOP) 3-5, Lithologic Logging, with the following project-specific modifications. The specific lithologic information recorded for each sample included the following:

- Identification of soil classification using the Unified Soil Classification System (USCS) abbreviations (use of sieves not required).
- Description of primary lithology.
- Description of sulfide mineralization including presence of pyrite (FeS_2), chalcopyrite ($CuFeS_2$), and sphalerite (ZnS).
- Description of alteration minerals including iron oxide/hydroxide and jarosite group minerals.
- Test results for presence of calcite with 10 percent hydrochloric acid solution as appropriate; very few locations required calcite analysis because of acidic paste pH. Sample materials tested with hydrochloric acid were discarded in areas separate from materials collected for paste pH and laboratory analysis.

- Identification of color using a Munsell color chart.

The results of the field testing, lithologic logs and observations relevant to the collection of the samples were recorded on field sheets which are included in Appendix B.

Surface mine material samples for laboratory analyses were planned to be collected at a rate of approximately 20 percent of the total locations. Based on the overall number of surface samples collected, laboratory samples were submitted at a rate of approximately 15 percent. The selection of specific samples for laboratory analysis was made by the field geologist or field team leader and covered the range of paste pH and conductivity values and material types. Samples were collected with a dedicated disposable plastic scoop to fill one 8-ounce glass jar, one 16-ounce glass jar, and one or two 18-ounce Whirl-pak® bags for total metals analysis, SPLP metals analysis, ABA, and SEM-EDS (for a select number of Pxxx laboratory samples only), respectively. All sample containers were labeled and the glass jars for metals analyses were placed in a cooler with ice.

Downslope surface mine materials and soils were also collected for field analysis by FPXRF, to delineate the boundaries of downslope mine materials. Samples were collected at sufficient spacing along the visual mine material boundary to delineate the downslope extent of mine materials based on field observations, FPXRF, and paste pH, and conductivity. Samples were analyzed within obvious mine materials such as the toe of WRDs and also from native soil areas below WRDs. As the toe of waste rock areas were traversed, samples were generally taken above and below the visual mine material line in a zigzag pattern to delineate the boundary. In some cases elevated metals were detected by FPXRF in native soil samples, and a subsequent native soil sample was collected downslope of the first sample to determine if metals concentrations had decreased with distance downslope. This approach provided an estimate of the areal extent of metals contamination into native soil materials downslope.

At each FPXRF sampling location, material was collected from 0 to 6 in (sometimes deeper in gravelly soils) with a disposable plastic scoop and placed in a disposable mesh sieve with a mesh size of 1.5 to 1.6 millimeters (mm) inside a 1-gal ziptop bag. The sample was sieved by agitation of the closed sieve and bag. Particles that passed through the sieve were then transferred from the bag to a 2-ounce Whirl-pak® bag, which was closed and labeled with the location ID. Samples were analyzed with the FPXRF directly through the Whirl-pak® bag after packing the sample tightly in the bag to remove air space between the sample and the FPXRF instrument. The metals results from the analyses were stored in the FPXRF instrument software for later downloading and results for five metals (arsenic, cadmium, copper, iron, and zinc) were also recorded on the field sheets manually.

Field measurements for paste pH and conductivity were also performed at each FPXRF location following the procedures described above with the exception that only sieved fines were included in the analyses. A brief lithologic description was noted for each sample, although less extensive than for surface “P” samples. The results of the field testing and data relevant to the collection of the sample such as time of collection for the FPXRF samples were recorded on field sheets which are included in Appendix B.

Each surface soil FPXRF sample location was assigned an ID of XPxxx, where XP indicates an FPXRF sample location and the following three characters were digits indicating the sequential order in which the samples were collected (values between 001 and 202). FPXRF sample locations are shown on Figure 2.3-2 as a general overview of locations. Specific location information is shown on figures presented in Section 4.

Soil samples for confirmatory laboratory analysis for total metals were planned to be selected from XPxxx samples at a rate of approximately 20 percent of the total number of samples analyzed by FPXRF. Based on the overall number of samples collected, laboratory samples were submitted at a rate of approximately 25 percent. The selection of specific samples was made after a number of samples were collected. For a set of samples from which laboratory samples were to be selected, the FPXRF results were reviewed and ranked from lowest to highest concentrations for indicator metals such as arsenic, copper, iron, and zinc. Once the data were ranked, decitile groups were created from 10 to 100 based on the concentrations. Representative samples were selected from each decitile for laboratory analysis, which provided comparison of field and laboratory sample results from across the range of field measured concentrations. FPXRF samples for laboratory analysis were submitted to the CLP laboratory in the Whirl-pak® bags in which they had been analyzed by FPXRF.

Subsurface Mine Materials Sampling

Subsurface samples were collected by direct-push technology (DPT) and excavation test pit methods. DPT subsurface mine material samples were collected during the August 2010 field event and excavator subsurface mine material samples were collected during the October/ November 2010 field event. Proposed locations for subsurface samples (DPT boring or test pit) were planned during preparation of SAP2 and provided on the subsurface sampling locations figure for SAP2 (CDM 2010). Locations were developed to investigate the depth of mine materials present in locations of known contamination, based on review of surface mine material sampling data collected in October 2009 and knowledge of areas that would be accessible to subsurface sampling equipment. The actual locations sampled in the field were generally similar to those proposed in the SAP (CDM 2010), with slight modifications based on field conditions. In many cases, observations in subsurface borings or pits at one location guided selection of adjacent sample locations to confirm depth of materials. All subsurface mine material sample locations were surveyed in the field with a GPS unit following the same procedure described above for surface soil sample locations.

During the August 2010 field event, subsurface mine material samples were collected using DPT sample collection techniques. The DPT drilling was conducted by the EPA Office of Research and Development Geoprobe 66100T DPT rig. DPT borings were advanced to collect continuous core samples of subsurface mine materials. Borings were advanced until bedrock was encountered or the drill rig encountered refusal. If shallow drill rig refusal was encountered (i.e., 1 to 2 ft), the boring location was offset and attempted again. Soil cores were collected from each boring in 4 ft long acetate sleeves, which were cut open to expose the cores. Recovery for each sampling core interval was noted and soils were logged by the field geologist. Lithologic logging information was recorded on a drilling log completed for each boring as described above. Soils from depth intervals determined by the field geologist were sampled for field paste pH and conductivity analyses. Field samples were selected at specific depths to provide characteristics of each of the

major lithology types observed in the borings. Samples were collected directly from the acetate sleeve with a disposable scoop or a clean nitrile glove. Seven of the DPT borings were completed as shallow monitoring wells. The well installations are discussed below in Section 2.3.4.2.

During the October/ November 2010 field event, subsurface mine materials were collected from excavated test pits. Test pits were excavated by a trained CDM equipment operator using a John Deere 120 track-mounted hydraulic excavator. As soil was excavated from each test pit, it was placed in piles on the ground near the test pit. Each pile of soil corresponded to an approximate 4-ft depth interval of soil. Piles of soil were identified by an assigned test pit ID number and depth, and each location was photographed. Test pits were excavated down to bedrock or to the limit of the excavator. After being photographed, soils from piles were sampled for paste pH and conductivity analyses and lithologic logging as described above for surface mine materials, as directed by the field geologist. Field samples were selected at specific depths to provide characteristics of each of the major lithology types observed in the test pits. Aliquots of soil from several locations within each pile were combined for the field analyses to provide representative samples of the depth interval. After each pile of soil was photographed, logged, and sampled for field analyses, the soil was replaced in the test pit from which it had been excavated and was compacted with the excavator or a bulldozer.

Each subsurface mine material DPT and test pit sample location was assigned a location ID following the formula "SPxxx" where SP indicates a subsurface location and the following three characters were digits indicating the order in which the borings and test pits were completed (values between 001 and 184). DPT sample locations were identified as SP001 through SP070 and test pit sample locations were identified as SP071 through SP184. Subsurface mine material sample locations are shown on Figure 2.3-3 as a general overview of locations. Specific location information is shown on figures presented in Section 4.

Field notes including results of the field analyses and lithologic logging of the subsurface soil sampling, were recorded on DPT and test pit logs which are included in Appendix B.

Subsurface mine materials samples for laboratory analysis were planned to be collected at a rate of approximately 20 percent. Based on the overall number of subsurface samples collected, laboratory samples were submitted at a rate of approximately 7 percent. The selection of specific samples was made by the field geologist. As described above for selection of surface mine materials laboratory samples, subsurface laboratory samples were selected to cover a range of paste pH and conductivity results as well as material types. Each laboratory sample was comprised of a composite of aliquots of soil collected from several locations in the pile. Samples for laboratory analysis were collected with a dedicated disposable plastic scoop or clean nitrile glove to fill one 8-ounce glass jar, one 16-ounce glass jar, and one 18-ounce Whirl-pak® bag, for total metals, a modified SPLP metals analysis, and ABA, respectively. All sample containers were labeled and the glass jars for metals analyses were placed in a cooler with ice.

2.3.1.3 Deviations from the SAPs

The collection of surface and subsurface surface mine materials was conducted according to the applicable SAPs, with the following deviations:

- The drying, splitting, and sieving to 60 mesh (250 micrometers [µm]) of the samples before analysis for total metals by the CLP laboratory was performed by MEL rather than the CDM Denver laboratory. MEL also performed the SPLP leaching procedure. The change in laboratories for these activities was a cost-saving measure and does not affect the DQOs.

- SAP1 stated an electron microprobe analyses would be performed on a subset of mine materials collected for offsite laboratory analysis. However, SEM-EDS was substituted for microprobe analyses. Although a large number of samples were collected for mineralogical analyses, the completed analyses were restricted to six samples. These samples were selected to provide information regarding sulfide mineralogy of the mine materials. SEM-EDS provided adequate detection levels to meet the needs of the project.

- SAP1 stated that sample volumes for laboratory analyses for ABA, SPLP, total metals, and SEM-EDS would be splits of the sample after drying at the CDM Denver laboratory; however, the sample volumes for these analyses were collected directly in the field. Several aliquots of material were collected within a small area (i.e., 1 ft by 1 ft) and portions of each aliquot were placed into each sampling container. The change in sampling approach was a cost-saving measure, but still provided an overall representative sample of the 'grab' sample area. Some sample heterogeneity is expected with this sampling approach, potentially more so than if one sample was collected and split using a rifle splitter. However, the co-located sample analyses are still considered adequate for characterization of nature and extent of contamination presented in Section 4 because ABA, SPLP, total metals, and SEM-EDS data from the various analyses are analyzed separately. Accordingly, results of each analysis type are analyzed as individual data sets to understand the extent of contamination at the site.

- Downslope soils analyzed by FPXRF were analyzed directly in 7-ounce Whirl-pak® bags (3.75 in by 7 in size bag) in which they were collected rather than in prepared sample cups. After sieving, sample material was packed tightly into the bottom of the Whirl-pak® bag and the FPXRF unit was pressed firmly against the bag surface. Care was taken to minimize void space between the sample and the FPXRF instrument window, which can lead to a reduction in sample accuracy. Preparation of sample cups involves placement of mylar window film over the sample cup, securing the film with a collar, placement of an aliquot of the sieved sample into the cup against the film, placement of a filter over the sample, packing the sample tight against the filter with polyester fiber, and placing the backing cap on the cup to secure the entire sample inside the cup. The FPXRF sample preparation and analysis approach was modified in the field because the cup preparation procedure was not practical on the steep terrain. In addition, the increased handling of sample material and cup consumables in the field may have led to increased potential of sample loss and/or cross contamination. Because samples were sieved and void space was minimized, the quality of the FPXRF data is not expected to be compromised using the bag analysis method. The greater thickness of the plastic bag versus that of the mylar film for the cup method is not expected to affect accuracy of results. Research by others using a Niton FPXRF unit for copper and cobalt analysis in soils indicates that there is no discernable difference in accuracy of results from bag analysis versus cup analysis given consistent preparation procedures for each analysis (Thermo Scientific 2008).

- Rather than excavating trenches, a series of test pits were excavated over the distance of the planned trenches because of accessibility issues with the excavator. Excavating test pits instead of trenches did not compromise the information obtained.
- Test pits were performed rather than DPT borings at locations SP181, SP182, SP183, and SP184 because of the inability of the DPT rig to travel down the steep South Fork Rroad. Some road improvement was done with the bulldozer to enable the excavator to travel down the road.
- The boring planned for the southwest corner of the encapsulation mound was not completed because the DPT lost a track towards the end of the sampling event before the advancement of this boring.
- As noted above, test pits were excavated instead of trenches because of accessibility issues with the excavator. Test pits could not be excavated over the distance of the planned trench near the 404 adit because of the difficult terrain. Therefore, only two test pits were excavated near the 404 adit.
- Three borings, rather than four, were advanced on the encapsulation mound. The field team leader determined that because of the consistency of the geology observed in the first three borings, the fourth boring was not necessary.
- The rate of laboratory analyses for total metals, SPLP, and ABA submitted to complement the field samples was less than the 20 percent goal for surface samples (15 percent) and subsurface samples (7 percent). Because a large number of field samples were collected for all the sampling events and the surface sampling had been completed before subsurface sampling, it was determined that sufficient laboratory samples had been collected to characterize the mine materials and native soils present at the Site. In addition, laboratory analyses do not validate or re-test field measurements (pH and conductivity), so the actual percentage of laboratory samples compared to field samples has no statistical significance with respect to data quality or verification. The reduction in laboratory samples compared to field samples does not affect data quality and all DQOs were met to adequately characterize the mine materials and soils.

2.3.1.4 Data Evaluation

Data were validated by EPA and EPA provided validation reports with data qualifiers applied. Data validation reports are provided in Appendix C. Validation was performed according to the EPA CLP NFG for Inorganic Data Review (EPA 2010). All sample result qualifiers were applied to the sample results in the database and tables presented herein. One hundred percent of the data were validated. All data were evaluated and determined usable, except where noted in this section.

Achievement of the DQOs was determined by the use of data quality indicators (DQIs). DQI criteria were established in the SAPs and are expressed in terms of PARCCS parameters. Precision and accuracy are quantitative parameters that are measured with the use of QC samples. Data validation criteria for the acceptance of data on the basis of these QC sample results are defined in the NFGs. According to the NFGs, data were accepted, accepted as estimated (qualified “J” or “UJ”),

or rejected (qualified "R"). The data validation reports in Appendix C provide rationale for all qualification; however, only the rejected data will be summarized here. The percentage of data estimated and rejected is shown on the data completeness table, Table 2.2-3.

Summary of Rejected Results

In 2009, samples were analyzed by the EPA CLP laboratory Chemtech Consulting Group, in Mountainside, New Jersey. Nickel data were rejected in the mass spectrometry analyses in 19 out of 20 soil samples in sample delivery group (SDG) MJBS74, and in 10 samples in SDG MJBSB4, including field duplicate results. The data were rejected, because the recovery of nickel in the quantitation verification standards ranged from 188 to 267 percent, outside the QC acceptance criteria, and, according to the NFGs, the data were rejected. Samples for which the total nickel results have been rejected are shown in Exhibit 2.3-1. Field duplicates are identified as (FD).

Exhibit 2.3-1: Rejected Nickel Results in SDG MJBS74 and MJBSB4

P002	P032	P062	P089	P114 (FD)	P129
P008	P038	P068	P095	P122	P130
P014	P044	P074	P101	P122 (FD)	P131
P020	P050	P077	P112	P124	P132
P026	P056	P083	P114	P124 (FD)	

In July 2010, samples were analyzed by EPA CLP laboratory Chemtech Consulting Group, in Mountainside, New Jersey. The MS recoveries for silver, thallium, thorium, and uranium in SDG MJCJE5, were below the QC acceptance criteria. Sample P286 was spiked with metals analytes and all matrix spike recoveries were within QC limits with the exception of the recoveries of silver and thallium at 16 and 6 percent, respectively, thorium was 56 percent, and uranium at 57 percent. Positive results for these analytes were qualified as estimated (J). Undetected results were qualified as rejected (R) and, because of the low spike recoveries, it could not be determined that these analytes were not present in the samples. The rejected undetected results are unusable. Silver and thallium data were rejected in four samples, thorium and uranium data were each rejected in two samples (see Exhibit 2.3-2).

Exhibit 2.3-2: Rejected Silver, Thallium, Thorium, and Uranium Results in SDG MJCJE5

Silver	Thallium	Thorium	Uranium
P214		P214	P214
P221	P221	P221	P221
	P248		
P419	P419		
P419 (FD)	P419 (FD)		

In November 2010, samples were analyzed by EPA CLP laboratory Bonner Analytical Testing located in Hattiesburg, Mississippi. In SDG MJDE31, the recovery of antimony from the inductively coupled plasma – atomic emission spectroscopy (ICP-AES) MS analysis was 20 percent, below the QC acceptance criteria. Antimony data in samples associated with this MS were estimated when

detected in the samples and rejected when antimony was not detected. Antimony was rejected in seven samples in SDG MJDE31; SP111, SP119, SP126, SP129, SP129 (FD), SP135, and SP138.

In SDG MJDE75, the recoveries of antimony and selenium in the ICP-AES analysis were 19 percent and 0 percent, respectively in the MS analysis, below the QC acceptance criteria. Undetected results were rejected and qualified (R). Selenium was rejected in 19 samples; XP127, XP133, XP137, XP143, XP155, XP160, XP164, XP166, XP178, XP183, XP185, XP189, XP191, XP193, XP194, XP195, XP198, XP199, and XP201. Antimony was also rejected in XP201.

In SDG MJDE17, the recovery of antimony in the ICP-AES analysis was 23 percent. The presence or absence of antimony could not be determined and the undetected results were rejected and qualified (R). Antimony was rejected in SP073.

In SDG MJDE61, the recovery of antimony in the ICP-AES analysis was 14 percent. The presence or absence of antimony could not be determined and the undetected results were rejected and qualified (R). Antimony was rejected in two samples; SP155 and SP179.

Summary of Duplicate Results

Duplicate analysis provides a measure of precision, for both the analytical laboratory and the field procedures. During the collection of the surface and subsurface mine materials samples, six field duplicates were collected for 60 surface samples and five field duplicates were collected for 47 subsurface samples. This rate of collection meets the 10 percent rate specified in SAP1 and SAP2. Field duplicates for the FPXRF samples (XP locations) were not a requirement of SAP2.

The field duplicate QC limit specified in the SAP is 35 percent relative percent difference (RPD) between the primary sample and duplicate sample result when both the primary and duplicate results are greater than or equal to five times the contract required quantitation limit (CRQL). When the concentration for either result is less than five times the CRQL, the QC limit is such that the absolute value of the difference between the two results is required to be less than or equal to the CRQL. In most cases, the field duplicate comparisons met these criteria, indicating that the field procedures resulted in representative sampling. Field duplicate comparison results are summarized in Tables 2.2-1. In the instances where these criteria were not met, the exact cause is unknown, but is likely to be an indication of sample heterogeneity, field sampling error, and/or laboratory analyses error. No qualifiers have been applied to the data on the basis of field duplicate results.

Summary of Equipment Rinsate Results

Equipment rinsate samples provide a measure of the representativeness of the field procedures in that they demonstrate the efficiency of the decontamination procedures between samples. Rinsate blanks were not required for surface paste pH and conductivity samples, subsurface samples collected from test pits, or the surface FPXRF samples because only dedicated equipment was used to collect these samples. Rinsate blanks were required for the subsurface soil samples collected with DPT techniques; the rinsate was collected from the DPT rig drive shoe, which was decontaminated between borings. For borings completed as monitoring wells, expendable drive shoes were used and no rinsate blanks were necessary. Six rinsate blanks were collected – one for each day during which soil borings were advanced with the decontaminated drive shoe with the exception of one day, August 21, because of an oversight. This issue does not affect data quality,

because consistent decontamination techniques were used throughout the field event for the drive shoe. Results for the rinsate blanks are presented in Table 2.2-2 and indicate the decontamination procedure was effective.

Summary of MS/MSD Sample Collection

Matrix spike and matrix spike duplicate (MS/MSD) analyses provide an indication of precision and accuracy for the laboratory analysis within the actual sample matrix. Both the RPD between the two spike analyses and the recovery of the spiked analyte (accuracy) are calculated and reported. Collection of sample volumes for MS/MSD analyses for the "Pxxx" and "SPxxx" samples was performed at rates greater than 5 percent during the October 2009 and July 2010 field events, which met the SAP1 and SAP2 requirements. During the October 2009 field event, out of 27 "Pxxx" laboratory samples, two "Pxxx" samples were collected to be used for MS/MSD analyses. During the July 2010 field event two "XPxxx" samples were collected for MS/MSD volumes out of a total of 33 "XPxxx" laboratory samples. During the October/ November 2010 field event, one MS/MSD volume was submitted with 17 "XPxxx" samples collected. No MS/MSD volumes were provided for the one "Pxxx" sample collected during the August 2010 field event or the two "Pxxx" samples collected during the October/ November 2010 field event.

2.3.2 Potentially Affected Soils and Background Soils

The soils investigation was designed to support assessment of risk to human and ecological receptors from exposure to contaminated soils and to evaluate if the surface and subsurface mine materials investigation had adequately delineated the downslope extent of contamination.

This section presents the DQOs for soils downslope from mine materials and background soils, and field activities conducted in 2009 and 2010 in support of these DQOs.

2.3.2.1 DQOs

Incremental sampling techniques were used to evaluate potentially affected soils downslope from the mine materials, as well as background soils. This sampling approach was detailed in SAP2 as multi-increment sampling (MIS); however, to be consistent with anticipated EPA guidance on this sampling technique, the sampling approach is referred to in this RI report as incremental sampling. Samples were analyzed in the field using FPXRF, and 20 percent of these samples were submitted to the CLP laboratories for confirmation analysis. The DQOs addressed by the collection of these samples were:

- Determine background concentrations of COCs in soils in the vicinity of the Site (CDM 2010); and.
- Determine if soils located downslope from mine waste areas are contaminated with COCs at levels that require additional investigation to support the risk assessments (CDM 2010).

These DQOs were presented in SAP2. Both DQOs for potentially affected soils downslope from mine materials areas and background soils were achieved during the field events in 2009 and 2010.

2.3.2.2 Sampling Approach

Potentially affected surface soils downslope from mine material areas were collected during the July 2010 and October/ November 2010 field events and background soil samples were collected during the July 2010 field event.

FPXRF Sampling

During the field events in July 2010 and October/ November 2010, FPXRF, paste pH, and conductivity measurements were collected for sieved surface soil samples at a total of 202 XP locations. Samples were collected from 52 of these locations and submitted to a CLP laboratory for total metals analysis, for comparison with the results from the FPXRF. A portion of these XP sample locations were collected within mine material areas and a portion of these samples were collected within potentially affected soil areas downslope of mine materials. Samples for FPXRF analyses were collected and analyzed with the same procedures described above in Section 2.3.1. These FPXRF sample locations are shown on Figure 2.3-2. Specific location information is shown on Figures presented in Section 4.

FPXRF screening of background soil samples was also conducted during the July 2010 sampling event. This field screening approach was not included within SAP2 (CDM 2010), but provided a field estimation of background concentrations of metals to assist with determination of the mine materials extent boundary. Background soil samples were analyzed by FPXRF through the sample bags (2.5-gal zip-lock). Samples were not sieved for analysis. Three FPXRF tests were conducted on each side of the bag for a total of six tests per sample bag. The following section describes further information on collection of background soil samples.

Incremental Soil Sampling

Incremental samples were collected from both background soil and from potentially affected soil downslope from mine materials. At each soil collection point, duff and other organic matter were carefully removed from the ground surface. Soil was then collected from a depth of 0 to 6 in bgs. Deeper samples up to 2 ft bgs were collected in some areas because of very gravelly soils. Sufficient gravel had to be dug and sieved to obtain an adequate sample volume of finer material. An approximately equivalent volume of soil was collected from each individual sample point (or "increment"), and was combined with samples from other sampling points within a decision unit, to make up one incremental sample. The number of points in a decision unit (DU) varied from 30 to 88 increments (see Exhibit 2.3-4). Soil from individual sampling points was collected in a 1-gal or 2.5-gal resealable plastic bag by each sampler.

Each incremental sample was collected in triplicate. At each sampling location, after clearing an approximate square ft area, each sampler collected a total of three equal soil volumes and transferred each volume to its own gallon resealable bag. The three bags were given identifiers of "A," "B," "C," or other uniquely identifying numbers or characters. Once the line of samplers had progressed across the entire DU area, one set of bags from each sampler was combined into a larger resealable zip-top bag to be sample "A." A second set of bags from all samplers was then combined to be the "B" replicate and the third set of bags was combined to be the "C" replicate.

All incremental samples were analyzed for total metals at MEL. Incremental samples were first processed at the CDM Denver laboratory before submission of the samples in an involved drying,

grinding, sieving, and splitting process designed to maximize the representativeness of the incremental sample. Preparation performed by the CDM Denver laboratory consisted of an initial drying of the soil for each sample. Once dried, each sample was sieved through a 2-mm mesh sieve and split into two subsamples. For background incremental samples, these samples were processed as follows:

- For the subsample designated as the "2-mm" sample, this fraction was ground to 100 percent passing a 60-mesh or 0.25-mm (250 µm) sieve, followed by splitting into two 10-gram subsamples for analysis. Grinding was conducted using a vertical plate grinder. The grinder was decontaminated between samples by passing clean quartz sand through the grinder.
- For the subsample designated as the "250-µm" sample, this fraction was sieved through a 60 mesh or 0.25-mm (250 µm) sieve, followed by splitting into two 10-gram subsamples for analysis.

For downslope incremental samples, only a 2-mm sample was prepared and submitted for analysis. After sieving to -2 mm, each of the subsamples was split by passing the soil material through a 3/8-in riffle splitter. Sample material that had passed through the riffle splitter was caught in steel catch pans. After each pass through the splitter, half of the material was archived and half was passed through the splitter again. Soil was passed through the splitter in this way until an approximate 10-gram mass of material remained in the catch pans. Each 10-gram aliquot for sample analysis was collected in a resealable bag and labeled for the laboratory. The laboratory digested the full 10-gram sample in the metals procedure, a deviation from the standard CLP metals method of digesting 1 gram of sample, in another effort to maximize the sample representativeness.

Incremental samples were assigned IDs that were a string of alphanumeric characters that were an acronym of, or representative of, the full sample name. The initial two to four characters are the acronym that indicates the sample location, the next three letters (MIS) indicate an incremental sample, the next letter indicates "upper" or "lower" if the MIS sample were a ribbon sample (U or L) and the last letter designates which replicate (A, B, or C). Exhibit 2.3-4 provides a summary of the number of sampling points and surface area in each DU.

Potentially Affected Soils Downslope of Mine Material Incremental Samples

The exact locations of downslope incremental samples were not planned in SAP2 (CDM 2010). Rather, the general area of natural soils below mine materials was targeted and field sampling data (visual observations, FPXRF, and paste pH/conductivity measurements) were utilized to determine the exact sample areas (DUs). The DUs were selected to be downslope of the field-delineated mine materials boundary after review assessment of field data by the sampling team. The incremental samples of potentially affected soils downslope from mine materials are shown on Figure 2.3-4. At each of the downslope incremental sample locations, the corners of the DU were surveyed with GPS and additional GPS measurements were collected along the side boundaries of the DU.

Exhibit 2.3-4. Incremental Sampling Locations, Number of Increments, and DU Surface Area

Sample ID	Full Location Name for DU	Upper/Lower (U/L)	Number of Increments	DU Surface Area (ft^2)
BKG1	Background 1	not applicable	88	43,617
BKG2	Background 2	not applicable	60	37,317
FA	Formosa Adit	U	34	20,158
FA	Formosa Adit	L	34	20,376
EMW	Encapsulation Mound West	U	30	26,452
EMW	Encapsulation Mound West	L	30	25,208
EME	Encapsulation Mound East	U	36	16,326
EME	Encapsulation Mound East	L	36	13,381
EMSE	Encapsulation Mound South East	U	32	25,841
EMSE	Encapsulation Mound South East	L	32	27.779
EMWD1	Encapsulation Mound West Drainage 1	not applicable	30	1,218
EMWD2	Encapsulation Mound West Drainage 2	not applicable	30	642
SB	Silver Butte	not applicable	30	1,686

The intent of the downslope incremental sampling was not to characterize the extent of contamination in 100 percent of the downslope areas (CDM 2010). Rather, the sampling was intended to provide a generally representative data subset for the overall downslope contamination at the Site and to support risk assessment and feasibility study evaluations. The data set developed from the sampling could then be utilized to correlate to other downslope areas of the Site that were not sampled using this method.

Factors that affected placement of downslope incremental sampling areas included site topography, accessibility, safety concerns, and the presence of the adit water diversion drainfields. Generally, the topography along the downslope areas varies between valleys and ridges. Downslope physical dispersion of mine materials is concentrated into valley areas. Physical dispersion of mine materials was observed within these valleys for several tens to hundreds of feet downslope from mine waste dumps. Downslope incremental samples were not collected within these dispersion pathways, except for two drainages below the west encapsulation mound WRD as described below. In addition, some areas downslope of mine materials were inaccessible because of steep terrain or cliffs and the widespread presence of poison oak.

Incremental soil samples were collected downslope from four areas (Formosa Adit, Encapsulation Mound West, Encapsulation Mound East, and Encapsulation Mound South East). Samples were collected as upper and lower 'ribbon' shaped samples. The shape the DUs for these samples was a ribbon that approximately paralleled the field-delineated downslope boundary of the mine materials for these WRD areas. For these ribbon incremental sample locations, upper and lower incremental samples were collected. Each of the upper and lower samples were separate DUs and had triplicate samples collected for both DUs. The original SAP2 (CDM 2010) sampling approach only included collection of one ribbon sample (upper ribbon); however, based on further planning after completion of the SAP, a second ribbon was added to improve

characterization of these downslope areas. This modification provided additional data downslope in the event that the upper ribbon sample revealed contamination. Samples from ribbon DUs were collected with two samplers per DU. The two samplers travelled in parallel along the ribbon at a specified distance (approximately 25 ft on slope) apart. Once each sampler was established in their general location for a point, individual sampler discretion determined the specific location for collection of soil, employing a "systematic random" approach (Hawaii Department of Health [HDOH] 2008). The two samplers just below the mine material boundary collected the "upper" sample and two additional samplers further downslope collected the "lower" sample.

Three incremental samples were also collected from two drainages located downslope of the west encapsulation mound WRD (Encapsulation Mound West Drainage 1 and Encapsulation Mound West Drainage 2) and at the toe of the Silver Butte waste rock dump. Incremental samples were collected from potentially affected soils below the field-delineated boundary of the mine materials in the drainages. The toe of the Silver Butte WRD is shaped as a valley or drainage, where all or most of the mine materials dispersing downslope of the mine dump move to the center of the drainage. In the upper and north part of the Silver Butte WRD, the boundary between the adit drainfield areas and the dump extent could not be discerned; therefore, an incremental sample was not collected in this area. For these reasons, an incremental sample at the Silver Butte WRD was collected only at the toe of the dump within the valley. The Encapsulation Mound West Drainage samples were collected as discrete DUs from the Encapsulation Mound West Upper and Lower incremental samples. The DU areas for the upper and lower ribbon samples did not extend into the drainage areas because mine materials are transported down the drainage and not up the sides of the drainage channel.

The drainage incremental samples were also collected in triplicate. For these drainage samples, only one incremental sample was collected with no "upper" or "lower" designation. The drainage samples were confined to the drainage channel; therefore, the surface area for the samples was much smaller than for the ribbon samples.

Background Incremental Samples

Incremental sampling techniques were also used to collect two background samples from soils unaffected by the dispersion of contaminants from mine materials, but from soils developed from underlying rock units with similar lithologies to soils in the Formosa Mine area. The locations of background soil sampling areas were developed in SAP2 (CDM 2010). These locations were selected to represent a potentially mineralized area along the trend of the massive sulfide ore body and a non-mineralized area to the south of the Site. The intent of the two background soil sampling areas is to account for potential differences between naturally mineralized and non-mineralized areas. Background soil sample locations were also placed upgradient of the dominant wind direction, based on review of wind data from the Silver Butt fire lookout station. The background incremental soil sample locations ultimately selected in the field are shown on Figure 2.3-4, which are similar to the planned locations. At each of the two background locations, the DU area was surveyed with a compass and hip chain. The corners of each DU were marked with flagging and surveyed with GPS.

The background incremental samples were each collected by a team of four samplers who traveled either across the width of the DU along the slope or down the height of the DU down the

slope. Once the DU area was determined, four individual samplers spaced themselves across one side of the DU area, separated by approximately equal distances and began collecting soil from their locations. After collection of soil from the initial locations for all samplers, the line of samplers then progressed a specified distance away from the initial locations, traveling in parallel lines. The distances between samplers and the individual collection points for each sampler were established to cover the DU area. Although this approach was designed based on a grid pattern within the DU, the specific sampling location was determined in the field by each sampler using a systematic random approach.

2.3.2.3 Deviations from the SAPs

The collection of potentially affected surface soils downslope of mine materials and background soils for FPXRF analyses, and the collection of incremental samples, was conducted according to SAP2, with the following deviations:

- The FPXRF samples collected from sample locations XP156, XP197, XP198, and XP199 could not be sieved when collected because of high moisture content. The FPXRF analyses of these samples were performed on the bulk materials as collected. Drying equipment was not utilized on site, because sampling was conducted during drier parts of the year. Samples XP198 and XP199 were also submitted to the analytical laboratory for confirmation testing for total metals. This deviation may have caused an increase in FPXRF sample measurement error because of the presence of larger particles (causing air voids) and the presence of high moisture content that can cause interference. An adequate number of FPXRF samples were collected to characterize downslope areas and the increased error for this small fraction of samples does not significantly affect characterization of downslope areas.

- As shown in Exhibit 2.3-4, all incremental samples consisted of less than 100 individual sampling points (SAP2 required 100 individual sampling points for each incremental sample). The decision to collect less than 100 points for the incremental samples was made based upon the difficulty of the terrain and time constraints encountered in the field. A minimum of 30 points was always collected for each incremental sample to maintain statistical integrity of the incremental samples. The sampling approach to include a minimum of 30 increments stems from the central limit theorem which states that the mean of a sufficiently large number of random samples will be approximately normally distributed even if the underlying population is not normally distributed, as long as enough random samples are collected (Koch and Link 1980). The required number of samples is generally considered to be 30, although more samples may be required with particularly non-normal populations (Ramsey 2007). This deviation from 100 increments may affect data quality; further details on this assessment are provided in Section 4.1.

- SAP2 did not include collection of a second lower ribbon sample. The addition of a lower incremental sample ribbon in downslope areas provided additional data regarding potential migration of contamination downslope of the upper ribbon sample area. This deviation provides further data for site characterization to help meet the DQOs.

2.3.2.4 Data Evaluation

FPXRF data evaluation was presented in Section 2.3.1.4.

All incremental sample soil data were evaluated and determined usable. All sample results met the QC guidelines as stated in SAP2. All results are usable for their intended purpose.

No field sample duplicates were collected for the FPXRF samples (XP locations) as discussed above in Section 2.3.1.3. Field duplicates were not required for the incremental samples, because all incremental samples were collected in triplicate to support sound statistical analysis of the data.

Summary of Equipment Rinsate Results

Rinsate blanks were not required for the surface FPXRF as discussed above in Section 2.3.1.4. Rinsate blanks were required for the trowels used for collection of incremental soil samples. Six rinsate blanks were collected for the trowels used to collect the incremental samples, meeting the specified frequency in the SAP. Results for the rinsate blanks are presented in Table 2.2-2. The water rinsate results are reported µg/L, part per billion, units. The soil sample results are reported in mg/kg, or part per million, results. Results demonstrate that the decontamination procedure was effective.

Laboratory rinsate blanks (process blanks) and sand blanks were also collected from the CDM Denver laboratory during processing of incremental samples. A clean quartz sand was utilized to decontaminate the vertical plate grinder between each sample grinding process; water cannot be used to clean the grinder. At least once per batch of soil samples that were processed, a process blank sample was collected to verify that decontamination procedure was adequate. After cleaning with the sand, a second batch of sand was run through the same grinding process as each individual incremental sample to collect the process blank. One process blank was collected during sample processing in July 2010 and another process blank was collected for the November 2010 samples. In addition, one sample of the raw quartz sand (not ground) was submitted to the laboratory in November 2010 to test for any trace metal content in the sand that may be present. The process and sand blanks were not requirements from SAP2; however, upon further planning for the sample processing work these QC samples were suggested by the laboratory manager.

Results for process and sand blanks are presented in Table 2.2. Target analytes are present in the clean sand, as well as the process blanks; however, the level in the quart sand blank is lower than in the samples with the interesting exception of uranium, which is present in the quart sand at concentrations ranging from 0.46 mg/kg to 0.77 mg/kg. The sand process blank results are comparable to the levels in the raw quartz sand and indicate the decontamination process is effective.

Summary of MS/MSD Sample Collection

MS/MSD volumes were submitted for “XPxxx” samples as discussed above in Section 2.3.1.4. MS/MSD volumes were not submitted with the incremental samples collected in July 2010 because it was believed that MS/MSD volumes would not be required for triplicate samples. Volume for MS/MSD was submitted with one sample for the samples collected during the October/ November 2010 field event.

2.3.3 Surface Water

This section presents the DQOs for surface water and the field activities conducted in 2009, 2010 and 2011 in support of these DQOs. Surface water sampling is ongoing as part of the OU2 RI. Information provided in this section represents surface water sampling conducted in support of the OU1 RI and as the initial phase of the OU2 RI.

2.3.3.1 DQOs

The DQOs for surface water sampling are as follows:

- Determine the nature and extent of surface water contamination discharged from the Formosa Mine and if the observed concentrations exceed water quality screening criteria (CDM 2009a).
- Determine the quantity and quality of water draining from the Formosa adit and other ARD sources on the Site and how the flow rate and quality vary over time (CDM 2009a).
- Determine the quantity and quality of flow in ARD-affected streams at the Site and how their flow rates and quality vary over time (CDM 2009a).

The DQOs for surface water were presented in SAP1. The RI for OU2, which includes surface water, is not yet complete. Consequently, the surface water DQOs have not been completed.

2.3.3.2 Sampling Approach

Surface water samples were collected during the October 2009, January/February 2010, October/ November 2010, and January 2011 field events. Surface water samples were collected from seeps, springs, creeks, and the intake for the Riddle Water Treatment Plant. Seep and spring surveys were conducted during the October 2009 and January/February 2010 field events in the Upper Middle Creek, South Fork Middle Creek, West Fork Canyon Creek, and Russell Creek drainages. Generally a seep is defined as an area where groundwater discharges to the surface with very low flow (e.g., less than 1 gpm), whereas a spring refers to a location where groundwater discharges to the surface at higher flow (e.g., more than 1 gpm). Biannual surface water sampling events in October/ November 2010 and January 2011 were focused on a small set of locations to continue monitoring the Site. An additional biannual surface water sampling event was conducted in September 2011; however, the data collected is not included in this RI report. An overview of surface water sampling locations from the seep and spring surveys and other surface water sampling locations are shown on Figures 2.3-5a, 2.3-5b, and 2.3-5c. Specific location information is shown on Figures presented in Section 4.

The majority of surface water samples were collected as grab samples. Field measurements for pH, temperature, conductivity, oxidation-reduction potential (ORP), and dissolved oxygen (DO) were taken with a YSI-556 multiparameter water quality meter at all surface water locations with sufficient water. At locations where flow was recorded, it was either measured with the flume, a bucket/cup and stopwatch, a Marsh McBirney flow-meter, or estimated visually.

Samples for laboratory analysis were collected at a number of in-stream locations identified in SAP1 and at a subset of new surface water features identified in the seep and spring surveys.

Laboratory samples were analyzed for total metals, dissolved metals, TDS, total suspended solids (TSS), alkalinity, nitrate plus nitrate, chloride, fluoride, sulfate, ammonia, and acidity.

Ferrous iron (Fe^{2+}) and alkalinity measurements were made in the field at the time of laboratory sample collection for most laboratory samples. The Fe^{2+} measurement was measured with a Hach DR/890 colorimeter. A fixed quantity of the reagent, d-1,10-phenanthroline, was added to a fixed volume of sample to react with Fe^{2+} and form a characteristic orange-colored complex. The intensity of the color produced is directly proportional to the amount of Fe^{2+}, which is measured with the colorimeter. During the October 2009 field event, vacuum ampoules with the d-1,10-phenanthroline reagent were used, resulting in an inability to dilute the sample if its Fe^{2+} concentration exceeded the upper reporting limit of the colorimeter. During subsequent field events, the reagent was added from a reagent pillow to a 25-milliliter (mL) volume of sample in a vial. This method allowed for dilution of the sample after the color was generated and the solution was stable. When the measurements exceeded the colorimeter's upper limit of 3.3 mg/L, dilution was performed to bring the reading within the reporting range of the instrument and the sample concentrations were calculated from the dilution.

The field alkalinity measurement was made by titrating a fixed amount of sample with H_2SO_4 to an end-point with phenolphthalein indicator followed by an endpoint with bromo-cresol green indicator. The alkalinity concentration is calculated from the drops of H_2SO_4 required to reach the final endpoint.

To collect volumes for laboratory analyses, unpreserved bottles were immersed into the stream if the water depth was sufficient, otherwise, a peristaltic pump was used to fill sample bottles from the stream or a small seep pool. At locations where unpreserved bottles were submerged, the sample was subsequently transferred from the unpreserved containers to preserved containers to avoid rinsing the sample preservatives out during sampling.

At locations with higher flows such as those locations near the confluence of Cow Creek and Middle Creek, samples were collected as depth integrated and/or width integrated samples. The total width of the stream at the sampling point was measured with a measuring tape. The stream width was divided into approximately 10 equal segments and the width of the stream was waded. Within each segment, flow measurements were taken and a bottle of water was collected. Width integration was achieved through the use of a churn splitter. In the approximate center of each segment, a liter of sample was collected by immersing a 1-liter plastic wide-mouth bottle and transferring the contents to the churn splitter. Once water was collected from each segment, water was sampled from the churn splitter through the spigot while the plunger of the churn splitter was activated.

Depth integration was achieved by the use of a depth-integrated sampler. A restricted opening glass bottle affixed to a rod was slowly lowered through the water column until sufficient water was collected or the bottle was full as appropriate to provide sufficient volume to fill all sample bottles, but not overfill the churn splitter. The same volume of water was collected from each stream segment. Collected water was transferred from the glass collection bottle to the churn splitter for sampling. Sample bottles were filled as the water was churned.

The sample volumes for the dissolved metals and anions (chloride, fluoride, and sulfate) analyses were always collected with a peristaltic pump and a dedicated, disposable filter (0.45 µm) placed in-line with the tubing. The field notes and results of the field testing and data relevant to the collection of the samples such as time of collection and containers collected were recorded on field sheets and/or in log books which are included in Appendix B.

Surface water samples collected from seep/spring and stream locations were assigned a location ID corresponding to the stream, or tributary where it was located and a unique number for multiple samples collected along one stream or tributary. Surface water samples collected from adits or other designated locations such as MXR or the Riddle Intake were named accordingly. Historic sampling location names were utilized as appropriate for direct comparison to historic data for that location.

2.3.3.3 Deviations from the SAPs

Collection of surface water samples was conducted according to SAP1 with the following deviations:

- Surface water samples collected from locations where flow was sufficient for width and depth: integrated composite samples were collected as width-integrated only during the October 2009 and January/February 2010 field events because the depth integrated sampling equipment was not available until the October/November 2010 field event.
- Before filtration of sample volumes for the dissolved metals and anion analyses, only sample water was run through the filter rather than de-ionized water followed by sample water. This change was made because after SAP1 was finalized, further research and team discussions revealed information that the filters are certified to be clean to very low levels for metals and anions and running de-ionized water through the filter could result in possible dilution of the sample if the de-ionized water was not fully rinsed out of the filter before collection of sample volumes.
- Hardness was not directly analyzed at an offsite laboratory. Hardness was calculated from the calcium and magnesium concentrations that were analyzed by an offsite laboratory.
- Flow rates were not directly measured at all surface water locations. Flow rates at many low-flow locations such as seeps were often estimated visually, utilizing measured streams as a frame of reference. The field team leader determined where flow measurements versus estimates were necessary to provide sufficient data during the seep and spring surveys. In addition in some instances, neither measured nor estimated flow rates were recorded at surface water locations. These data were not recorded because of physical constraints and/or time limitations of completing the work, or it was determined that flow was not deemed necessary for characterization.

2.3.3.4 Data Evaluation

Data were validated by EPA and EPA provided validation reports with data qualifiers applied. Data validation reports are provided in Appendix C. Validation was performed according to the EPA CLP NFG for Inorganic Data Review (EPA 2010). All sample result qualifiers were applied to the sample results in the database and tables presented herein. One hundred percent of the data

were validated. All data were evaluated and determined usable, except where noted in this Section.

Achievement of the DQOs was determined by the use of DQI criteria which were established in the SAPs and are expressed in terms of PARCCS parameters as discussed above in Section 2.3.1.4. The data validation reports in Appendix C provide rationale for all qualification; however, only the rejected data will be summarized here. The percentage of data estimated and rejected is shown on the data completeness table, Table 2.2-3.

Surface waters collected in October 2009 were submitted to Chemtech in Mountainside, New Jersey for analysis. Both a dissolved and total fraction were collected, with the dissolved fraction filtered in the field before preservation. In SDG MJDSD3 the MS/MSD recoveries for thorium were 11 and 12 percent, respectively. Thorium results for five samples were rejected. The dissolved thorium result for the sample collected from SW5 in October 2009 and the dissolved and total thorium results for the samples collected from SW6 and SW7 in October 2009 have been rejected and the data is not usable. All other results are usable for their intended purpose.

During collection of the surface water samples in October 2009, January/February 2010, October/ November 2010, and January 2011, six field duplicates were collected. One surface water field duplicate was collected during each of the October 2009, October/ November 2010, and January 2011 events. The total number of surface water samples collected during each of these field events was less than 10. During the January/February 2010 field event a total of 31 surface water samples were collected and three surface water field duplicates were collected. This rate of collection of field duplicates was just slightly less than the 10 percent rate specified in SAP2; however, the data quality is not affected by this deviation.

The frequency of rinsate blanks collected for the churn splitter and depth-integrated sampler was according to the SAPs. During the October 2009 sampling event, two rinsate blanks were collected for composite surface water samples collected on October 20 and 21, 2009. During the January/February 2010 field event, one rinsate blank was collected between the two composite surface water samples collected on February 2 and 5, 2010. During the October/November 2010 field event, one rinsate blank was collected for a composite surface water sample collected on October 26, 2010. During the January 2011 field event, one rinsate blank was collected for the composite surface water sample collected on January 28, 2011. These rates of collection for rinsate blanks met the specified rate of collection described in the SAPs.

During the October 2009, October/November 2010, and January 2011 field events, sample volumes for one MS/MSD set was collected during each of the field events. At each of these field events, less than 20 surface water samples were collected. During the January/February 2010 field event, two sample volumes for MS/MSD were collected for a total of 31 surface waters samples collected. The rates of collection for surface water MS/MSDs met the rate specified in SAP1.

2.3.4 Groundwater

This section presents DQOs for groundwater and the field activities conducted in 2009 and 2010 in support of these DQOs. Groundwater sampling is ongoing as part of the OU2 RI. Information

provided in this section represents groundwater sampling conducted in support of the OU1 RI and as the initial phase of the OU2 RI.

2.3.4.1 DQOs

The DQOs for groundwater sampling are as follows:

- Determine the nature and extent of groundwater contamination present at the Site and how groundwater contamination contributes to affected surface water through seeps and springs (CDM 2010).
- Determine the background groundwater quality (CDM 2009a).
- Determine if groundwater in the mine area is contaminated and if so, how far does the contamination extend (CDM 2009a).
- Determine the physical and geochemical characteristics of the alluvial and bedrock aquifers that control contaminant migration in the groundwater system and interactions between groundwater and surface water (CDM 2009a).

The first DQO was presented in SAP1 and the last three DQOs were presented in SAP2. The DQO for SAP1 was more general for the Site, and did not include additional characterization of groundwater through installation of new monitoring wells. The DQOs presented in SAP2 indicate that more information was needed to meet the groundwater DQOs. The RI for OU2, which includes groundwater, is ongoing. Consequently, the groundwater DQOs have not been completed.

2.3.4.2 Sampling Approach

Groundwater was collected from the existing deep monitoring wells in October 2009, January/February 2010, October 2010, and January 2011 and from shallow wells installed in August 2010 and January 2011. As part of the biannual monitoring at the Site, groundwater wells were also sampled in September 2011. Only groundwater level data from transducers collected in September 2011 is included in this RI report; analytical data will be reported in the OU2 RI.

During the October 2009 field event, the conditions of the existing deep monitoring wells were assessed. Monitoring wells MW-1 and MW-3 had only a few inches of water in the casings, which was insufficient to sample. Monitoring well MW-4 was determined to be damaged as a probe could only be lowered to approximately 146 ft, though historical well construction information identify a well depth of 270 ft. MW-2 and MW-5 both had significant volumes of water in the casings and were determined to be viable for sampling.

During the August 2010 field event, subsurface borings SP035, SP063, SP064, SP069, and SP070 were completed as shallow and alluvial monitoring wells MW-7A, MW-21A, MW-13A, MW-16A, and MW-15A, respectively. Subsurface borings SP060 and SP061 were also completed as shallow piezometers MW-22 and MW-23 in the encapsulation mound, respectively. Each of the wells or piezometers installed in August 2010 consisted of 1.5-in diameter Schedule 40 PVC. Alluvial wells MW-7A, MW-21A, MW-13A, MW-16A, and MW-15A were each set with a 5-ft Geoprobe pre-pack screen with 0.01-in slot size with 20/40 pre-pack sand. Shallow piezometers MW-22 and MW-23 were installed on the encapsulation mound, and were set with a 10 ft of Geoprobe Pre-pack

screen with 0.01-in slot size and 20/40 pre-pack sand. The alluvial wells were finished with approximately 2.5 to 3 ft of stickup, which was enclosed in a 4-in square steel monument with a locking lid, set in a 2-ft diameter concrete pad. The two shallow piezometers installed on the encapsulation mound were completed with approximately 1.5 ft of stick-up, and were enclosed within a 4-in square steel monument with a locking lid, set in a 2-ft square concrete pad. After field activities were completed, padlocks were placed on the well monuments. Well construction diagrams for wells and piezometers are provided in Appendix D.

In the existing deep wells during the October 2009, January/February 2010, and October/November 2010 field events, water was purged and collected according to SAP1. During the October 2009 field event, the deep wells were purged and sampled with bailers using the volumetric method of purging because the bladder pump apparatus was not functioning properly. During the January/February 2010 field event, the deep wells were purged and sampled with a 1.75-in bladder pump using the volumetric method of purging. During the January 2011 field event, the deep wells were purged and sampled with a 1.75-in bladder pump using the parameter stabilization method of purging. Dedicated, disposable tubing was used for each well.

The shallow wells were sampled with a peristaltic pump and dedicated tubing. During the initial purging and sampling of the shallow wells during the August field event, the shallow wells were purged and sampled using the volumetric method of purging. Three well casing volumes were removed from the wells during purging before sample collection. Water quality parameters (i.e., ORP, pH, temperature, DO, and conductivity) were measured after each well casing volume. The groundwater was sampled after the third well casing volume of water was removed. FE^{2+} and alkalinity were measured in the field at the time of sampling with the methods described in Section 2.3.1.4 Surface Water. The sample volumes for dissolved metals and anions were filtered in the field with dedicated, disposable metals filters (0.45 µm) placed in-line with the tubing. The results of the field testing and data relevant to the collection of the sample such as time of collection, sampling depth, and containers collected were recorded on field sheets which are included in Appendix B.

During the January 2011 field event, the shallow wells were purged and sampled with the peristaltic pump and dedicated tubing using the parameter stabilization method of purging. The shallow wells that had been sampled in August 2010 were sampled as well as monitoring wells MW-16A and MW-7A, which now had sufficient water level and recharge rates for sampling. In January 2011, monitoring well MW-21A had sufficient water for development, but did not recharge sufficiently for sampling.

During the October/November 2010 field event, pressure transducers were placed in all of the newly installed wells and piezometers, including the wells that were dry and the two viable existing bedrock wells, MW-2 and MW-5, to collect water elevation data. The water elevation pressure transducers with data loggers were placed in the wells approximately 1- to 2-in up from the bottoms of the wells, suspended from the well caps. A barometric pressure transducer with a data logger was placed into one of the piezometers (MW-22) to allow correction of the water level data for barometric pressure. The barometric transducer was placed approximately 1 to 2 ft from the top of the well (unsubmerged), also suspended from the well cap.

Because pressure transducers measure water pressure, which is calibrated to a water elevation, a sealed well with a cap could provide incorrect measurement of water level due to suction created inside the well casing. Therefore, well caps were vented to allow equilibrium of pressure inside the well casing with atmospheric pressure. To vent the wells, a small hole was drilled into each of the well caps. Because existing bedrock wells are flush-mount with the ground surface, runoff water leakage into the well monuments is often observed. To prevent leakage of this water through the vented well cap, a small piece of tubing was epoxied to the well cap hole and the tubing was coiled up to the top of the well monument just below the steel monument lid. After conclusion of field activities during the October/November 2010 field event, the well monuments for these wells were also sealed with silicone to prevent leakage of water into the well casings. For new wells and piezometers installed with an above ground monument, no tubing was used because the well is elevated off the ground in a monument with a weep hole drain, which will prevent flooding of the monument and potential leakage through the well cap hole.

The water level and barometric pressure transducers log data hourly. Data from the transducers was manually downloaded during the September 2011 field event and will be downloaded during each subsequent field event. The monuments for MW-2 and MW-5 are sealed with silicone when not being sampled.

2.3.4.3 Deviations from the SAPs

The collection of groundwater samples was conducted according to SAPs 1 and 2 with the following deviations:

- Bailers were used to sample the deep wells during the October 2009 field event according to CDM SOP 1-5, Groundwater Sampling with Bailers. The deep well groundwater samples were collected with bailers during the October 2009 sampling event because the bladder pump apparatus was not functioning properly.
- During the January 2011 field event, wells were purged with the indicator parameter method rather than the volumetric method. Both methods are included in the standard operating procedures in the SAP (CDM 2010). SAP2 stated that the volumetric method would be used; however, the indicator method is also an appropriate method for purging and is more cost effective for the deep wells that have a large water column. This change was made after a team discussion because of the length of time required to purge three well casing volumes with the volumetric method from the bedrock wells, which could have as much as 10 gal of water in the well casing. For indicator parameter purging of the bedrock wells, the pump intake depths were lowered to be within the screened intervals. Samples were collected after field parameters stabilized. The indicator parameter method of purging will be used for groundwater sampling during future field events.
- Turbidity was measured in the field for well development, but not during sampling. This change was made because dissolved metals and anions were field filtered and turbidity was not determined to be necessary for characterization of groundwater.
- A DPT drill rig was used to install all shallow wells during the July 2010 field event rather than an air rotary drill rig. This change was made because an air rotary drill rig was unavailable for July 2010. The EPA Office of Research and Development offered their DPT

rig for the July 2010 event, which provided an acceptable well installation methodology and some reduced costs. However, limitations of the DPT rig prevented installation of some of the alluvial wells, as discussed further below.

- Because of the shallow nature of many of the monitoring wells installed in August 2010, the filterpack seal sand interval (between well screen and bentonite seal) in many of the wells was less than the planned interval of 2 ft.
- Six of the shallow wells could not be installed in August 2010. Alluvial monitoring well MW-6A, which was planned for the MA sub-drainage, was not installed because the drilling rods necessary to install a monitoring well could not be advanced farther than approximately 3.5 ft bgs in several attempts because of refusal believed to be due to boulders within the colluvium/alluvium. A test pit was later excavated in the same area as the borings. This test pit encountered bedrock at a depth of 5.2 ft, which confirms the assumption that refusal of the borings was due to boulders rather than bedrock. Monitoring well MW-14A, to be located in the Middle Creek E (ME) sub-drainage, was not installed because road construction would be necessary to access the location. Funding for road construction work was not available at the time of well drilling. Monitoring wells MW-17, MW-18, MW-19, and MW-20, to be installed along the South Fork A (SFA) drainage, were not installed because the slope of the access road was too steep for the DPT drill rig. All activities that have not yet been completed are still planned for the OU2 RI. An air-rotary or similar drill-rig is planned to be used for installation of these alluvial wells to ensure that drilling can be completed to bedrock.

2.3.4.4 Data Evaluation

All data were evaluated and determined usable, except where noted in this Section, and summarized in Table 2.2-3.

Boron results were rejected in three groundwater samples and a field duplicate in SDG MJD122; MW-22, MW-22 (FD), MW-23, and MW-15A. The dissolved metals analysis of the sample collected from MW-22 during August 2010 was spiked and the boron recovery was 0 percent. The presence or absence of boron in these groundwater samples (MW-15A, MW-22 and its field duplicate, and MW-23) cannot be determined. These data are not acceptable for use.

During each of the October 2009, January/February 2010, August 2010, October/November 2010, and January 2011 field events, one rinsate blank was collected. This met the rate stated in the SAPs. Rinsate blanks were required for the bladder pump used for sampling the bedrock monitoring wells MW-2 and MW-5. During the October 2009 field event, the groundwater samples from these wells were collected with dedicated, disposable bailers and no rinsate blank was required. During the remaining field events when the bedrock monitoring wells were sampled, a minimum of one rinsate blank for the bladder pump was collected between the sampling of the two bedrock wells. A rinsate blank was collected after the sampling of each of the two bedrock wells during the January 2011 field event. The frequency of rinsate blank collection was conducted according to the SAPs.

Sample volumes for MS/MSD were collected for one groundwater sample during each of the field events when groundwater samples were collected. This rate of collection met the rate specified in the SAPs.

2.4 Laboratory Methods and Analyses

Evaluation of ARD generating mine materials involves the use of specialized analytical methods. Correct interpretation and understanding of results requires understanding of the analytical methods as well as the mineralogy of the rock. The following subsection provides a description of the analytical methods used to evaluate OU1 source materials to provide necessary background to understand nature and extent discussions for the source materials. Methods for analysis of surface water and groundwater are also provided. Interpretations of analytical data relevant to the various source materials are discussed in Section 4. The analytical methods used in evaluation of source materials include total metal analyses, SPLP extraction tests, ABA, and SEM-EDS (mineralogy). Surface water and groundwater samples were also analyzed for total metals, as well as dissolved metals and several other inorganic parameters.

In addition to analytical methods pertinent to evaluation of ARD generation, analyses for diesel- and motor oil-range hydrocarbons and polycyclic aromatic hydrocarbons (PAHs) were requested on one soil sample, SP-155. The potential for hydrocarbon contamination to be encountered in the surface was known based on historical information indicating that diesel spills had occurred at various locations throughout the Site and diesel-contaminated soil had been excavated from several locations on the Site. Evidence of diesel contamination was observed in soil from one of the test pits in the area of the former mill building, SP155.

Although SW846 method EPA 8015C was listed in SAP2 for the analysis for TPH-d range, the actual method performed was Northwest Total Petroleum Hydrocarbons – diesel and extended ranges (NWTPH-Dx). This is the analytical method used by ODEQ for diesel contamination and was consequently the method that MEL typically performs for diesel analysis. The methods are basically equivalent as SW846 method 8015C is a generic non-volatile analysis.

2.4.1 Mine Material and Soil Analyses

Laboratory analyses for total metals, SPLP metals, ABA, SEM-EDS, PAHs, and NWTPH-Dx were performed on mine material and/or soil samples.

2.4.1.1 Total Metals Analyses of Mine Material Samples

Total metals analyses were performed on surface and subsurface mine materials. The Pxxx and SPxxx identified samples were screened to -60 mesh (250 µm) to provide a sample of the size fraction most likely to be inhaled or ingested. Drying and sieving of the surface and subsurface samples selected for laboratory analysis was performed by MEL before analysis for total metals by the CLP laboratory.

Total metal analyses were completed by EPA CLP laboratories according to CLP SOW ILM05.4. Total metal and metalloid concentrations were determined using ICP-AES with a nitric acid/hydrogen peroxide digestion and inductively coupled plasma mass spectrometry (ICP-MS) with a nitric acid/hydrochloric acid digestion as specified in the SOW. These digestions are not a total digestion for elements bound in aluminum silicate structures, such as feldspar, a common

mineral in source rocks. The digestion is intended to dissolve elements that are most likely to impact the environment.

2.4.1.2 Total Metals Analyses of FPXRF Samples

The FPXRF samples selected for laboratory analyses were sieved to less than approximately 1.5 mm in the field before analysis by the CLP laboratory. The same sample bag that was analyzed by FPXRF in the field was submitted to the laboratory for the confirmatory total metal analyses, as described above.

2.4.1.3 Total Metals Analyses of Incremental Samples

The preparation for the incremental samples is described in Section 2.3.2.2 and was performed by the CDM laboratory. MEL performed the total metals analyses of the incremental samples and digested 10-gram aliquots of sample rather than the typical 1 to 2 grams of sample. The larger sample size was used to minimize effects of sample heterogeneity and reduce fundamental error. SAP2 (CDM 2010) provided a detailed assessment of error associated with sampling, processing, and analysis of incremental samples. This assessment resulted in the required sample preparation procedures necessary to achieve a fundamental error of less than 15 to 25 percent for the metals analyses. The fundamental error is the minimum error that would occur if all other factors such as delineation of individual increments, preventing sample contamination, and analyzing total metals in the laboratory are perfect.

2.4.1.4 SPLP Analysis of Mine Material Samples

A modified EPA Method 1312 SPLP method was performed on mine materials and soil samples selected from the paste pH and conductivity survey. The extraction fluid is intended to simulate natural precipitation, which is slightly acidic. Acid liberates contaminants from the mineral matrix into forms that dissolve readily and this significantly increases the mobility of the contaminants into surface or groundwater. Extraction tests evaluate the mobility of contaminants in solid phase mine materials in an extraction fluid.

The SPLP leaching procedure consists of the following:

- Addition of a known quantity of mine materials into an extraction vessel
- Addition of the extraction fluid with specified acidity
- Agitation of the mixture for a specified amount of time

The extraction fluid specified in the method is dependent on the location of the samples. In the United States west of the Mississippi River, the extraction fluid is deionized water acidified to a pH of 5.00 ±0.05 su with a 60:40 mixture of H_2SO_4 and nitric acid. The proper ratios of extraction fluid and solids are placed in a bottle and rolled end over end for a period of 18 ±2 hours. The extraction fluid is removed and filtered through a 0.6- to 0.8-µm filter and is preserved for analysis. The SPLP method performed on the mine materials was a modified version of EPA Method 1312, which reduced the solution to solids ratio to 3:1 to more closely reflect field conditions and to increase the sensitivity of the method to contaminants that desorb at low concentrations. The use of the 3:1 extraction fluid to solid ratio as compared to the 20:1 ratio set forth in EPA Method 1312 tends to cause higher concentrations of soluble contaminants in the

resulting extraction fluid. The leachate generated by the SPLP extraction was subsequently analyzed by the CLP laboratory as a water matrix.

The modified procedure is valuable for mine materials samples for several reasons. Mine materials, such as waste rock and spent ore in the field, generally exhibits much lower solution to solids ratios than utilized in the SPLP procedure. The moisture content of unsaturated mine materials is generally in the range of 5 to 10 percent, which corresponds to a solution to solids ratio of about 1:10. The effective porosity of saturated mine materials ranges from about 20 percent to 50 percent (Freeze and Cherry 1979). This corresponds to a solution to solid ratio of about 1:2. So under natural conditions, the solution to solid ratio of mine materials under natural conditions is far lower than the 30:1 solution to solid ratio of the EPA Method 1312 SPLP test. The modified procedure decreases the error associated with the solution to solid ratio.

Large unsaturated mine materials piles may release very low concentrations of contaminants, which still exceed regulatory criteria and require long term collection and treatment (Nelson 2003). The 20:1 solution to solid ratio of the SPLP method is problematic in this case because very low concentrations are diluted by the 20:1 ratio, and are reported as undetected results in the standard SPLP test. The modified procedure decreases somewhat the errors attributed to dilution of very low concentrations of mobile contaminants. However, it is important to recognize that undetected results in a SPLP leachate for contaminants in the SPLP test or the modified SPLP test do not prove that discharge from mine materials will meet regulatory criteria because of the lack of sensitivity that is caused by the high ratio of extraction fluid to solids.

Although the extraction fluid in the modified SPLP procedures is acidified, the buffering capacity of the extraction fluid is very low. In the case of strongly ARD-generating mine materials sample, the pH of the extraction is controlled by soluble acidity in the mine materials rather than the pH of the extraction fluid. In this case, the extraction is effectively conducted at significantly more acid pH values for strongly acid generating samples as compared to non acid generating samples. Accordingly, the sample pH is the dominant control on the pH of the SPLP extraction test, rather than the initial pH of the simulated precipitation.

2.4.1.5 ABA Analysis of Mine Material Samples

ABA analyses are widely used to evaluate the potential for mine materials and soils to generate ARD. ABA is a method to estimate the potential for a sample to generate acid at some time in the future. The propensity for a rock to generate acid drainage is dependent on both the acid-generating and acid-neutralizing potential of a rock. Acid generation results from oxidation of sulfide minerals, such as FeS_2. Acid neutralization results from minerals that will neutralize acid, such as calcium carbonate ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$). Numerous other minerals have the potential to neutralize acid; however, they dissolve slowly and are less effective at preventing acid rock drainage. ABA is not a quantitative method, and correct data interpretation requires an understanding of the mineralogy of the rock as well as assumptions inherent in the specific ABA method used (Jambor et al. 2003).

In ABA analyses, acid potential is estimated based on a series of sulfur analyses. Sulfur is analyzed in fractions of the sample that are soluble in water, hydrochloric acid, and/or nitric acid. A total sulfur analysis is also performed. Sulfur measured in the various digestions is interpreted to represent different types of sulfur-containing minerals. It is important to understand that the

ABA method does not measure the content of any specific minerals. The content of the different types of sulfur-containing minerals is estimated based on interpretations of the sulfur digestions in relation to the mineralogy of the rock.

The quantity of sulfur in the water or hydrochloric acid digestion is commonly assumed to be gypsum ($CaSO_4 \cdot 2H_2O$), other non-acid-generating sulfate minerals, or efflorescent iron sulfate minerals, such as coquimbite ($Fe_2[SO4]_3 \cdot 9H_2O$), rhomboclase ($[H_3O]Fe[SO4]2 \cdot 3H_20$), or roemerite ($Fe_3[SO_4]_4 \cdot 14H_2O$). Many of the efflorescent iron sulfate minerals can generate acid upon dissolution. Acidity produced by these minerals is best evaluated using modified SPLP tests or paste pH, because they are soluble in water.

The quantity of "sulfide sulfur" (e.g., sulfur present in the minerals such as FeS_2 or $CuFeS_2$) is estimated based on sulfur that reports to the nitric acid plus residual digestions. These sulfur fractions from the ABA test are assumed to represent the acid potential (AP) of the sample. Generally, all sulfide is assumed to be FeS_2 which is a conservative assumption based on the amount of acid generated by FeS_2 in relation to other sulfide minerals. This assumption may overestimate the AP in samples from the Formosa Mine, because the massive sulfide ore bodies contain numerous other sulfide minerals.

Barite ($BaSO_4$) is reported as a gangue mineral at the Formosa Mine based on descriptions of FRC (1987) and Derkey and Matsueda (1989). SEM-EDS analyses of Formosa Mine samples show that the some of the rock contains $BaSO_4$ (see Section 3 for analysis). Barite is not acid-generating, but is relatively insoluble as compared to other sulfate minerals and tends to report to the nitric and/or residual sulfur fractions. Therefore, the presence of common barite in the samples has the potential to cause overestimation of the acid potential of a sample, if the sulfur occurring in barite is interpreted to be pyrite. Barite is the only mineral reported to contain barium at the Site. Accordingly, ABA data were adjusted for the presence of barite based on the total barium concentration identified in TAL metals analyses. This adjustment used a stoichiometric conversion factor to subtract sulfur associated with barite from the sum of the residual and nitric acid soluble fractions to prevent overestimation of acid potential.

Estimating neutralization potential (NP) of ABA samples is completed using a titration method. NP is estimated by adding a known quantity of hydrochloric acid to the ground sample followed by titration of the solution back to a pH of 8.3 using sodium hydroxide. The quantity of remaining acid is estimated based on the amount of sodium hydroxide necessary to raise the pH back to a value of 8.3 su. The quantity of acid consumed by the sample is the NP, which is estimated by difference and expressed in units of tons per kiloton calcium carbonate equivalent (t/kt $CaCO_3$ eq).

The ABA method has a basic assumption that FeS_2 is the only sulfide mineral present and that the FeS_2 is oxidized by oxygen producing 4 moles of hydrogen (H^+) per mole of FeS_2 as shown below:

$$FeS_2 + 3.75O_2 + 3.5H_2O \rightarrow Fe(OH)_3 + 2SO_4^{2-} + 4H^+$$

The four protons generated in this reaction are then assumed to be neutralized by calcite as described below:

$$2CaCO_3 + 4H^+ \rightarrow 2Ca^2 + 2H_2CO_3$$

In interpretation of ABA analyses, acidity produced by 1 mole of FeS_2 is assumed to be neutralized by 2 moles of calcite, which results in a stoichiometric conversion factor of 31.25 t/kt $CaCO_3$ eq. per percent pyritic sulfur. This allows both the AP and NP of a sample to be expressed in equal units of t/kt $CaCO_3$ eq. The assumed neutralization path for neutralization of acidity by calcite is not unique, and up to 4 moles of calcite may be required to neutralize the acidity formed by oxidation of 1 mole of FeS_2 (i.e., the required amount of calcite may be 2 times that assumed in reaction 2 [Rose and Cravotta 1994]). FeS_2 oxidation by dissolved ferric iron (Fe^{+3}) is also common, and the quantity of acid generated per mole of FeS_2e varies based on the reaction path. In addition, other sulfide or sulfosalt minerals are commonly present, which may or may not generate acid.

As a result of the uncertainties described in preceding paragraphs, interpretation of ABA data is based on a weight of evidence approach using empirically derived thresholds. Application of these thresholds is site-specific and based on an understanding of the mineralogy of the mine materials and other factors. AP and NP are expressed in equal units of t/kt $CaCO_3$ eq. The difference between NP and AP is termed the net neutralization potential (NNP), which can be calculated based on total sulfur or sulfide sulfur. Evaluation of ABA data also considers the ratio of neutralization potential to acid potential (NP:AP ratio). Threshold values used in analysis of site ABA data are discussed in Section 4.1.

2.4.1.6 SEM-EDS Analysis for Mine Material Samples

SEM-EDS analyses were performed on soil samples collected from the paste pH and conductivity surveys to determine mineralogical content. SEM–EDS measures X-rays generated when a beam of electrons is focused into a solid sample. The electron beam can excite an electron in inner electron shells or energy levels of an atom in the sample, which is then expelled from the electron shell. The result is replacement of the expelled electron with an electron from a higher energy level shell of the atom. The energy lost by the electron moving from a higher to lower energy level is emitted as an X-ray. Both the number of X-rays and energy of the X-rays are then measured with an energy dispersive spectrometer. The element can be determined at the atomic level from the energy of the X-ray, which is characteristic of the element as well as the energy difference between electron shells. The mineralogy of the sample can be determined from the ratios of elements present.

2.4.1.7 NWTPH-Dx Analysis for Mine Material Samples

NWTPH-Dx analysis covers the qualitative and quantitative analysis of semi-volatile petroleum products in soil and water. Samples are extracted with methylene chloride and the extract is analyzed with a gas chromatograph equipped with a flame ionization detector. Diesel #2 fuel is used as the default product against which products eluting in the diesel range in the sample are quantified. Product identification is made by matching the pattern eluting in the sample to the pattern for the standard.

2.4.1.8 PAHs for Mine Material Samples

The analysis for PAHs was performed by EPA method 8270 selected ion monitoring (SIM). The sample is extracted with solvent, which is concentrated down to a small final volume. The extract

is then analyzed with a gas chromatograph equipped with a mass spectrometer detector. Compounds are separated by retention times on the gas chromatograph capillary column and are broken into ionized fragments which are detected by their charge to mass ratio in the mass spectrometer. Compounds are identified by the relative amounts of their ionic fragments. The SIM option allows for lower detection limits because the instrument is set to scan for and detect specific ionic fragments and more scans per second can occur during the analysis.

2.4.2 Surface Water and Groundwater

Laboratory analyses for total metals, dissolved metals, TDS, TSS, alkalinity, nitrate plus nitrate, chloride, fluoride, sulfate, ammonia, and acidity were performed on surface water and groundwater samples.

2.4.2.1 Total and Dissolved Metals

Total and dissolved metals analyses were performed on surface water and dissolved metals analyses only were performed on groundwater. The dissolved metals volumes were field-filtered using a 0.45-µm filter.

The digestions performed for total metals analyses by ICP-AES and ICP-MS are similar to those for soils except that a volume of water is used rather than a mass of soil. Analysis by ICP-MS is capable of achieving lower reporting limits than ICP-AES for water.

2.4.2.2. TSS

Analysis for TSS by USGS method I3765 is used to determine the concentration of suspended solids in natural waters. Suspended solids are defined as those solids that will be retained on a glass-fiber filter that collects solids larger than 1.5 µm. The sample volume is homogenized and poured rapidly into a graduated cylinder with a glass-fiber filter to retain solids. Material retained on the glass-fiber filter is dried and weighed to calculate the TSS concentration.

2.4.2.3 TDS

Analysis for TDS by Standard Method 2540C consists of homogenizing a sample and pouring a volume through a standard glass fiber filter such as is used for TSS analysis. The filtrate that passes through the glass fiber filter is dried and the remaining solids are weighed to determine the concentration of TDS.

2.4.2.4 Alkalinity

Analysis for alkalinity by Standard Method 2320 B measures the acid-neutralizing capacity of the sample. The alkalinity of many surface waters comes from the carbonate, bicarbonate, and hydroxide concentrations and the results of the alkalinity analysis are reported as concentrations of these components or the sum of these components expressed as calcium carbonate. The sample is titrated with a standard concentration of H_2SO_4 or hydrochloric acid to endpoints at pH 8.3 and pH 4.5 or a final endpoint of pH 4.5.

2.4.2.5 Nitrate plus Nitrite

Method 353.2 for the sum of nitrate and nitrite is an automated colorimetric analysis. A filtered sample is passed through a column of granulated copper-cadmium to reduce the nitrate to nitrite. The total amount of nitrite present at this stage is measured colorimetrically as the concentration

of a highly colored azo dye that is formed by diazotizing the nitrite with sulfanilamide and coupling with N-(1-naphthyl)-ethylenediamine dihydrochloride.

2.4.2.6 Anions

Anions chloride, fluoride, and sulfate were measured by method 300.0 with ion chromatography. A few mL of sample are injected and the various ions are separated and measured with a guard column to protect the analytical column from non-target components, an analytical column, a suppressor device to potentially mitigate conductivity from the mobile phase, and a conductivity detector.

2.4.2.7 Acidity

Method 305.1 for acidity measures the mineral acidity of a sample as well as the acidity resulting from oxidation and hydrolysis of polyvalent cations, including the salts of aluminum and iron. After the pH of a sample is determined, a measured amount of standard acid is added in 5.0-mL increments to reach a pH of 4 or less. If the pH of the sample is 4 or less, no acid is added. Hydrogen peroxide is then added and the solution is boiled for several minutes, cooled, and titrated electrometrically with standard alkali to a pH of 8.2. The results are expressed as the concentration of calcium carbonate ($CaCO_3$).

2.4.2.8 Ammonia

Analysis for ammonia by method 350.1 is a semi-automated colorimetric method. A borate buffer is used to buffer the sample at a pH of 9.5 to decrease hydrolosis of cyanates and organic nitrogen compounds and is distilled into a boric acid solution. Alkaline phenol and hypochlorite react with ammonia to form indophenols blue, which is proportional to the concentration of ammonia. Sodium nitroprusside is used to intensify the blue color, which is measured colorimetrically.

Distillation of samples is not a required step in the analytical SOP for the Region 5 ESAT laboratory, CRL SOP AIG029A, if it can be shown that the results of undistilled and distilled analyses agree. For the first round of surface water and groundwater samples in October 2009, the laboratory analyzed the samples both with and without distillation. Poor agreement of the distilled and undistilled results as well as poor agreement between undistilled diluted and undiluted analyses indicated matrix interference. Only the distilled results have been reported. It was determined that distillation was necessary for the samples and subsequent analyses of water samples for the project during the later field events were and will be distilled.

Section 3
Physical Characteristics

Section 3 describes the physical characteristics of the Site. As set forth by CERCLA guidance (EPA 1988), the purpose of this section is to detail the environmental setting at the Site, including features such as roads, WRDs, former mining facilities, hydrology, geology, groundwater hydrogeology, climate, ecology, land use, and demographics. Developing an adequate understanding of site physical characteristics is vital to characterizing the nature and extent of contamination, fate and transport, and risk assessments, which are discussed in detail in Sections 4, 5, and 6.

3.1 Site Features

This section describes the various site features, including the road network, the locations of mine materials within WRDs and other areas, former mining facilities and observations of current conditions in these areas, the underground mine, and the adit water diversion system.

3.1.1 Road Network

The road network is shown on Figure 3.1-1. The roads on and around the Site are unpaved and maintained by BLM or private logging companies. The majority of the Site can be accessed off of Shoestring Road using Silver Butte Road (Road 30-6-35.1). This road is wide enough for large vehicle access and is generally maintained so that 4-wheel drive is not required unless snow or ice is present. An additional access road off of Shoestring Road is Road 30-6-35.0, followed by Road 31-6-13.1. This route has fewer sharp turns and is more amenable to large trucks or semi trailers than Road 30-6-35.1. Some monitoring locations, such as MXR and MW-13A are accessible by way of more narrow, less maintained roads. Alternatively, these areas may be accessed via the Cow Creek Byway (Road 30-6-32).

3.1.2 OU1 Mine Materials

OU1 mine material areas were generally described in Section 1 and are shown on Figure 1.3-2. This section provides a more detailed description of areas containing OU1 mine materials in relation to historic mining features, reclamation of these features, and current observations. Descriptions of historic features and reclamation were obtained from a number of references including DOGAMI (1990 – 1999, 1995, 1996); Heenan (2000); Northwest Environmental Resources (2003); and the Data Summary Report (Appendix A).

3.1.2.1 Mine Portal Waste Rock Dumps

Exhibit 3.1-1. Silver Butte 1 adit WRD 3D view, looking from west

WRDs associated with the mine portals are present at the Formosa 1, 2, and 3 adits; Silver Butte 1 adit (Exhibit 3.1-1); 1090 raise; and 404 adit. These are all relic features that were initially associated with historic mining conducted during the 1920s and 1930s. During modern mining activities, expansion of road and access areas resulted in placement of additional mine materials on the WRD areas over top of mine materials placed during early mining. These areas were also regraded as part of reclamation work in 1993 to 1994.

During historic mining, as the underground mine was excavated, waste rock materials were dumped on the hillsides adjacent to the mine portals. This was a common practice during that era of mining. These WRDs likely include both acid-generating sulfide mineralized rock that was excavated near the ore zones and non-ARD-generating metavolcanic rock that was excavated to access the ore. All of these mine portal WRDs range from several feet to several tens of feet deep near the mine portal areas and then decrease in thickness moving down the steep hill slope.

3.1.2.2 Encapsulation Mound and Former Water and Tailings Storage Pond

Historic Characteristics

The encapsulation mound is a mine material repository that was constructed as part of the reclamation work conducted in 1993/1994. The purpose of the encapsulation mound was to utilize the lined pond infrastructure to contain and cap some of the most reactive ARD-generating mine materials that remained on the surface. These remaining mine materials could not be backfilled into the underground mine workings because of lack of available space at the end of the reclamation.

The water and tailings storage pond was originally used for process water to feed the milling operations. The pond was excavated mostly into bedrock and blasted/excavated material was used as fill to expand the flat area at the top of the ridge. The southeast and northwest side berms were stabilized with the construction of the wood and steel rebar retaining walls (i.e., crib walls) on both sides of the pond area. The pond liner was constructed of two layers of HDPE (60 mil upper and 40 mil lower) with an internal drainage net between the layers and a leak detection system. Three sample ports were installed to test for leakage of the upper liner

Exhibit 3.1-2. Drained water and tailings storage pond, April 1994

and a sump was installed to collect leakage in the drainage net if it occurred. The upper liner was reportedly punctured at some point during mining operations, although the location of the tear is unknown. The pond was originally constructed at a depth of 25.5 ft and could contain approximately 3.5 million gal of water with 3 ft of freeboard below the crest of the liner system. If filled completely to the crest, the pond could hold a volume of 4.2 million gal. In 1992, the pond was expanded by embanking additional fill and adding additional liner along the crest, which raised the crest elevation by 2.5 ft to a total pond depth of 28 ft.

Because of a lack of available storage in the underground mine workings during operation of the mine, tailings from the mill were placed into the pond and on the south end of the pond. During reclamation of the mine, the majority of tailings were placed into the underground mine workings. DOGAMI (1995) reported that 2,500 yd^3 of tailings remained in the pond. Following grading of the tailings material, approximately 17,000 tons of low-grade ore were backfilled above the tailings (DOGAMI 1995). Quantity units shown are as reported in the references. Using a typical density of loose granite rock (Caterpillar 2006) of 2,800 pounds per yd^3, the volume of low-grade ore is estimated to be approximately 12,150 yd^3. Northwest Environmental Resources (2003) reported that the total volume of backfilled materials in the pond is approximately 35,000 yd^3 and is composed of 20 percent tailings (7,000 yd^3) and 80 percent low-grade ore (28,000 yd^3). The difference in reported volumes between these references is significant. Advancement of DPT borings in the encapsulation mound during this RI provided data to confirm the volume of both tailings and rock; these data are discussed further below and in Section 4.1 with regards to estimation of volume of mine materials.

During excavation of the tailings material on the south portion of the pond, both the upper and lower pond liners were reportedly ripped but no documentation was provided if the rip was repaired. A low-permeability cover system was placed over the ore layer, followed by a layer of crib wall fill material. Bentomat™ was used as the low-permeability cover material, which consists of a layer of bentonite clay sandwiched between two layers of geotextile fabric. The top layer of soil was amended with limestone, biosolids, mulch, and the area was seeded. Attempts at revegetation with Douglas fir and blackberry cuttings were also reported.

Current Observations

Historic information as well as current observations of the encapsulation mound (Exhibit 3.1-3) suggest that the cover material contains some amount of ARD-generating mine materials as well as dispersed rebar from crib wall demolition. The west side of the mound area contains a poorly established vegetative cover; however, the east side of the mound is devoid of vegetation and has undergone significant erosion over the years. A fabric geotextile material is exposed on the southern corner of the encapsulation mound; possibly from erosion that has resulted in complete loss of the cover system.

Exhibit 3.1-3. Current encapsulation mound and milling facility area

DPT Borings

Three DPT borings (SP060, SP061, and SP062) were advanced into the encapsulation mound. These borings were targeted along the long axis of the pond and in the center of the pond (deepest portion). The borings were advanced only to a safe depth (no more than 27 ft) to avoid damage to the bottom liner system. These borings provided the following observations regarding construction of the encapsulation mound (see Figure 4.1-11b for locations and Appendix D for boring logs):

- The cover material layer consists of a mix of sulfide mineralized waste rock, construction rock, and soil. The cover material thickness in the three borings ranged from 2 ft to 7.5 ft. A geotextile material was intersected and is presumed to be the Bentomat™ clay liner utilized for the low-permeability cover.
- A mix of low-grade ore and other mine materials were detected below the cover system. The thickness of this layer of material ranged from 14 ft to 6.5 ft.
- Tailings were detected below the low-grade ore at a depth of 13 to 14 ft down to the bottom of the borings. The south boring (SP062) was advanced to a total of 24 ft and the middle (SP061) and north (SP060) borings were advanced to approximately 27 ft.

Encapsulation Mound Piezometers

Based on detection of saturated conditions in these borings, two piezometers (MW-22 and MW-23) were installed on the encapsulation mound within the borings (SP060 and SP061) in August 2010. These piezometers were installed to monitor water levels, characterize the water quality, and gain an understanding of the current function of the encapsulation mound. Piezometer data are presented in Section 3.4,;however, some discussion is presented here to evaluate the effectiveness of the encapsulation mound as a repository to prevent water infiltration and acid generation of the mine materials.

In August 2010, the initial water levels after well development were measured below top of casing. Based on surveyed top of casing elevations, the water levels measured for MW-22 and MW-23 were 3343.56 ft and 3343.11 ft, respectively (15.15 ft and 14.80 ft below top of casing). Pressure transducer data (see Figure 3.4-9) indicate a maximum change in water elevation of 1.59 ft and 1.33 ft for MW-22 and MW-23, respectively. Based on available information regarding the pond and encapsulation mound construction, the pond bottom liner is set at an elevation of 3314 ft and the total height of the lined portion of the pond is 28 ft (top of liner elevation at 3342 ft). Based on this historical data, a saturated thickness of approximately 29 to 30 ft appears to be present within the encapsulation mound, and the maximum water level is 2 ft above the top of the pond liner. However, the vertical survey datum used to document the pond bottom elevation by FEI (constructed in 1990) is unknown. A potential discrepancy between the vertical datum used by FEI and the current survey could mean that the true top of liner elevation is different than 3342 ft. Temporary mounding of water above the top of liner elevation is possible, because the pond liner is keyed into the Bentomat™ liner at the sides and this may restrict water flow from leaving the encapsulated mound (see cover and liner construction cross section in Exhibit 3.1-4).

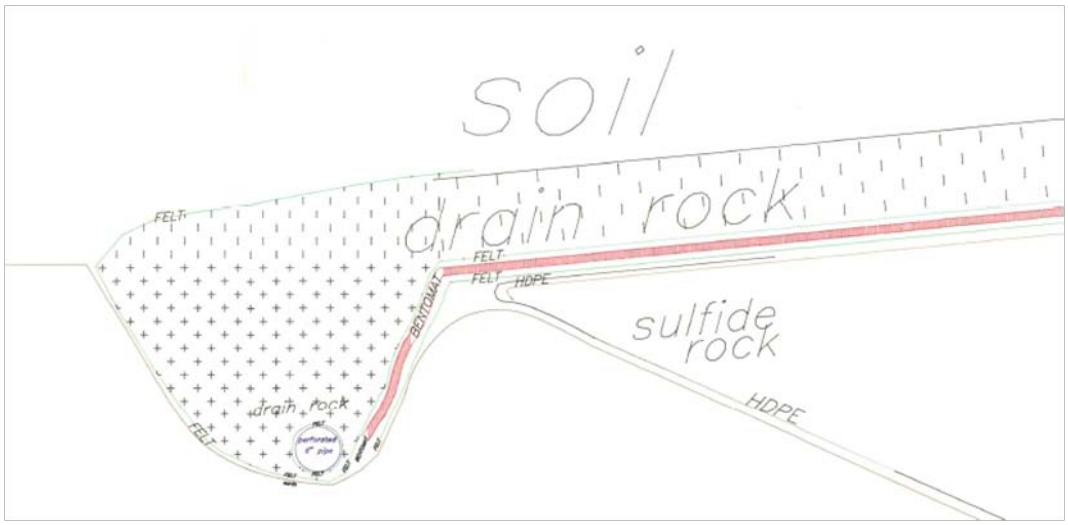


Exhibit 3.1-4. Encapsulation mound ditch and cover cross section.

Regardless of whether water is mounded above the pond liner level or below the liner elevation, the materials backfilled into the pond are saturated for nearly the entire pond depth. The presence of a large volume of water and seasonal fluctuations in water level in the pond indicate that the cover system is compromised and water is leaking into the encapsulation mound. Field measurements collected in November 2010, January 2011, and September 2011 and pressure transducer data (see Figure 3.4-9) indicate that the water level increases in response to precipitation and decreases during periods of reduced precipitation. Based on surface observations, the leakage into the mound may be occurring on the southern corner of the pond, where the cover material may be degraded or damaged. The native bedrock groundwater level in the area, as detected in MW-5, ranges between approximately 3275 ft in the dry season and 3310 ft in the wet season. This range in water level is below the depth of the pond, so recharge to the pond by bedrock groundwater is unlikely.

Estimation of Infiltration and Leakage Volume

The saturated conditions within the pond indicate that the original pond liner is holding water to some extent. As noted above, there were reports of tears in the liner system although the exact locations or repairs to the system are unknown. The lowest measured water level from August 2010 through September 2011 may represent the approximate elevation at which there is a liner leak. The infiltration and leakage volume can be estimated by applying a basic water balance equation:

$$\sum Inflows - \sum outflows = \Delta storage \qquad \text{(Eq. 1)}$$

Where,

Inflows = Infiltration of precipitation through cover system

Outflows = Encapsulation mound leakage (evapotranspiration through the cover is assumed to be negligible)

The change in storage can be estimated based on piezometer data. Considering the period November 2010 through May 2011, the approximate change (increase) in storage is 1.4 ft (3344.2 ft minus 3342.8 ft). The total surface area of the pond at the top of liner elevation is approximately 51,000 ft^2. Using an assumed 30 percent porosity of the backfilled mine materials, the change in storage is approximately 171,700 gal. Actual outflow is not known; however, the inflow (cover infiltration) is at least equal to the increase in storage based on Equation 1. During the dry season, the water level continually decreased from May/June to the end of September. This decrease in storage (-0.9 ft) can be interpreted as the leakage from the encapsulation mound (approximately 103,000 gal).

The fraction of precipitation infiltrating into the encapsulation mound can also be estimated. Since infiltration is at least equal to the increase in storage during the wet season, the infiltration volume can be converted to inches of water (precipitation):

$$(171{,}700\ gal)\left(\frac{1\ ft^3}{7.4805\ gal}\right)\left(\frac{1}{51{,}000 ft^2}\right)\left(\frac{12\ in}{1\ ft}\right) = 5.4\ in\ of\ water$$

The precipitation total for November 2010 through May 2011 is 31.27 in (see Table 3.6-1 for data from water year 2010 to 2011). Assuming run-on to the encapsulation mound is zero, the percentage of precipitation that leaked though the cover is approximately 17 percent (5.4 in/31.27 in X 100).

3.1.2.3 Former Milling Facility

The former milling facility (Exhibit 3.1-5) was located on the north side of the encapsulation mound (Figure 1.3-2). To provide sufficient space for milling operations, crib walls were installed on the southeast and northwest sides of the mill area. The milling facility was utilized to crush, screen, and float out copper and zinc concentrates using flotation reagents. Power to the facility was supplied using onsite diesel generators. Diesel fuel tanks to power the generators and onsite mobile equipment were located next to the milling facility building. Diesel fuel spills were reported in this area based on DOGMI records.

During reclamation of this area, the main building and ancillary structures were completely dismantled and removed from the Site. Diesel fuel spill areas were identified through sampling and the contaminated areas were excavated and treated as described in Section 1.4. Crib walls were either partially demolished or buried in place. The mill building foundation was left intact and covered with remediated diesel-fuel soil. Concentrations of diesel in these soils were reported in 1996 to be approximately 200 mg/kg TPH-d.

Exhibit 3.1-5. The water and tailings storage pond and milling facility, January 1991

Current observations of the milling facility area show that the southeast side of the area has a poorly established vegetative cover including a small patch of established trees. The northwest

side of the area including the road is devoid of vegetation and has undergone significant erosion. The foundation of the former milling facility remains in place buried under a shallow layer of fill. Based on test pits excavated during the RI sampling, the concrete slab covers an area of approximately 130 ft by 130 ft and is approximately 12 in thick. Field logs for test pits collected at the mill foundation area are provided in Appendix B.4.

Exhibit 3.1-6. In-tact crib wall between former shop and milling facilities

3.1.2.4 Former Shop Facility

The former shop facility was located along Road 30-6-35.1, just northeast of the milling facility (Figure 1.3-2). The shop facility was used for servicing onsite mining equipment such as drill hammers, trucks, excavators, and pumps. Diesel and oil storage tanks were also located in this area which resulted in diesel and oil spill contamination in surrounding soil. To accommodate this facility, mine materials were filled in on the northwest side of the original road. This action created a small WRD associated with the former shop facility.

During reclamation of this area, the shop facility and all ancillary structures were removed. Diesel fuel spill areas were also identified through sampling and the areas were excavated and treated with the milling facility soils. No revegetation efforts were reported to have occurred in this area and current observations indicate this area is part of the main road and is devoid of vegetation. The WRD created to expand the road area was not reclaimed and remains today. One crib wall also remains intact between the former shop and milling facilities, and is supporting the road fill in the area (Exhibit 3.1-6). The current structural condition of this crib wall is poor and may be prone to failure if allowed to continue to degrade.

3.1.2.5 Encapsulation Mound Waste Rock Dumps

The east and west encapsulation mound WRDs were generated as a result of construction of the milling facility and the water and tailings storage pond (Figure 1.3-2). The native mountain ridge colluvium was excavated and bedrock was blasted to construct these facilities. Excavated and blasted materials were utilized as construction rock for several mining features including roads, foundations, and as fill placed behind crib walls. The excavated material was located along the strike of the massive sulfide ore

Exhibit 3.1-7. Current east encapsulation WRD

body and may have contained natural outcrops of sulfide bearing rocks. Such outcropping is currently observed to the northeast of the excavation. In addition, waste mine materials excavated from the underground mine were co-mingled with the excavated and blasted materials from the ridge. During reclamation, the crib walls were demolished or buried and materials behind the crib walls were excavated and placed as the encapsulation mound cover. The remaining materials not used for cover were pushed over the southeast and northwest sides of the ridge and remain at present day.

Current observations indicate that significant erosion has occurred along these steep WRDs and has resulted in dispersion of mine materials into downslope vegetated areas. The slopes of the WRDs are mostly barren with some patches of vegetation (Exhibit 3.1-7). The east encapsulation mound WRD also contains a significant amount of highly ARD-generating material that has eroded from the encapsulation mound.

3.1.2.6 Former Ore and Water Storage Area

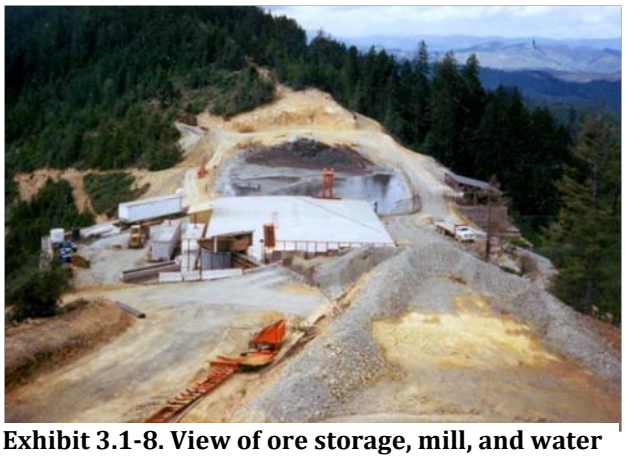


Exhibit 3.1-8. View of ore storage, mill, and water and tailings storage pond during mining

The ore and water storage areas were located northeast topographically above the milling facility (Figure 1.3-2). These areas were used for storage of ore excavated from the mine before processing at the mill and for storage of makeup water for the mill (Exhibit 3.1-8). The water storage area was originally constructed with a rectangular primary water storage tank located above ground at the top of the cleared area. The ore and water storage areas underwent constant reworking as materials were stockpiled and processed. As a result of storage of tailings in the water storage pond located next to the milling facility, the pond water became too contaminated to be used for milling operations. Therefore, a much larger one-million-gal cylindrical tank was constructed in the place of the original rectangular primary water storage tank to provide process water to the mill (Exhibit 3.1-9). The million-gal tank was significantly larger than the original tank and required a significant expansion of the flat area along the ridge. To accommodate the tank, a foundation was constructed utilizing the stockpiled ore materials from the area.

Exhibit 3.1-9. Million-gal tank

Approximately 750 tons of crushed ore were stockpiled in the ore storage area at the time of mine closure. During mining operations, extracted ore was crushed to gravel size and stockpiled in this area to be fed to the mill for processing. During reclamation, a large portion of the ore stored in this area was backfilled into the underground mine workings. An additional 17,000 tons of the ore located in the million-gal tank area was placed in the encapsulation

mound over the tailings material (see Section 3.1.2.2). The million-gal tank was completely dismantled and all construction materials were removed from the Site. Remaining ore and other mine materials were segregated to the extent possible and the most reactive material was covered with a limestone cap in the area of the former million-gal tank. The purpose of the limestone layer was to provide neutralizing capacity to water that infiltrates into the stored ore material. Less reactive ore materials were then placed over the limestone layer. The surface of the regraded area was then amended with limestone and seeded.

Current observations of the area indicate significant erosion of the mine materials and no established vegetation. Trenches excavated during the RI sampling indicate a varying thickness of mine materials in the area, with the deepest mine materials in the area of the former million-gal tank. The limestone layer installed during the reclamation was also observed. Outcrops in the area included gossan (weathered massive sulfide), associated mineralized rock containing pyrite, and other metavolcanic rock that does not contain sulfide mineralization. Because of these outcrops, the near-surface mine materials outside of the former million-gal tank area are fairly shallow.

3.1.2.7 Illegal Dump Area

The illegal dump area (Figure 1.3-2) is located to the south of the ore and water storage areas and below Road 30-6-35.0, and is essentially an extension to the northeast of the east encapsulation WRD (Figure 1.3-2). This area was reportedly utilized for disposal of mine materials including zinc concentrates that was not approved by the state permit. Little information is available about this area of the Site during mining operations or reclamation except that the area was part of the old road network around the crib wall structures. Zinc concentrates stored in the illegal dump area were reportedly excavated and backfilled into the underground mine workings.

Current observations in the area indicate moderate natural revegetation by trees along the margins and sparse trees in the dump area. The far southeast side of the illegal dump area has been significantly affected by the mine materials located along Road 30-6-35.0, which are eroding downslope from the road into this area. The native area is similar to the ore storage area and contains outcrops of mineralized rock and other non-mineralized metavolcanic rocks.

3.1.2.8 Water Diversion, Collection, and Treatment Features

During modern mining operations, several infrastructure features were constructed to manage water; however, exact details on management of water pumped from the mine, process water management, and water treatment and discharge are difficult to discern. Failure to comply with water management stipulations in FEI's permit was one of the reasons for the ultimate closure of the mine. Documentation of some features was obtained from mine as-built drawings (ODEQ and DOGAMI files) and historic photographs. These features are shown on Figure 1.3-2 and include the following:

- A four-tank water treatment system located on the Silver Butte ridge southeast of the 1090 raise area. This system was utilized to treat water that was pumped from the underground mine workings. Water was pumped out through the 1090 raise and piped to the treatment tanks. The treatment system utilized alkaline addition to treat water and precipitate metals. The four tanks were used in series to clarify water before discharge. Water was discharged

within the water dispersion area located along the Silver Butte ridge. Details regarding the volume of water treated and discharged using this system are unknown.

- A two-tank water treatment system located just outside of the Silver Butte 1 adit. This system also used lime addition to treat water pumped from the underground mine workings via the Silver Butte 1 adit portal. Treated water was dispersed on the hillside of the Silver Butte 1 WRD.
- Various freshwater water diversion ditches, such as those located to the south of the water and tailings storage pond, to the northeast and southeast of the milling facility, and to the southeast side of the water and tailings storage pond.

Mine materials are not present in the water treatment and dispersion areas on Silver Butte ridge.

3.1.2.9 Crusher Facility

The crusher facility was located adjacent to the Formosa 1 adit (Figure 1.3-2). Ore mined from the underground mine workings was processed at this facility to separate ore grades and crush ore to a finer particle size (i.e., gravel) to be hauled to the ore storage area and milling facility. Ore was further ground in the milling facility to a fine powder to be fed into the flotation circuit. As stated in Section 1.4, crusher fines generated by the crushing process were inadvertently discharged directly into Upper Middle Creek during modern mining; Upper Middle Creek was remediated to remove these crusher fines in 1994 as described in Section 1.4.

In 1996, additional restoration efforts on Upper Middle Creek were conducted. As a result of the tailings cleanup efforts in 1994, the stream alluvium had been completed removed in some areas and habitat had been significantly altered. BLM, in coordination with the Oregon Youth Conservation Corps, worked in July 1996 to hand place organic material such as forest litter, branches, and logs into the stream and along the stream banks. Observations of Upper Middle Creek today indicate healthy riparian vegetation along stream banks, despite the poor stream water quality and sediment contamination.

During reclamation, the crusher was completely dismantled and removed from the Site. The area was regraded to place backfill over the Formosa 1 adit plug. Revegetation of the area was also attempted; however, current observations indicate no vegetation in the area, potentially a result of ARD discharge from the adit portal and acidic source materials. The former crusher area is considered part of the Formosa 1 adit WRD for the purposes of this RI report.

3.1.2.10 Tailings Thickener and Transport Facilities

Tailings discharged from the mill were originally backfilled into the underground mine workings. Tailings were hydraulically transported via the main tailings pipe from the mill up to the 1090 raise area where a tailings thickener facility was located (Figure 1.3-2). Tailings were thickened and pumped into the underground mine workings through the 1090 raise. Water recovered from the tailings at the thickener facility was drained back into the water storage pond at the mill and/or recycled into the mill water circuit. The tailings were either mixed with concrete before backfill into the workings or directly backfilled without concrete (J. Wilson, personnel communication, 2009). These facilities were used during mining and during reclamation when

tailings from the water and tailings storage pond were pumped from the pond into the underground mine workings.

During reclamation, all facilities associated with tailings transport and processing were removed from the Site. The foundation for the 1090 raise thickener facility was removed and the area was regraded. The former road leading to the 1090 raise has been partially reclaimed and has good forest revegetation since 1994; however, mine materials remain in the 1090 raise area and below the area that are eroding into the forest downslope.

3.1.2.11 Miscellaneous Road Areas

The majority of the primary mine disturbance area has been constructed with mine materials either during historic mining or during modern mining. As a result, many of the Site road areas are essentially small mine material dumps that are eroding into the downslope vegetated areas below the roads. Along the major WRDs at the Site (i.e., Formosa 1 adit, Silver Butte 1 adit, west encapsulation mound), the road prism is part of the WRD. The road prism is the mine material that was used to construct and support the road structure. Site roads that contain mine materials are Roads 30-6-35.0 (Site access from north and south), 30-6-35.1 (Site access that winds around West Fork Canyon Creek ridge and enters the Site from the east), 31-6-13.1 (Site access from the north), and 31-6-26.1 (Silver Butte Peak road).

3.1.3 Underground Mine

The following subsections describe the underground mine in terms of the mine portals, configuration of the underground mine workings, and backfill material placed in the workings.

3.1.3.1 Mine Portals and Adit Water Diversion

The main access to the original Silver Peak Mine included five mine portals (Formosa 1 [Exhibit 3.1-10], Formosa 2, Formosa 3, and Silver Butte 1 adits; and 1090 raise). These five portals were backfilled and covered as part of reclamation in 1994. Two other mine portals (K1G adit and the 404 adit) are located southwest and are not connected with the main underground mine. These portals were not associated with modern mining and have not been reclaimed.

Historic underground mine tunnels were designed to drain by gravity to the Formosa 1 adit. From the 1930s until modern mining, approximately 5 gpm to 20 gpm of ARD flowed out of the Formosa 1 adit and up to 10 gpm flowed out of the Silver Butte 1 adit (DOGAMI 1994, 1996). The Formosa 2 and 3 adits and the 1090 raise are situated at higher elevations and were used to access the higher levels of the ore body at the Silver Peak Mine. No water flows out of these upper portals. Intermittent water has been reported from the Silver Butte 1 adit, although flow was not observed during the RI.

Exhibit 3.1-10. The Formosa 1 adit during modern mining

Reclamation and closure of the adit portals was described in Section 1.4. This section focuses on observations of the current state of this reclamation infrastructure. Exhibit 3.1-11 details the closure of the Formosa 1 adit.

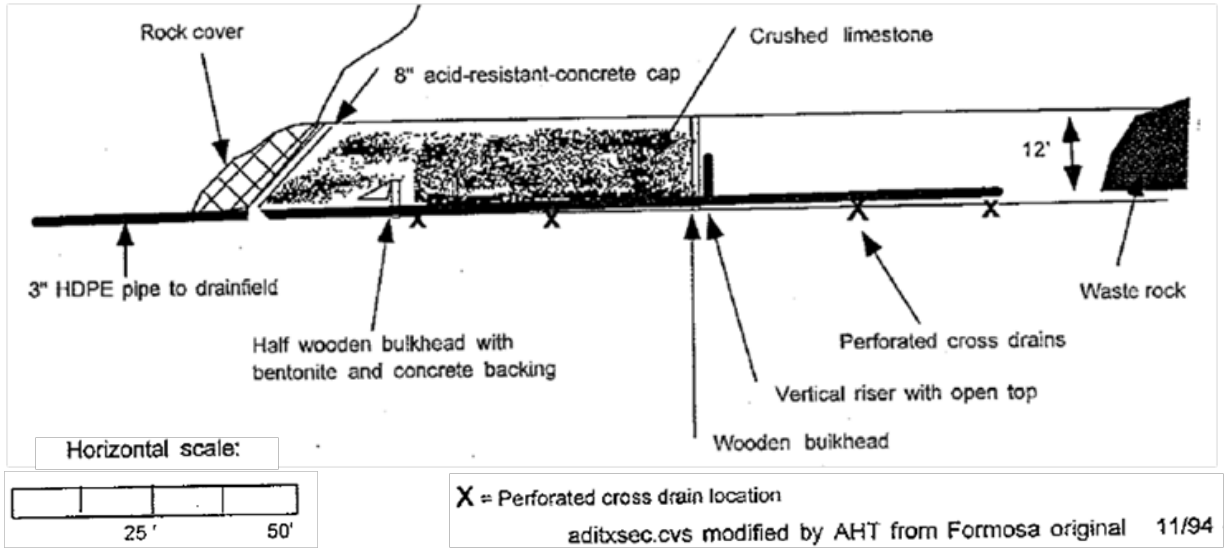


Exhibit 3.1-11. As-built diagram of Formosa 1 adit plug (from DOGAMI 1995)

This exhibit shows that the plug was designed to drain adit water. However, the original infrastructure had an inadequate pipe size (i.e., only 3-in drain pipe) and was not designed in anticipation of sludge clogging (e.g., cleanout ports). As a result, the drain pipes clogged and the Formosa 1 adit water has drained through or around the concrete cap since 1995. It is also likely that that the acidic water has corroded some of the original concrete cap structure. As described in detail in Section 1.4, significant efforts to properly collect the seeping adit water have been conducted over the years. These efforts included installation of a subsurface collection gallery to collect flow that was not captured by the surface collection system in 1996. However, the IRAM adit water diversion system installed in 2000 did not include measures to collect subsurface flow. The area of mine material fill up to the adit, the subsurface collection gallery, and the access manhole vault placed as part of the rehabilitation efforts in 1996 still remain in place at the adit.

Exhibit 3.1-12. Seeps emanating from backfill at Formosa 1 adit, March 1996

Based on historic observations in the 1990s during system maintenance, the adit water is known to flow subsurface beneath the adit portal and express as seeps within the mine material fill around the adit portal (Exhibit 3.1-12). Since the current system is not designed to capture subsurface flow, it is likely that ARD from the adit is moving through the subsurface system and into the

Exhibit 3.1-13. Current 404 adit portal

MB sub-drainage. This is an important transport pathway that may be causing significant contamination in Upper Middle Creek.

The K1G adit and the 404 adit (Exhibit 3.1-13) are located on the southwest side of the Site along the general trend of the massive sulfide ore body (035 to 050 degrees). These mines may have been associated with exploration of the ore deposit in the early days of mining. Little information is available on the extent or configuration of the underground mine workings in these areas. The K1G adit is located along the east side of the road, south of the encapsulation mound. The 404 adit is a smaller mine working driven along the contact between dacite tuff and foliated tuff unit, apparently to explore southern extension of the Silver Peak ore deposit. The 404 adit is accessed through a small wooden timber reinforced portal. Currently, the adit remains open and ARD perennially discharges from the adit.

3.1.3.2 Configuration of the Underground Mine Workings

Data obtained during the RI regarding the extent and location of existing underground mine workings at the Site is limited to one AutoCAD file and a series of drawings that were generated by Mr. Jay Wilson, a former mine engineer for FEI. A series of 1987 plan maps and sections prepared by FEI also exists, but the 1987 maps do not include underground mine development that was completed in the most recent period of underground mining. The AutoCAD file was obtained on compact disk from ODEQ files, and some compilation and analysis of the information contained within the file has been conducted for the RI. The information contained within the AutoCAD file and on hard-copy drawings are critical to understanding Site conditions, because access to the underground mine workings is not possible without a substantial investment in reopening and rehabilitating the mine. A cross sectional view of the underground workings is presented in Exhibit 3.1-14.

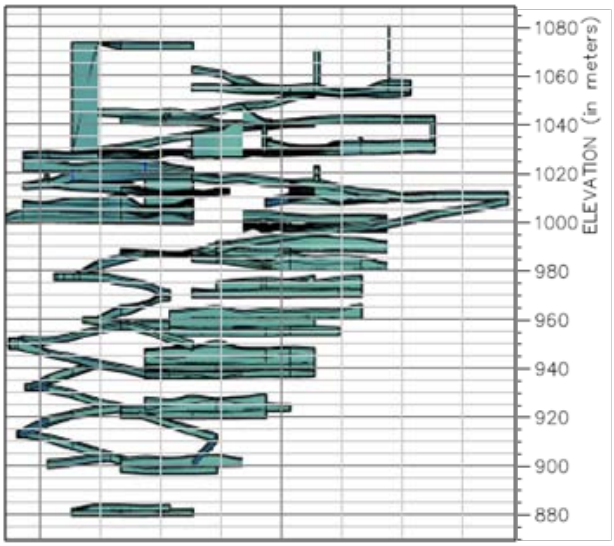


Exhibit 3.1-14. Cross section of underground workings looking west

The areal extent of the underground mine workings are shown in Figure 3.1-2. This extent is based on compilation of the AutoCAD data provided by Mr. Wilson. The original AutoCAD file is referenced in a local mine grid, which is a common practice at mine sites in general. The local mine grid on the AutoCAD file is thought to be orientated at an azimuth of 055 degrees,

and earlier hard-copy exploration maps and cross-sections (pre-1990) are thought to be orientated at an azimuth of 037 degrees (Wilson 2009). To understand specifically where the underground mine workings are located, it was first necessary to georeference the local mine grid to the existing grid system of the surface feature data (e.g., Oregon State Plane South, NAD 1983).

Based on the current stage of data compilation and other historic documents, the underground mine workings extend from an elevation of approximately 2,890 ft amsl to 3,510 ft amsl). The areal extent of the underground mine projected to the surface is relatively small as shown on Figure 3.1-2. This is a result of the relatively compact nature of the massive sulfide ore bodies excavated during the recent period of mining. The underground mine included a spiral ramp system accessing the lower levels of the mine and a series of mining tunnels orientated along the steeply dipping lenses of massive sulfide mineralization.

3.1.3.3 Backfill Material Placed in the Underground Mine Workings

The underground mining process consisted of tunneling along the strike length of the ore body at a given level. As described in Section 1.4, the void space in the rock left by excavation of the ore was backfilled using a mixture of tailings and concrete slurry or a pure tailings slurry during mining. During reclamation, the state agencies and FEI agreed that the most reactive materials (i.e., tailings and crushed ore) should be placed in the underground mine.

The hard-copy drawings that were obtained from ODEQ and DOGAMI files also provide the location of various types of mine backfill within the underground mine workings. Detailed backfill reports are also available from Northwest Environmental Resources (2003). The backfill includes tailings pumped into mine voids as a slurry, waste rock and lean ore hauled into the mine from the surface, tailings and sediment removed from Middle Creek, and gob (a mining term for waste rock mined underground and never hauled to the surface).

It is recognized that the draining Formosa 1 adit is a major source of ARD contamination at the Site. It is inferred that mine materials backfilled within the underground mine are strongly ARD-generating based on the perennial ARD discharge from the Formosa 1 adit and RI data from similar materials that were sampled during the OU1 RI. However, the focus of the OU1 RI is to identify surface source materials outside of the underground mine workings to provide data to evaluate OU1 remedial actions in the FS. Additional compilation and characterization of source materials located in the underground mine workings will be completed as part of the OU2 RI report.

3.2 Surface Water

The Site is located within the Lower Cow Creek Watershed of the South Umpqua Sub-Basin, one of three sub-basins in the Umpqua Basin. It is situated near the top of Silver Butte Peak which divides several subwatersheds. Figure 3.2-1 presents a watershed map showing the subwatersheds and drainages near the Site. Several individual drainage basins comprise of each subwatershed. The Riddle subwatershed lies to the north of the Site, the Upper Middle Creek subwatershed lies to the west and south, and the Canyon Creek subwatershed lies to the southeast and east. Russell Creek and Upper West Fork Canyon Creek are the main drainages in the Riddle and Canyon Creek subwatersheds that have headwaters near the Site, respectively. Within the Upper Middle Creek subwatershed, both Upper Middle Creek and South Fork Middle

Creek drainages have headwaters near the Site. Both of these drainages as well as other drainages in the Upper Middle Creek subwatershed drain into and combine with the Lower Middle Creek subwatershed, which then flows into the Upper Cow Creek subwatershed. The areal coverage of each of these drainages is listed in Exhibit 3.2-1, as well as the Middle Creek subwatersheds. Surface water sample locations are shown generally on Figures 2.3-5a through 2.3-5c and in more detail on figures in Section 4.2. In addition, Figures 2.3-5c shows the sub-drainages (i.e., MA, MB, SFA, SFB) on Upper Middle Creek and South Fork Middle Creek that are near the Site.

Exhibit 3.2-1. Drainage/Subwatershed Areal Extent

Drainage/Subwatershed	Area (acres)
Upper Middle Creek Drainage	2,310
South Fork Middle Creek Drainage	4,157
Russell Creek Drainage	3,877
Upper West Fork Canyon Creek Drainage	5,108
Upper Middle Creek Subwatershed	11,599
Lower Middle Creek Subwatershed	15,321

In general, creek flows in the Site area are highest from December to March (wet season) and lowest from July to early November (dry season). The following subsections present available flow data for the various drainages located near the Site. Available data collected before the RI sampling program was summarized in the Data Summary Report (Appendix A). Some of these data (e.g., flow) are also presented in the following sections to provide a historical comparison of flow data. All flow data from RI sampling locations is presented in tables in Section 4.2.

3.2.1 Middle Creek

The total Middle Creek stream length from the upper perennial section of Middle Creek to the confluence at Cow Creek is approximately 13 miles. The Upper Middle Creek drainage is approximately 3 miles long, is part of the Upper Middle Creek subwatershed, and includes the western portion of the Site. Site features located within this drainage include the Formosa 1, 2 and 3 adits and the 1090 raise; Silver Butte 1 adit; the adit water diversion system; Formosa 1 adit WRD; Silver Butte 1 adit WRD; and west encapsulation mound WRD, and the Formosa Mine underground workings. The drainage is 2,310 acres in size, and includes the headwaters of Middle Creek.

The uppermost observed perennial flow near the Site in the Upper Middle Creek drainage is downslope from the Formosa 1 adit WRD in the MA sub-drainage, near the MA sample location. Intermittent flows have been observed upslope of MA to a spring above Road 30-6-35.1, labeled as sample locations MA10, MA11, and MA13 (see Figure 4.2-1). Ephemeral flows likely occur farther upslope, above the Formosa 1 Adit during storm events. Headwaters of the Upper Middle Creek drainage are also located farther north of the Site within the northern portion of Section 22 and in Section 21; however, these sub-drainages are not near the mine area and therefore have not been studied. Flow data at four historically sampled locations along the creek is described below.

3.2.1.1 Middle Creek Flow Data

Seep and spring flows in Upper Middle Creek near the Site range from less than 0.1 gpm to 12 gpm with many seeps/springs only present in the wet season. Generally, seeps are considered low flow (less than 1 gpm) whereas springs are higher flow discharges to surface water. The largest seeps/springs were observed during the wet season near the MA/MB sub-drainage confluence and on the MA sub-drainage above the confluence. The following four locations on Middle Creek are some of the most frequently sampled surface water locations associated with the Site. The locations described are in order from upstream (closest to the Site) to downstream. Flow ranges given are based on data from previous investigations, available since 1999, and data collected as part of the RI sampling program from October 2009 through February 2011.

Location MA

The complete flow data for sample location MA is shown in Figure 3.2-2. MA is located within the uppermost perennial section of Upper Middle Creek. It is an in-stream sample location on the MA sub-drainage, north of the Formosa 1 adit WRD, approximately 380 horizontal feet west of Road 30-6-35.1. MA is a historic location, first established by Norecol's baseline sampling in 1989 and sampled continuously through mining, reclamation, and during investigation activities from 1999 through 2002 (see Appendix A). This location has been historically defined as a seep and referenced as 'Seep A' in various reports by others; however, observations during the 2000s and the RI sampling period indicate this is an in-stream sample site. Measured flow at MA ranged from no flow to 2.5 gpm during the dry season and 12.1 gpm to 200 gpm during the wet season. In October 2009 and January 2010, laboratory samples and flow measurements were collected at a location termed 'Seep A.' The location is actually 180 horizontal feet upstream from the MA location (based on the MA survey pin established by BLM in 1998). The measured Seep A flow data for the January 2010 sampling event is provided in Figure 3.2-2 for comparison of relative flows in this portion of Upper Middle Creek.

Location A4

A4 is an in-stream sample location approximately 35 ft downstream of the confluence of the MA and MB sub-drainages (Exhibit 3.2-1). This location has been sampled under previous investigations since 1999 and provides a measure of loading at a section of the creek that has been severely degraded as a result of acid seeps/springs. Measured flow at A4 ranged from no flow to 2.6 gpm during the dry season and 12.1 gpm to 128.9 gpm during the wet season. Figure 3.2-3 shows the complete flow data for this location.

Exhibit 3.2-1. Surface water sampling location A4

Location MXR

MXR is an in-stream sample location approximately 0.75 miles downstream of the Middle Creek headwaters near the Site, on the border of BLM and private logging company land. This has been

the most frequently sampled location on the Site since the 1990s and as early as the baseline water quality studies in 1988 and 1989. Measured flow at MXR ranged from 9.5 gpm to 66 gpm during the dry season and 58 gpm to 2,038 gpm during the wet season. Figure 3.2-4 shows the complete flow data for this location.

Location M13.0

M13.0 is located much farther downstream than the previous locations, just upstream of the confluence of Middle Creek and Cow Creek, about 13 miles from the headwaters (Exhibit 3.2-3). Flow from this location represents the entire Upper and Lower Middle Creek subwatersheds. Although this location has been infrequently sampled, the data collected provides an overall measure of the watershed affected by the Site. M13.0 flows have been measured from 1,638 to 102,033 gpm. Figure 3.2-5 presents the complete data set for this location.

Exhibit 3.2-3. Surface water sampling location M13.0

3.2.2 South Fork Middle Creek Drainage

The South Fork Middle Creek and Upper Middle Creek drainages are separated by the Silver Butte ridge. The South Fork Middle Creek drainage is also part of the Upper Middle Creek subwatershed. The basin has an area of 4,157 acres and contains a large portion of the Site including the east encapsulation mound WRD, the ore and water storage areas, the illegal dump area southeast of the encapsulation mound, and the 404 Adit. South Fork Middle Creek begins in this drainage and two headwater locations have been monitored near the Site, SFA and South Fork B (SFB). SFA is located directly downslope of the encapsulation mound, and is crossed multiple times by the South Fork access road. Based on 2009 and 2010 RI observations, perennial flow in SFA begins approximately 900 ft downslope of the encapsulation mound between sample locations SFA5 and SFA4 (See Figure 4.2-6). SFB is located north of SFA and is aligned downslope of the illegal dump area. Perennial flow in SFB begins approximately 800 ft downslope of the illegal dump, around the SFB4 sample location. In both sub-drainages, intermittent flows have been observed farther upstream in the wet season. During storm events, ephemeral flows likely occur farther upslope, all the way up to the Site WRD areas. These two sub-drainages are of interest because of their proximity to the Site. Similar to Upper Middle Creek, additional South Fork headwaters are present in sub-drainages to the north, south, and east of the surface waters of interest. The upper perennial portions of SFA and SFB are about 4.6 miles upstream of the confluence with Upper Middle Creek.

3.2.2.1 South Fork Middle Creek Flow Data

Flow measurements of seeps/springs in the upper reaches of SFA and SFB sub-drainages ranged from 0.1 to 15 gpm. Similar to Upper Middle Creek, many of the seeps/springs were only flowing during the wet season and at perennial seeps/springs, flows were much higher in the wet season.

An example of this kind of seep/spring is SFA5 which had an estimated flow of 0.1 gpm in October 2009 and a measured flow of 5.7 gpm in February 2010. Flow from the SFA and SFB sub-drainages were measured to be roughly equal during the wet season sampling event. Two locations just above the confluence flows, SFA2 and SFB14 were measured at 61.8 gpm and 69.25 gpm, respectively.

SF1.0 is the most frequently sampled location at on South Fork Middle Creek since 1999 (Exhibit 3.2-4). It is located about 1 mile downstream of the South Fork headwaters near the Site and about 3.7 miles upstream of the Upper Middle Creek confluence. Measured flow at SF1.0 ranged from 35.9 gpm to 305 gpm during the dry season and 300.7 gpm to 4,017 gpm during the wet season. Figure 3.2-6 shows the complete data set for this location. The SF1.0 location is similar in distance from the Site as MXR. In comparison to flow data collected MXR at similar dates, SF1.0 flow is consitently greater than MXR and in some cases twice as high.

Exhibit 3.2-4. Surface water sampling location SF1.0

3.2.3 Russell Creek Drainage

The Russell Creek drainage extends from the top of Silver Butte to the north of the Site. The drainage does not contain any known mine waste dumps, adits, or other mine-related materials. The drainage is 3,877 acres in size and encompasses Russell Creek from the headwaters to the confluence with Cow Creek to the north. According to BLM water course data, the headwaters are 4.9 miles upstream from the confluence with Cow Creek, and approximately ¾ of a mile downslope from Silver Butte Peak. There is little known flow data for Russell Creek near the Site. Surface water samples collected from Russell Creek were focused near the upper reaches of the system nearest to the Site between Roads 30-6-35.1 and 31-6-13.1. Measured flow from these areas (locations SW3 and SW4) ranged from 1 gpm to 5 gpm in the dry season and 11 gpm to 100 gpm during the wet season.

3.2.4 Upper West Fork Canyon Creek Drainage

The Upper West Fork Canyon Creek drainage is located northwest of the Site, on the northwestern slope of the Silver Butte ridge. Road 31-6-26.1 along the ridge leading up to Silver Butte Peak roughly divides this drainage from the Upper Middle Creek drainage. Of all the drainages described in this report, this is the only one that is not part of the Lower Cow Creek watershed. Upper West Fork Canyon Creek is part of the Days Creek-South Umpqua River subwatershed. As with the Russell Creek drainage, this drainage does not contain any known mine materials or mine related structures. The drainage is 5,108 acres in size and contains the Upper West Fork Canyon Creek. According to the BLM water course data, the perennial stream length in the drainage is 4.4 miles. The headwaters are located approximately 0.4 miles east of the

drainage border, close to sample location SW5 along Road 31-6-35.0. Minimal stream flow data is available for this drainage; some measurements have been collected at upstream locations close to the headwaters along Road 31-6-35.0. Measured flow from these areas (locations SW5, SW6, and SW7) ranged from 2 gpm to 7 gpm in the dry season and 40 gpm to 72.4 gpm during the wet season.

3.2.5 Cow Creek

The Lower Cow Creek watershed includes all the drainages described above, except the West Fork Canyon Creek drainage. The Site is located in the southeast portion of the lower Cow Creek watershed, which covers a total area of 102,447 acres and includes the City of Riddle. The watershed terminates at the confluence of Cow Creek and the South Umpqua River, 2 miles downstream of Riddle. The Middle Creek confluence with Cow Creek is located 24 miles upstream of Riddle or approximately 26 miles from the South Umpqua confluence.

Exhibit 3.2-5. Surface water sampling location C1 on Cow Creek

3.2.5.1 Cow Creek Flow Data

C1

Sample location C1 is on Cow Creek, just upstream of the confluence with Middle Creek (Exhibit 3.2-5). Since it is upstream of the Middle Creek confluence, it has been used as a Cow Creek background sample location. Measured flow at C1 ranged from 37,231 gpm to 98,841 gpm during the dry season. One wet season reading of 165,056 gpm was taken in February 2010.

USGS Gage Station 41310000

This gage station is located approximately 19.4 miles downstream from C1 and M13.0, and 4.6 miles upstream of Riddle. The period of record at this station dates back to water year 1955 and is summarized in Figure 3.2-7. This is the closest continuously monitored station downstream of the Site, and includes all known affected streams. Because of this, it is the best candidate for use in estimating relative flows at upstream locations at the Site through time. This is desirable because of the limited flow data available and lack of real time monitoring at the Site.

3.2.5.2 Cow Creek Water Intakes

There are three water intakes along Cow Creek, they are:

- Riddle public intake: municipal water supply for the town of Riddle, located approximately 2 miles upstream of the South Umpqua confluence;
- Mayberry private intake: drinking water for a private community of residences, located approximately 6.5 miles upstream of the South Umpqua confluence; and

- Chamber's private intake: irrigation water for agricultural use, located approximately 15.8 miles upstream of the South Umpqua confluence.

When including the sections of the Upper Middle Creek and the South Fork of Middle Creek, the total perennial stream length from waters closest to the Site to intakes are shown in Exhibit 3.2-6.

Exhibit 3.2-6. Total Flow Length to Sites of Interest

Site of Interest	Distance from Upper Middle Creek headwaters closest to Site (miles)	Distance from South Fork Middle Creek headwaters closest to Site (miles)
Middle Creek Cow Creek Confluence	13	15.6
Chamber's Intake	23.2	25.8
USGS Gage Station 14310000	32.44	35.04
Mayberry Intake	32.5	35.1
Riddle Intake	37	39.6
South Umpqua Confluence	39	41.6

3.2.6 Adit Water

There are two adits at the Site that drain continuously: 1) the Formosa 1 adit that drains, by way of the adit water diversion system, to the Upper Middle Creek drainage; and 2) the 404 adit that drains into the South Fork Middle Creek drainage. The Silver Butte 1 adit is also known to flow during very wet conditions, but this has not been observed during the RI. Flow from the Silver Butte 1 adit was noted in previous investigations during the winter of 2000/2001 (0 to 20 gpm). When this adit drains, it is also collected by the adit water diversion system and discharged to the Upper Middle Creek drainage.

3.2.6.1 Adit Flow Data

Formosa 1 Adit

The Formosa 1 adit is located in the very upper part of the MB drainage, approximately 150 ft east and above Road 31-6-35.1 (Figure 1.3-2). The adit water diversion system collects and transfers the flow downhill and southwest to a drainfield area located northwest of the Silver Butte 1 adit WRD. The drainfield area is within the upper part of a watershed that feeds into the ME sub-drainage (see Figure 2.3-6). Historic flow measurements for the Formosa 1 adit are available from 1999 to 2002, and flows were measured as part of the RI. Measured flow at Formosa 1 adit ranged from 0.8 gpm to 4 gpm during the dry season and 2.5 gpm to 190.3 gpm during the wet season. See Figure 3-2.8 for the complete data set. Observations at the discharge of the adit water diversion system indicate that this water flows on the surface approximately 170 ft downslope of the discharge and then becomes subsurface flow. This subsurface flow is likely contributing to baseflow in the ME sub-drainage.

404 Adit

The 404 adit is located high up in the South Fork Middle Creek drainage, approximately 0.5 miles southwest of the encapsulation mound and close to the Silver Butte ridge that separates the Upper Middle Creek and South Fork Middle Creek drainages. Measured flow at 404 adit ranged from no flow to 0.1 gpm during the dry season and 0.4 gpm to 3.5 gpm during the wet season.

3.3 Geology

The geology of the Site is described in previous reports including FRC (1987; 1988), Derkey and Matsueda (1989), and Derkey (1981; 1982). Although these reports focus primarily on the economic geology of the Silver Peak Mine, they provide excellent background information to understand the causes of acid generation and to understand aspects of the hydrogeological framework of the Site. To be consistent with historical information, geology is discussed below with respect to the Silver Peak Mine. This section summarizes pertinent information presented by FRC (1987), Derkey and Matsueda (1989) and focuses on:

- Relevant aspects of the regional geologic framework;
- Local geology in the vicinity of the mine;
- Ore mineralogy and mineralogy of rock units intersected by underground mine workings with respect to the potential to generate ARD; and
- Local structural geology pertinent to potential contaminant migration.

3.3.1 Regional Geology

The Site is located in the Western Jurassic Belt of the Klamath Mountains. The Klamath Mountains consist of four north-south trending belts of accreted Paleozoic and Mesozoic rocks. The Western Jurassic Belt is the westernmost of the four belts. Each belt is bounded on the west by an easterly-dipping thrust fault. The Western Jurassic Belt is bounded on the west by the Coast Range thrust, which separates Franciscan rocks of the Coast Range Province from the Western Jurassic Belt rocks. The Coast Range thrust trends generally northeast and is located approximately 2,600 ft west of the Site (Derkey and Matsueda 1989, FRC 1987). A subsidiary sub-parallel thrust fault, called the Silver Butte thrust, is located just east of the Silver Peak Mine. The trend of lithological units, the bedding and foliation of the rocks, and the orientation of subsidiary structures is sub-parallel to these major northeast trending fault units (FRC 1987). The locations of the Coast Range thrust and Silver Butte thrust are shown on Figure 3.3-1.

The Coast Range thrust forms the structural boundary between the Coast Range Province and the Klamath Mountains Province. The fault marks a major change in lithology, with primarily sedimentary rocks on the west side of the fault and metavolcanic rocks (metamorphic rock formed from volcanic rocks) on the east side. Rocks on the west side of the Coast Range thrust are primarily sedimentary rocks of the Dothan Formation, which includes lithologies such as mudstones, greywacke with local chert and pillow basalt. Rocks on the east side of the Coast Range thrust in the general vicinity of the mine consist of primarily metavolcanic rocks of the Rogue Formation including metamorphosed tuff, agglomerate, flow breccia and lava flows. The contrast between primarily sedimentary rocks on the west side of the Coast Range thrust and primarily metavolcanic rocks on the east side of the Coast Range thrust may contribute to contrasting hydrogeological characteristics as well.

3.3.2 Local Geology

The local geology consists of bedrock overlain by a thin layer of unconsolidated soil. Fill consisting primarily of mine waste overlies the primary mine disturbance areas of the Site.

3.3.2.1 Bedrock

The bedrock units in the direct vicinity of the Silver Peak Mine were described by Derkey and Matsueda 1989, and consist of the following units:

- Basalt flows and tuffs;
- Dacite tuffs;
- Foliated tuff;
- Bedded tuff; and
- Basaltic tuff.

These rock units are generally composed of subaqueously deposited volcanic rocks that are spatially and genetically associated with the massive sulfide mineralization at the Silver Peak deposit. Basalt and dacite are rock names that are dependent on the chemistry and mineralogy of the rocks. Derkey and Matsueda (1989) note that field delineation of many basaltic versus dacitic metavolcanic rocks is difficult where the rock units are weathered. Derkey and Matsueda (1989) utilized normative mineralogical analyses based on laboratory whole rock geochemistry to delineate the units. In contrast, the foliated tuff unit is a very characteristic unit that is readily identified in the field. This unit is present in the underground mine and hosts the massive sulfide mineralization (the ore body). Each of the units is described in the following sections. A local geological map is presented as Figure 3.3-1.

The basalt flows and tuffs are lowermost in the stratigraphic sequence, and are up to 2,000 ft thick. The basalt flows are crystalline rocks that are characterized by large augite phenocrysts (relatively large crystals) in a groundmass (relatively fine-grained crystals) of albite, chlorite, and epidote. The rock is locally vesicular (containing holes formed from escaping gas) and is medium to light green in color.

The dacite tuff generally overlies the basalt flows and tuffs. This unit is light grey to tan and consists of 5 percent altered plagioclase phenocrysts in a groundmass of fine-grained submicroscopic quartz, epidote, chlorite and albite. This unit is interbedded with the basalt flows and tuffs unit in some areas, and contains common clots and veins of secondary quartz near the mine.

The foliated tuff unit is a foliated ash-flow tuff, which is host to ore mineralization at the Silver Peak deposit. The tuff matrix consists of chlorite, albite, quartz, and epidote. The tuff matrix contains a high percentage of sericite near the ore bodies. A quartz-sericite-pyrite lithological variation is common near mineralized areas, with pyrite occurring as abraded lapilli (pyroclastic rock fragments generally between 2 and 64 mm). This unit will be discussed further in Section 3.3.3, which focuses on ore mineralogy.

The bedded tuff unit overlies the foliated tuff and is at least 980 ft thick in the Silver Butte Peak area. This unit ranges in color from pale grey to light green to light brown. Bedding ranges from thin bedded to massive bedded. Most occurrences of this unit are soft and weakly indurated. The term induration refers to the degree of hardening or consolidation of the rock caused by pressure

or heat. Portions of the unit are well indurated and porcelaneous (having a smooth fracture surface). This unit is overlain by a basaltic tuff unit.

Several aspects of the local geology are important with respect to the environmental issues present at the Site. First, the rock units include crystalline flows and indurated tuffs as well as soft weakly indurated tuffs. Second, variations in the degree of induration of the bedded tuff unit may affect the hydrogeological characteristics of the unit such as the degree to which water tends to move through primary intergranular porosity or secondary porosity related to fractures. Third, no carbonate minerals are reported in any of the rock units, which indicates that these units would be unlikely to significantly buffer pH changes caused by ARD generation in the mine area.

3.3.2.2 Unconsolidated Deposits

Unconsolidated deposits identified during the RI include colluvium, alluvium, and mine materials. Mine materials, which include mine waste rock, tailings, and construction fill, are described in Section 4.

Colluvial soils cover the steep slopes at the Site. Colluvium consists of unconsolidated mixtures of rock fragments and soil that are transported downslope by gravity. The colluvium present at the Site is generally green to brown in color and comprises a heterogeneous mixture of silt, sand, and gravel. The most common colluvial soil type is silt or silt with gravel. Soil structures including bedding and rootlets are often present in the colluvium. Based on borings and test pits conducted during the 2010 RI, the thickness of the colluvium at the Site ranges from less than 0.5 ft to 11 ft, with thicknesses of less than 1-ft the most common. In some areas no colluvium is present and bedrock is exposed at the ground surface or fill directly overlies bedrock.

Alluvium is generally present within streambeds and drainages at the Site. Alluvium consists of unconsolidated mixtures of clay, silt, sand, gravel, and cobbles that are deposited by moving water. The thickness of alluvium ranges from less than a foot in minor drainages to over 10 ft in the more prominent drainages.

3.3.3 Mineralogy and Alteration

The mineralogy of the ore bodies and associated rocks intersected by mine workings is an important aspect controlling ARD at the Site. The Silver Peak deposit is classified as a volcanogenic massive sulfide deposit. This type of deposit contains very high concentration of sulfide minerals and, therefore, the deposit has a very high potential for acid generation. This is exacerbated by a lack of ARD-neutralizing carbonate minerals in the country rocks surrounding the mine.

3.3.3.1 Historical Information

The ore bodies and portions of the foliated tuff unit contain high concentrations of numerous sulfide minerals including pyrite (FeS_2), chalcopyrite ($CuFeS_2$), sphalerite (ZnS), bornite ($Cu5FeS_4$), tennantite ($(Cu, Fe, Zn, Ag)_{12}As_4S_{13}$), tetrahedrite ($(Cu, Fe, Zn, Ag)_{12}Sb_4S_{13}$), galena ($PbS$), and chalcocite ($Cu_2S$) (FRC 1987). Pyrite is a major contributor to ARD generation at mine sites worldwide, and it is important at the Silver Peak Mine both in terms of direct ARD generation by pyrite and the effect of the products of pyrite oxidation on oxidation of other sulfide minerals.

There are four rock units containing sulfide mineralization at the Silver Peak deposit, all of which are contained within the foliated tuff unit that was described in Section 3.3.2 and shown on the geologic map in Figure 3.3-1 (Derkey and Matsueda1989). These units consist of:

- Quartz-sericite-pyrite foliated tuff;
- Quartz-sulfide tuff;
- Sulfide lapilli tuff; and
- Massive sulfide.

The quartz-sericite-pyrite foliated tuff is the thickest of the three units, and is up to 33 feet thick in the mine area (Derkey and Matsueda 1989). It is grey to white in color and consists of sand-sized grains of quartz and pyrite with varying amounts of platy sericite. Pyrite is detrital when it occurs in grains exceeding 0.1 mm in diameter, as evidenced by abraded textures. Trace chalcopyrite and sphalerite are also present in this unit (FRC 1987). Norecol (1989) provides estimates of the sulfide content of quartz-sericite-pyrite foliated tuff based on total sulfur analyses. Based on 11 samples, the estimated sulfur content ranges from 4.98 to 19.20 percent, which corresponds to a pyrite content in the rock ranging from approximately 10 to 40 percent. This rock is highly ARD-generating.

The quartz-sulfide tuff occurs in the footwall of the massive sulfide zones. This unit is dense and siliceous and not strongly foliated. It contains sphalerite and chalcopyrite in addition to pyrite (FRC 1987), and is also ARD-generating.

Sulfide lapilli tuff is defined by Derkey and Matseueda (1989). It consists of cream-colored tuff containing scattered lapilli size fragments of sulfides including pyrite, chalcopyrite, tennantite, and sphalerite. The sulfide lapilli tuff occurs in the hanging wall of the massive sulfide mineralization. This unit contains up to 10 percent sulfide minerals in a fine-grained well-indurated matrix, which causes this unit to be ARD-generating.

Massive sulfide at the Silver Peak Mine occurs in four distinct lenticular bodies. The massive sulfide lenses are relatively small in overall size, but they contain large accumulations of sulfide minerals. The massive sulfide lenses range from less than 1 meter to approximately 5 meters thick. FRC (1987) reports the strike extent of the massive sulfide lenses to range from 20 to 90 meters, with a down-dip extent of approximately 100 meters. Work by FRC (1987) was completed before initiation of mine development during the most recent period of mining at Silver Peak Mine, and further extensions of massive sulfide mineralization may have been discovered during the course of subsequent exploration and mine development.

Massive sulfide mineralization at Silver Peak Mine is predominantly pyrite with chalcopyrite, sphalerite and local bornite, tennantite, galena, and chalcocite. Barite and quartz occur within the massive sulfide lenses as gangue minerals. Four types of massive sulfide mineralization are present in the deposit (FRC 1987):

- Pyrite ore is principally pyrite with minor quartz and chalcopyrite;
- Yellow ore is pyrite and chalcopyrite;

- Semi-black ore is pyrite and chalcopyrite with sphalerite, barite and quartz; and
- Black ore is sphalerite, barite, pyrite, galena, chalcopyrite, tetrahedrite, and tennantite.

The primary payable metal at the Silver Peak Mine during the most recent period of mining was copper. Zinc concentrates were initially produced, but the zinc concentrate was not of sufficient quality to be an economic product from the mine. Therefore, the massive sulfide mineralization most profitable to mine would be the yellow ores because of the high chalcopyrite content. In addition, semi-black ore and black ore may have been economic to mine if the copper content was high enough to support mining and mineral processing costs.

The most important conclusion of this examination of ore mineralization data is that the entire foliated tuff unit contains pyrite and other potentially ARD-generating minerals. This includes the lenses of massive sulfide mineralization as well as the various subdivisions of the foliated tuff unit. Only the portions of this unit containing the highest copper concentrations were likely mined, but mine tunnels accessing the copper ore very likely exposed ARD-generating minerals where they penetrated the other massive sulfide units and the foliated tuff units. In addition, pillars of massive sulfide mineralization were not mined to provide ground support within the mine as described in Section 3.1. Therefore, exposed rock surfaces within the underground mine are an important source of acid generation in addition to backfilled tailings and other mine waste. Furthermore, cycling of dissolved ferric iron into submerged portions of the underground mine workings and subsequent discharge from groundwater to surface water is potentially occurring, which suggests that acid generation and associated metal dissolution may be occurring both within the vadose and saturated portions of the underground mine.

3.3.3.2 SEM Mineralogical Data

Mineralogical analyses using SEM-EDS were conducted by CDM at the South Dakota School of Mines Engineering and Mining Experiment Station on six samples collected during the RI. This analysis identified many of the same minerals reported by FRC (1987) and illustrated the importance of the sulfate mineral barite ($BaSO_4$) as an important constituent of the mine materials, which required special analysis of ABA data collected from mine materials as discussed in Section 2. Selected SEM data are described below, which illustrate the primary occurrence of several COPCs in the mine rock. Additional SEM data are presented in Appendix E.

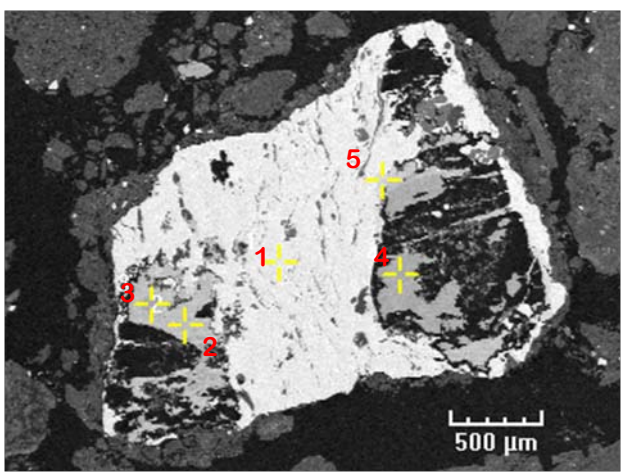


Exhibit 3.3-1. SEM-EDS photomicrograph of barite mineral grain (1), associated with chalcopyrite (2 and 3), pyrite (4), and tennantite (5).

Exhibit 3.3-1 is a photomicrograph of a barite mineral grain from sample P002 which was collected from the former mineral processing plant area. This sample shows the association of barite with sulfide minerals chalcopyrite and pyrite and the sulfosalt mineral tennantite. This grain

shows the primary occurrence of several COPCs including copper in chalcopyrite, iron in pyrite and chalcopyrite, and arsenic in tennantite. The paste pH of this sample was 1.96 su, and the sample contained pervasive jarosite, an alteration mineral associated with pyrite oxidation.

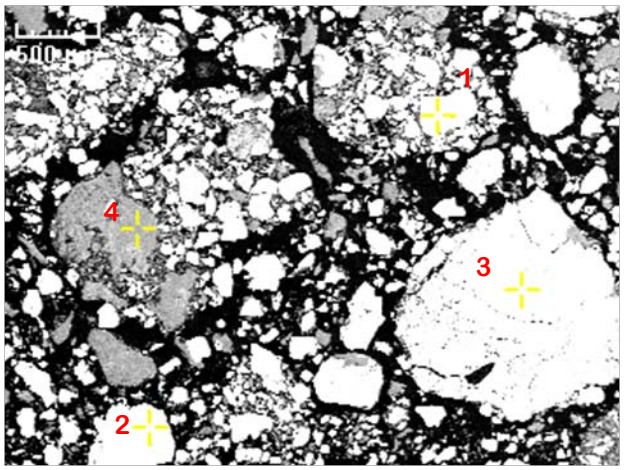


Exhibit 3.3-2. SEM-EDS photomicrograph of pyrite mineral grains (1, 2 & 3) with quartz (4).

Exhibit 3.3-2 shows a SEM-EDS photomicrograph from sample P062 (located on the eastern edge of the encapsulation mound, which was logged in the field as tailings. The photomicrograph shows how particle size reduction and flotation during mineral processing has formed a mine material containing a high concentration of very fine-grained and liberated pyrite grains. The pyrite grains range in size from approximately 1 mm to less than 50 µm, which greatly increases the ratio of exposed surface area to mass of the pyrite grains. The fine grain size increases the rate of ARD generation from the mine material, which is discussed further in Section 5.2.2. This observation is supported by the field paste pH of the sample, which was 1.81 su. Chalcopyrite and/or sphalerite were removed by flotation during mineral processing to produce copper and/or zinc concentrates. This process produced strongly ARD generating tailings, which were backfilled into the underground mine and placed into the encapsulation mound.

Exhibits 3.3-1 and 3.3-2 shown previously are mineral grains that are composed dominantly of ore minerals. In contrast, Exhibit 3.3-3 shows a photomicrograph of grain composed dominantly of anothrite and quartz, two common rock forming minerals. This grain is from sample P077, which was collected along the the road leading to the Silver Butte fire tower. This sample was logged in the field as dominantly undifferentiated metavolcanics with trace quartz sericite pyrite phyllite (QSP) and trace pyrite. This particular grain shows minor chalcopyrite and sphalerite as inclusions within the dacitic mineral grain. Chalcopyrite and shpalerite do not generate ARD when oxidized by oxygen. However, these minerals will oxidize and release copper and zinc into the environment and can form acidity if oxidized by ferric iron.

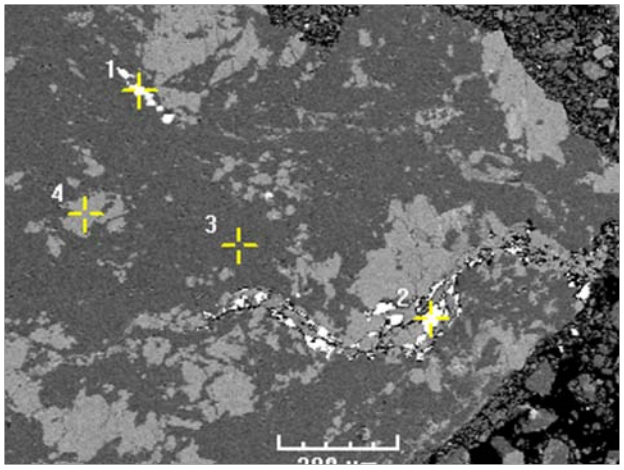


Exhibit 3.3-3. SEM-EDS photomicrograph of dacite grain containing chalcopyrite (1), sphalerite (2), quartz (3), and anorthite (4).

Exhibit 3.3-4 shows a photomicrograph of a mineral grain that contains chromite ($FeCr_2O_4$). This grain is from sample P106,

1 4

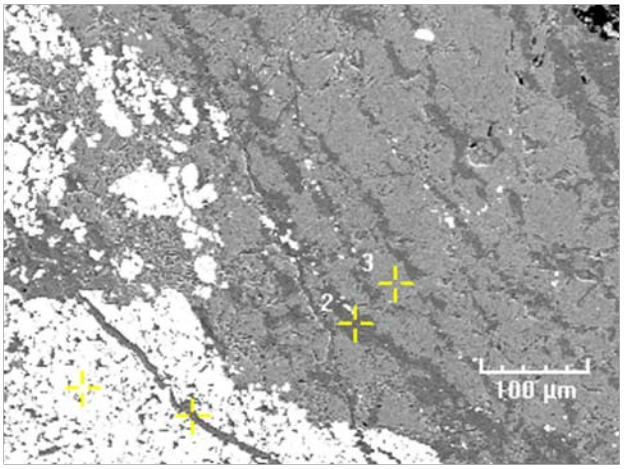


Exhibit 3.3-4. SEM-EDS photomicrograph of basalt grain containing chromite (1), forsterite (2 &4), and olivine (3).

which was located along a rock outcrop on the north end of the former ore storage area. This sample was described in the field as undifferentiated metavolvcanics. The sample contained trace particles of massive sulfide, which is attributed to presence of the former ore storage area. However, this grain is unmineralized country rock, as evidenced by lack of pyrite or other sulfide or sulfosalt minerals and field paste pH of 4.3 su. Common minerals in the samples include forsterite ($MgSiO_4$) and olivine ($[Mg,Fe]SiO_4$). Chromite in this sample is likely a natural trace mineral constituent of the basaltic county rock. Chromite can be of environmental concern, particularly if it occurs in the hexavalent state (Cr^{+6}). Chromium in chromite is in the trivalent state (Cr^{+3}), although upon weathering and oxidation chromite can form aquatic complexes with chromium in the hexavalent state (Rose et al. 1979). Chromite is not associated with massive sulfide ore deposits, and therefore, the presence of chromium in mine materials is thought to represent natural variation in background conditions.

3.3.4 Site Structural Geology

The Formosa Mine is located within an accommodation zone, which is an area of rocks that accommodate differential displacement between the Coast Range and Silver Butte thrust faults. The Coast Range thrust fault is approximately 3,200 ft west of the Formosa mine and the Silver Butte thrust fault is approximately 1,900 ft east of the Formosa mine. Each of these faults trend northeasterly and dip towards the east. Deformation associated with these features is compressional. A set of approximately perpendicular subsidiary faults is present in the Silver Butte Peak area with high angle northwesterly trends and apparent strike-slip displacement. These subsidiary faults accommodate differences in the magnitude of compressional displacement along the Coast Range and Silver Butte thrust faults. Several of these northwesterly-trending subsidiary faults are within the area of the underground mine, and fracture zones associated with these structures may provide local zones of secondary porosity and influence migration of contaminants in groundwater.

The massive sulfide mineralization occurs within an approximately 500- to 650-ft thick sequence of foliated tuff. The fabric of the foliated tuff includes a well defined foliation sub-parallel to bedding. This foliation is absent in adjacent dacite and basalt tuff units. FRC (1987) believes that this foliation is an expression of shearing deformation, which occurred in the general plane of the foliated tuff units (including zones of massive sulfide mineralization). The foliation is generally parallel to the strike of the rock units (strike 035 to 050 degrees, dip 60 to 75 degrees southeast), the orientation of the regional thrust faults, and the bedding of the massive sulfide units.

The subsidiary faults cross-cutting the orientation of the major thrust faults and the Silver Peak ore bodies are shown on various geological maps of the Site. A fault offsetting ore mineralization

is shown on a series of plan maps at various depths through the mine developed by FRC (1987). This structure is located approximately 100 ft south of the Formosa 1 adit. The structure is a right-lateral fault which displaces the ore zone by approximately 100 ft. The trend of this structure is generally west to northwest towards the Middle Creek drainage. Several other faults of similar orientation are provided on maps included in Derkey and Matsueda (1989) in the general area of the Silver Peak Mine and are shown on the geologic map presented in Figure 3.3-1.

3.4 Groundwater

This section provides a description of the current understanding of the hydrogeologic framework of the Site, which is based on review of historical data and consideration of data collected during RI activities occurring between October 2009 and September 2011. Understanding the hydrogeologic framework is an ongoing process that will evolve as additional data are collected during the OU2 RI. The following discussion describes the current understanding of the hydrogeologic framework to support evaluation of contaminant sources, transport pathways, and receptors. This evaluation is important to understand the potential effects on groundwater from OU1 source materials, which is addressed in Section 4.

Transport of contaminants in MIW is a major factor affecting surface water quality in the Middle Creek watershed. This is shown by a series of seeps/springs in both the South Fork Middle Creek and Upper Middle Creek areas where MIW discharges to surface water. Previous investigators have conducted limited hydrogeologic characterization, which is summarized in the Data Summary Report (CDM 2009b). These data are supplemented with recent dry season and wet season seep and spring surveys, groundwater quality monitoring, continuous groundwater level monitoring (November 2010 through September 2011), and bedrock fracture mapping that was conducted in February 2010.

Two major groundwater flow systems are important in the area of the Site:

- Bedrock groundwater system, and
- Alluvial groundwater system.

3.4.1 Hydrogeologic Framework of the Bedrock Groundwater System

Characterization of the bedrock groundwater system is incomplete. However, several aspects of this system are addressed below based on RI data and analysis of historical data. These aspects include structural controls on groundwater flow and groundwater elevation data. Available groundwater quality data are discussed in Section 4.3.

3.4.1.1 Structural Controls on Groundwater Flow

The geology of the Formosa Mine area generally consists of a series of steeply dipping metavolcanic rocks overlain by a veneer of unconsolidated sediments. Based on field observations at road cuts in the area, these rocks are well indurated and exhibit low primary permeability. RI investigations conducted to date indicate that groundwater flow though these rock units is controlled by fractures, which represent secondary porosity within the bedrock units.

Data regarding fracture orientation in the bedrock units were collected during January/February 2010 in the area of the Formosa 1 Adit. A major fracture zone was observed, which crops out behind the concrete tanks of the adit water diversion system near the Formosa 1 adit. This fracture zone is termed the Formosa 1 fracture zone for purposes of this description and ongoing hydrogeologic investigations at the Site. The Formosa 1 fracture zone was observed to be actively conveying water through bedrock during the wet season seep and spring survey. Photos of this fracture zone are shown as Exhibit 3.4-1.

Exhibit 3.4-1. Photo of water discharging from Formosa 1 fracture zone collected on January 26, 2010.

The Formosa 1 fracture zone is characterized by abundant closely spaced, interconnected fractures with open apertures caused by intersecting fractures and displacement along individual arcuate fracture surfaces. This fracture zone was conveying flows of several gpm during the January/February 2010 seep and spring survey. Less fractured bedrock directly adjacent to the fracture zone was not conveying significant water. This demonstrates that water movement within the fracture controlled bedrock aquifer may be localized in distinct fracture zones.

Fracture measurements were collected in the general area of the Formosa 1 fracture zone to evaluate the dominant fracture trends within the bedrock. These trends are not random and are controlled by the history of structural displacement within the accommodation zone between the Coast Range and Silver Butte thrust faults. A stereonet illustrating these fracture trends is shown in Figure 3.4-1. A steronet is a graphical tool used to illustrate and understand fracture patterns in rocks. It is a projection of lines and planes on the lower half of a sphere, which facilitates evaluation of the 3-dimensional orientation of fracture measurements collected in the area of the Formosa 1 fracture zone. In Figure 3.4-1, the poles to measured fractures (lines perpendicular to the measured fracture planes) are statistically contoured. The contours show that the measured poles generally form three groups. A best fit plane is then interpreted based on the contoured data. These planes define the dominant 3-dimensional orientation (i.e.; strike and dip) of sets of sub-parallel fractures.

Statistical evaluation of the fracture data indicates that three fracture sets are present in the area. These fracture sets are denoted as Surface 1 (S1), Surface 2 (S2), and Surface 3 (S3). Fracture set S1 strikes approximately north at an azimuth of 003 degrees and dips towards the east at an angle of 69 degrees. S2 strikes northwest at an azimuth of 297 degrees and dips northeasterly at 63 degrees. Fracture set S3 strikes northeasterly at an azimuth of 40 degrees and dips towards southeast at an angle of 76 degrees. S3 is subparallel to the orientation of primary bedding based on mine maps and geological cross-sections archived by ODEQ and DOGAMI, and present in the project file.

Future evaluation of the bedrock aquifer during the OU2 feasibility study should consider preferential groundwater movement along these fracture orientations, and assess associated anisoptropy in hydrological characteristics of the bedrock aquifer. Future work should also consider features such as the Formosa 1 fracture zone, which may be important in controlling COPC transport within the bedrock aquifer.

3.4.1.2 Groundwater Elevation Data

Additional information supporting fracture control of the bedrock aquifer is provided by spatial and temporal variation in groundwater elevation data including historical data and RI data. Available data are reviewed in the following sections.

Historical Data

Monitoring wells T1, T2, T3, and T4 were constructed near the area of the current encapsulation mound in 1989 to provide baseline groundwater data before mine construction. Water levels in the wells were measured for approximately 7 months in 1989. The data are plotted on the hydrograph in Figure 3.4-2, and show that the water elevation decreased by values ranging from 26 to 84 ft between March and September 1989. These data also show variable water levels in wells located within a relatively small area with water levels measured in March 1989 ranging from approximately 3,200 ft to 3,320 ft amsl. The large seasonal fluctuation in water levels suggests that the storage coefficient of the bedrock aquifer may be low, resulting in large increases in water level in relation to seasonal recharge by precipitation. The storage coefficient is the amount of water taken into or released from storage per unit change in head per unit area. The wide range in water table elevations measured during March 1989 at bedrock wells located close to each other suggests that the fracture systems intersected by the monitoring wells may not be well connected.

RI Data

Automated water level sensors were placed in operable bedrock monitoring wells at the Site, MW-2 and MW-5.These sensors were monitored during the period of November 2010 through September 2011. These groundwater level monitoring data are plotted on the hydrograph in Figure 3.4-3 (refer to Figure 2.3-6 for the well locations).

Similar to wells T1 through T4, the hydrograph for MW-5 shows the high variability in groundwater elevations ranging from approximately 3,282 ft amsl elevation 3,309 ft amsl . The hydrograph also shows precipitation data for the period of record. The water level in MW-5 shows a rapid response to precipitation events, and to the onset of the fall/winter wet season starting in November 2010. Individual responses to precipitation events are evident and show that the lag time between precipitation events and water level changes in MW-5 is on the order of days. This indicates that the bedrock aquifer at MW-5 is well connected with the surface. The large and rapid fluctuations also suggest the storage coefficient of the aquifer may be relatively low, which is compatible with a bedrock groundwater system controlled by secondary porosity in the form of fractures. The geochemical characteristics of OU1 mine materials in the MW-5 area will be discussed in Section 4. The water level data indicate that ARD that percolates through OU1 mine materials in the MW-5 area would be expected to rapidly infiltrate to the bedrock aquifer, and cause adverse effects to groundwater quality.

Water level data at MW-2 show a more subdued response to precipitation events, although the water level increases in response to the fall/winter wet season starting in November 2010. The overall fluctuation of the water level over the period of record is also lower, with fluctuation of approximately 4 ft over the period of record. Fluctuation of the MW-5 water level over the same period was approximately 35 ft. This suggests that the fractures intersected by the screened interval of MW-2 are relatively less connected with the surface as compared to MW-5.

These observations illustrate the relatively local nature of zones of secondary porosity within the bedrock units and the associated heterogeneity of permeability within the bedrock system. One approach to characterizing fracture flow groundwater systems is the equivalent porous media (EPM) approach, which assumes that fractures are so interconnected and closely spaced that the system can be conceptualized as a porous media. Based on available data, it is unlikely that the bedrock groundwater system can be adequately evaluated with an EPM approach on a local scale (for example, in the direct vicinity of the Formosa 1 adit, upper Middle Creek, or encapsulation mound areas). On a broader geographic scale, evaluation of the bedrock groundwater system with an EPM approach may adequately represent the system. The hydraulics of the bedrock groundwater system will be further characterized and evaluated during the OU2 RI.

3.4.2 Hydrogeologic Framework of the Alluvial Groundwater System

The importance of the alluvial groundwater system was recognized during the seep and spring surveys, particularly the wet season survey conducted during January/February 2010. Active alluvial groundwater systems were observed in most upland tributaries during the wet season survey. For purposes of this RI report, the term “alluvial groundwater system” describes areas where groundwater is present in unconsolidated alluvium, colluvium, and/or fill on either a perennial or ephemeral basis. These aquifers are located only within tributary drainages where unconsolidated alluvium, colluvium or fill has accumulated. In the upper portions of the alluvial groundwater system, groundwater is likely present only seasonally or after major storms. This type of flow is called interflow, which is the subsurface component of runoff. As this alluvial groundwater water flows downstream, the aquifers become perennial, and the alluvial aquifers are in hydraulic connection with surface water. Water would be expected to move either from the alluvial aquifers into surface water or from surface water into the alluvial aquifers depending on local conditions and seasonal variations in precipitation. In active streams, this type of subsurface flow is called hyporheic flow. The term alluvial groundwater system is used in this RI report to refer to the overall system ranging from seasonal interflow in the upper portion of tributary drainages, to hyporheic flow in lower portions of the tributary drainages where stream flow is perennial.

Alluvial groundwater is perched above the bedrock aquifer in upland areas, because runoff accumulates in the tributary drainages faster than it can infiltrate into the deeper bedrock system. These systems were observed during the wet season seep and spring survey, because road cuts commonly intersect the alluvial aquifers. At the location of the road cut, the alluvium was removed and this water flowed over the surface. During the seep and spring survey, flows within the alluvial aquifers were measured as surface water flow were the tributary drainages intersected by the road cuts. Often, water was flowing in the subsurface through an alluvial aquifer upstream and downstream of the roads, with surface water present only as a result of the road cuts. Exhibit 3.4-2 is a photo of water flowing through an alluvial groundwater system

observed during the January/February 2010 seep and spring survey. These alluvial aquifers were observed to actively convey water downslope towards perennial surface water bodies in the Upper Middle Creek, South Fork Middle Creek, West Fork Canyon Creek, and Russell Creek drainages.

Five alluvial groundwater monitoring wells were installed and sampled in August 2010 and January 2011 to further assess this system. The locations of the groundwater monitoring wells are shown in Figure 2.3-6. These wells were installed with a DPT rig in conjunction with the subsurface mine materials investigation. DPT rigs are subject to refusal if the drill bit encounters large boulders. This causes uncertainty in some measurements, which will be discussed below.

Based on observations during installation of the alluvial groundwater monitoring wells in August 2010, the alluvial groundwater systems occur within alluvial sediments in the larger drainages (e.g., MXR drainage) and colluvium in the less prominent drainages (e.g., Middle Creek F [MF] drainage). The thicknesses of the alluvium/colluvium range from less than 1 ft to up to 10 ft and soil types range from silt to gravel. Where mine materials have been placed into tributary drainages, these unconsolidated materials may also host alluvial groundwater flow. Because of the limited aquifer thickness and steep slopes at the Site, the alluvial groundwater system has limited storage capacity. Figures 3.4-4 through 3.4-8 present transducer water level data collected from November 2010 through September 2011 and precipitation data for the Silver Butte weather station (see Section 3.6).

Exhibit 3.4-2. Groundwater discharging from a road cut in January 2010. Water is flowing within alluvium at the interface between unconsolidated sediments and bedrock.

Figure 3.4-4 shows data for alluvial groundwater within monitoring well MW-7a, which is located in the MB tributary of Upper Middle Creek, downgradient from the Formosa 1 Adit and up-gradient from a series of MIW seeps/springs that discharge to Upper Middle Creek. The water level in the alluvial well ranged from approximately 3261.2 to 3262.6 ft amsl. The water level responds quickly to precipitation events, which is expected in these near-surface alluvial aquifers. Water is present in the monitoring well on a perennial basis.

Water level data for alluvial monitoring well MW-13A is shown in Figure 3.4-5. This well is located in an intermittent drainage west of the encapsulation mound. The water level in this well also shows rapid responses to precipitation events. However, the monitoring well contains very little water, with approximately 0.3 ft of water measured during dry periods of the year. This well generally does not contain sufficient water to be sampled. It is possible that this well is either not installed in the low point of the tributary drainage where alluvial groundwater flow occurs or that

the well was not installed at the base of the alluvial sediments as a result of refusal of the DPT drill bit caused by a boulder.

Figure 3.4-6 shows water level data for alluvial monitoring well MW-15A. This well is located along Middle Creek near surface water sampling location MXR, approximately 0.75 miles downstream from the Formosa 1 adit. At this location, stream flow within Middle Creek is perennial, and the stream flow is gaining as the water moves downstream. This indicates that bedrock groundwater is discharging into Middle Creek at this location. Water may flow into and out of the alluvial aquifer at this location in response to changing precipitation conditions. Water is always present within this alluvial well, and the water level varies over a range of approximately 1 ft in response to precipitation events and seasonal precipitation patterns.

Water level data for alluvial monitoring well MW-16A is shown in Figure 3.4-7. This well is located in a perennial reach of South Fork Middle Creek approximately 2,000 ft downstream of the encapsulation mound area. Very little water is present within this well, although the water level increases in response to precipitation events. It is likely that this well was not installed at the base of the alluvium as a result of DPT drill bit refusal, or that the well is not installed within the deepest portion of the tributary drainage. The lack of water within the alluvial monitoring well is not compatible with observation of perennial flow at this point in the stream.

MW-21 is located at the 404 adit area, and water level data are shown in Figure 3.4-8. The water level data indicate that only a few inches of water are present in the well with occasional responses to precipitation events. Based on the location data for this well, it appears that this well was not installed in the deepest portion of the tributary drainage where alluvial groundwater would be present, or the well was installed too high in the alluvial system where perennial flow does not occur. Therefore, the measurements are not considered to be representative of alluvial flow within this tributary drainage.

3.4.3 Encapsulation Mound Water

Water is present within the backfilled former water and tailings storage pond at the encapsulation mound. In August 2010, the shallow piezometers MW-22 and MW-23 were installed within the encapsulation mound. A discussion of observations from these piezometers was presented in Section 3.1.2.2. Although these are primarily piezometers for measurement of water level, several laboratory samples have also been collected.

Water level data for MW-22 and MW-23 are shown on Figure 3.4-9. The data show increases in water levels of approximately 1.5 ft over the period from November 2010 through May 2011. This trend is followed by a steady water level decrease back to near November 2010 levels by September 2011. This overall trend corresponds to the change in precipitation between the wet season and dry season. At a smaller time scale (days to weeks), temporary rises in water level are observed shortly after major rainfall events, which indicates a fast recharge to the system in response to precipitation. A recovery trend following each rise in water level and the overall decreasing trend during the dry season also indicates water is flowing out of the system. Estimation of infiltration and leakage volume was presented in Section 3.1.2.2.

A comparison of the hydrographs for the encapsulation mound wells and the nearby bedrock monitoring well, MW-5, does not indicate a direct hydraulic connection between the encapsulation mound and the bedrock aquifer at MW-5.

3.4.4 Groundwater Uses

Local groundwater is not used for potable supply. There are no privately owned wells or public water supply wells located in the OU1 Site boundary or within a several mile radius of this area.

3.5 Surface Water-Groundwater Interactions

An overview of surface water-groundwater interactions at Upper Middle Creek and the South Fork Middle Creek is presented in this section. A more detailed discussion of surface water-groundwater interactions with supporting groundwater and surface water chemical results is presented in Sections 4.2 and 4.3. MIW is discharging from the reclaimed Formosa 1 adit portal and is partially captured by the current adit diversion system. Surface water monitoring at the portion of Middle Creek located below the confluence of the MA/MB drainages indicates that MIW is discharging to surface water. The current fate and transport conceptual site model is that a portion of the MIW that discharges from Formosa 1 Adit is not captured by the current adit diversion system and that this water flows down the MB drainage within the alluvial groundwater system. The proportion of water that may leak into the MB alluvial aquifer is unknown. This alluvial groundwater then discharges to surface water in the portion of Middle Creek extending downstream from the confluence of the MA/MB drainages to Raymond Bear Falls, a distance of approximately 350 ft.

Raymond Bear Falls is located at the outcrop of an andesite sill where the stream flows for a short distance directly over bedrock. This geologic feature truncates the Upper Middle Creek alluvial aquifer, forcing all alluvial groundwater to discharge to surface water upstream from Raymond Bear Falls. Leakage of MIW from the Formosa 1 Adit into the alluvial aquifer of the MB drainage may be a major source of metals loading affecting Middle Creek. This area of metals loading to surface water in Middle Creek was observed both during the dry season seep and spring survey conducted in October 2009 and the wet season seep and spring survey conducted during January/February 2010. This suggests that discharge from the upper Middle Creek alluvial aquifer may be a perennial source of metals loading to Middle Creek, and that it is not an ephemeral interflow system.

Surface discharge from the Formosa 1 Adit into the adit diversion system is also perennial. The Formosa 1 Adit could, therefore, provide perennial recharge into the MB alluvial aquifer and a perennial source for MIW discharge from the alluvial aquifer into upper Middle Creek in the area between the MA/MB confluence and Raymond Bear Falls. The groundwater level monitoring at the alluvial monitoring well MW-7A confirms that groundwater flow in the alluvial aquifer of the MB drainage is perennial. The MW-7A field water quality monitoring data (pH and conductivity) also confirms that groundwater in the MB alluvial aquifer is affected by MIW.

Surface water quality in upper South Fork is affected by MIW, based on low pH and high concentrations of sulfate and metals. The close proximity of bedrock well MW-5, which contains MIW, to the headwaters of South Fork indicates that MIW impacted groundwater is likely discharging from the bedrock aquifer to surface water in South Fork. Areas of strongly ARD-

generating surface mine waste are also present in the headwaters area of South Fork and it is likely that MIW is also transported towards South Fork via the alluvial groundwater system and surface water runoff.

3.6 Climate

The climate of the Klamath Mountains is characterized by hot dry summers followed by wet winters of low to moderate temperatures. The following sections describe Site climate data in terms of precipitation, wind, and temperature.

The Site climate evaluation is based on data collected at the Sexton Summit and Silver Butte weather stations. Although the Silver Butte Station provides climate data close to the Site, the longer period of record for Sexton Summit station makes the Sexton Summit data most useful for purposes of characterizing Site climatic conditions. The period of record for the Silver Butte station is water year 1988 through 2010 and the period of record for the Sexton Summit station is water year 1949 through 2010. The Silver Butte data sets are incomplete for years 1988 and 2002 and the Sexton Summit data set is incomplete for years 1985, 1990, and 1993 through 1998. Years with incomplete data sets are excluded from the climate data statistical analysis.

The Sexton Summit weather station is located approximately 30 miles south of the Site at an elevation of 3,837 ft amsl. The Sexton Summit station is operated by the National Oceanic and Atmospheric Administration (NOAA) and is located at latitude 42.600028 longitude 123.36417. The Silver Butte weather station is operated by BLM and the Boise Interagency Fire Center and is located approximately 1,000 ft north of the Site at the summit of Silver Butte Peak situated at an elevation of 3,973 ft amsl (latitude 42.8589 longitude 123.3783). The Formosa Mine is situated between elevations of 3,200 and 3,700 ft amsl.

3.6.1 Precipitation

Precipitation can vary between 15 and 70 inches per year. Table 3.6-1 lists the Silver Butte monthly precipitation totals for water years 1988 through water year 2011 and Table 3.6-2 lists the Sexton Summit monthly precipitation totals for water years 1949 through 2011. A water year begins on October 1 of the previous calendar year and ends on September 30 of the current calendar year. Figure 3.6-1 is a box plot showing the monthly precipitation statistics (minimum, maximum, median, and 25th and 75th percentiles) for the Silver Butte and Sexton Summit weather stations. November through March are the wettest months of the year, with median precipitation of 4.48, 5.75, 5.02, 3.58, and 3.35 in, respectively. The higher precipitation during these months bring a high surface water flow in streams at the Site that generally peaks in March and declines during spring, summer, and fall. Precipitation during winter may fall as snow in higher elevations, especially above 3,200 ft amsl.

Figure 3.6-2 shows the annual departure from long-term average precipitation for the period of record. This figure is useful to evaluate trends in annual precipitation. Most years are within about 15 in of the long-term average. 1974, 1995, 2005, and 2006 were particularly wet years, with departures ranging from 22 to 37 in above the average. 1990, 1999, and 2001 were particularly dry years, with departures ranging from 21 to 28 in below average precipitation.

3.6.2 Wind

Wind speed and direction data from the Silver Butte fire lookout station were compiled to create a wind rose diagram (Figure 3.6-3). The wind rose diagram shows a resultant vector of 198 degrees (south-southwest), which indicates that the prevailing wind blows from this direction towards the Site. The wind rose figure indicates that a high percentage of wind also blows from the west and northeast, but very rarely from the northwest.

3.6.3 Temperature

The warmest months are July and August, when the high temperatures average around 76 degrees Fahrenheit. The coldest month is January, when the high averages around 41 degrees Fahrenheit and a low of 31 degrees Fahrenheit. Plots of the average monthly low and high temperatures at the Silver Butte and Sexton Summit weather stations are provided in Figure 3.6-4 and Figure 3.6-5, respectively.

3.7 Ecology

The following sections describe the Site ecology, including vegetation and wildlife, as well as descriptions of federally threatened and endangered species potentially located near the Site. It should be noted that suitable habitat for most species of wildlife and plants, other than those tolerant of disturbed conditions, is very limited in or near OU1.

3.7.1 Vegetation

3.7.1.1 Upland

Upland vegetation in and around the Site consists primarily of coniferous forest dominated by Douglas fir (Pseudotsuga menziesii). Golden chinkapin (*Castanopsis chrysophylla*) and Pacific madrone (*Arbutus menziesii*) also commonly occur in drier areas, while western redcedar (*Thuja plicata*) and western hemlock (*Tsuga heterophylla*) occur in wetter areas or on north aspects. Canyon live oak (*Quercus chrysolepis*) is occasionally found in open, drier areas on rocky soils.

Forest age in and around the Site varies from old-growth stands to younger successional forest and areas of recent timber harvest. Old growth forest stands consist of large Douglas fir trees that form a closed canopy and a fairly open understory consisting of salal (*Gaultheria shallon*), Oregon grape (*Mahonia aquifolium*), and other shade-tolerant species. Openings in the canopy allow for growth of herbaceous vegetation, shrubs, and saplings. Open dry areas are dominated by wedgeleaf ceanothus (*Ceanothus cuneatus*) and other shrubs as well as Douglas fir saplings. Grasses and poison oak (*Toxicodendron diversilobum*) also become more abundant on open, sunny, south aspects within the study area.

3.7.1.2 Riparian

Riparian vegetation in and around the Site is dominated by deciduous trees and shrubs including vine maple (Acer circinatum), bigleaf maple (*Acer macrophyllum*), and red alder (*Alnus rubra)*. Along larger streams such as Cow Creek, black cottonwood (*Populus trichocarpa*), willow (*Salix sp.*), Oregon ash (*Fraxinus latifolia*), and Oregon myrtle (*Umbellularia californica*) also occur. Sword fern (*Polystichum munitum*) and thimbleberry (*Rubus parviflorus*) are common understory riparian species. Douglas fir also occurs adjacent to streams in and around the Site.

3.7.2 Wildlife

3.7.2.1 Terrestrial

Common wildlife in the vicinity of the Site includes several species of mammals such as Roosevelt elk (*Cervus canadensis roosevelti*), black-tailed deer (*Odocoileus hemionus columbianus*), coyote (*Canis latrans*) and western gray squirrel (*Sciurus griseus*). Black bear (*Ursus americanus*) also occur. Common bird species include common raven (*Corvus corax*), Steller's jay (*Cyanocitta stelleri*), mountain quail (*Oreortyx pic*tus), red-breasted nuthatch (*Sitta canadensis*), black-capped chickadee (*Poecile atricapillus*), bushtit (*Psaltriparus minimus*), and rufous hummingbird (*Selasphorus rufus*).

3.7.2.2 Aquatic

Common wildlife species associated with aquatic habitats in the vicinity of the Site include Pacific tree frog (*Pseudacris regilla*) and Pacific giant salamander (*Dicamptodon tenebrosus*). Larger creeks within the study area also support fish. Winter steelhead and resident rainbow trout (*Oncorhynchus mykiss*), fall and spring chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*Oncorhynchus kisutch*), and cutthroat trout (*Oncorhynchus clarki*) have been documented by the Oregon Department of Fish and Wildlife (ODFW) using the Lower Cow Creek Watershed Analysis Unit (BLM 2002).

Other native fish species inhabiting Cow Creek include Pacific lamprey (*Lampetra tridentata*), Umpqua pikeminnow (*Ptychocheilus oregonensis*), redside shiner (*Richardsonius balteatus hydrophlox*), sculpin (*Cottus spp.*), speckleddace (*Rhinichthys osculus*), longnose dace (*Rhinichthys cataractae dulcis*), and coarse-scale sucker (*Catostomus macrocheilus*). Many non-native fish species also occur in Cow Creek, including black crappie, brown bullhead, bluegill, and smallmouth bass (BLM 2002).

Natural and man-made barriers (dams, bridges, etc.) to fish have limited access to surface waters close to the Site. In addition, acid mine drainage from the Site may be limiting to fish species within the Middle Creek system (BLM 2002). Other limiting factors for steelhead within the Lower Cow Creek watershed include lack of large woody debris, high water temperatures due to lack of riparian shade, and stream bank instability.

3.7.3 Federally Threatened and Endangered Species

There are 11 federally threatened or endangered species with the potential to occur in Douglas County (U.S. Fish and Wildlife Service [USFWS] 2011a). Of these, seven are marine species or associated with coastal habitats not found close to the Site. The remaining four species include the Northern spotted owl (*Strix occidentalis caurina*) and three plants: Gentner's fritillary (*Fritillaria gentneri*), Kincaid's lupine (*Lupinus sulphureus ssp. kincaidii*), and rough popcornflower (*Plagiobothrys hirtus*). In addition, two species, the fisher (Martes pennant) and North American wolverine (*Gulo gulo luscus*) are candidates for listing. Federally listed species that may use the Site along with their status and habitat requirements, and their potential to occur in the project area are listed in Table 3.7-1. Species with some likelihood to occur at the Site are discussed below.

3.7.3.1 Northern Spotted Owl

The Northern spotted owl is known to occur in the vicinity of the Site. Designated critical habitat for the Northern spotted owl is located within the project area (USFWS 2008a, USFWS 2008b, BLM 2002). This species inhabits structurally complex forests from southwest British Columbia through the Cascade Mountains and coastal ranges in Washington, Oregon, and California, as far south as Marin County. Northern spotted owls generally rely on mature and old-growth forests, because these habitats contain the structures and characteristics required for nesting, roosting, and foraging, although they can disperse through highly fragmented forested areas (USFWS 2008c).

The Northern spotted owl is known to nest, roost, and feed in a wide variety of habitat types, but prefers older forest stands with dense canopy closure of mature and old-growth trees, abundant logs, standing snags, and live trees with broken tops (USFWS 2010). The area around the Site supports suitable nesting, roosting, and foraging habitat for the Northern spotted owl. However, spotted owl habitat is lacking in or near OU1.

3.7.3.2 Fisher

The fisher has a low potential to occur at or around the Site. The fisher inhabits forests with high canopy closure, large trees, and a high percentage of conifers. The west coast population of the fisher was accorded federal candidate status in April 2004. The remaining populations of fishers are restricted to two separate and genetically isolated populations in southwestern Oregon; one in the northern Siskiyou Mountains and one in the southern Cascade Range. Verifiable records have been found in Douglas County, east of the project area (USFWS 2011b). Habitat suitable for fisher is limited in and near OU1.

3.7.3.3 Columbian White-Tailed Deer

In addition to those species listed above and in Table 3.7-1, the Columbian white-tailed deer (*Odecoilus virginianus leucurus*) occurs in Douglas County. The Columbian white-tailed deer was federally listed as endangered in 1968. Until 1978, when a small population of Columbian white-tailed deer was identified in Douglas County, only a small population was known to survive on islands in and along the lower Columbia River. With implementation of a recovery plan, the Douglas County population has rebounded and was delisted in July 2003 (USFWS 2011c). The Columbia River population remains endangered.

The North Bank Habitat Management Area was established to provide 6,000 acres of protected habitat for the Columbian white-tailed deer and was instrumental to the delisting of the Douglas County population in 2003 (USFWS 2011c). The BLM manages the North Bank Habitat Management Area in partnership with the USFWS and ODFW. The North Bank Habitat Management Area is located north and east of the North Umpqua River, northeast of the project area. In Douglas County, the deer use riparian willow and cottonwood habitats and are also found in upland oak-savannah habitats (USFWS 2011c). The species is not expected to occur at or near the Site and suitable habitat for Columbia white-tailed deer does not occur in or near OU1.

3.8 Land Use and Demographics

This section describes the Site land use and demographics. Figure 3.8-1 presents the property ownership information for the Site and surrounding areas.

3.8.1 Land Use

3.8.1.1 Timber

The Site area for OU1 includes approximately 25 acres of mining-affected area (see Figure 1.3-2), as well as potentially contaminated soil outside this area. This area is located on private land owned by FEI, with some areas managed by BLM. Timber harvest is the predominant land use in the area, and the majority of land surrounding the OU1 Site area is either owned by private timber companies, chiefly Silver Butte Timber Company and Roseburg Resources, or is Oregon and California revested grant land managed by BLM. The BLM land in the area is designated using one of two land use allocations, either as a General Forest Management Area or Connectivity/Diversity Block. In both cases the land is available for timber harvest at varying frequencies, with the Connectivity/Diversity Block being more restrictive. Land ownership boundaries are shown on Figure 3.8-1.

3.8.1.2 Mining

There are a few open mining claims in the area, notably one in Township 31 South, Range 6 West, Section 23, along the east side of Road 30-6-35.1. This is the closest active claim in the area, being approximately 1,500 ft northwest from the north edge of OU1. Additionally there are open claims in Sections 21, 22, and 29. The claims in Section 21 and 22 are along the Upper Middle Creek drainage over half a mile from the Site and the claim in Section 29 is over two miles from the Site. These are historic claims, and their presence does not mean that mining operations are underway or authorized by the regulatory agencies.

3.8.1.3 Residences

There are no known permanent residences at or near the Site. Review of parcel data from the Douglas County Base Map and aerial photography shows that the closest permanent residence is at the intersection of Shoestring Road and Silver Butte Road, approximately 3.75 miles north of the Site. This area is zoned as Farm Forest (FF) land by Douglas County. This type of zoning use allows permanent residences and farming. Although there are no permanent residences in the area long-term camping (RV) has been observed along Road 30-6-35.1 and road areas near the confluence of upper Middle Creek and South Fork Middle Creek. This long-term camping is likely associated with forest management activities.

The OU1 Site area (Figure 1.3-2) and all adjacent areas are zoned by Douglas County as Timberland Resource (TR) land. This type of zoning use is intended primarily for forest operations (harvesting, reforestation, and maintenance), with limited use of temporary onsite structures associated with forest operations. Use of onsite residences on TR land is limited or not allowed.

3.8.1.4 Recreation

Recreation activities including hiking, camping, hunting, shooting, and all-terrain vehicle (ATV) use are common at the Site and on the surrounding public land. During RI sampling activities

hunting, camping, recreational driving and ATV use have been frequently observed. Existing roads and trails in the area are open to vehicles, many of which are fairly well maintained because of active logging. BLM land in the area is classified under their Visual Resource Management Classification as Class IV, which allows "major modifications to the landscape" (BLM 2002).

3.8.1.5 Critical Habitat

There is Designated Critical Habitat for Northern Spotted Owl close to the Site (USFWS 2008a) but the OU1 disturbance area does not fall within the habitat; however, a future OU2 evaluation of downgradient surface water and groundwater may fall within this habitat zone. There are no other special habitat designations in this area. Further information on the North Spotted Owl was provided in Section 3.7.

3.8.2 Demographics

Demographic information for Douglas County, Oregon was obtained from the United States Census Bureau. According to 2005-2009 estimates (2010 census data not yet available) the population of Douglas County is 103,385, including 42,370 households and 28,728 families. Average household size is 2.41 individuals and average family size is 2.90 individuals. Douglas County has a land area of 5,036.62 square miles equating to a population density of 20.53 individuals per square mile and a household density of 8.41 per square mile. 26.9 percent of households have one or more children under the age of 18 and 33.9 percent have one or more adults over the age of 65. Age distribution in the county is as follows: 23.7 percent are 19 and under, 5.1 percent are 20 to 24, 20.8 percent are 25 to 44, 30.4 percent are 45 to 64 and 20 percent are 65 and over, with the median age being 45.3 (U.S. Census Bureau 2005-2009).

Section 4
Nature and Extent of Contamination

A major facet of the RI is characterizing the nature and extent of contamination to facilitate informed decisions regarding the level of risk at the site and the appropriate type of remedial response (EPA 1988). This section includes detailed discussions of the nature and extent of contamination based on results of the RI sampling program introduced in Section 2.

Discussion of nature and extent of contamination considers:

- OU1 Mine Materials and Soils (Section 4.1);
- Surface Water (Section 4.2); and
- Groundwater (Section 4.3).

Site contamination is caused by ARD generation from OU1 and OU2 mine materials, which are primary contaminant sources. ARD generated from these mine materials results in mobilization and transport of COPCs into downslope soils, surface water, and groundwater. To date, characterization of contaminant sources has focused on OU1 mine materials, because they are readily accessible for both characterization and remediation. The presence of ARD-generating source materials within the underground mine (OU2 mine materials) is inferred based on perennial discharge of ARD from the Formosa 1 Adit, and historical information regarding mining and reclamation at the Site as summarized in Sections 1 and 3.

The topography of the Site is quite steep, and mine materials are present in waste dumps located in the upper portions of the Upper Middle Creek and South Fork Middle Creek drainages as described in Section 3. Downslope physical dispersion of mine materials is readily evident at the base of the mine waste dumps. Areas downslope from the waste dumps may also be subject to periodic chemical dispersion of COPCs, because ARD is periodically flushed from mine materials by precipitation events and snowmelt. Accordingly, the nature and extent of contamination in soils downslope from the waste dumps were investigated during this RI.

COPCs associated with ARD are transported from mine materials into groundwater as precipitation percolates through the source materials and recharges the alluvial and bedrock aquifers. The nature and extent of contamination in groundwater at the Site is not yet fully characterized. However, groundwater has been evaluated in RI activities completed to date, and these data document effects to alluvial and bedrock aquifers caused by OU1 mine materials and discharge of MIW from the underground mine at the Formosa 1 Adit.

Groundwater/surface water interactions are integral to the severe effects to aquatic resources in the Middle Creek watershed, which have been documented by previous investigations. Numerous springs (higher flow) and seeps (lower flow) are present in South Fork and Upper Middle Creek, where MIW discharges from groundwater to surface water. The contaminant transport pathways that contribute to seeps/springs have not yet been fully characterized. However, information collected to date is presented to illustrate the importance of groundwater/surface water pathways in transporting COPCs into South Fork and Upper Middle Creek.

After MIW enters surface water of South Fork and Upper Middle Creek via either direct runoff or the groundwater/surface water transport pathway, it flows downstream and concentrations of COPCs are attenuated through various processes including dilution, mineral precipitation, and adsorption. Some data have been collected to understand these processes, although effects to surface water have not yet been completely characterized and evaluations of effects to stream sediments have not yet begun. The data collected validate historic data collected by others in the Middle Creek watershed, and evaluates potential downstream effects within Cow Creek that could affect surface water uses such as irrigation water and drinking water intakes.

4.1 OU1 Mine Materials and Soil

4.1.1 Introduction

OU1 mine materials are defined to support practical characterization, spatial delineation, and remediation of the Site. OU1 mine materials are primary source materials, which may generate ARD and/or contribute to COPC dispersion. As used in this RI, OU1 mine materials are composed of the following material types:

- **Waste rock** is unconsolidated rock that was excavated to provide access to the ore. Waste rock is commonly ARD-generating, and includes a mixture of undifferentiated metavolcanic rock, quartz sercite pyrite phyllite, and massive sulfide.
- **Ore** is rock associated with massive sulfide mineralization that was mined for payable metals, primarily copper and zinc. Some ore that was not processed during mining was disposed of within the various WRDs and in the encapsulation mound. Because of the high sulfide mineral content of the ore, it is strongly ARD-generating.
- **Tailings** are finely ground ore that has been processed in the mineral processing plant. Mineral processing included crushing, grinding, and flotation. This process removed the minerals chalcopyrite and sphalerite, but concentrated pyrite in the tailings, which is strongly ARD-generating.
- **Construction Rock** is rock that was excavated during construction of roads, the water and tailings storage pond (now the encapsulation pond), and general site infrastructure. Originally, construction rock was mostly non-ARD-generating, with the exception of a few road cuts and other excavations that disturbed ARD-generating rock. However, past construction, waste rock management and reclamation practices caused extensive mixing of waste rock and construction rock at the Site, and most construction rock contains some ARD-generating waste rock.

- **Road Surfaces** were armored with waste rock in several areas and spillage of waste rock may have occurred. Waste rock is now mixed with the original road surface in several areas. Generally, these roads are natural-surface roads constructed with rock excavated from the road cut. However, some road aggregate may have been applied in the mine area. In some areas, such as adjacent to the Formosa 1 and Silver Butte adits, the road is constructed predominantly of waste rock. Road surfaces are classified together and grouped with other mine materials. Many road surfaces within the mine area are ARD-generating.
- **ARD-generating Exposed Rock Surfaces** are outcrops of ARD-generating rock that are exposed as a result of mining or construction activities. The volume and environmental significance of these exposed rock surfaces is far less significant at the Site as compared to other OU1 mine materials; however, these ARD-generating outcrops are documented.
- **Contaminated Soils** are natural soils that are close to, or are co-mingled with waste rock, ore, or tailings. Contaminated soils are included within the definition of mine materials, because these soils are intimately mixed with other types of mine materials and cannot be practically delineated. These soils may also be contaminated by hydrogeochemical dispersion of COPCs from ARD-generating mine materials.

Similar mine materials are also present within the underground mine (OU2 mine materials). Since this RI is focused on OU1 mine materials, OU2 mine materials are not discussed further in this section. However, information collected during this RI related to the MIW discharge from the underground mine and the effects of this discharge to Upper Middle Creek are addressed in Sections 4.2 and 4.3. Contaminant fate and transport pathways with regards to OU2 mine materials are also discussed in Section 5 to provide an overall understanding of the conceptual model of the Site.

As used in this RI, soils include natural unconsolidated soils such as subsoil, topsoil, and duff. These soils may be affected by COPCs that have dispersed from mine materials through physical or hydrogeochemical processes. Physical dispersion processes include downslope movement of mine materials caused by erosion, and wind dispersion of fine-grained mine materials. Hydrogeochemical dispersion includes ARD generation and subsequent dispersion of dissolved COPCs in MIW. As MIW moves through the environment the pH increases and various COPCs precipitate from the dissolved form to various solid phases. In addition, COPCs are removed from solution by adsorption to solids such as iron hydroxides, organic matter, and clays.

4.1.2 Screening Criteria

Data collected in the RI are compared to several different benchmarks, or screening criteria. The purpose of screening criteria is to provide thresholds related to COPC concentrations or other metrics, which are used to characterize nature and extent of contamination. Screening criteria are not intended to address risk, rather the criteria are tools to help EPA and other stakeholders identify OU1 mine materials that may require mitigation. Potential risks to human or ecological receptors are addressed in Section 6.

OU1 mine materials characterization utilized a combination of field and laboratory characterization methods. The materials are inherently heterogeneous, because mine surface

facility construction, underground mine development, and mineral processing activities produced mine wastes with varying geochemical characteristics and these wastes were intermingled during the course of construction, mining and mine reclamation. Over 900 samples were analyzed by a field geochemical characterization procedure. A subset of 107 samples from this group was submitted for laboratory analysis including ABA and modified SPLP. The ABA and SPLP analyses demonstrate the geochemical characteristics of the mine materials including the propensity of the mine materials to generate ARD and release dissolved COPCs to groundwater or surface water. Field data provide additional information to evaluate the geochemistry of OU1 mine materials, although these data are most useful to accurately delineate the extent of OU1 mine materials that generate ARD or release dissolved COPCs to the environment. There is no one test that can determine the propensity for a rock to generate ARD (White, Lapakko, and Cox 1999); therefore, the field and laboratory geochemical data are assessed using a weight of evidence approach.

In the following sections, screening criteria for the laboratory characterization methods are defined first. These screening criteria are based on water quality standards and other factors, which identify mine materials that may require mitigation. Screening criteria for the field geochemical data consider the laboratory results, and are used to support detailed delineation of OU1 mine materials in terms of spatial extent, depth, and volume.

4.1.2.1 TAL Metals Screening Criteria

Screening criteria for TAL metals were developed based on concentrations of metals in background soil. Data and screening criteria refer generally to 'metals' in this report, although some metalloids (arsenic and selenium) are included the TAL metals analysis. Sample results and statistics for background soil samples are provided in Table 4.1-1. Triplicate samples were collected at each of the two background locations (BKG1: mineralized background and BKG2: non-mineralized background) and are identified as BKG1/2A, 1B, and 1C. Triplicate samples were also processed into two particle size fractions in the laboratory for analysis: the -2-mm size fraction and the -250-µm fraction.

The two different sieve size preparation and analysis methods were conducted so the background concentrations could be directly compared to both mine materials and soil sample data which had different sample preparation procedures established in the SAPs (CDM 2009a and 2010) based on recommendations of risk-assessors and project stakeholders. The purpose of the -2-mm fraction is to provide data that represent the general definition of 'soil' (less than 2 mm size). This fraction is utilized for comparison of downslope incremental samples, which were processed in the same manner. The purpose of the -250-µm fraction is to provide data representing the fraction of soil that is most easily inhaled or ingested during various activities. This fraction was utilized for evaluation of mine materials samples, which were sieved to less than 250 µm.

Statistical Analysis of Background Data

Metal concentrations measured in background samples from sites BKG1 and BKG2 were analyzed statistically to evaluate the precision of the incremental sampling approach. The arithmetic mean, standard deviation and relative standard deviation of the triplicate background samples are shown on Table 4.1-1. The relative standard deviation (RSD) is the standard deviation divided by the arithmetic mean expressed as a percentage. The RSD of incremental samples is a measure of precision of the samples, which is controlled by numerous factors including the number of sample

increments, the heterogeneity of the sampled media, sample preparation and subsampling procedures, and laboratory errors (Ramsey 2007). Calculated RSDs shown in Table 4.1-1 were evaluated based on an assessment goal that the RSD be less than 30 percent. Values of RSD that are greater than 30 percent indicate that the variability between the triplicate incremental samples is high, which causes uncertainty in conclusions based on the incremental sampling program. High RSDs suggest that the number of increments was not large enough, that laboratory subsampling procedures were not adequate, or that laboratory analyses are uncertain. Laboratory QA/QC was addressed previously in Section 2.

The RSDs of the triplicate background samples are below the 30 percent RSD goal, with a few exceptions. For the -250-µm analysis of background sample BKG2, the boron RSD is 51 percent, and the thorium RSD is 41 percent. This is partially because of qualified data, which were estimated or less than detection. All other values for the -250-µm and -2-mm samples of both BKG1 and BKG 2 are well below 30 percent, with most RSD values below 15 percent. This indicates that the various components of the background sampling program including the number of increments, sample preparation, subsampling procedures, and laboratory analyses were sufficient to meet the 30 percent RSD goal. Eighty-eight increments were collected for sample location BKG1, and 30 increments were collected for sample location BKG2. The smaller number of increments collected at sample location BKG2 was required because of safety concerns related to abundant poison oak within the DU.

Development of TAL Metals Screening Criteria

Screening criteria for TAL metals concentrations were developed based on data from sample site BKG1 (mineralized background) rather than BKG2 (non-mineralized background), because OU1 is located in areas of known natural outcrops of massive sulfides and other strongly mineralized rocks. As shown in Table 4.1-1, the metal concentrations in sample BKG1 were higher than sample BKG2. It should be noted that no massive sulfide outcrops or weathering products of massive sulfide outcrops were observed in or near the BKG1 sample area; however, this area is located along the general mineralized trend and has the potential to contain elevated metals compared to non-mineralized areas. Therefore, natural background concentrations in OU1 (or portions of OU1) may have been higher than represented by sample BKG1, thereby making the screening criteria potentially overly conservative.

For analytes where the sample data were above the laboratory detection limit, the 95th percentile upper confidence limit (UCL) of the mean was used to develop screening criteria for each incremental sample. The UCL for mineralized background (BKG1) and non-mineralized background (BKG2) is shown in Table 4.1-1. The 95th percentile UCL was calculated using a two-sided Student's T distribution, which is compatible with the central limit theorem. Use of the Students T distribution requires an assumption that the population is normally distributed. The central limit theorem states that the mean of a sufficiently large number of random samples will be approximately normally distributed even if the underlying population is not normally distributed, as long as enough random samples are collected (Koch and Link 1980). The required number of samples is generally considered to be 30, although more samples may be required with particularly non-normal populations (Ramsey 2007).

For analytes where the sample data were less than the detection limit, the detection limit was designated as the screening criteria. Analyte concentrations that were less than detection limit in all three triplicate incremental samples for at least one background sample area and particle size include antimony, cadmium, molybdenum, selenium, thallium, and thorium.

Screening criteria that were used for evaluation of nature and extent of contamination are as follows:

- Surface and subsurface point samples of mine materials (sieved to -250 µm) were compared to sample BKG1, -250UM fraction;
- FPXRF point samples that were analyzed by the laboratory (sieved to -1.6 mm) were compared to sample BKG1, -2MM fraction; and
- Downslope incremental samples (sieved to -2 mm) were compared to sample BKG1, -2MM fraction.

Comparison of point sample data to a physical average of 30 or more point samples is not strictly valid, because the physically averaged background data do not provide any information regarding the variability in the underlying background populations. For example, if the background population sampled by the incremental method was normally distributed, approximately 50 percent of the individual increments within the background sampling area would be expected to exceed the screening value. Therefore, if a point sample exceeds the screening criteria, it should not be construed to imply that metals concentrations at that location are known to be higher than background. However, the screening criteria are useful as a general benchmark to evaluate relative differences in metal concentrations between sampled areas. Accordingly, the average of the individual point samples collected from mine materials were also screened with respect to the background concentration, which is a better statistical comparison.

These screening criteria are statistically valid for comparison to downslope incremental samples, because the downslope DUs were sampled using a similar incremental approach. The screening criteria were used to identify soils that contain anomalous metal concentrations as compared to concentrations measured at background sampling location BKG1. These anomalous metal concentrations may result from dispersion of COPCs from mine materials, or natural enrichment resulting from weathering of known massive sulfide outcrops in the area.

4.1.2.2 SPLP Screening Criteria

Sulfide mineral oxidation releases metals from the solid sulfide mineral structure, and transforms the metals into forms that are readily soluble. Sulfide mineral oxidation also forms secondary minerals, which are soluble in water and cause infiltrating precipitation or snowmelt to become acidic. This process is the dominant contaminant release mechanism for the OU1 mine materials. Modified SPLP analyses measure the load of contaminants that are dissolved when simulated rainwater is mixed with a sample in a bottle roll test. The SPLP method is a semi-quantitative method because of the following practical limitations:

- The load of soluble contaminants in mine materials varies throughout the year. For example, secondary products of sulfide mineral oxidation accumulate during the dry summer as the

minerals oxidize, and these products are flushed during the high precipitation periods of late fall and winter.

- The water to rock ratio of the modified SPLP tests (3:1) is higher than actual field conditions (approximately 0.3:1 or less), and therefore contaminant concentrations in SPLP extract solutions may be diluted by the higher water to rock ratio of the modified SPLP test.
- Some amount of COPC attenuation may occur as leachate from OU1 mine materials flows along the contaminant transport pathway. During many periods of the year, this contaminant transport pathway includes MIW migration into groundwater and subsequent discharge from groundwater into area streams. During particularly heavy precipitation events, direct runoff may occur causing more direct discharge of leachate into area streams.

Accordingly, comparison of metal concentrations in SPLP extract solutions to screening criteria based on water quality standards should not be construed as definitive data showing adverse effects. However, SPLP concentrations that are higher than standards indicate that the OU1 mine materials are likely to cause adverse effects to groundwater and/or surface water quality.

Screening criteria selected for analysis of SPLP data in this RI report are the Numerical Groundwater Quality Guidance and Reference Levels, obtained from Oregon Administrative Rule (OAR) 340-40-020 (ODEQ 2010) and the acute surface water standards for fresh water aquatic life set forth OAR 340-041-0033 Table 20 (ODEQ 2010). These screening criteria are shown in Table 4.1-2. Groundwater standards were chosen because the contaminant transport pathway of leachate discharge to alluvial groundwater and subsequent discharge to area streams is thought to be the dominant pathway during most seasons of the year. Acute surface water standards were chosen because direct runoff of MIW from the mine materials would only be expected to occur after intense but short-term precipitation or snow melt events. Because the direct runoff pathway is time-limited, comparison to the much lower chronic surface water standards would not be appropriate and would lead to a misclassification of unaffected materials. In addition, it is likely that attenuation of COPC concentrations occurs along the mine materials-surface water contaminant transport pathway.

4.1.2.3 Acid Base Accounting Screening Criteria

ABA criteria are determined based on assumptions inherent to the laboratory method, which are described in detail in Section 2.4.1.5. ABA screening criteria are defined as follows:

- NP:AP ratio of less than 1 indicates high potential to generate acid;
- NP:AP ratio between 1 and 2 indicates moderate potential to generate acid; and
- NP:AP ratio of greater than 2 indicates low potential to generate acid.

4.1.2.4 Lithology Indicative of ARD-generating Materials

ARD-generating contaminant sources at the Site originated within the underground mine or in areas where outcropping mineralized rock was disturbed by construction or mining activities. The lithology (mineral composition of the rock) for ore and other mineralized rock at the Site is well-described by published geological reports (Derkey and Matsueda 1989), and this rock displays characteristic alteration minerals commonly associated with ARD generation such as the

secondary jarosite-group minerals, which form as a result of surface oxidation that occurred after the rock was mined. Three rock types were identified during field geological reconnaissance of the Site that are indicative of ARD-generating conditions: massive sulfide, QSP and quartz sericite tuff (QST). The presence of these rocks indicates that the rock originated in the underground mine or was excavated from exposed outcrops of mineralized rock. The presence of these lithological types was utilized in a weight of evidence approach as likely evidence that the rock was ARD-generating.

ARD generated through sulfide oxidation can be neutralized in-place if the rock contains sufficient NP in the form of carbonate minerals (e.g., calcite, ankerite). However, the only carbonate minerals that were identified during field surveys were associated with local areas where limestone had been hauled to the site and used in mine reclamation. Neither waste rock, ore, tailings nor construction rock at the Site contains appreciable carbonate minerals. Therefore, the presence of visible sulfide minerals in the rock was also used in the weight of evidence approach as an indicator of ARD-generating rock. The visible sulfide minerals were dominantly pyrite, although chalcopyrite and shpalerite are present in massive sulfide in association with pyrite. As discussed in Section 3, other sulfide mineral species are also present, but they are not visible during field examination with a hand lens.

4.1.2.5 Field Paste pH Screening Criteria

Field paste pH is a useful indicator of ARD generation at the Site, because the mine materials have been exposed on the surface for several decades and active ARD generation in these materials has commenced. Generally, an acidic field paste pH of less than approximately 4 is used as a screening criterion to identify ARD-generating rock (e.g., Sobek et al. 1979). The field paste pH screening criteria was further defined at the Site based on evaluation of SPLP data. Paired field paste pH and SPLP data for surface and subsurface samples were evaluated for cadmium, copper, and zinc concentrations, which are indicators of ARD generation and are critical contaminants that affect downstream aquatic habitat. The solubility of cadmium, copper and zinc is strongly controlled by pH, and these metals display clear trends of increased concentrations with more acidic pH values in SPLP data and MIW.

Field paste pH screening criteria were developed to identify mine materials that are likely to release cadmium, copper, or zinc into infiltrating rainwater or snowmelt in concentrations that exceed the laboratory SPLP screening criteria. The SPLP data for cadmium, copper, and zinc are compared to paired field paste pH data in Figures 4.1-1, 4.1-2, and 4.1-3, respectively. These data were evaluated using a non-parametric statistical approach described in *Demonstrations of Method Applicability under a TRIAD Approach for Site Assessment and Cleanup* (EPA 2008b). The field paste pH screening criteria of 4.6 su was developed to achieve reasonable and practicable decision error rates during classification of the risk of cadmium, copper, and zinc release from mine materials based on field paste pH. Predicted decision error rates based on this approach are summarized in Exhibit 4.1-1.

Samples with a field paste pH of less than 4.6 su are classified as potentially ARD-generating, and the field paste pH is used in conjunction with the other weight of evidence criteria to evaluate mine materials for ARD potential. As shown in Exhibit 4.1-1, when applying a weight of evidence

Exhibit 4.1-1. Predicted Decision Error Rates Associated with Field Paste pH Criteria

	All Lithologies		Lithologies indicative of Waste Rock[1]	
COPC	**Type 1 (False Positive) Decision Error Rate**	**Type 2 (False Negative) Decision Error Rate**	**Type 1 (False Positive) Decision Error Rate**	**Type 2 (False Negative) Decision Error Rate**
Cadmium	11	5	10	2
Copper	2	7	0	4
Zinc	2	8	1	3

[1]These lithologies include QSP, QST, and mixed mine waste containing QSP or QST.

approach including visual examination of lithologies indicative of waste rock in addition to field paste pH, the field screening process provides for accurate identification of rocks that will produce leachate exceeding the SPLP laboratory screening criteria. This relationship provides for effective delineation of OU1 mine materials in the RI as discussed in following sections, and it may also be useful for delineation of OU1 mine materials during remedial action.

4.1.2.6 FPXRF Screening Criteria

FPXRF was used to screen metal concentrations in mine materials located along the toe of the WRDs and soils located downslope from mine materials. This process supported delineation of the downslope extent of mine materials. Development of FPXRF screening criteria included analysis of the FPXRF accuracy based on field and laboratory data, as described below.

FPXRF Accuracy

Several inherent issues affect FPXRF accuracy (EPA 2007) including:

- Physical matrix effects related to grain size distribution and percent moisture; and
- Chemical matrix effects related to interferences between the various chemical elements that constitute the sample.

In addition, FPXRF instruments are calibrated to perform within a specific concentration range and various calibration modes can be selected based on the sample type and the purpose of the investigation. The bulk soil mode of the Niton Model XL3T 600 Series FPXRF instrument was used for FPXRF analysis during the RI. This mode was selected to facilitate accurate measurements at concentrations within the general range of background. Paired laboratory analyses were conducted for a subset of these samples (approximately 20 percent) to evaluate FPXRF accuracy. Paired laboratory and FPXRF analyses are shown in Table 4.1-3. These data are evaluated in the following paragraphs for arsenic, copper, and zinc, indicator parameters for COPC dispersion. Although cadmium is also a good indicator of site contamination, FPXRF assessment for this metal was not conducted because FPXRF detection levels are not low enough to analyze cadmium in many samples at the Site. The lack of cadmium data is acceptable for this field characterization approach, because the FPXRF data are used as one component in the overall weight of evidence approach used to identify and delineate mine materials.

Evaluation of the accuracy of FPXRF analyses over a range of concentrations is evaluated based on comparison of the RPD to concentration. RPD is calculated as follows:

$$RPD = \frac{x_{xrf} - x_{lab}}{\bar{x}} \times 100$$

Where x_{xrf} is the FPXRF measurement, x_{lab} is the laboratory measurement of the same sample, and $\bar{x}$ is the mean of the two measurements. A positive RPD indicates that the FPXRF analysis reported a higher concentration than the paired laboratory analyses, and a negative RPD indicates that the FPXRF analysis reported a lower value than paired laboratory analysis.

Comparison of RPD to laboratory concentration for arsenic is shown in Figure 4.1-4. Samples with concentrations below the detection limit of FPXRF for arsenic are shown in the figure, and range from approximately 6 mg/kg to 14 mg/kg. FPXRF is not suitable to measure arsenic concentrations in the range of background (3.4 mg/kg in -2-mm particles at BKG1), because the background arsenic concentration is lower than the detection limit of the FPXRF instrument. At arsenic concentrations detectable by FPXRF, the data show variability in RPD over the range of -87.3 percent to +58.5 percent at concentrations of up to 191 mg/kg. The data show some low bias, in which FPXRF underestimates the laboratory concentration of the samples. Two outlier points are not shown on Figure 4.1-4, which have RPDs of +205 percent and -805 percent for concentrations of 321 mg/kg and 576 mg/kg respectively. This shows particularly low accuracy of FPXRF arsenic measurements at higher concentrations.

Comparison of RPD to laboratory concentrations for copper is shown in Figure 4.1-5. These data show that FPXRF is relatively accurate up to concentrations approaching background (146.5 mg/kg in -2-mm particles at BKG1), but the FPXRF data become increasingly biased low at concentrations exceeding background, with a maximum low-biased RPD of -133 percent at a concentration of 1,420 mg/kg.

Comparison of RPD to laboratory concentrations for zinc is shown in Figure 4.1-6. These data show a similar distribution to copper, with relatively accurate RPDs at concentrations near background (111.58 mg/kg in minus2 mm particles at BKG1), but the FPXRF data become increasing biased low at concentrations exceeding background.

Development of FPXRF Screening Criteria

Based on these comparisons to laboratory data, FPXRF data are not accurate enough to use in definitive estimates of COPC concentrations. However, the purpose of the FPXRF program was to assist in delineating the downslope extent of OU1 mine materials using a weight of evidence approach, rather than providing a definitive estimate of the concentration of COPCs in OU1 mine materials. Therefore, FPXRF screening criteria were developed to assist in delineation of the downslope boundary of mine materials using exploratory data analysis (EDA) and spatial examination of data according to recommendations of Reimann et al. (2005). EDA included histogram and boxplot analyses, and examination of cumulative probability plots. EDA was used to analyze these data, because these methods make no assumptions regarding the distribution of the underlying populations. Copper and zinc were selected for analysis because they are indicator COPCs for ARD dispersion, and occur at concentrations that are detectable by FPXRF. Arsenic and cadmium have also been used as indicator parameters for other screening criteria; however, these analytes are not generally detectable with FPXRF in OU1 mine materials, which limits their usefulness as FPXRF screening criteria.

Histograms of raw and log-transformed FPXRF data are shown in Figure 4.1-7. Based on visual evaluation of the histograms, it is evident that the FPXRF data are positively skewed, and that generally, a logarithmic distribution better fits the data. FPXRF data were collected near the downslope boundary of mine materials both above and below the visual extent of mine materials. This sampling process was intentionally biased within this transition zone between obvious mine materials and potentially affected soils. Therefore, this data set is expected to contain at least two populations: mine materials and soils. Although the logarithmic distribution better fits the FPXRF data, further analysis using boxplots and cumulative probability plots was conducted to evaluate potential presence of multiple populations in the data set.

Boxplots of raw and log-transformed FPXRF data were plotted as described by Tukey (1977), and are shown in Figure 4.1-8. The boxplot is a visual tool to understand distribution of the data, which displays a box, the median of the data, whiskers, and outlier points. The box extends over the interquartile range of the data (from the 25th percentile to the 75th percentile), the median of the data is displayed as a line within the box, the whiskers extend 1.5 times the interquartile range, and individual outlier points are plotted which lie beyond the whiskers. These data are classified based on the lithological description of the FPXRF samples into three groups: mine materials, soils, and "seep affected soil." Mine materials and soils have been described previously. Seep affected soils are an additional classification for natural soils that were observed in several discrete areas of MIW discharge to soils from groundwater. The boxplots show that the three populations overlap to some extent. The median and interquartile range of copper and zinc in mine materials is higher than the soils; however, the maximum observed values occur in soils. This shows the effect of hydrogeochemical dispersion of copper and zinc from mine materials, and subsequent sequestration of the metals in soils through adsorption to organic matter or other sorbent matter (e.g., iron oxide, clays).

Cumulative probability plots of the FPXRF data are shown in Figure 4.1-9. These diagrams plot the log-transformed FPXRF values for copper and zinc versus a normal probability scale. Inflection points or "break points" in the cumulative probability plot most likely represent the presence of multiple populations in the data (Reimann et al. 2005). Screening criteria for FPXRF copper and zinc concentrations were developed based on the location of break points in the cumulative probability plots. The FPXRF copper screening criteria is 190 mg/kg, and the FPXRF zinc screening criteria is 288 mg/kg. These criteria are interpreted to delineate the boundary between soils and mine materials. FPXRF data were also evaluated spatially using Geographic Information System (GIS) methods, which plotted the spatial location of copper and zinc samples with values above and below the respective FPXRF screening criteria in relation to the location of known accumulations of mine materials. This spatial analysis will be described further in Section 4.1.4.2, and supports the selected screening criteria for the FPXRF data.

4.1.3 Nature and Extent of Contamination in OU1 Mine Materials

In this section, OU1 mine materials are characterized and delineated based on the RI data and associated screening criteria. These materials are characterized and delineated as follows:

- Analysis of field and laboratory geochemical data
- Delineation of OU1 mine materials

- Evaluation of potentially beneficial metals in OU1 mine materials
- Identification of ARD-generating exposed rock surfaces

Potential risks of the OU1 mine materials are addressed in Section 6. For purposes of risk assessment, the area delineated as containing OU1 mine materials is defined as exposure area 1 (EA1) as discussed in Section 6.

4.1.3.1 Analysis of Field and Laboratory Geochemical Data

Field and laboratory data are evaluated in the following sections. This analysis focuses on P and SP samples and considers:

- SPLP data analysis;
- ARD generation potential based on field paste pH and ABA; and
- TAL metals data analysis.

During the RI, 923 field paste pH samples were collected and analyzed including surface samples ("P-" samples), subsurface samples ("SP-" samples) and samples collected at the downslope margin of the mine materials ("XP-" samples). A total of 107 P and SP samples were analyzed for SPLP and ABA. The following analyses focus on the P and SP samples, because these samples are spatially representative of all accessible areas. The XP samples are spatially biased at the downslope margins of the mine material areas, and are best suited for delineating the downslope boundary of the OU1 mine materials. Delineation of OU1 mine materials is presented in Section 4.1.3.2.

SPLP Data Analysis

All SPLP data are shown in Table 4.1-4, along with field paste pH and conductivity data of the samples. The SPLP data are screened with regard to groundwater standards and acute surface water standards. Exhibit 4.1-2 summarizes the screened data for analytes that exceeded the respective screening value in at least one sample.

Potential to Generate ARD

Because no single test can determine whether a mine material will generate acid, evaluation of ARD data is conducted using a weight of evidence approach considering field paste pH and ABA. Field paste pH is an excellent method to evaluate ARD in rocks and soils that have been exposed to surface weathering conditions for decades, which makes the method well-suited for the for OU1 evaluations. Field paste pH provides data regarding the current load of the products of previous ARD generation in waste rock and other mine materials. In contrast, ABA data provide information regarding the likelihood that the materials will generate acid in the future.

Exhibit 4.1-2. SPLP Summary Statistics for Selected Analytes

Analyte	Groundwater Screening Criteria	Acute Surface Water Screening Criteria	SPLP Summary Statistics			
			Minimum	Maximum	Average	Median
Aluminum	NA	750	15.0	130,000	10,459	1,520
Arsenic	50.0	360.0	0.14	6,520	63.0	1.0
Cadmium	10.0	3.9	0.34	2,140	66.4	13.3
Chromium	50.0	16.0	0.27	114	4.5	1.0
Copper	1,000.0	18.0	1.5	133,000	6,951	1,240
Iron	3,000.0	NA	8.4	1,710,000	32,587	100
Lead	50.0	82.0	0.025	227	5.0	0.37
Manganese	50.0	NA	2.1	49,900	3,031	1,290
Mercury	2.0	2.4	0.061	8.3	0.3	0.2
Nickel	NA	1400	0.26	3,360	86.6	13.7
Silver	50.0	4.1	0.0068	18.5	0.5	0.1
Zinc	5,000.0	120.0	29.4	382,000	11,857	2,290
pH	4.3	NA	1.34	9.3	3.7	3.62

Note: All values in µg/L.

Figures 4.1-10a and b show the location of P and XP samples, which are surface samples. Figures 4.1-11a and b shows the locations of the SP samples, which were collected using either a DPT rig or an excavator. Figures 4.1-10a and b and 4.1-11a and b also show the distinction between field-only samples and field and laboratory samples. Tables 4.1-5 and 4.1-6 show field data collected during the mine material geochemical characterization program. These tables also identify which field samples were submitted for laboratory analysis, as well as the depth of subsurface samples.

A histogram summarizing all SP and XP field paste pH data is shown in Figure 4.1-12. Surface field paste pH values ranged from 1.22 su to 7.88 su with a median of 3.5 su, and subsurface field paste pH values ranged from 1.34 su to 9.25 su with a median of 3.93 su. The maximum subsurface field paste pH value is an outlier that is associated with a local area where limestone was added to waste rock during the 1994 reclamation in the former ore storage area. Eighty-four percent of the surface and subsurface field paste pH samples are below the screening criteria of 4.6 su, which are classified as potentially ARD-generating. Samples with field paste pH values above the screening criteria (i.e., non-ARD-generating samples) were collected from relatively undisturbed areas outside of the primary mine disturbance area, and within local isolated zones within the primary mine disturbance area where ARD-generating rock has been blended with non-ARD-generating rock during mining and/or reclamation activities. ARD-generating rock was identified in all major WRDs, in reclaimed mine areas, and along many roads.

The SP samples were collected to evaluate geochemical characteristics of mine materials at depth, and to evaluate the overall depth of the mine materials to support volume estimation. These samples were collected from depths ranging from 0.5 ft to 27.1 ft with an average depth of 9.1 ft, which shows that the depth of the OU1 mine materials is relatively shallow in many areas of the Site. The depth of OU1 mine materials in the encapsulation mound exceeds 27.1 ft; however, boreholes were not advanced beyond 27.1 ft to protect the integrity of the liner at the base of the

encapsulation mound. The field paste pH values for the subsurface samples are similar in range to the surface samples.

ABA data are presented in Table 4.1-7 for the surface and subsurface samples. ABA analyses were conducted on the same subset of samples as the SPLP analyses, which were discussed previously. Interpretation of ABA data requires knowledge of the sample mineralogy, because ABA analyses are based on sequential digestions of sulfur in the sample rather than mineralogical analyses. Mineralogical information collected during field investigations, SEM-EDS analyses, and previous work (e.g., Derkey and Matsueada 1989) are considered in this assessment. The mineralogical information shows that pyrite (FeS_2) is the predominant sulfide mineral in the mine materials, but that other sulfide and sulfosalt minerals area also present such as chalcopyrite ($CuFeS_2$) and sphalerite (ZnS). Chalcopyrite and sphalerite may generate ARD under some conditions. However, in the case of sulfide oxidation by oxygen, these minerals contribute dissolved copper and zinc to mine waters, but do not generate acid. For purposes of interpretation of site ABA data, all sulfide minerals are assumed to be pyrite, which is a conservative approach. Barite is also present in some samples, and ABA data were corrected for barite as discussed in Section 2.4.1.5.

To provide an example narrative of how calculations were performed in Table 4.1-7, a description for sample P002 follows. This sample has a total sulfur content of 9.44 percent. After the first sulfur extraction step with hydrochloric acid, 6.17 percent sulfur is remaining in the sample. The difference between 9.44 percent and 6.17 percent represents the amount of sulfur leached from the sample using hydrochloric acid (3.27 percent). This difference value is then interpreted to be the sulfate sulfur percentage. Similarly, after the nitric acid extraction step, 2.63 percent sulfur remains in the sample. The difference between the hydrochloric acid (6.17 percent) and nitric acid (2.63 percent) fractions represents the amount of sulfur leached from the sample using nitric acid (3.54 percent), the nitric acid digestible fraction of the sample. Finally, the sulfur remaining after nitric acid extraction represents the residual sulfur (i.e., the fraction of sulfur that is not digested by either hydrochloric acid or nitric acid.

The sum of the nitric acid digestible and residual sulfur is assumed to be to be pyritic sulfur (sulfur contained in the mineral pyrite [FeS2]), because the initial hydrochloric acid extraction step is assumed to remove sulfate sulfur from the sample. For sample P002, the pyritic sulfur content is 6.17 percent. Before calculation of AP, the total barium concentration is converted to an equivalent sulfur concentration based on the molecular equation for $BaSO_4$. The sulfur percentage based on $BaSO_4$ is then subtracted from the pyritic sulfur to account for barite in the acid potential calculation. For P002, the calculated percentage of sulfur based on $BaSO_4$ is 0.003 percent. Therefore, the final pyritic sulfur content for the sample is 6.167 percent. The affect of this calculation for this particular sample is small; however, some samples contain a higher barium concentration and have a larger affect on the pyritic sulfur calculation.

NP in the samples is assumed to be calcite ($CaCO_3$) according to standard procedures for interpretation of ABA data (e.g., White, Lapakko, and Cox 1999; Jambor et al. 2003). However, calcite was only observed in a few mine materials samples where granular limestone was added during reclamation. Generally, calcite is not present in the samples, because it is not a significant mineralogical component of the metavolcanic rocks present at the Site. This is evident in the ABA data, which show that the majority of samples contain low to negligible NP. Other minerals

present in the sample may dissolve slightly during the NP test, and contribute to the measured NP (Jambor et al. 2003). However, under natural conditions, only the carbonate minerals provide effective buffering capacity. Therefore, the measured NP values may slightly overestimate the effective NP of the samples. It is also possible, that some of these samples contained trace amounts of limestone resulting from past reclamation activities, which were not identified in the field lithological survey.

Interpreted ABA data are shown in Figures 4.1-13a, 4.1-13b, 4.1-14 and 4.1-15. Figure 4.1-13a is a graph of total sulfur versus NP:AP ratio, which shows screening criteria for acid generation based on NP:AP ratio as horizontal lines. The graph displays variation of NP:AP ratio over the range of total sulfur values. The vast majority of ABA samples exhibit an NP:AP ratio of less than 1, and are classified with a high potential to generate ARD in the future. The graph shows a subset of samples that contain very low total sulfur values, which are classified with either moderate or low potential to generate acidity. Several of these samples are outliers with very high NP:AP ratios. These samples contain limestone, which was added to waste rock in local areas during reclamation. Figure 4.1-13b is a similar graph with the NP:AP axis scale truncated to less than 10, to provide better detail in assessing the majority of ABA samples. Figure 4.1-14 is a graph of AP versus NP, which shows NP:AP ratio screening criteria as diagonal lines. The figure also shows that the vast majority of ABA samples are classified as ARD-generating. The two samples with very high total sulfur contents described above plot as outliers on the x-axis of the graph. Figure 4.1-15 is similar to Figure 4.1-14, but the X and Y axis are truncated to show better definition of most ABA data.

Less than 5 percent of the ABA samples are interpreted to have a low potential for ARD generation, and most samples are classified with high potential for ARD generation. Some samples had particularly high concentrations of nitric and residual sulfur (pyritic); the sample with the highest pyritic sulfur concentration (47 percent) was collected from the surface of the former ore storage area. This material was logged as ground massive sulfide material. Another sample with very high pyritic sulfur (39 percent) was collected from the surface of the encapsulation mound in an area where the encapsulation mound cover appeared to be compromised because of erosion. This material is pyrite-rich tailings produced during mineral processing. Pure pyrite contains approximately 50 weight percent sulfur, which shows that these samples are almost entirely composed of pyrite. The tailings are also extremely fine-grained, which greatly exacerbates the potential for the material to generate ARD. Most ABA samples had lower, but still significant acid potential, with pyritic sulfur concentrations ranging from less than 0.01 percent (i.e., non-detect) to 47.4 percent with an average of 1.75 percent. Overall, the ABA data support the field paste pH data, and show that the materials are strongly ARD-generating and have high potential to cause deleterious effects to surface water and groundwater.

ABA data can also be used in conjunction with field paste pH data to assess the relative maturity of the ARD-generating rock. When an ARD-generating mine rock is exposed to weathering, pyrite in the rock starts to oxidize and the rock becomes progressively more ARD-generating until some terminal pH is reached (the most acidic pH that will be produced by the rock). This maturation process causes formation of ARD with decreasing pH and increasing concentrations of metals over time, until all pyrite within the rock is oxidized. Once all pyrite within the rock is oxidized,

sulfide mineral oxidation will cease; however, secondary minerals formed in the weathering process will remain, and can produce acidic conditions for decades (Langmuir 1997).

Figure 4.1-16 compares total sulfur to field paste pH and assesses the degree of maturation of surface and subsurface mine materials. The evaluation shows that surface and subsurface mine materials have similar levels of maturation, which is supported by the generally shallow depth of most mine materials. The evaluation suggests that most mine materials are not yet mature with respect to ARD generation, and that worsening ARD water quality would be expected in the future. The terminal pH of the mine materials appears to be in the range of approximately 1.3 su to 4.0 su at pyritic sulfur concentrations ranging from 50 percent to 0.1 percent respectively. At the average pyritic sulfur content of 1.75 percent, the terminal pH is estimated to be within the range of approximately 1.6 su to 2.6 su. This assessment suggests that the downstream extent of effects to Upper Middle Creek and South Fork Middle Creek would be expected to increase in the future if the mine materials are not remediated.

TAL Metals Data Analysis

The subset of 107 samples analyzed for modified SPLP and ABA analyses were also analyzed for TAL metals. These data were collected to support assessment of direct contact risks to humans or ecological receptors. The data are shown in Tables 4.1-8a and 4.1-8b, which show surface and subsurface data, respectively. In addition, Table 4.1-c shows metals concentrations analyzed by FPXRF.

Metals concentrations are screened with respect to the mineralized background concentrations (BKG1). As discussed previously, the use of screening criteria based on incremental samples to assess metal concentrations in individual point samples is not ideal, because the variability of the individual point samples is expected to be higher than the physically averaged background concentrations based on the incremental sampling method. However, this screening comparison is provided in Tables 4.1-8a, b, and c to generally illustrate samples with relatively higher metals concentrations as compared to background.

A more robust approach is comparison of the arithmetic mean of the P and SP samples (a statistical average) with estimated background concentrations developed through incremental sampling (a physical average). Exhibit 4.1-2 compares estimated mineralized background (i.e., BKG1) concentrations to average metal concentrations from the mine materials. The exhibit includes only metals that are enriched in mine materials as compared to background.

4.1.3.2 Delineation of OU1 Mine Materials

The primary purpose of an RI is to provide adequate information to support the FS. The previous sections focus on characterizing the materials with respect to ARD generation potential and metal content. This section focuses on delineation of OU1 mine materials to support development and assessment of remedial alternatives in the FS.

Exhibit 4.1-2. Metals that are Enriched in P and SP Samples as Compared to Mineralized Background (BKG1)

COPC	Average background[1] (mg/kg)	Average of P and SP samples[2] (mg/kg)	Percent Difference
Antimony	0.98	6.87	701%
Arsenic	4.528	82.73	1,827%
Barium	225.23	1088.41	483%
Cadmium	0.49	3.45	704%
Copper	164.66	771.01	468%
Iron	43,758	62,220	142%
Lead	13.251	131.37	991%
Mercury	0.21689	2.24	1,033%
Molybdenum	0.59	6.21	1,053%
Selenium	0.7751	1.36	175%
Silver	0.2184	7.86	3,599%
Zinc	122.35	740.66	605%

Notes:
[1] Arithmetic mean of three 88-point incremental samples from background sample BKG1
[2] Arithmetic mean of 107 P and SP samples

Areal Extent of OU1 Mine Materials

Delineation of areal extent is based on information collected during surface sampling activities including both the surface mine materials samples ("P-"samples) and the samples collected at the downslope margins of the mine materials ("XP-" samples). These sampling activities utilized several methods including: visual observations of lithology, mineralization and alteration; field paste pH and conductivity; FPXRF metals analyses; and LiDAR topographic and aerial photography data.

- **Visual observations** identified mine materials based on observation of lithology, mineralogy, and alteration. Mine waste rock was identified based on the presence of micaceous and fissile fragments of QSP and QST, particles of massive sulfides, pyrite, or jarosite alteration minerals, which identifies rock that originated in the mineralized portions of the mine. If sampled materials were composed of waste rock in whole or in part, they are classified as mine materials.

- **Field paste pH** values of less than 4.6 su further identified mine materials, and commonly rock with acidic field paste pH values is also recognizable based on lithological observations.

- **FPXRF** data were used to further define the downslope boundaries of mine materials, based on the screening criteria of 190 mg/kg for copper and 288 mg/kg for zinc.

- **LiDAR topographic and aerial photography data** were used in conjunction with on-the-ground visual observations to identify pathways of physical dispersion of mine materials downslope in areas of potentially affected soils, and to identify the extent of vegetation, which is an indicator of disturbed areas.

The delineated areal extent of mine materials is shown on Figures 4.1-17a and b, 4.1-18, and 4.1-19. These figures show the delineated boundaries of mine materials, based on the weight of evidence approach. The delineated boundary is shown in relation to field paste pH data in Figures

4.1-17a and b. The delineated boundary is shown in relation to the FPXRF screening criteria for copper and zinc in Figures 4.1-18 and 4.1-19, respectively. Characterization of soils downslope from the mine materials is discussed in Section 4.1.4.1, which is focused on evaluation of nature and extent of contamination in potentially affected soils.

Depth and Volume of Mine Materials

It is necessary to define the volume of the mine materials to support FS evaluations of potential remedial alternatives. Volume estimation was conducted using the areal distribution defined above, data regarding the depth of mine materials developed during the subsurface investigation, and historical data for the encapsulation mound, which was recovered archived by DOGAMI. Volume estimation procedures are described below for:

- Surface and near-surface mine materials in the primary mine disturbance area;
- Mine materials currently stored below the cover of the encapsulation mound;
- Mine materials in the 404 adit area; and
- Total volume of OU1 mine materials.

<u>Surface and Near-Surface Mine Materials in the Primary Mine Disturbance Area</u>

The volume of surface and near-surface mine materials within the primary mine disturbance area was calculated from RI data using a process that included construction of a thickness isopach map and subsequent volume estimation using the ArcGIS spatial analyst computer program. The thickness isopach map is a map that shows depth contours of the mine materials, based on the aerial distribution and depth information developed in the RI.

The thickness isopach map is shown as Figure 4.1-20. This map was developed by hand contouring the estimated thickness of the mine waste using the depth data developed in the subsurface investigation. This map does not include mine materials located within the encapsulation mound below the low-permeability cover. The depth of the mine materials is measured from the current surface to the bedrock interface as identified by DPT boring holes and excavator trenching during the subsurface investigation. As discussed previously, a layer of unconsolidated natural colluvial sediments 1-2 ft thick was identified at the base of some subsurface excavations. This colluvial materials are included in delineation of mine materials, because it is unlikely that the material can be practicably separated from mine materials during remedial action, and SPLP data suggest that portions of this colluvium may be affected by downward dispersion of COPCs from overlying ARD-generating waste rock. The very steep topography restricted access for the DPT rig and the excavator, and portions of the Site located in inaccessible areas were not sampled. In this case, the hand-contouring method is more accurate than computerized contouring methods, because it provides for interpretation of depth information in areas that were not sampled based on data from nearby adjacent areas, LiDAR topography data, and visual observations from site investigations. The figure shows the locations of the subsurface samples to illustrate the portions of the site where interpretation was necessary to estimate thickness isopachs.

The hand-contoured thickness isopach map was then digitized and georeferenced to utilize the thickness isopach contours in ArcGIS. The program ArcGIS Spatial Analyst was used to estimate the volume. The estimate used the LiDAR topographic data to define the upper surface of the volume. The lower surface was defined based on the thickness isopach data and the subsurface points. Based on this method, the volume of surface and near-surface mine materials within the primary mine disturbance area is estimated to be 280,000 bank cubic yards (BCY). The BCY unit is used in this case, because this refers to an in-place volume of the mine materials.

Mine Materials currently stored below the Cover of the Encapsulation Mound

The volume of mine materials stored below the encapsulation mound is estimated based on historical data recovered from DOGAMI archives during completion of the Data Summary Report (CDM 2009b). Northwest Environmental Resources (2003) estimated that 35,000 BCY of mine materials were present beneath the low-permeability cover of the encapsulation mound. They also provide a historical volume diagram for the pond before backfilling with tailings and waste rock, and construction of the encapsulation mound. The initial volume of the water and tailings storage pond used to construct the encapsulation mound was 21,000 yd^3 with a gauge depth of 15 ft. In 1992, the pond crest was raised by 3 ft to provide additional capacity. Based on a regression analysis of pond depth to capacity, it is estimated that this increased the capacity of the pond to 25,000 yd^3. In addition, during construction of the encapsulation mound, the mine materials were heaped in the center section of the pond to provide for positive drainage from the center of the encapsulation mound cover system to the outside, which increased capacity further. Therefore, the Northwest Environmental Resources (2003) estimate of 35,000 BCY of mine materials below the low-permeability cover system is considered adequate for purposes of the RI. Additional AutoCAD as-built data for the encapsulation mound are available, which will provide for further refinement of this volume during the FS.

Mine Materials in the 404 Adit Area

The volume of mine materials in the 404 adit are much lower than the volume of mine materials in the primary mine disturbance area. Therefore, for purposes of the RI, the volume of mine materials in this area is estimated roughly based on multiplying the delineated area of mine materials in the 404 adit area by the thickness of the mine materials measured in the subsurface excavation. Based on this approach, approximately 2,000 BCY of mine materials are estimated to be present in the 404 adit area. This is likely a conservative estimate of the volume of mine materials in this area.

Total volume of OU1 mine materials

The total estimated volume of mine materials in OU1 is presented in Exhibit 4.1-3. During the FS, it is assumed that these volume estimates will be refined as necessary to support development and assessment of remedial alternatives.

Exhibit 4.1-3. Estimated Volume of Mine Materials in OU1

Area	Estimated Volume (BCY)
Surface and near-surface mine materials in primary mine disturbance area	280,000
Mine materials below low-permeability cover in encapsulation mound	35,000
Mine materials located near 404 adit	2,000
Total	**317,000**

4.1.3.3 Content of Potentially Beneficial Metals in OU1 Mine Materials

Although development of remedial alternatives will not be conducted until the FS, several stakeholders have expressed interest in evaluating whether there are potentially recoverable quantities of copper, zinc, or other metals in the mine materials. To facilitate this evaluation, the volume estimate, estimates of average metal concentrations for several potentially beneficial metals, and density estimates developed from literature were used to estimate the quantity of contained metals in the OU1 mine materials. These estimates were multiplied by spot metal prices of June 11, 2011 to evaluate the potential gross value of metals contained within the mine materials. In addition, the potential net smelter return for these metals was also estimated by multiplying the gross metals content by 50 percent. Results of this evaluation are summarized in Exhibit 4.1-4.

This evaluation of contained metals in the mine materials provides an approximation of the content of potentially beneficial metals. To recover these metals, a mineral processing plant would need to be constructed, and a metal concentrate suitable for shipment to a smelter would need to be generated and transported to the smelter. Commonly, the net smelter return is approximately 50 percent for copper and zinc, assuming that a suitable smelter concentrate is generated during mineral processing. The difference between the gross value of metals in the concentrate and the net smelter return, accounts for the cost of smelting the metals. In addition, metals such as cobalt, lead, nickel, and silver may not be payable in copper or zinc concentrates.

Exhibit 4.1-4. Estimated Content of Potentially Beneficial Metals in Mine Materials

Metal	Avg. Metal Content	Spot Metals Price (June 11, 2011)		Contained Metal		Estimated Gross Value	Potential Net Smelter Return[1]
	mg/kg	Spot Price	Unit	weight	Unit		
Copper	825.8	$4.10	$/pound	994,727	pounds	$4,078,381	$2,039,190
Lead	108.6	$1.13	$/pound	130,821	pounds	$147,828	$73,914
Nickel	34.9	$10.41	$/pound	42,044	pounds	$437,675	$218,837
Silver	6.4	$36.19	$/troy ounce	7,717	troy ounces	$279,266	$139,633
Zinc	947.0	$1.01	$/pound	1,140,712	pounds	$1,152,119	$576,060

[1]Potential net smelter return assumed to be 50 percent of the value of contained metals

Although potentially beneficial metals are present in the mine materials, the potential net smelter return is relatively low compared to likely costs of constructing a mineral processing facility,

completing onsite mineral processing to generate a concentrate, and shipping the concentrate to a smelter. However, it is possible that tailings (one component of the mine materials) may be more favourable in terms of supporting recovery of potentially beneficial metals. Remedial technologies and process options that could recover potentially beneficial metals at the site will be addressed in the FS.

4.1.3.4 Location of ARD-generating Rock Outcrops

Massive sulfide ore bodies exploited at the Formosa Mine and associated mineralized rock cropped out at the surface, and some of these outcrops remain. Weathered massive sulfide outcrops termed "gossan" have generally been mined, but outcrops of QSP are present in several areas. QSP is mineralized rock that contains common pyrite, which was not economic to mine. Low field paste pH values were observed in samples collected from fine-grained materials eroding from these outcrops in several locations.

Interestingly, a very low field paste pH sample of 1.4 su was collected from an eroding QSP outcrop located along a road cut north of the encapsulation mound (southeast side of the former ore storage area). This illustrates the natural variation in background concentrations associated with these mineralized outcrops. In areas where these outcrops are present, natural enrichments of COPCs would be expected, which are higher than background conditions measured only a few tens of feet away from the outcrop. Similar outcrops were observed in the area of the Formosa 2 and 3 adits, along Road 31-6-26.1 leading to the Silver Butte fire tower, and in the area of the illegal dump. Figure 4.1-21 shows the location of mineralized outcrops, which were observed during the RI.

4.1.3.5 Contaminant Loading Associated with OU1 Mine Materials

The previous subsections have characterized and delineated OU1 mine materials based on data collected during the RI. This section provides additional analysis of the data focused on understanding the potential effects of OU1 mine materials on the environment. The primary environmental issue associated with OU1 mine materials is ARD generation and transport of MIW, which affects both surface water and groundwater quality in the area of the Site. This section illustrates the potential quantities of ARD that could be generated in by OU1 mine materials, and released to surface water and ground water.

This section describes:

- The volume of MIW generated by OU1 mine materials
- The chemistry of MIW generated by OU1 mine materials

Volume of MIW Generated by OU1 Mine Materials

Important factors controlling ARD generation and subsequent transport of MIW include geochemical characteristics of the mine materials, physical characteristics of the mine materials, and climate conditions. The climate is an important factor because ARD is generated from interaction of ARD-generating source materials with precipitation. After ARD is produced and is discharged to either groundwater or surface water, the transport pathways are difficult to quantify. However, the volume of MIW generated by OU1 mine materials can be estimated using a water balance approach.

Some portion of precipitation infiltrates into OU1 mine materials, percolates through the mine materials becoming ARD, and is discharged to either groundwater or surface water. Schafer and Benowitz (2000) estimate that infiltration into mine waste rock piles ranges from approximately 1-2 percent of precipitation for a waste rock pile reclaimed with a well designed low-permeability cover to over 50 percent of precipitation for an operating waste dump. Physical characteristics of the OU1 mine materials are a major control on the infiltration rate. The dominant texture of the OU1 mine materials is a sandy gravel based on visual logs of hundreds of samples. This type of mine waste is relatively permeable, and rapid infiltration and percolation of water through the mine materials is likely.

In Section 3, it is estimated that leakage through the existing low- permeability cover on the encapsulation mound is at least 17 percent of precipitation based on detailed monitoring conducted over a 5 month period during fall and winter 2010/2011. The encapsulation mound cover system consists of a lined basin overlain by a low-permeability cover and 5 to 15 ft of waste and construction rock. This facility approximates the configuration of a basin lysimeter, which is a monitoring method used to measure percolation through mine wastes on a large scale (Duex 2000). A basin lysimeter consists of a basin lined with a geosynthetic liner, which is constructed within a mine waste pile. The volume of water reporting to the basin is measured, and used to estimate infiltration and percolation through the mine waste pile. When considered as an approximate basin lysimeter, the encapsulation mound is not ideal because of the low-permeability cover system that lies between the waste rock and the basin and observed leakage from the facility. Both of these uncertainties would cause underestimation of infiltration through the overlying layer of waste and construction rock, rather than overestimation. Therefore, the estimated leakage rate through the low-permeability cover of 17 percent of precipitation represents the minimum rate at which precipitation infiltrates and percolates through the overlying rock materials.

Based on the above information, it is estimated that direct infiltration and percolation of precipitation through OU1 mine materials at the Site is between approximately 17 and 50 percent. The area of the OU1 mine materials based on the delineation presented in Section 4.1.3.2 is 25.7 acres. Based on available data from the Silver Butte weather station described in Section 3.6.1, the Formosa Mine receives approximately 36 inches of precipitation per year, most of that falling during the fall and winter.

The average volume of MIW generated by the OU1 mine materials can be estimated as follows:

$$(V) = (A)(P)(I)$$

Where: A=Delineated Horizontal Area of OU1 mine materials (25.7 acres)

P=Average Annual Precipitation (34.34 inches per year)

I=Rate of infiltration/percolation of precipitation through mine materials (17-50%)

V=Average annual volume of MIW generated by OU1 mine materials

Based on this approach, it is estimated that the average rate of MIW generation caused by the OU1 mine materials is between 4 million and 12 million gallons per year. During particularly wet

years such as 2005 (70.76 inches precipitation), the MIW generation rate could range between 8 and 25 million gallons per year. After percolating through the OU1 mine materials, this MIW either recharges the alluvial and/or bedrock aquifers or is discharged directly to surface water. Based on work conducted to date, the dominant contaminant transport pathway is thought to be: 1) percolation of MIW into the alluvial or bedrock groundwater; 2) COPC transport in groundwater; and 3) discharge of contaminated groundwater to surface water. The OU1 mine materials are an important ARD source, which is providing a continuing flux of acidity and metals into the environment.

The relative environmental importance of OU1 mine materials in relation to other source materials can be evaluated based on MIW volumes produced. Hart Crowser (2004b) estimated that annual discharge from the Formosa 1 adit is 5 million gallons per year. Data collected during this RI are not adequate to validate the reported discharge rate from the Formosa 1 adit, and installation of a flume with an automated flow monitoring device is planned as part of future OU2 activities. However, it is evident that the OU1 mine materials produce a comparable and potentially higher volume of ARD than the Formosa 1 adit. Leakage of ARD at the Encapsulation Mound is significantly less, approximately 171,700 gallons per year as discussed in Section 3.

Chemistry ARD Generated by OU1 Mine Materials

The flux of COPCs into the environment caused by the Formosa Mine is related to both the concentration of COPCs and the volume of MIW, The chemistry of MIW generated by OU1 mine materials likely varies depending on the geochemical characteristics of mine materials present within any given area. SPLP data are evaluated with respect to specific areas within the delineated OU1 mine materials boundary to summarize characteristics of specific OU1 mine materials, and support assessment of surface water and groundwater contamination in the following sections.

This approach considers the concentration of COPCs in MIW produced in various areas of the Site. However, further delineation of specific areas within the OU1 mine materials may not be feasible because of the heterogeneous nature of the mine materials present. The specific site areas are developed based on general areas of OU1 mine materials described in Section 1.3.3:

- Formosa 1 adit WRD;
- Formosa 2 Adit, Formosa 3 Adit, and 1090 raise WRDs;
- Silver Butte 1 adit WRD;
- 404 adit WRD;
- East and west encapsulation mound WRDs;
- Encapsulation mound, former milling facility area, and former shop facility area;
- Former ore storage and water storage areas;
- Illegal dump area; and
- Miscellaneous road areas constructed of co-mingled construction rock and soils.

Exhibit 4.1-5 compares the average COPC concentration in SPLP samples collected in these areas. Generally, the exhibit shows that OU1 Mine Materials in the Formosa 1 adit WRD and the former ore and water storage area produce MIW with the highest concentrations of COPCs. The Silver Butte WRD; encapsulation mound, milling and shop facility area; east and west encapsulation mound WRDs; and illegal dump produce MIW with intermediate concentrations. The remaining areas (Formosa 2 adit, Formosa 3 adit, 1090 raise, and 404 adit WRDs and miscellaneous road areas produce MIW with the lowest concentrations of COPCs. The SPLP data show that some COPC concentrations are orders of magnitude above screening criteria. When this MIW enters groundwater or surface water, the resulting contamination can cause widespread effects.

Exhibit 4.1-5. Average Concentration of Cadmium, Copper, Iron, Manganese, and Zinc in SPLP Samples by Area

Area	N	Cadmium	Copper	Iron	Manganese	Lead	Zinc
Formosa 1 adit WRD	4	123.7	15,195	141,158	1,705	0.877	24,065
Formosa 2 Adit, Formosa 3 Adit, 1090 WRD	6	8.5	3,473	9,000	668	1.30	1,309
Silver Butte 1 WRD	5	36.5	7,916	11,809	1,953	1.126	12,531
404 Adit WRD	4	0.952	206.8	50.5	150.3	1.40	188.7
Encapsulation Mound, Milling and Shop Facility Area	7	40.1	5,436	587	2,388	1.276	5,240
East Encapsulation Mound WRD	13	29.4	6,800	17,806	3,425	4.82	5,088
West Encapsulation Mound WRD	9	37.7	4,064	976	3,722	0.317	6,123
Former Ore and Water Storage Area	19	242.0	21,591	130,907	7,082	19.2	41,178
Illegal Dump Area	9	69.4	3,369	250.2	1,767	1.086	11,428
Misc. Road Areas	25	26.2	3,645	2,730	2,256	1.575	2,256

Notes: N=number of samples, average metal concentrations in µg/L, WRD = waste rock dump

4.1.4 Nature and Extent of Contamination in Soils

Soils located downslope from the mine materials are classified as potentially affected, because physical and hydrogeochemical dispersion is expected to have caused some downslope migration of COPCs into natural soils. These natural soils are generally well vegetated, and contain valuable habitat and timber. They represent a different matrix as compared to mine materials, which are largely composed of waste rock, tailings and mixtures of other materials with waste rock and

tailings. Potentially affected soils are also not source materials for ARD generation. Rather, they are potential sinks for contamination that has dispersed downslope from mine materials or natural outcrops. Therefore, potentially affected soils are characterized and discussed separately from mine materials.

Remnants of mineralized outcrops are present in several areas at the site and consist of gossan, intensely weathered massive sulfide, and variably weathered outcrops of QSP. Gossan is a pourous rock composed almost entirely of iron oxides. This material is the remnant of a massive sulfide outcrop after copper, zinc, and other metals have dissolved through chemical weathering and dispersed from the outcrop into the environment. Similarly, QSP outcrops are also weathering naturally, and field paste pH values as low as 1.4 su were observed at actively weathering QSP outcrops. Over geological time, these processes have likely resulted in natural geochemical dispersion of copper, zinc, and other COPCs downslope from the outcrops. These outcrops are located in the Upper Middle Creek watershed in the area of the Formosa 1, 2 and 3 adits and the Silver Butte adit, and in the South Fork watershed in the area of the encapsulation mound. Therefore, the expected locations of soils with natural geochemical enrichments related to eroding massive sulfide and QSP outcrops include soils in the areas of the Formosa and Silver Butte WRDs, and the waste dumps on the east side of the encapsulation mound.

Physical and hydrogeochemical dispersion of COPCs downslope from accumulations of mine materials has also contaminated soils. These materials are more abundant than natural mineralized outcrops, and they have a smaller particle size as compared to the outcrops, which results in faster weathering and oxidation. However, mine materials have generally been exposed to weathering for a period of decades, whereas the natural outcrops have likely been eroding for thousands to millions of years. In both cases, the COPCs produced are similar, and no geochemical indicator elements are available to differentiate between COPC concentrations in soils that were caused by natural versus anthropogenic processes. The mineralized background sample (BKG1) is located south of the primary mine disturbance area along the general trend of the massive sulfide mineralization. However, no outcrops of mineralized rock were observed in the area of sample BKG1, and no mineralized outcrops are reported in the area based on geological maps prepared by previous workers.

Natural background concentrations of copper, zinc and other elements associated with massive sulfide mineralization must be considered as a range of values that varies in relation to the location of ore bodies and other strongly enriched rocks. COPC concentrations at the mineralized background location (BKG1) are relatively higher than COPC concentrations at the non-mineralized background location (BKG2); however, it is important to recognize that natural background COPC concentrations in soils downslope from massive sulfide and QSP outcrops may be enriched further. The COPC concentrations of soils located downslope from mine materials are characterized in the following sections, but it must be recognized that the cause of metal enrichment within the soils is not always clear.

Two cases where the cause of metal enrichment in soils are known are the adit discharge system outfall, and several local areas where active discharge of MIW from groundwater is affecting soils in areas downslope from mine materials. The adit diversion system has operated at the Site since reclamation in 1994. This system collects ARD from the Formosa 1 adit and conveys the

contaminated water to an area where it is discharged to the surface, causing severe effects to soils in the discharge area. The groundwater discharge areas were identified during field surveys based on damp soils with anomalously high concentrations of copper and zinc based on FPXRF data. These areas will also be discussed in the sections that follow.

4.1.4.1 COPC Concentrations in Potentially Affected Soils

COPC concentrations in potentially affected soils downslope from accumulations of mine materials were evaluated using incremental sampling as discussed in previous sections. The location of the incremental sample DUs was shown previously in Figure 2.3-4, and laboratory data from the DUs are shown in Table 4.1-9. These data are screened with respect to background concentrations at BKG1, and are evaluated based on the RSD of the triplicate samples from each DU.

Calculated RSDs shown in Table 4.1-9 are evaluated based on an assessment goal that the RSD be less than 30 percent. Values of RSD greater than 30 percent indicate that the variability between the triplicate incremental samples is high, which causes uncertainty in conclusions based on the incremental sampling program. High RSDs suggest that the number of increments was not large enough, that laboratory subsampling procedures were not adequate, or that laboratory analyses are uncertain. Generally, most of the RSDs from the potentially affected soils are less than the 30 percent goal. The RSD exceeded 30 percent for boron at DUs EMEMISU, EMESEMISU, and FAMISL. However, as shown on Table 4.1-9, the average concentration of the triplicate samples is lower than the background concentration, and boron data from the incremental samples that comprise each average are also lower than the background concentration, with the exception of sample FAMISLA. The boron concentration of sample FAMISLA was 4.7 mg/kg, which is slightly higher than the background concentration of 4.595 mg/kg. Therefore, uncertainty regarding the boron concentration is unlikely to affect evaluation of the data. In addition, boron does not occur in concentrations exceeding background in the mine material samples, which shows that it is unlikely that significant boron dispersion from mine materials has occurred.

Two incremental samples of potentially affected soils display RSD values that exceed 30 percent for metals that are enriched in mine materials and may have dispersed into downslope soils. These include cadmium, molybdenum, and zinc at DU EMEMISU, and lead at DU EMWD2MIS. Decision unit EMEMISU lies at the base of a waste dump on the east side of the encapsulation mound. This waste dump contains very strongly mineralized rock including massive sulfide fragments. It is possible that the distribution of cadmium, molybdenum, and zinc within this DU is strongly skewed as a result of the presence of mineralized rock fragments that have dispersed downslope from the waste dump. The RSD values for cadmium, molybdenum, and zinc in this sample are 61 percent, 39 percent, and 58 percent, respectively. The RSD for lead in DU EMWD2MIS is 54 percent. The cause of this variation in lead concentration between the three triplicate samples is unknown.

The arithmetic means of COPC concentrations within each DU are compared to background screening criteria in Table 4.1-9. Numerous COPCs exceed the screening criteria in the samples as summarized in Exhibit 4.1-6. With the exception of beryllium, all of these COPCs are also present in many P and SP samples at concentrations that exceed background as shown in Exhibit 4.1-1.

Incremental sample data for arsenic, cadmium, copper, and zinc are summarized in bar charts presented on Figure 4.1-22. These charts graphically display the average concentration of the three incremental sample replicates collected from each DU. For DUs that were sampled with upper and lower bands, it is evident that lower concentrations are generally observed in the lowest DU for cadmium, copper, and zinc, which suggests that the intensity of dispersion decreases with further distance from the OU1 mine materials. However, this dispersion pattern may also be related to increasing distance from the natural massive sulfide and QSP outcrops in the area. No clear trend is evident for arsenic concentrations.

Potential risks to human or ecological receptors from COPCs in potentially affected soils are addressed in Section 6.

Exhibit 4.1-6. COPCs that Exceed Background in Downslope DUs

Decision Unit	COPCs that exceed background concentrations
EMEMISL	Antimony, arsenic, barium, *beryllium*, cadmium, copper, lead, mercury, molybdenum, silver, zinc
EMEMISU	Antimony, arsenic, barium, *beryllium*, cadmium, copper, lead, mercury, molybdenum, silver, zinc
EMSEMISL	Antimony, barium, *beryllium*, cadmium, molybdenum, silver, zinc
EMWMISL	Beryllium, cadmium, molybdenum, silver, zinc
EMWMISU	Beryllium, cadmium, selenium, uranium, zinc
FAMISL	Arsenic, barium, *beryllium*, cadmium, copper, silver, zinc
FAMISU	Antimony, barium, *beryllium*, cadmium, copper, molybdenum, silver, zinc
EMWD1MIS	Antimony, barium, *beryllium*, cadmium, manganese, mercury, silver, zinc
EMED2MIS	Antimony, arsenic, *beryllium*, cadmium, lead, molybdenum, mercury, silver

Note: COPCs that are not enriched in P and SP samples are shown in italics.

4.1.4.2 COPC Concentrations in Seep Areas

During field sampling in areas downslope from mine materials and contaminated soils, several areas were identified where MIW was discharging from groundwater to the surface. Soils in these areas have high concentrations of copper and zinc, which is thought to result from discharge of MIW over time and sequestration of metals in soils. During field sampling in July, August and October 2010, these seep areas were identified based on the presence of damp soils, observed hydrophilic mosses, and white crystalline precipitates within local areas, with associated anomalous FPXRF metals concentrations. Organic matter in soils is an important adsorption substrate for copper and zinc, which is thought to cause sequestration of metals within these areas.

The scale of these seep-affected soils is very local, with observed areal extent of less than 0.1 acre. The locations of observed seep-affected soils are shown on Figures 4.1-17 through 4.1-19. They are present downslope from the Formosa WRD, on the south side of the Silver Butte WRD, and in a local area east of the encapsulation mound. Metal concentrations in these soils measured by FPXRF were presented previously in Figure 4.1-8. These seep-affected areas show that COPC transport in groundwater is occurring in some areas. It is unknown if these seeps result from groundwater discharge from shallow alluvial aquifers or deeper bedrock aquifers.

4.1.4.3 COPC Concentrations in Soils Affected by Adit Water Diversion System Outfall

Operation of the various adit water diversion systems has caused pronounced effects to soils in the discharge areas, and in an area where leakage of the diversion pipeline occurred. The current system is the IRAM adit water diversion system, but previous adit water diversion systems were also operated at the Site as discussed in Sections 1.4 and 3.1. The adit water diversion system collects MIW from the Formosa 1 adit and the Silver Butte 1 adit, and conveys this water to a previously undisturbed area where it is discharged to the surface. Obvious visual effects are present in the discharge area including accumulations of iron precipitate, areas of MIW saturated soils, and dead vegetation. Sampling of these areas was not a planned component of the RI; however, several opportunity samples of these areas were collected during the investigation. In addition, a GPS survey was conducted to provide general location information regarding the spatial extent of obviously affected areas based on visual observations. These locations are shown on Figures 4.1-17 through 4.1-19.

Five opportunity samples were collected from these areas during mine materials sampling ("P-" samples) and sampling of the downslope extent of mine materials ("XP-" samples). Laboratory data for these samples are shown in Table 4.1-10. The samples are highly enriched in iron and arsenic, two COPCs present in ARD discharged from the adit water diversion system. Iron concentrations ranged from 36 percent to 50 percent, and arsenic concentrations ranged from 247 mg/kg to 576 mg/kg. Arsenic concentrations in these samples are two orders of magnitude higher than concentrations measured at background location BKG1. Other metals associated with MIW such as cadmium, copper and zinc were less enriched in the soil samples, but still exceed the background concentration at BKG1.

Identification of contaminated soils strongly enriched in iron and arsenic in the area of marked visual effects to soils from the adit discharge is compatible with the geochemistry of COPCs. As the discharged water moves through the environment, the pH of the solution gradually increases through interaction with soils and dilution. The various COPCs present in ARD gradually precipitate from the solution as the pH increases. Under oxidizing conditions, iron precipitates from the solution to form iron hydroxide at a pH of approximately 3.5 su. Arsenic adsorbs and coprecipitates with the iron hydroxides at this pH range. Although the Formosa adit MIW contained relatively low arsenic concentrations during the RI sampling events (i.e., 2.8 to 167 µg/L), arsenic adsorption and coprecipitation causes accumulation of arsenic in the adit diversion system discharge area. This process is responsible for the strong enrichment of iron and arsenic at the location of the adit water discharge. This is the area that has been approximately delineated with the GPS survey of the visual extent of iron precipitates.

Other COPCs are removed from solution through precipitation and/or adsorption as the pH of the discharge water gradually changes along the surface and subsurface flow path of the MIW. COPCs that may precipitate and/or adsorb along the solution flow include aluminum, copper, zinc, and cadmium, which precipitate and/or adsorb as the pH increases. Some COPCs such as zinc and cadmium remain soluble at concentrations exceeding screening criteria until the pH is over approximately 8 to 9 su. This pH range is not observed in surface water or groundwater in vicinity of the Site, and is generally observed in natural environments only in areas of widespread carbonate bedrock (e.g., areas underlain by limestone or dolomite). Therefore, complete attenuation of COPCs in MIW through interaction with soil and subsoil in the area of the adit

diversion discharge may not occur, and these COPCs may be infiltrating to groundwater. Additionally, this process transfers the COPC load from the dissolved phase in MIW to solid phases in other media in the area downgradient from the discharge.

It is expected that a series of geochemical dispersion halos is present in soil, subsoil, and groundwater in the area of the adit diversion discharge, with iron and arsenic present close to the discharge pipe, and other COPCs such as aluminum, copper, zinc, and cadmium present in halos located further from the discharge location within the subsurface. In addition, the GPS survey identified the extent of visual surface effects of this discharge only. Once the ARD discharged from this system infiltrates into the subsurface, the flow path likely occurs through unconsolidated subsoil and colluvium overlying bedrock, and within the bedrock aquifer. Therefore, the five opportunity samples collected in the areas of visual surface effects are very unlikely to fully characterize the extent of the geochemical dispersion halos associated with the adit water diversion system. In addition, work to date has not characterized subsurface conditions or effects to groundwater associated with this system. Additional discussion relevant to understanding potential effects of the adit diversion system is presented in Section 5, which focuses on contaminant fate and transport.

4.2 Surface Water

The following sections describe available information regarding surface water. Effects to surface water have not been fully characterized to date, particularly within the reaches of South Fork and Upper Middle Creek that are located beyond approximately one half mile downstream of the Site. More focused sampling has been conducted in areas near the Site.

This discussion of surface water is organized as follows:

- Screening Criteria (Section 4.2.1);
- Middle Creek (Section 4.2.2);
- South Fork Middle Creek (Section 4.2.3);
- West Fork Canyon Creek (Section 4.2.4);
- Russell Creek (Section 4.2.5); and
- Cow Creek (Section 4.2.6).

The discussion of Middle Creek, South Fork Middle Creek, West Fork Canyon Creek, and Russell Creek addresses the major watersheds draining near the OU1 Site area. Cow Creek is the receiving stream that receives flow from each of these tributary drainages, except West Fork Canyon Creek. Cow Creek also provides water to the City of Riddle water intake as well as several private water intakes.

4.2.1 Screening Criteria

Water quality screening criteria were obtained from OAR 340-041-0033 Table 20 (ODEQ 2010) for protection of aquatic life, using fresh water chronic criteria, EPA National Recommended

Water Quality Criteria (EPA 2009c), or EPA Quality Criteria for Water (EPA 1986), whichever was most stringent. As set forth by OAR 340-041-0033 Table 20, chronic refers to an average concentration over 96 hours, which should not be exceeded more than once every three years. For some compounds of interest, ODEQ screening criteria were not available. In these cases EPA National Recommended Water Quality Criteria (EPA 2009c), or EPA Quality Criteria for Water (EPA 1986) were used. Drinking water criteria such as maximum contaminant levels or maximum contaminant level goals were not considered in this section.

Field pH was used for sample screening purposes; pH was not measured in the laboratory. The field pH screening criteria is 6.5-9.0 su, which is used based on EPA Quality Criteria for Water (EPA 1986). Chronic criteria were used instead of acute because MIW is continuously discharged. Although concentrations vary, exposure of resident aquatic life is continuous. Hardness for each water sample was computed using the measured dissolved calcium and magnesium concentrations. For applicable metals, the chronic screening criteria were calculated based on hardness. If more than one sample was collected at a particular location, an average hardness was calculated for that location and used to compute the hardness-dependent criteria.

Table 4-2.1 compares surface water sample results to screening criteria. Only applicable surface water data are shown in this table, which includes only a fraction of the metals analyses and other parameters as well only dissolved metals analyses. Table 4.2-2 presents all of the surface water sampling data collected for the RI. Table 4.2-3 presents the remaining surface water field data collected from locations that did not have laboratory analysis and are not presented on Table 4.2-2.

4.2.2 Middle Creek

Because of known impact of MIW in the area (CDM 2009), a high density of laboratory samples and field measurements were collected along Upper Middle Creek near the Site. The RI sampling activities assessed MIW effects to Upper Middle Creek, potential ARD sources, and contaminant transport pathways. Additional information regarding the sampling programs and associated DQOs is presented in Section 2.

ARD sources affecting Upper Middle Creek include OU1 and OU2 mine materials. The generation of ARD from OU1 mine materials and transport pathways to surface water and groundwater were described in detail in Section 4.1. The presence of OU2 mine materials result in perennial MIW discharge from the underground mine at the Formosa 1 adit and discharge via the adit water diversions system. A portion of the MIW discharged from the Formosa 1 adit also bypasses the adit water diversion system and is transported to Upper Middle Creek via the alluvial groundwater system. The effects to surface water from the OU1 and OU2 mine material transport pathways to Upper Middle Creek are described in this section. Transport of MIW from the underground mine towards Middle Creek via the bedrock aquifer is also a possible contaminant transport mechanism; this is addressed in Section 4.3.

Two Middle Creek surface water sample locations are included in biannual sampling. MXR and M13.0 are located in lower Middle Creek, and document MIW effects to surface water quality at points approximately 0.75 and 13 miles downstream from the Formosa Mine respectively.

The following sections describe surface water characteristics at:

- Formosa 1 adit
- MA and MB sub-drainages
- Lower Middle Creek

4.2.2.1 Formosa 1 Adit

ARD discharges from the Formosa 1 adit on a perennial basis, although the discharge rate varies markedly during the dry and wet seasons as discussed in Section 3. The adit water diversion system is designed to collect this water and convey it away from Upper Middle Creek. ARD discharging from the Formosa 1 adit is sampled on a biannual basis. Exhibit 4.2-1 summarizes the quality of water discharging from the Formosa 1 adit to contrast water quality during the wet and dry seasons.

Exhibit 4.2-1. Comparison of Formosa 1 Adit Water Chemistry during Wet and Dry Season Sampling

Analyte	Dry Season Sampling		Wet Season Sampling	
	10/19/2009	10/25/2010	1/26/2010	1/26/2011
Aluminum (µg/L)	9,240	9,340	27,700	21,700
Cadmium (µg/L)	130	131	666	366
Copper (µg/L)	3,150	2,700	42,800	32,200
Iron (µg/L)	74,700	88,600	264,000	187,000
Lead (µg/L)	15.3	14.6	78.2	73.6
Zinc (µg/L)	61,200	61,500	146,000	88,100
pH (su)	2.98	2.15	3.13	2.85
Acidity (mg/L CaCO3)	340	1,200	400	820
Flow (gpm)	2.0	0.8	42.91	29.94

As shown in Exhibit 4.2-1, ARD that discharges from the Formosa 1 adit during the wet season contains higher concentrations of COPCs. The discharge rate from the adit is also higher during the wet season. Therefore, the load of COPCs discharged is markedly higher during the wet season. The higher concentration of metals and lower pH during the wet season agrees with historic data at this location (see Appendix A), and displays seasonal flushing of COPCs from OU2 mine materials within the underground mine during high flow. As discussed in Section 3, the adit water diversion system is not designed to collect subsurface discharge from the Formosa 1 adit. It is likely that subsurface discharge from Formosa 1 adit flows into the alluvial aquifer of the MB aquifer.

The adit water diversion system appears to collect all surface water flow discharging from the Formosa 1 adit and conveys the water to the discharge point when properly functioning;

however, subsurface discharge from the adit may bypass the existing adit water diversion system. Some evidence including areas of iron hydroxide precipitates located near pipe junctions display effects of periodic leaks that have occurred in the adit water diversion pipeline. Large accumulations of affected soils are present in the area of the adit water discharge as discussed in Section 4.1.4.3. During the wet season and dry season sampling events, water discharging from the adit water diversion system was not observed to be flowing directly into Middle Creek via overland flow. Flow leaving the diversion pipe was observed to travel downslope as surface flow for approximately 160 ft before completely infiltrating. It is likely that this water recharges the alluvial and/or bedrock aquifer systems, and contributes to base flow in the ME watershed.

One laboratory sample was collected from location ME1, within the sub-drainage ME, approximately 300 ft above the confluence with Middle Creek and approximately 1,700 ft downslope from the adit water diversion system discharge point and the Silver Butte WRD. This sample had slightly affected water quality as shown by elevated conductivity (508 microSiemens per centimeter [µS/cm]) and high zinc concentration (2,800 µg/L). This high zinc concentration may be evidence of the downstream effects of the adit water diversion that is discharging into the upper alluvial groundwater system that potentially feeds the sub-drainage ME. Zinc has the greatest tendency to stay in solution because of its high pH of minimum solubility; therefore, zinc has a greater mobility than any other metal associated with the Site contamination. The remaining metals associated with the adit water discharge may be precipitated and absorbed to surface or subsurface soil surfaces before reaching the surface flow of ME sub-drainage. This suggests that the adit water diversion system discharge may be affecting surface water quality in Middle Creek as well as groundwater in the area of the diversion. However, the adit water diversion system discharge is not causing effects to Upper Middle Creek in areas of known MIW effects (MA and MB drainages) except for brief periods when the diversion pipeline has leaked. 4.2.2.2 MA and MB.

4.2.2.2 Sub-Drainages

Numerous areas of observed ARD discharge from groundwater to surface water are present along Upper Middle Creek, beginning approximately 200 horizontal ft west of Road 30-6-35.1 and ending upstream of the bedrock outcrop known as Raymond Bear Falls. Many of these MIW discharges exhibit low pH, high conductivity, high sulfate concentration, and high concentrations of metals such as cadmium, copper, iron, and zinc. These water quality characteristics are similar to ARD that discharges from the Formosa 1 adit and similar to results from SPLP tests of mine materials.

The ARD seeps/springs are identified by the visual presence of precipitate immediately downstream of the seep/spring area. Formation of precipitate at seeps/springs occurs as low pH water with high dissolved metals concentration mixes with higher pH water. The resulting change in pH causes metals to precipitate out of solution and accumulate in sediments. A pattern of mineral precipitate formation is observed at the Site, which corresponds to gradually increasing pH conditions as MIW flows through the watershed. Iron precipitates out of solution first, and forms orange precipitates. Iron precipitation is followed by aluminum (white precipitates), copper (green precipitates), and zinc (white precipitates) as the pH of the water gradually increases through mixing and other processes. As the pH increases, different metal precipitates form at various pH ranges as follows (refer to Section 5 for further information):

- Iron precipitates at approximately 3-3.5 su;
- Aluminum precipitates at approximately 4.5-5 su;
- Copper precipitates at approximately 6.5-7 su; and
- Zinc precipitates at approximately 8-8.5 su.

The metal precipitate phenomenon occurs in two ways as groundwater interacts with surface water in Upper Middle Creek:

- Seep/spring water with high metal concentrations and low pH flows into stream water with lower metals and more neutral pH; or
- Seep/spring water with low metals concentrations and near-neutral pH flows into stream water with high metal concentrations and low pH.

As an example of the first interaction, during the wet season seep and spring survey (Figures 4.2-1 and 4.2-2) the in-stream surface water at location Seep A had a pH of 6.68 su, conductivity of 76 µs/cm, and stream water appeared clear. Below this location, a seep area (MA17 and MA18) was observed with lower pH (4.87 su and 4.74 su) and higher conductivity (375 µs/cm and 369 µs/cm). White precipitates (aluminum) were observed within the mixing zone of the seep area and the creek. Adjacent to and downstream of the seep area, the stream color changed to green as copper precipitates began to form from the seep water entering the stream.

Downstream of Raymond Bear Falls, the opposite reaction occurred within an area of Upper Middle Creek that had a pH of approximately 3.6 to 4 su. At this pH, iron originally dissolved in the MIW is no longer in solution, but aluminum and copper remain in solution. Inflowing groundwater seeps/springs in this area have a higher pH of approximately 4.9-5.7 su. In local areas where groundwater was observed to be discharging to surface water in this stream reach, the surface water pH increased in seep areas, and white aluminum precipitates were observed. As the MIW continued to flow downstream, the pH continued to increase, which further reduced the solubility of dissolved metals in surface water and caused additional precipitation of aluminum and eventually copper.

Most seeps were observed and sampled during the wet season; during the dry season the rate of discharge from groundwater to surface water is lower and fewer seeps are present. Generally, seep location names between the dry season and wet season sampling events were not kept consistent. This was done to capture what was observed at the time of sampling. Upon review of the locations and field notes, some of the dry and wet season locations are from the same general seep sources and appear to be discharging on a perennial basis. This pattern mimics the observed seasonal change in MIW discharge rate at the Formosa 1 adit.

Seeps that were observed to be discharging MIW are listed below from upstream to downstream. At a minimum, pH at these locations was measured to be ≤ 4.87, and conductivity ≥ 198 µS/cm. Some of these seeps have a much lower pH (2.40 su to 3.5 su) and much higher conductivity (greater than 1,000 µS/cm). The similar locations between dry and wet season locations are noted below as well as observations of precipitates noted in the stream and/or seep area):

- MA1 and MA16 – wet and dry season seep next to Seep A stream location (Figures 4.2-1 through 4.2-4). MA1 is dry season location and MA16 is wet season location. White precipitate was observed in the seep pool next to stream.
- MA17, MA18, and MA9 – wet and dry season moss-covered seep area below Seep A stream location (Figures 4.2-1 through 4.2-4). MA9 is a dry season location that is similar to the MA17 and MA18 wet season locations. White precipitates were observed at the seep area and copper precipitates were observed in-stream.
- MA22 – wet season seep near confluence of MA and MB tributaries (Figures 4.2-1 and 4.2-2). No precipitates observed at seep.
- MB1, MB2, and MB3 – wet season seeps near confluence of MA and MB tributaries (Figures 4.2-1 and 4.2-2). No precipitates observed at seeps.
- MA38 and MA40 – wet season seeps below A4 stream location (Figures 4.2-1 and 4.2-2). Orange-brown precipitates were observed in-stream. This area was not sampled during the dry season survey, so is unknown if these are also a dry season seeps.
- MA44 and MA3 – wet and dry season seep just above Raymond Bear Falls (Figures 4.2-1 through 4.2-4). No precipitates observed at seeps.

The uppermost acidic seeps are locations MA17 and MA18 (wet season) and MA9 (dry season). These locations are just below in-stream sampling location Seep A. Although these seeps are not all in the same exact location, they represent a broad area in which groundwater seeps are entering Upper Middle Creek during the wet and dry seasons. The area exhibits heavy moss growth on the south side of the creek because of the seeping groundwater. These seep locations are of particular interest because they are much higher in the watershed than highly acidic seeps observed at the MA/MB confluence and below, and exhibit a more moderate pH (4.15 su – 4.87 su). However, laboratory sample MA17 did show cadmium, copper, and zinc concentrations indicative of MIW. Copper precipitates were observed in the stream bed adjacent to and below these seeps, which suggests inflow of copper from groundwater into the stream system. The higher pH of these seeps relative to the discharge from the Formosa 1 adit suggests that the water is a more diluted MIW and is from a different source such as seepage from the Formosa 1 adit WRD. One additional seep adjacent to Seep A, MA1/MA16 was identified during the dry/wet season surveys and the seep had white precipitates noted in the stream mixing zone. No metals data were collected from this location, so it is unknown if this was a fresh water (clean) seep or a MIW seep. However, the fact that Seep A water has near-neutral pH, very low metals, and that precipitates were observed in the mixing zone suggests that this could be an MIW seep. This location is upstream from MA17/MA18/MA9, but could be associated with the same contaminated groundwater source.

Seeps MB3, MA40 and MA44 had the highest metals concentrations with cadmium, copper and zinc concentrations ranging from 37 to 170 µg/L, 3,890 to 17,700 µg/L, and 7,670 to 34,000 µg/L respectively. The pH at these locations was also among the lowest of all sampled seeps with a range of 2.4-3.7 su. These severely impacted seeps are located at the confluence of the MA and MB drainage or below the confluence, suggesting that this is the area of greatest MIW discharge to the

surface. All of these seeps were located above Raymond Bear Falls. At the falls, the alluvial gravels that host the alluvial groundwater system of Upper Middle Creek are truncated by a bedrock outcrop. As a result of this bedrock geological feature, alluvial groundwater discharges to the surface upstream from Raymond Bear Falls. In this area upstream of the falls, ARD migrating though the alluvial groundwater system discharges to the surface and is expressed by MIW seeps. This occurrence can be seen especially with seeps MA3 and MA44, which are located just above the falls. The water quality of this seep area shows extremely low pH (2.40 su during the wet season), high conductivity (1,084 µS/cm during the wet season), and high concentrations of dissolved metals (sampled in wet season only). This is similar to water quality observed at the Formosa 1 adit.

Below Raymond Bear Falls, the water quality of Upper Middle Creek begins to improve. In-stream pH measured above the falls is at its lowest point within the Upper Middle Creek system. After this point, the pH of the stream begins to gradually increase as a result of fresh water seeps entering the system; these seeps are listed below:

- Seep at A9
- MA50
- MA6
- MA54

These seeps are higher pH (4.95 su to 5.73 su) than the adjacent stream. As a result of the dilution by fresh water, the pH of the stream locally increases, and aluminum precipitates form within the mixing zone of the creek and seep. The resulting increase in stream pH is only a few su, but is within the range of pH that causes aluminum to precipitate from solution, which is characterized by the white color.

Further downstream, sampling locations show a continuous increase in stream pH as a result of dilution. As the pH continues to increase, copper precipitates are observed as dissolved copper precipitates from the surface water. Further downstream, whitish precipitates are again observed, which may be indicative of zinc precipitating from the solution.

4.2.2.3 Lower Middle Creek

Two sample locations were monitored in Lower Middle Creek, MXR and M13.0. Sample location MXR was sampled four times. Exhibit 4.2-2 summarizes water quality observed at MXR during the dry and wet seasons to illustrate the changes in water quality that occur between the source area and sample location MXR, approximately 0.75 miles downstream. Measurements of pH at MXR are between 6.21 su and 6.28 su, and as expected, the aluminum, iron, and copper concentrations are very low relative to concentrations measured at the Formosa 1 adit. As discussed above, extensive areas of aluminum, iron, and copper precipitates were observed in the stream substrate of Upper Middle Creek, which illustrates sequestration of these COPCs from MIW into sediments. Concentrations of cadmium, copper, lead, and zinc are also lower, which may be related to precipitation, adsorption to iron oxides or organic matter, or dilution. At MXR, the water quality exceeds screening values for cadmium, copper, and zinc. Contaminant transport

downstream from MXR is associated both with dissolved COPCs in the water column and transport of precipitated or absorbed COPCs as suspended solids in the water column.

Sampling Location M13.0 was sampled once during the RI as shown in Table 4.2-1. At that location, surface water quality did not exceed the screening values. However, historical sample data at M13.0 indicate that effects to water quality have extended as far a M13.0.

Exhibit 4.2-2. Comparison of MXR Water Chemistry During Wet and Dry Season Sampling Events

Analyte	Dry Season Sampling		Wet Season Sampling	
	10/19/2009	10/28/2010	1/30/2010	1/24/2011
Aluminum (µg/L)	6.3 U	200 U	33.7 J	200 U
Cadmium (µg/L)	13	9.8	14.2	7.4
Copper (µg/L)	190	206	530	329
Iron (µg/L)	31.5 U	100 U	20.6 J	100 U
Lead (µg/L)	0.85 J	1.0 U	0.38 J	1.0 U
Zinc (µg/L)	2,230	2,020	3,260	2,150
pH (su)	6.21	7.8	6.28	6.51
Acidity (mg/L CaCO3)	10 U	10 U	10 U	10 U
Flow (gpm)	11.9	36.8	303	1,020

Notes: U= less than detection, J=Estimated

4.2.2.4 Piper Diagram Analysis

Piper diagram analysis is a method to compare water based on ratios of major ions. This approach is useful to identify MIW. The piper diagram in Figure 4.2-5 shows that the majority of samples are closely grouped with calcium (Ca^{2+}) is the predominant cation and sulfate (SO_4^{2-}) being the predominant anion. These calcium-sulfate waters are commonly associated with ARD, because ARD generation produces sulfate as sulfide minerals such as pyrite are oxidized. In contrast, water quality at location MA13 is calcium-bicarbonate water. This water is the least affected by MIW based on the piper diagram and the detailed water chemistry shown in Table 4.2-1. It was sampled once during January 2010 and shows low dissolved solids and pH of 5.92. MA13 is the uppermost observed seep in the MA drainage. It is located about 400 ft north and about 100 ft downhill of the Formosa 1 adit; water quality data suggest that this is not a MIW seep.

A group of four samples show intermediate chemistries on the piper diagram: M13.0, Seep A, and Seep at A9. These water chemistries indicate mixing of MIW with other non-affected water. Seep A (in-stream location) is located about 250 ft downslope from MA13 and is close to the uppermost perennial surface water in the MA drainage. Seep A is located above the MA/MB

confluence, and Seep A data show that, although the MB tributary may be an important contaminant transport pathway for MIW migration to Upper Middle Creek, contaminant transport pathways are active within the MA tributary upstream of the MA/MB confluence. The sampling site Seep at A9 is below Raymond Bear Falls in an area of Upper Middle Creek where the groundwater inflows are less affected than the stream. This also leads to mixing as demonstrated by the piper diagram. M13.0 is the most downstream location, and comparison of ion concentration shows that dilution has mitigated MIW impact at this point in the watershed.

4.2.3 South Fork Middle Creek

South Fork Middle Creek is the other major drainage affected by MIW from the Site. Source materials that contribute to ARD generation in this area are OU1 mine materials in the east encapsulation mound WRD, the illegal dump area, the encapsulation mound, milling and shop facility area, and the former ore and water storage area (Figure 1.3-2). OU1 mine materials in these areas are strongly ARD-generating, and contribute ARD to groundwater and surface water in response to precipitation and snow melt events. Direct runoff of ARD from OU1 mine materials into South Fork Middle Creek is not presumed to occur because of the long distance between the mine materials and perennial headwaters. The dominant contaminant transport pathway is thought to be infiltration of precipitation into OU1 mine materials, recharge of alluvial and bedrock aquifers, MIW transport through groundwater, and subsequent discharge of MIW from groundwater to surface water within South Fork Middle Creek. It is likely that the encapsulation mound leakage identified in Section 3 also contributes MIW discharge into South Fork Middle Creek.

Although it is possible that OU2 mine materials affect South Fork Middle Creek via some unknown groundwater transport pathway, there are no data to suggest that this is occurring. The closest underground workings are located approximately 1,500 ft north of the areas where MIW water discharges from groundwater to surface water in South Fork Middle Creek. Also as shown in Figure 3.1-2, the underground workings are entirely located west of the Silver Butte topographic divide. Assuming that a groundwater divide is present coincident with this surface water divide, groundwater is not expected to flow east from the underground workings toward the discharge areas on South Fork Middle Creek. In addition, the uppermost MIW spring on South Fork Middle Creek, SFA5, is located at an elevation of approximately 3320 feet, which is above the discharge point of the underground mine at the Formosa 1 adit at 3310 ft. Therefore, water within the underground mine would be expected to flow towards the discharge point at the Formosa 1 adit rather than towards South Fork Middle Creek. A groundwater monitoring well is included in SAP2 to further evaluate any potential connection between the underground workings and MIW discharges at the South Fork Middle Creek. However, this well has not yet been installed.

The following sections described surface water data collected at:

- SFA sub-drainage
- SFB sub-drainage
- Lower South Fork Middle Creek

- The 404 Adit

4.2.3.1 SFA Sub-Drainage

Sample locations in the upper portion of the SFA sub-drainage are located at the areas of MIW discharge, namely SFA5, SFA4, SFA3 and SFA2. Locations SFA3 through SFA5 are present where the South Fork road crosses the SFA sub-drainage, and the road cut intersects the alluvial aquifer system. MIW is readily observed at these locations to be flowing at the base of a transmissive zone of alluvium that overlies bedrock. At this interface, MIW discharge has eroded the alluvial systems and local pipe flow was observed. After the MIW discharges from the road cut and flows over the road (or through a culvert), it often re-infiltrates into the alluvial aquifer and travels in the subsurface until it discharges at the next lower road cut. The relationship between the alluvial and bedrock aquifers is unknown in the upper South Fork area, although it is possible that the bedrock aquifer in South Fork contributes flow to the alluvial system. The bedrock aquifer in the South Fork headwaters east of the encapsulation mound is strongly affected by MIW, and will be discussed in Section 4.3.

Site SFA5 is the upstream-most sampling point in the SFA sub-drainage. A laboratory sample was collected once during the wet season seep and spring survey in February 2010. Laboratory metals concentrations indicate that water quality at SFA5 is some of the most affected water sampled at the Site. Exhibit 4.2-3 compares the water quality measured at SFA5 to the water quality measured at the Formosa 1 adit during the wet season field activities in January/February 2010. This exhibit illustrates the affect of OU1 mine materials on surface water quality in relation to the affect of OU2 source materials present within the underground mine.

Exhibit 4.2-3. Comparison of SFA5 and Formosa 1 Adit Water Chemistry during the Wet Season 2010 Sampling

Analyte	SFA5: 2/2/2010	Formosa 1 adit: 1/26/2010
Aluminum (µg/L)	75,300	27,700
Cadmium (µg/L)	564	666
Copper (µg/L)	72,300	42,800
Iron (µg/L)	4,570	264,000
Lead (µg/L)	0.63 J	78.2
Zinc (µg/L)	126,000	146,000
pH (su)	3.25	2.15
Acidity (mg/L CaCO3)	1,600	1,200
Flow (gpm)	5.72	42.91

Notes: J=Estimated

The primary difference in the waters is a lower pH at the Formosa 1 adit and higher iron concentrations. Concentrations of aluminum, cadmium, copper, and zinc are quite high in both samples. It is thought that dilution or water-rock interactions have caused an increase in pH of the MIW discharging at SFA5 during the transport pathway from OU1 source materials towards South Fork via the groundwater system. This increase in pH reduces the solubility of iron and causes rapid precipitation of iron hydroxides (Nordstrom and Alpers 1999). The comparison shows that OU1 mine materials produce similar effects to water quality to OU2 mine materials present within the underground mine.

The metals concentration and conductivity gradually decrease and pH increases moving downstream from SFA5 to SFA4 to SFA3 and finally to SFA2, just above the confluence with the SFB sub-drainage. The data suggest that the most severely affected water is discharging to the surface furthest upslope, closest to the OU1 mine materials. As the MIW travels downgradient on the surface and in the alluvial aquifer system, less severe MIW, natural dilution, and/or water-rock interactions attenuate dissolved COPC concentrations. Inflows of unaffected water are documented at the SFE sub-drainage located southwest of the SFA sub-drainage. Unaffected alluvial groundwater was observed flowing at the interface between unconsolidated alluvial sediments and bedrock where the South Fork road intersects the SFE alluvial aquifer system during January/February, 2010 field activities. This water mixed downstream with the MIW discharge from the SFA alluvial aquifer.

4.2.3.2 SFB Sub-Drainage and Confluence of SFA Sub-Drainage

SFB is a largely unaffected sub-drainage located north of SFA. Field samples at seep locations throughout the SFB sub-drainage show very similar pH values, ranging from 6.16 to 6.59 su. Conductivity values cover a broader range, from 96 µS/cm at SFB12 to 750 µS/cm at SFB4 (average of wet and dry season value). The two lowest conductivity values are found at the very upper reaches of the sub-drainage, which suggest that the upper section of SFB is not affected. Conductivity values at SFB4, SFB5 and SFB6 are higher than background values (SFD1 and SFE1 sample results) but not as high as other MIW impacted areas. Metals concentrations at SFB4 on February 3, 2010 were: cadmium = 17.6 µg/L, copper = 44.9 µg/L, and zinc = 6,570 µg/L. When compared to values from SFA, metals concentrations at SFB4 are lower but they exceed screening criteria for cadmium, copper, and zinc. The seep conductivity data and SFB4 metals data suggest that MIW is entering the drainage in the lower section of SFB, before combining with SFA. This may be related to discharge of MIW affected groundwater to SFB.

The confluence of the SFA and SFB sub-drainages occurs just downstream from locations SFA2 and SFB14 and has been measured as location SFA8. Flow measurements at SFA2 and SFB14 were approximately equal during the wet season sampling event. After the confluence, a significant volume of white precipitate forms as a result of dilution of the acidic metal-laden water in SFA sub-drainage with the SFB sub-drainage water. Although a laboratory sample was not collected at SFB14, the pH and conductivity between SFA2, SFB14, and SFA8 can be compared for the wet season sampling event (See Exhibit 4.2-4). These results show the abrupt change in pH and conductivity of the SFA sub-drainage as a result of the dilution by the SFB sub-drainage.

Exhibit 4.2-4. Comparison of SFA2, SFB14, and SFA8 Field Results during the Wet Season 2010 Sampling

Location	pH (su)	Conductivity (µS/cm)
SFA2 (SFA upstream of confluence)	4.07	1,054
SFB14 (SFB upstream of confluence)	5.72	324
SFA8 (SFA downstream of confluence)	4.59	631

The laboratory results between SFA2 and SFA8 can also be compared to understand the composition of the precipiate produced by this mixing reaction and to review how metals are

being sequestered from MIW into sediments in this area of the Site. Select metal and other analyte results are shown in Exhibit 4.2-5. This comparison shows a large decrease in several dissolved metals in the SFA8 sample compared to the SFA2 sample. The decrease also includes major ions such as a calcium, magnesium, sulfate, and TDS. Although the composition of the precipitate is unknown, Exhibit 4.2-5 indicates that it contains a number of metal compounds, including a large amount of aluminum, copper, and zinc.

Exhibit 4.2-5. Comparison of SFA2 and SFA8 Water Chemistry during the Wet Season 2010 Sampling

Location	SFA2		SFA8	
Sample Date	2/3/2010		2/3/2010	
Total/Dissolved	T	D	T	D
Analyte	Result	Result	Result	Result
Aluminum (µg/L)	23,100	22,700	11,100	8,800
Cadmium (µg/L)	156	158	64	65
Calcium (µg/L)	105,000	103,000	66,900	66,200
Cobalt (µg/L)	36	36	15	15
Copper (µg/L)	16,000	16,000	5,870	5,770
Iron (µg/L)	60.9 U	59.3 U	346	46.2 U
Magnesium (µg/L)	38,400	38,000	23,500	23,300
Manganese (µg/L)	6,050	6,070	2,490	2,480
Nickel (µg/L)	148	148	61	63
Potassium (µg/L)	1,270 J	1,300 J	605 J	779 J
Sodium (µg/L)	7,310	7,310	5,690	5,880
Zinc (µg/L)	41,600	41,500	17,200	17,200
Sulfate (mg/L)		836		454
TDS (mg/L)	1,300		704	
TSS (mg/L)	2.1 U		21	
Flow (gpm)	62		151	

Notes: J=Estimated; U = non detect.

4.2.3.3 Lower South Fork Middle Creek

Sampling location SF1.0 is located in South Fork Middle Creek approximately 1 mile downstream from the OU1 mine materials area at the encapsulation mound. This sampling location is monitored on a biannual basis, and has been sampled four times. Surface water at SF1.0 exceeds screening criteria for cadmium, copper, and zinc. The water has neutral pH and moderate concentrations of TDS. Water quality screening criteria were exceeded for cadmium, copper and zinc for all sampling events including both dry season and wet season sampling. This suggests that the MIW discharge to upper South Fork Middle Creek is perennial, and supports the hypothesis that MIW discharges from bedrock groundwater to surface water within the upper reaches of South Fork Middle Creek.

4.2.3.4 404 Adit

The 404 adit is located above the headwaters of a sub-drainage to South Fork Middle Creek. This sub-drainage discharges to South Fork Middle Creek downstream of SF1.0. Surface water present at the 404 adit was sampled in October 2009 and February 2010. The water quality exceeds the

screening criteria for aluminum, copper, iron, lead, and zinc at least seasonally and exhibited pH of 2.53 to 3.49 su. However, the discharge rate from the 404 adit is low, ranging from 0.1 to 0.36 gpm. Effects to South Fork Middle Creek as a result of the 404 adit discharge have not been further assessed.

4.2.3.5 Piper Diagram Analysis

The major ion chemistry of samples collected within the South Fork Middle Creek watershed are plotted in a Piper diagram (Figure 4.2-10). Samples from SFA5, SFB4, and SFA8 plot as the calcium-sulfate water type (MIW). Conversely, water from sites SFD1 and SFE1 in tributaries to South Fork Middle Creek are calcium-bicarbonate waters that are not affected by MIW. Samples collected at sites SFB2 and SF1.0 are mixtures of mine-influenced calcium-sulfate waters and unaffected calcium-bicarbonate waters. The SFA sub-drainage is clearly shown to be affected, which was expected based on the known severe effects to bedrock groundwater quality, extensive groundwater surface water interactions, and presence of metal precipitates. In contrast, the SFB drainage appears to be less affected; however, water quality data from surface water sampling site SFB4 suggest that mine influenced groundwater may be present in the MB sub-drainage and is discharging to surface water.

4.2.4 West Fork Canyon Creek

West Fork Canyon Creek is located east of the Site, and historically has not been observed to contain MIW. Samples were taken during the wet and dry season in multiple sub-drainages closest to the Site to further investigate any possible impact. No known ARD sources are present within the West Fork Canyon Creek watershed.

Five locations were sampled, consisting of three laboratory sample locations and two field sample locations. Samples were taken in the following sub-drainages, listed in order from south to north, mostly along Road 30-6-35.0: West Fork A (WFA), West Fork C (WFC), West Fork E (WFE) and West Fork F (WFF). Additional sub-drainages were identified (West Fork B [WFB], West Fork D [WFD], and West Fork G [WFG]); however, no flow was observed in these areas during the RI. In smaller tributaries, the occurrence of surface water within these tributaries was commonly at areas where the road cut had truncated an alluvial groundwater system. Often this water re-infiltrated into the alluvial aquifer downslope from the road. See Figures 4-2.11 and 4-2.12 for wet and dry season sample locations with pH and conductivity values.

Piper analysis (Figure 4-2.13) of laboratory samples, SW5 (WFE), SW6 (WFF) and SW7 (WFC) shows calcium and bicarbonate as the predominant ions in all samples with very little sulfate present. This analysis and review of laboratory metals data indicate that these waters are not MIW. Metals concentrations in the laboratory samples were as follows: cadmium < 0.5 µg/L, copper < 2.5 µg/L and zinc < 60 µg/L. The average conductivity in laboratory and field samples was 104 µS/cm and average pH in laboratory and field samples was 7.07.

4.2.5 Russell Creek

Russell Creek is located north of the Site, and as with West Fork Canyon Creek, historically has not been observed to contain MIW. Samples were taken, mostly during the wet season, in multiple sub-drainages closest to the site to investigate any possible impact. The occurrence of

water within these tributaries was often within alluvial aquifers that were intersected by the road cut as described previously. No known ARD sources are present within the Russell Creek watershed.

Nine locations were sampled, consisting of two laboratory sample locations and seven field sample locations. Samples were taken in the following sub-drainages, listed from west to east: Russell Creek D (RCD), Russell Creek A (RCA), Russell Creek C (RCC), Russell Creek B (RCB) and Russell Creek E (RCE). Samples were taken along BLM Road 31-6-13.1 and BLM Road 31-06-12.2. See Figures 4-2.11 and 4-2.12 for wet and dry season sample locations with pH and conductivity values.

Piper analysis (Figure 4-2.14) of laboratory samples, SW3 and SW4, shows calcium and bicarbonate as the predominant ions in SW4 and magnesium and bicarbonate predominating in SW3. In both samples very little sulfate is present, similar to the West Fork Canyon Creek samples, and to other non-affected samples found around the Site. Metals concentrations in the laboratory samples were as follows: cadmium < 0.5 µg/L, copper < 18.7 µg/L, and zinc < 20.2 µg/L. The average conductivity in laboratory and field samples was 159 µS/cm, and the average pH in laboratory and field samples was 7.0. It is interesting to note that samples from sub-drainage RCD had conductivity ranging from 281 to 404 µS/cm and SW3 had some of the highest concentrations of magnesium of all samples taken. MIW indicating metals were low to non-detect in all Russell Creek samples and pH was near-neutral, which does not indicate MIW impacts in the Russell Creek drainage.

4.2.6 Cow Creek

Cow Creek receives water from the entire Lower Cow Creek watershed, a small part of which is flow from all the drainages listed above except West Fork Canyon Creek. Thus, all known MIW eventually drains into Cow Creek via Middle Creek. It is also the water source for the town of Riddle and a few other residences upstream of the town. Section 3 presented a description of the private residences and intakes. Cow Creek sampling locations are shown on Figures 4.2-15 and 4.2-16.

Five locations have been sampled in Cow Creek, all of which were laboratory samples. The most upstream location sampled was C1, which is located just upstream of the Middle Creek confluence, and therefore upstream of any MIW from the Site. Moving downstream, Chambers is the location of a private intake and was sampled during the wet and dry survey in 2009/2010. SW1 and SW2 were each sampled once as part of the October 2009 dry season sampling event. The furthest downstream sample location is the Riddle Intake which is one of the biannual sampling locations.

Average metals concentrations, conductivity and pH at all locations except C1 are as follows: cadmium < 0.5 µg/L, copper = 2.69 µg/L, zinc = 7.56 µg/L, conductivity = 142 µS/cm, and pH = 7.06 su. Average metals concentrations, conductivity and pH at C1 are as follows: cadmium < 0.5 µg/L, copper = 1.35 µg/L, zinc = 1.91 µg/L, conductivity = 116 µS/cm, and pH = 7.41 su. Generally, surface water quality in Cow Creek is at background concentrations or non-detect for MIW-related COPCs. These data indicate that although severe degradation to Middle Creek has occurred upstream, significant dilution by other drainages in the Cow Creek watershed are

mitigating the downstream effects. Very high relative flows in the Cow Creek system result in non-detectable levels of the majority of metals and other COPCs.

4.3 Groundwater

A limited discussion of the nature and extent of groundwater contamination is presented to support understanding of groundwater effects and groundwater/surface water interactions. This discussion is based on recent sampling at a limited number of wells. The nature and extent of groundwater contamination will be further evaluated when additional groundwater monitoring wells are installed and sampled during the OU2 RI.

Groundwater quality data used for this evaluation were collected at bedrock monitoring wells MW-2 and MW-5 and alluvial monitoring wells MW-7A, MW-13A, MW-15A, and MW-16A. In addition, this section describes data collected at the encapsulation mound piezometers, MW-22 and MW-23. These groundwater sampling activities are described in Section 2, and the monitoring well locations are shown in Figure 2.3-6. Physical characteristics of the groundwater systems including water level data are described in Section 3.4.

4.3.1 Groundwater Screening Criteria

Groundwater quality screening criteria are based on minimum groundwater quality protection requirements (GWPRs) established in OAR Chapter 340, Division 40 (OAR 340-40-020) - Department of Environmental Quality. The levels listed under OAR 340-40-020 were derived from the Safe Drinking Water Act and these levels indicate when groundwater is not suitable for human consumption or when aesthetic qualities (taste, odor, or color) of groundwater are compromised. Further screening of groundwater quality including comparison with surface water quality standards to address discharge of groundwater to surface water will be completed during the OU2 RI. The GWPRs, along with the groundwater monitoring well data, are listed in Table 4.3-2.

4.3.2 Data Evaluation

Preliminary evaluation of the nature and extent of groundwater contamination is based on evaluation of COPC concentrations in relation to screening levels and Piper diagram analysis. As discussed in the previous section with regard to surface water, Piper diagram analysis is useful to identify MIW based on the major ion concentrations.

The following sections describe:

- Bedrock groundwater;
- Alluvial groundwater; and
- Encapsulation mound water.

4.3.2.1 Bedrock Groundwater

Two bedrock monitoring wells were sampled during the RI, MW-2 and MW-5.

Bedrock Groundwater at MW-2

One existing monitoring well remains operable in the area of the Formosa 1 adit. Monitoring well MW-2 is 148 ft deep and located just west of the Formosa 1 Adit. Bedrock monitoring well MW-4 is also located in this area; however, this well has not been sampled since 2002, because the well is inoperable because of damage to the well casing.

The results for MW-2 listed in Table 4.3-2 indicate that TDS is the only constituent detected in groundwater that exceeds the screening criteria. The pH in groundwater is near-neutral ranging from 5.9 to 7.1 su. Metals associated with ARD including zinc, copper, and cadmium are present at relatively low concentrations, below respective screening criteria. Review of the Piper diagram presented in Figure 4.3-1 shows groundwater samples from MW-2 to plot in a range that suggests that the water may contain a mixture of calcium-sulfate water (MIW) and non-affected calcium-bicarbonate water. However, groundwater samples from MW-2 do not plot in the range of strongly mine-influenced waters such as SFA5 or the Formosa 1 adit.

Previous investigations (HC, ODEQ, and BLM) hypothesize that MIW is conveyed through the bedrock aquifer from the underground mine pool to Upper Middle Creek. Monitoring well MW-2 is generally located in the area between the underground mine and Upper Middle Creek and groundwater quality at MW-2 is significantly less affected by MIW than either the Formosa 1 Adit (located west of MW-2) or the groundwater discharging into Upper Middle Creek. The MW-2 groundwater quality data do not support this hypothesis, because the groundwater at MW-2 is near neutral pH with relatively low concentrations of metals. However, as discussed previously, groundwater transport in the bedrock aquifer is associated with relatively local zones of secondary porosity (e.g. fractures and fracture zones). There is potential that MIW could be transported in the bedrock aquifer towards Upper Middle Creek within discrete fracture zones that are not intercepted by MW-2. This hypothesis will be further assessed during the OU2 RI.

Bedrock Groundwater at MW-5

Monitoring well MW-5 is 100 ft deep and located on the southeast side of the encapsulation mound in the headwaters area of South Fork Middle Creek. The results for MW-5 presented in Table 4.3-2 indicate that the groundwater is strongly affected by ARD. Cadmium, copper, iron, manganese, zinc, sulfate, and TDS concentrations in the samples exceed respective GWPRs, in some cases by orders of magnitude. The pH in groundwater is strongly acidic and ranges from approximately 3.0 to 3.2 su. The Piper diagram presented in Figure 4.3-1 indicates that groundwater at MW-5 is calcium-sulfate type MIW.

Seep and stream sampling locations in the headwaters of the South Fork of Middle Creek are shown in Figure 4.2-6. Surface water quality in upper South Fork is affected by MIW that exhibits acidic pH of 3.2 su and high concentrations of sulfate and metals. Piper diagrams for the samples collected at these locations are shown in Figure 4.2-10. Comparison of the Piper diagrams for MW-5 with surface water sampling locations SFA5, SFB4, and SFA8 shows similar major ion ratios in these waters, which suggests that MIW detected within the bedrock aquifer at MW-5 may be discharging to the tributaries of the South Fork Middle Creek. ARD generated from the east encapsulation mound WRD, illegal dump area, episodic surface water runoff, and transport in the alluvial aquifer also contribute to contamination in South Fork Middle Creek.

4.3.2.2 Alluvial Groundwater

Groundwater monitoring well data collected at MW-7A, MW-13A, MW-15A, and MW-16A is discussed in this section. Available water quality data for MW-13A is limited to field water quality parameters collected in August 2010 and January 2011. The field water parameters are recorded on the Groundwater Purging and Sampling Field Data Sheets, which are provided in Appendix B.

MW-7A

Groundwater monitoring well MW-7A is completed within the alluvial aquifer along the axis of the MB drainage, directly downhill of the Formosa 1 adit. The MB drainage is a tributary drainage to MA, which extends from the Formosa 1 adit area downstream approximately 400 ft where it intersects the MA drainage. The MA drainage is the main stem of Upper Middle Creek. The presence of the alluvial aquifer within the MB drainage is confirmed by the groundwater observed at MW-7A and groundwater seeps and springs discharging along the MB drainage.

Field water quality measurements collected in January 2011 indicate that groundwater at MW-7A is highly acidic with a pH of 3.3 su and a conductivity of 3,516 µS/cm. These field measurements indicate that groundwater at MW-7A is affected by MIW. Laboratory data show that this water contains high concentrations of dissolved metals and is calcium-sulfate-type water. Similar water chemistry is observed at groundwater seeps located downstream of the MA/MB drainage. The water chemistry at MW-7A and groundwater seeps along the MB drainage suggest that the MB alluvial aquifer is recharged by MIW leaking at the Formosa 1 adit plug. Groundwater was observed at MW-7A in August and October 2010 and January 2011 suggesting that groundwater flow within the MB alluvial aquifer is perennial. Discharge of MIW at the Formosa 1 adit and transport in the MB alluvial aquifer represents a significant source of MIW to Upper Middle Creek.

MW-13A

MW-13A is completed within the alluvial aquifer in the MF drainage, west of the encapsulation mound. Sufficient groundwater has not been present at MW 13A to collect laboratory samples. Field water quality measurements collected in January 2011 indicate that groundwater at MW-13A has a near-neutral pH of 6.2 su and a conductivity of 696 µS/cm. The elevated conductivity suggests that this water may be MIW.

An opportunity sample was collected at a point where the alluvial aquifer discharged to surface water at the road cut just up-gradient from the monitoring well, which is thought to be representative of the alluvial groundwater quality at this location. This sample is called MF2, and water quality data are included in Tables 4.2-1 and 4.2-2. The data show that the alluvial groundwater water is near-neutral pH (5.58 su) and that most metals concentrations are less than the detection limit. However, the sample exceeded the screening criteria for zinc with a concentration of 2,260 µg/L and has a sulfate concentration of 418 mg/L. This supports the field data collected above and indicates that the water is MIW.

MW-15A

Groundwater monitoring well MW-15A is completed within the alluvium of Upper Middle Creek near the MXR surface water sampling location. The results for MW-15A listed in Table 4.3-2 indicate that manganese is the only constituent detected in groundwater that exceeds the screening criteria. pH measurements in August 2010 and January 2011 were 7.23 and 5.78 su

respectively. Metals associated with ARD including zinc, copper, and cadmium are present at relatively low concentrations, below respective GWPRs, with the exception of manganese and iron.The Piper diagram presented in Figure 4.3-1 indicates that groundwater at MW-15A is calcium-sulfate type water with a sulfate concentration of 99.9 mg/L. The major ion ratios shown in the Piper diagram for MW-15A indicates a similar water chemistry to surface water sampled at MXR (refer to Figure 4.2-5 for the Piper diagram for surface water at MXR). Based on this similar water chemistry, groundwater at MW-15A appears to be in hydraulic communication with Middle Creek.

MW-16A

Groundwater monitoring well MW-16A is completed with the alluvial aquifer of the SFB drainage. Field water quality measurements collected in January 2011 indicate that groundwater at MW-16A has a near-neutral pH of 5.2 su and a conductivity of 1,121 µS/cm. The well was sampled during January, 2011. The chemical data meet the screening criteria for all analytes expect pH and manganese. The data suggest that the alluvial groundwater at this location is MIW.

4.3.2.3 Encapsulation Mound Water

Water contained within the encapsulation mound was sampled in August 2010 and January 2011 at MW-22 and MW-23. This water is moderately acidic with a pH ranging from 4.0 to 4.4 su. The results for MW-22 and MW-23 listed in Table 4.3-2 indicate that arsenic, cadmium, copper, iron, manganese, zinc, selenium, sulfate, and TDS concentrations exceed respective screening criteria. Sulfate is present at particularly high concentrations ranging from 27,800 to 27,900 mg/L. The high sulfate levels reflect the oxidation of the large quantities of sulfide minerals contained in tailings and mine waste, which are known to be present within the encapsulation mound. Zinc concentrations are in the range of 3,410 to 6,500 mg/L. TDS levels ranges from 44,500 to 45,700 mg/L. The Piper diagram in Figure 4.3-1 indicates water at the encapsulation mound is magnesium-sulfate type MIW.

Section 5
Fate and Transport

Evaluation of contaminant fate and transport considers the processes that contribute to contaminant generation, transport and fate in the environment. This section is organized as follows:

- Fate and transport conceptual model (Section 5.1);
- Contaminant release mechanisms (Section 5.2);
- Contaminant fate and persistence (Section 5.3); and
- Potential routes of pollutant migration (Section 5.4).

5.1 Fate and Transport Conceptual Model

Two schematic diagrams describing contaminant fate and transport were introduced in Section 1.3.4 (Figures 1.3-3 and 1.3-4). These diagrams illustrate the current conceptual model of contaminant fate and transport processes for the Site, including areas/media currently designated as OU1 and OU2. Development of this conceptual model is an evolving process, particularly with regard to OU2. However, this model provides a conceptual framework to understand how mining-related contamination located near the top of Silver Butte has affected 18 miles of aquatic habitat within the Middle Creek watershed. Current site conditions are a result of numerous factors discussed previously in this RI report including mining and reclamation practices, geology and mineralogy, topography, climate, and surface water and groundwater hydrogeology. The model provides a conceptual framework, which combines historical information, observations and data collected during the RI into a coherent model to support future site remedial action decisions for OU1 and to guide future investigations for OU2.

Exhibit 5.1-1. Metal precipitates in Upper Middle Creek Drainage

Two major drainages that are severely affected by MIW are the Upper Middle Creek drainage and the South Fork Middle Creek drainage. The schematic diagrams (Figures 1.3-3 and 1.3-4) illustrate processes that contribute to contaminant generation, transport, and fate within these drainages, and describe how

these processes synergistically contribute to severe effects to water quality and aquatic habitat in the Middle Creek watershed.

5.1.1 Formosa 1 Adit and Upper Middle Creek

The Upper Middle Creek drainage is essentially devoid of aquatic life in its upper reaches near the Site. Extensive metal precipitates vary in extent from season to season and often cover the entire natural substrate of the stream as shown in Exhibit 5.1-1. These substances form as metals precipitate from MIW, which discharges from numerous springs and seeps within the MB and MA sub-drainages. The Upper Middle Creek fate and transport conceptual model presented previously as Figure 1.3-3 illustrates the current conceptual understanding of how metals originating in primary source materials are dissolved, transported, and discharged into Upper Middle Creek.

Primary source materials in the Upper Middle Creek area can be conceptualized in two categories:

- **OU1 source materials** are ARD-generating mine materials that contain sulfide minerals or that contain products of previous acid generation. These materials include waste rock, tailings, ore, construction rock, and comingled waste rock and natural soils that were discarded into waste dumps associated with the major mine adits and placed on access roads. OU1 source materials are characterized and delineated as OU1 mine materials as described in Section 4.1.
- **OU2 source materials** are ARD-generating mine materials that are within the underground mine. These include backfilled waste rock, ore, tailings, concentrates, and exposed rock surfaces within the underground mine workings.

5.1.1.1 OU1 Source Materials

OU1 source materials are ARD-generating and produce leachate containing dissolved concentrations of COPCs orders of magnitude above screening criteria. Accumulations of OU1 source materials are present at each of the adit portals, where waste rock was placed into dumps. OU1 source materials are also present on all roads within the primary mine disturbance area. To varying extents, the waste rock is mixed with construction fill and natural soils. OU1 source materials are subject to rapid water infiltration and oxygen ingress, which are the components required for ARD generation and contaminant migration.

As ARD moves through the environment, the pH and dissolved metals content gradually changes as the water interacts with soils and is diluted by other waters. Therefore, the more general term, MIW, is used to represent this water as it is transported away from the source areas. MIW is transported via runoff and infiltration to alluvial or bedrock groundwater. The alluvial groundwater system is a major contaminant transport pathway for MIW. These alluvial aquifers rapidly convey MIW towards surface water within Upper Middle Creek. Transient runoff of MIW via overland flow may also occur during occasional periods of heavy precipitation or snow melt.

Discharge of MIW from the bedrock aquifer into surface water may also contribute to contaminant migration in Upper Middle Creek, but this pathway is currently thought to be less important in terms of overall contaminant mass loading to surface water as compared to the

alluvial groundwater system. Bedrock aquifer water quality data in the Formosa 1 adit area is limited to one functioning well, MW-2. Data from this well does not show significant effects to bedrock groundwater quality as discussed in Section 4.3. However, other fracture flow pathways for MIW to move through the bedrock aquifer may be present within the bedrock aquifer in the Upper Middle Creek area, which are not monitored by MW-2.

5.1.1.2 OU2 Source Materials

OU2 source materials include backfilled waste rock, tailings, ore, concentrates, and exposed rock surfaces within the underground mine workings. Some waste rock was never hauled to the surface, and was placed into underground mine workings during mining. Additional waste rock, as well as tailings, ore, and concentrates were also hauled from the surface into the mine during reclamation. During mining operations, tailings were pumped into the mine in a slurry to provide ground support within mined-out workings. This slurry was then allowed to dewater once the tailings backfills were in place. Exposed rock surfaces within underground mine workings are also likely to contain sulfide minerals and be ARD-generating within some areas of the underground mine.

Three hydrogeochemical zones are present within the underground mine, which control ARD generation from OU2 source materials, and subsequent migration of MIW into the environment:

- The permanently unsaturated zone;
- The seasonally saturated zone; and
- The permanently saturated zone.

The saturated portion of the underground mine is termed the *mine pool*. As a result of water infiltration and oxygen ingress through near surface fractured bedrock and mine portals, the permanently unsaturated zone is highly active in ARD generation. Products of ARD generation are transported downward via unsaturated flow through both mine voids and bedrock fractures towards the mine pool and the Formosa 1 adit. Within the seasonally saturated zone of the mine, active ARD generation occurs during dry periods of the year when the mine pool water level is depressed. Products of ARD generation are then rinsed during relatively wetter periods of the year and flushed out of the underground mine workings into fractures and/or through the Formosa 1 adit when the mine pool water level increases. The underground mine is in hydraulic communication with surrounding bedrock, although a contrast in permeability is likely present between the open and backfilled tunnels of the underground mine workings and the fracture controlled bedrock aquifer. The rate of ARD generation is likely much lower within the permanently saturated zone, because the rate of oxygen diffusion though water is slow. Water within the permanently saturated portion of the mine pool is likely to be MIW; however, the water quality within this zone, the degree of hydraulic connection between the bedrock groundwater system and the mine pool, and the potential extent of contamination within the bedrock aquifer are unknown.

MIW discharges from the Formosa 1 adit on a perennial basis. The discharge flow rate varies seasonally, with highest flows observed during heavy precipitation periods of late fall though winter. Much of the underground mine is partially backfilled, and water flow from the

underground mine towards the Formosa 1 adit likely occurs through a combination of pipe flow and porous media flow processes. The observed increase in discharge rate at the portal is evidence of a greater hydraulic head between the adit portal and the mine pool during these relatively wetter months. This variation in discharge rate is evidence that the water level of the mine pool varies seasonally. The water quality of the discharge is poorest during periods of high flow (CDM 2009b). This supports the hypothesis that ARD generation is occurring throughout the year within the seasonally saturated underground mine workings, and that products of this ARD generation are flushed from the mine when the mine pool water level rises.

The IRAM adit diversion system is designed to capture MIW discharging from the Formosa 1 adit and to convey this water to a discharge area located distal to perennial surface water bodies. Based on analysis of seep and spring data and review of historical information regarding construction of the adit plug and the MIW collection system, it is hypothesized that only a portion of the MIW discharging from the Formosa 1 adit is collected by the system. The remainder of the MIW is thought to bypass the collection system and recharge the alluvial aquifer. This MIW flows subsurface within the alluvial aquifer and discharges as seeps and dispersed inflows to surface water in an area upstream from a resistant rock outcrop at Raymond Bear Falls, which truncates the Upper Middle Creek alluvial aquifer.

5.1.2 Encapsulation Mound and South Fork Middle Creek

The current fate and transport conceptual model for the encapsulation mound and South Middle Creek was shown in Figure 1.3-4. Water quality effects to surface water and groundwater are severe in this area. Numerous MIW seeps/springs are present within the upper drainages of South Fork Middle Creek. The bedrock aquifer beneath/adjacent to the encapsulation mound is also severely affected by MIW, with strongly acidic pH and zinc concentrations exceeding 100 mg/L.

Primary source materials in the encapsulation mound and South Fork Middle Creek area can be conceptualized as follows:

- Mine materials in surface and near surface piles and waste dumps, which exhibit generally similar geochemical characteristics to mine materials in the Formosa 1 adit, Silver Butte 1 adit, and other site WRD areas; and
- Mine materials within the encapsulation mound, a structure designed to encapsulate ARD generating source materials and prevent adverse effects to water quality, which is not fully functioning.

Surface and near-surface source materials are located east and west of the encapsulation mound, in the former water and ore storage areas, illegal dump area, and on road surfaces. Contaminant fate and transport processes in these areas are similar to those discussed above with respect to the Upper Middle Creek area.

As discussed in Section 3, the encapsulation mound is a former water and tailings storage pond, which was backfilled with mine materials and covered with a low-permeability cover system during mine reclamation. Mine materials within the encapsulation mound include tailings, which are extremely ARD-generating. The performance of this structure is suspect, because of severe

effects to groundwater at MW-5, the presence of MIW seeps downslope from the encapsulation mound in South Fork Middle Creek, observations of extensive erosion to the cover system, and observations from piezometers in the encapsulation mound.

Piezometers installed in the encapsulation mound indicate that the structure is saturated for the full depth of the former lined pond. Data collected during 2010 and 2011 show that the water level within the structure increases during high-precipitation months of November through May and decreases from June through September (period of record of available data). This shows that water is infiltrating into the structure and indicates that the cover system is compromised. It also shows that water is discharging from the lined pond during drier periods, which indicates that the former pond liner is leaking. Paste pH samples collected from saturated tailings stored within the base of the structure indicate the tailings are not generating strongly acidic conditions, in spite of very high ARD-generating potential. This indicates that saturated conditions are maintained at the base of the pond, which mitigates sulfide mineral oxidation and ARD generation. The location where the pond is leaking is unknown, although piezometer data indicates that the leak may be near the top of the pond liner system. Alternatively, the rate of water infiltration into the pond may be greater than the leakage rate, thereby maintaining saturated conditions in the former pond throughout the year.

The observed discharge of MIW from groundwater to surface water within South Fork Middle Creek may be associated with both the alluvial and bedrock groundwater systems. In contrast to the Upper Middle Creek area, where available data from one monitoring well shows that the bedrock aquifer is not affected by MIW, bedrock groundwater monitored east of the encapsulation mound is severely affected by MIW. In addition, discharge of MIW from the alluvial groundwater system to surface water is directly observed in the upper portion of the South Fork Middle Creek drainage. MIW present in the South Fork Middle Creek area is not currently thought to be related to the underground mine pool, based the on evaluation of the MIW seeps in relation to discharge point of the Formosa 1 adit, the distance of the workings from South Fork Middle Creek, the lack of underground workings within the South Fork Middle Creek watershed, and the known presence of other ARD source materials on the surface in the encapsulation mound area. However, it is possible that there is some unknown hydraulic connection between the mine pool and South Fork Middle Creek.

5.2 Contaminant Release Mechanisms

Evaluation of contaminant release mechanisms further illustrates important contaminant fate and transport processes affecting the Site. Contaminant release mechanisms are processes that cause COPCs to be released from source materials. These mechanisms are described in terms of:

- Sulfide oxidation and ARD generation;
- Development and dissolution of secondary acidity; and
- Remobilization of secondary precipitates and contaminated sediments.

5.2.1 Sulfide Oxidation and ARD Generation

Pyrite is a major contributor to ARD generation at mine sites worldwide, and it is important at the Site both in terms of direct ARD generation by pyrite, the effect of the products of pyrite oxidation on oxidation of other sulfide minerals, and the resultant release of COPCs from mine materials and transport into the environment. Pyrite generates acid by numerous reaction paths, but the following reaction paths are particularly important in understanding the affect of the ore mineralogy on ARD generation. The first important reaction is oxidation of pyrite to form ferrous iron (Fe^{2+}), sulfate and hydrogen (H^{+}) as follows:

$$FeS_2 + 3.5O_2 + H_2O \rightarrow Fe^{2+} + 2SO_4^{2-} + 2H^+$$

Pyrite oxidation via this pathway is an exothermic reaction producing heat energy, and is catalyzed by microbacteria.

In an oxidizing environment such as surface exposures of mine materials and vadose portions of the underground mine, the Fe^{2+} may oxidize to ferric iron (Fe^{3+}) as follows:

$$Fe^{2+} + 0.25O_2 + H^+ \rightarrow Fe^{3+} + 0.5H_2O$$

In surficial mine waste, the Fe^{3+} may precipitate as an amorphous to microcrystalline iron hydroxide or hydroxysulfate mineral (Nordstrom and Alpers 1999) or as one of a number of efflorescent ferrous and ferric sulfate minerals, which can quickly dissolve releasing stored acidity during periods of high precipitation. These minerals constitute secondary acidity, which strongly affects water quality and is readily measured by field methods such as paste pH. These pathways are likely occurring in areas of ARD-generating mine waste exposed on the surface at the Site.

Dissolved ferric iron may further react with pyrite and other sulfide minerals. Dissolved ferric iron is an aggressive oxidant that, when it reacts with sulfide minerals, generates significantly greater quantities of acid than generated by oxygen-driven oxidation alone (Plumlee 1999). Dissolved ferric iron may lead to acid generation and mineral dissolution within the saturated zone of the underground mine, in areas that are not exposed to oxygen in significant quantities.

Dissolved ferric iron may lead to increased acid generation from pyrite by the following reaction:

$$FeS_2 + 14Fe^{3+} + 8H_2O \rightarrow 15Fe^{2+} + 16H^+ + 2SO_4^{2-}$$

Other ore minerals present at the Site including chalcopyrite, sphalerite, and galena also have the potential to generate acid if ferric iron is the oxidant. These reaction paths are described below based on the work of Plumlee (1999) and Seal and Hammarstrom (2003).

$$CuFeS_2 + 16Fe^{3+} + 8H_2O \rightarrow Cu^{2+} + 17Fe^{2+} + 2SO_4^{2-} + 16H^+$$

$$ZnS + 8Fe^{3+} + 4H_2O \rightarrow Zn^{2+} + 8Fe^{2+} + SO_4^{2-} + 8H^+$$

$$PbS + 8Fe^{3+} + 4H_2O \rightarrow Pb^{2+} + 8Fe^{2+} + SO_4^{2-} + 8H^+$$

Although chalcopyrite, sphalerite, and galena do not generate acid when oxidized by oxygen, they oxidize when exposed to the surface environment. This reaction may lead to liberation of copper and/or zinc from the solid mineral lattice, which creates a source of these metals in the environment. These reactions are shown below.

$$CuFeS_2 + 2O_2 \rightarrow Cu^{2+} + Fe^{2+} + 2SO_4^{\ 2-}$$

$$ZnS + 2O_2 \rightarrow Zn^{2+} + SO_4^{\ 2-}$$

$$PbS + 2O_2 \rightarrow Pb^{2+} + SO_4^{\ 2-}$$

5.2.2 Development and Dissolution of Secondary Acidity

Acidity and metals/metalloids released by ARD generation and dissolved in ARD may stay in solution and be transported away from the source material, or they may precipitate in a variety of secondary mineral phases in close proximity to the source material. These secondary mineral phases represent secondary acidity, which develops in unsaturated void space that is in contact with the atmosphere but not actively flushed with water (Younger et al. 2002). Understanding processes associated with precipitation and dissolution of these secondary mineral phases is critical to understanding fate and transport of ARD-related contaminants.

Evaporation of ARD is an important factor controlling generation of secondary acidity. Evaporation occurs in response to local climatic conditions and as a result of heat generated by pyrite oxidation. When the solubility limit for sulfate and hydroxysulfate minerals is reached, products of acid generation (e.g., H^+, SO_4^{2-} Al^{3+}, Fe^{3+}, Cd^{2+}, Cu^{2+}, Zn^{2+}) begin to precipitate. Acidity and metals are commonly stored intermittently in the form of efflorescent iron sulfate minerals. These minerals may form within unsaturated zones of waste rock and tailings piles, on exposed rock surfaces within underground mine workings, or within non-acid-generating rock or soil exposed to ARD. These minerals essentially represent "dried" acidity, which will be released in the event that the rock or soil surface is exposed to water. They may form during relatively dry periods, dissolve in response to precipitation, move in surface or groundwater, and subsequently re-precipitate in another location.

Efflorescent iron sulfate minerals may precipitate at various stages of pyrite oxidation. Melanterite ($Fe^{2+}SO_4 \cdot 7H_2O$) is an example of an efflorescent iron-sulfate mineral that includes only ferrous iron. Romerite ($Fe^{2+}Fe^{3+}{}_2[SO_4]_4 \cdot 14H_2O$) is an example of an efflorescent iron-sulfate mineral that is composed of a mixture of ferrous and ferric iron. Coquimbite ($Fe^{3+}{}_2[SO_4]_3 \cdot 9H_2O$) is an example of an efflorescent iron-sulfate mineral that contains all ferric iron. Ferric iron released as a result of coquimbite dissolution can provide an oxidation source for pyrite even in saturated conditions. The mineral rhomboclase ($[H_3O]Fe^{3+}[SO_4]_2 \cdot 3H_20$) is essentially a stored form of sulfuric acid and ferric sulfate (Nordstrom and Alpers 1999).

Another common group of secondary minerals found at ARD-generating sites are alunite-jarosite group minerals, which are common secondary minerals observed within mine materials in OU1. Alunite-jarosite group minerals are described by the general formula $AB_3(SO_4)_2(OH)_6$, where 'B' is occupied by Fe^{3+} (jarosites) and Al^{3+} (alunites) and 'A' is occupied most commonly by K^+, Na^+, or

H_3O^+ (Baron and Palmer 1996). The alteration minerals are identified based on visual recognition as accumulations of pale yellow precipitates on the surfaces of ARD-generating rock. These yellow precipitates are particularly apparent on exposed surfaces of mine materials containing significant QSP fragments. However, the specific mineralogical composition of the alunite-jarosite group minerals cannot be identified without laboratory analyses. Alunite-jarosite group minerals form hydrogen acidity upon dissolution as shown below (Langmuir 1997):

$$AB_3(SO_4)_2(OH)_6 + 3H_2O \rightarrow 3B(OH)_3 + A^+ + 2SO_4^{2-} + 3H^+$$

Concurrently, mineral acidity (Fe^{3+} or Al^{3+}) can also be formed upon dissolution (Baron and Palmer 1996):

$$AB_3(SO_4)_2(OH)_6 + 6H^+ \rightarrow A^+ + 3B^{3+} + 2SO_4^{2-} + 6H_2O$$

Jarosite and other secondary sulfate minerals formed during oxidation of pyrite are strong acid buffers in ARD-generating mine waste, and can keep pH values in leachate at strongly acid conditions until the minerals are dissolved (Langmuir 1997).

Dissolution of secondary acidity may have profound effects on the chemistry of mine drainage as well as the performance of remedial actions. Within the underground mine, these secondary minerals are likely controlling the seasonal flush of metals and acidity from the Formosa 1 adit, which occurs during the late fall to winter period. As discussed in Section 3, during the summer months, the climate of the Site area is relatively dry and the discharge rate of ARD from the Formosa 1 adit is relatively low. Flows from the adit increase markedly in the high-precipitation period, and a flush of metals loading and acidity is released in conjunction with the high flow. During this period, it is likely that the water elevation within the mine pool increases flushing secondary acidity and associated metals into the Upper Middle Creek watershed. It is during this high-flow period that the extent of downstream effects to water quality within the Middle Creek watershed are most extensive, with adverse effects observed 13 miles downstream of the site at the confluence of Middle Creek with Cow Creek.

5.2.3 Remobilization of Secondary Precipitates and Contaminated Sediments

Secondary precipitates are generally forming in Upper Middle Creek and South Fork Middle Creek, which vary in composition and abundance throughout the year. At Upper Middle Creek, these precipitates vary in color from orange-brown, to whitish-grey, to bluish-green, to white with increasing distance from MIW discharge areas in Upper Middle Creek. This is thought to be related to precipitation of iron-rich, aluminum-rich, copper-rich, and zinc-rich solids (with respect to color observations) as the pH of MIW gradually increases through dilution and other processes. The abundance of precipitates and the location of the transitions between types of precipitates vary temporally. A large accumulation of whitish-grey precipitates are also located in South Fork Middle Creek below the confluence of SFA and SFB sub-drainages, which is also thought to be an aluminum and zinc-rich precipitate. Further details on metal solubility and precipitate formation is provided in Section 5.3.1 below to illustrate this important process which governs COPC sequestration from MIW into sediments within Upper Middle Creek and South Fork Middle Creek.

Both physical and hydrogeochemical dispersion of these precipitates downstream in the Upper Middle Creek and South Fork Middle Creek drainages is likely occurring. The extent of downstream dispersion of metals caused by re-dissolution of precipitates (hydrogeochemical dispersion) versus physical transport as suspended sediment (physical dispersion) is unknown. In addition, neither downstream extent of contamination in sediments nor the potential risks to humans or ecological receptors have been assessed. This assessment, should it be necessary, will be conducted as part of the RI for OU2.

5.3 Contaminant Fate and Persistence

Fate and persistence of COPCs released by ARD generation in the environment is controlled by water pH, changes in metal solubility and sequestration of COPCs into soils and sediments as MIW moves through the ecosystem. As MIW flows downstream, the pH of the water gradually increases, which reduces COPC solubility and leads to formation of precipitates and associated sequestration of metals from MIW into sediments. The term sequestration refers to geochemical processes that cause COPCs to accumulate or sequester into specific media such as sediments. Adsorption processes also lead to attenuation of COPC concentrations in MIW, and sequestration of COPCs within soils affected by MIW. Processes of precipitation and adsorption are also active in the discharge area for the IRAM adit water diversion system.

5.3.1 Metal Solubility

Acidity is a primary control on the solubility of metals. Low pH conditions caused by ARD increase the solubility of metals, such as iron, aluminum, cadmium, copper, and zinc. As discharged MIW moves throughout the environment, neutralization of ARD through mixing with unaffected waters and various water-mineral interactions reduces the solubility of metals and causes precipitation of amorphous to microcrystalline metal oxides, hydroxides, or hydroxysulfates (generally referred to as oxy-hydroxides). As the pH increases, different metal precipitates form at various pH ranges. The precipitation/dissolution reaction process can be generalized as follows for hydroxides (Stumm and Morgan 1996):

$$Me(H_2O)_x^{z+} + z(OH)^-(H_2O)_y \Leftrightarrow Me(OH)_{z(s)} + (x+zy)H_2O$$

In this equation, Me represents any of the major metal cations in solution. Stumm and Morgan (1996) present an approach to rearrange and solve this equation based on solution pH, solubility products, and metal concentrations. Figure 5.3-1 is a graphical representation of this approach, which displays the solubility equilibrium of several metals with oxide and hydroxide phases. This figure illustrates the pH ranges where dissolved metals would tend to precipitate as oxides or hydroxides under ideal conditions and where the metal ions are in equilibrium with the oxide or hydroxide phases shown. The point where the metals begin to precipitate (near bottom of graph) is characteristic of the specific metals. As shown, some metals of concern (such as cadmium and zinc) require the pH to be above neutral before they begin to precipitate from solution. Based on Figure 5.3-1 and information presented in Nordstrom and Alpers (1999), the pH ranges at which the major metals precipitate are as follows:

- Ferric iron oxy-hydroxide precipitates form at pH greater than approximately 3-3.5 su;

- Aluminum oxy-hydroxide precipitates form at pH greater then approximately 4.5-5 su;
- Copper oxy-hydroxide precipitates form at pH greater than approximately 6.5-7 su; and
- Zinc oxy-hydroxide precipitates form at pH greater than approximately 8-8.5 su.

The rate or extent that precipitates form in solution is dependent on a number of factors such as temperature, pressure, ionic strength, oxidation state, and the competing reactions and equilibrium condition of numerous hydrolysis species (hydrated metal ions such as $FeOH^{2+}$ or $Fe(OH)_2^{+}$). Generally for Formosa Mine waters, the high concentrations of metals in solution drive the precipitation reactions to completion quickly; hence, graphs such as on Figure 5.3-1 are good approximations of the behavior of metals emanating from seeps at the Site. In addition, the much higher concentrations of metals (nearing saturated conditions) can result in metal precipitation at pH values lower than the ranges presented above. This is important for zinc, which is present in Site MIW at extremely high concentrations, leading to precipitation at pH values less than 8 su. The detailed composition of the precipitates is not known; however, a pattern of mineral precipitate formation is observed at the Site. This pattern corresponds to gradually increasing pH conditions as MIW flows through the watershed and to the pH ranges presented above. Iron precipitates out of solution first, and forms orange precipitates. Iron precipitation is followed by aluminum (whitish-gray precipitates), copper (bluish-green precipitates), and zinc (white precipitates) as the pH of the water gradually increases through mixing and other processes.

The curves presented in Figure 5.3-1 are ideal and do not account for other hydrolysis species during the precipitation process, which affect metal solubility. Figure 5.3-2 presents the solubility diagrams for aluminum, iron, and zinc and displays the relationship to other hydrolysis products. The important component of these diagrams are the observed pH range of minimum solubility, which is observed as the low point of the dashed line curve. At the solubility minima pH range, metals tend to precipitate from solution. The amphoteric nature of metals is also displayed on these diagrams, where an increase in solubility is observed at either lower or higher pH from the minimum solubility pH range.

The diagrams in Figure 5.3-2 are also based on ideal solutions and the pH range of minimum solubility varies depending on several factors mentioned above. Therefore, solubility controls in Site MIW is expected to deviate from ideal conditions displayed on diagrams such as Figure 5.3-2. The important conclusion is that the pH at which the various metals begin to precipitate in Upper Middle Creek or South Fork Middle Creek is near the solubility minimum, and the solubility of COPCs gradually decreases as the pH increases. Therefore, some metals such as zinc and cadmium remain in solution at low concentrations that exceed screening criteria, governed by equilibrium conditions between various dissolved and solid phases, which are dependent on pH and other factors.

5.3.2 Attenuation of Dissolved Contaminant Loads through Adsorption

Adsorption is an important mechanism that affects fate and transport of contaminants within mine environments. The term sorption refers to removal of a solute from solution to a solid phase. Adsorption refers to two-dimensional accumulation of a solute on a solid surface (Smith

1999). Adsorption within mine environments is generally pH dependant, and pH changes caused by acid generation exert strong controls on partitioning of contaminants between the aqueous and solid forms. Important adsorbent materials include iron oxides and hydroxides, manganese oxide, clay minerals, and particulate organic matter.

Important adsorbent materials at the Site are iron hydroxide and hydroxysulfate precipitates. Iron is a major component of MIW solutions and precipitation of ferric iron occurs within the Upper Middle Creek drainage and at the discharge of the adit water diversion system. Under oxidizing conditions, this metal precipitation reaction occurs rapidly in response to an increase in solution pH. Extensive areas of these precipitates are present in the Formosa 1 adit area, adit diversion discharge area, and Upper Middle Creek. These precipitates are not commonly present in the South Fork Middle Creek drainage. Iron hydroxide precipitates at the discharge of the adit water diversion system and at pipeline leak areas contain the highest concentrations of arsenic on the site, which is caused by adsorption of arsenic to the iron precipitates formed by the MIW discharge.

The tendency for dissolved contaminants to adsorb is controlled by a number of factors, including the pH of the aqueous solution, the type and concentration of adsorbent material, the presence of competing adsorbate ions, formation of aqueous complexes, the concentration of surface binding sites on the adsorbent material, and the available surface area of the adsorbent material. The predominant factor affecting metal adsorption within mine environments is pH. Therefore, adsorbed COPCs may be released back into solution if pH or other conditions change. Adsorption delays transport of certain COPCs, but it may not permanently sequester COPCs into solid forms.

Iron oxides and hydroxides possess variable surface charges that control the tendency for adsorption of various cations and anions. The surface charge varies in response to the pH of surrounding solutions because of interactions between iron atoms on the surface of the adsorbent and water molecules. At acid pH, the surface charge is predominantly positive, which increases the tendency for anions, such as arsenate and selenate, to adsorb. At neutral to alkaline pH, the surface charge is predominantly negative, which increases the tendency for cations to adsorb. At some pH, the density of positively charged surface sites and negatively charged surface sites is equal. This point is termed the *point of zero charge* and is characteristic of the adsorbent material. At solution pH values above the point of zero charge, cation adsorption would predominate. At solution pH values below the point of zero charge, anion adsorption would tend to predominate. The point of zero charge for several adsorbent species is shown as Exhibit 5.3-1.

Exhibit 5.3-1. The pH of the Point of Zero Charge for Several Adsorbent Species, data compiled from Langmuir (1997)

Adsorbent Species	pH (Standard Units)
Hematite (Fe_2O_3)	4.2 to 6.9
Amorphous iron hydroxide ($Fe[OH]_3$)	8.5 to 8.8
Goethite (FeOOH)	5.9 to 6.7

The tendency of a metal or metalloid to partition to the solid phase by adsorption generally increases from near 0 to almost 100 percent over a pH range of 1 to 2 units (Smith 1999). However, the specific range of pH at which this occurs varies for each metal or metalloid. This

range is a characteristic of adsorbate ions for a given adsorbent, such as iron hydroxide. Curves showing the tendency for several pertinent cations to adsorb to iron hydroxide (Figure 5.3-3) (based on Younger et al. [2002]) show that copper tends to adsorb to iron hydroxide at a lower pH than zinc and cadmium. Zinc and cadmium are not 100 percent adsorbed until a pH range of 9 to 9.5 is reached. In contrast, arsenic which is present in solution as an oxy-anion tends to precipitate at pH conditions associated with iron hydroxide precipitation (i.e., greater than 3 to 3.5 su).

5.4 Potential Routes of Pollutant Migration

5.4.1 Runoff

Runoff is the proportion of precipitation that reports to area streams within days to weeks after a major precipitation event. Runoff can be conceptualized in terms of two components: overland flow and interflow. Overland flow is the component of runoff that flows over the land surface toward stream channels. Interflow is downslope movement of water within the subsoil/near-surface fractured bedrock zone. In the upper reaches of tributary drainages at the Site, interflow conveys runoff into the alluvial groundwater systems. It can also convey water directly into the stream or return to the surface for subsequent overland flow.

5.4.2 Groundwater

The extent of contamination in groundwater has not been characterized to date; however, alluvial groundwater is known to be contaminated in both the Upper Middle Creek and South Fork Middle Creek areas, and bedrock groundwater contamination is known to present in the area of the encapsulation mound.

5.4.2.1 Alluvial Groundwater System

The alluvial groundwater system is thought to be a major route of pollutant migration into surface water of Upper Middle Creek and South Fork Middle Creek. As discussed in section 4, this contaminant transport pathway is important for ARD generated by OU1 mine materials and within the underground mine. Direct evidence collected from MIW discharges from seeps and springs show that MIW is discharging from the alluvial groundwater system into surface water. This alluvial groundwater system is recharged by leachate from OU1 mine materials, leakage at the Formosa 1 adit portal, and discharge from the bedrock aquifer depending on the location within the tributary drainages. Recharge from leachate released from OU1 mine materials is likely ephemeral in nature, occurring in response to major precipitation events or snowmelt. Recharge from leakage at the Formosa 1 adit is likely perennial, but the recharge rate is expected to vary seasonally on a similar magnitude to seasonal variations in MIW measured at the adit portal. Recharge from the bedrock aquifer is likely perennial, but the locations where this recharge occurs within the tributary drainages likely varies seasonally in relation to variations in the water level of the bedrock aquifer.

5.4.2.2 Bedrock Groundwater System

Currently, little is known about the physical characteristics or nature and extent of contamination in the bedrock groundwater system. Only two bedrock monitoring wells are functioning, MW-2 near the Formosa 1 adit and MW-5 on the east side of the encapsulation mound. Groundwater

quality at MW-5 is severely affected by MIW, which shows that this pathway for COPC migration is pertinent at the Site. Groundwater quality at MW-2 is not affected by MIW based on available data, although it is unknown if a fractured pathway for groundwater movement from the mine pool is present that is not detected by MW-2.

5.4.3 Physical Dispersion

Physical dispersion of mine materials also contributes to pollutant migration. Numerous areas of large-scale downslope movement of mine materials are present as a result of very steep topography and relatively high precipitation rates during some periods of the year. Slope failure of mine material piles has likely occurred in the past based on observations at the Site, and additional failure is possible based on observation of a major tension crack along the road across the Silver Butte 1 adit WRD. Numerous areas of smaller scale slope-movement and erosion were also observed during RI characterization of mine materials and potentially affected soils. Erosion rills of up to approximately 5 ft deep are present in some dumps, and downslope transport by erosion has displaced mine materials tens to hundreds of feet downslope in several areas.

Physical dispersion by wind may occur to a small extent, but the texture of the surface mine materials is relatively coarse. Therefore, wind dispersion is thought to be less important than other processes in COPC migration, although this migration pathway is still addressed in the risk assessment. No specific analyses or sampling was completed to address this potential contaminant transport mechanism during the OU1 RI. Along the main site road areas, wind dispersion of road materials has likely occurred onto road side ditches and embankments. This dispersion pathway has likely caused elevation of metals concentrations in natural soils along the road embankments. This pathway was evaluated by collection of surface samples along embankments as described in Section 4, which indicates elevated metals in some of these embankment areas.

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Section 6
Risk Assessment

A baseline human health risk assessment (HHRA) and an ecological risk assessment (ERA) have been performed for OU1. The HHRA evaluated the potential for adverse human health and environmental effects to occur from exposure to site-related contaminants. The ERA assessed the risk of adverse effects to ecological receptors as a result of exposure to site-related contaminants.

Both the HHRA and ERA evaluate risk to site-related contaminants for OU1 based on three exposure areas (EAs). The EAs are defined as follows:

- *EA-1* – this EA represents the primary mine disturbance area of the Site, as defined by the mine materials boundary delineated and described in detail in Section 4.1. Surface and subsurface mine materials samples collected with the mine materials boundary are used for evaluation of EA-1, excluding FPXRF samples. Since some surface and subsurface samples were collected outside of the mine materials boundary, not all laboratory samples are utilized for the risk assessments. In addition, some surface samples are utilized to characterize EA-3, as described below. Therefore, only 50 out of the 60 "Pxxx" laboratory samples and 42 out of the 47 "SPxxx" laboratory samples are utilized to define EA-1.

- *EA-2* – this EA represents the area immediately downslope of mine materials defined as EA-1. The area was characterized to determine whether impacts are present beyond the mine materials boundary, and was sampled using an incremental sampling approach. EA-2 is composed of 11 DUs as shown on Figure 2.3-4, and three replicate incremental samples were taken from each DU. Each replicate incremental sample is comprised of subsamples taken from 30 or more distinct locations within the DU. Analytical results from the three replicate incremental samples from each DU were averaged to get the mean concentration for that DU. In the human health assessment, each DU is evaluated separately. In the ecological health assessment, the DUs are grouped together in two groups referred to as the upper and lower ribbons.

- *EA*-3 – This EA represents the visibly impacted areas from the adit water diversion system pipeline and drainfields. This EA includes both the current pipeline and previous pipelines which discharged adit water in a drainfield further upgradient from the current pipeline. EA-3 is shown on Figure 4.1-17a as the 'adit drainage and leak extent' polygons. A total of five surface soil samples

were collected to provide information regarding potential contamination in these areas. Four of these samples were "Pxxx" samples and one sample was an "XPxxx" sample. These samples were collected from visually impacted areas as evident by orange-colored iron precipitates; therefore, EA-3 only represents this visually impacted area. Other impacted soils not within this visual boundary are not included within EA-3. Further, it should be noted this is a dynamic area, as discharge continues. More accurate delineation cannot be completed until the discharge has been remediated and/or terminated. *Ris*ks for these EAs are presented in the following sections with respect to the conceptual site model (CSM) for human and ecological exposures, as presented in Figure 6.1-1. This CSM builds upon the fate and transport conceptual models presented in Sections 1 and 5, and includes a detailed presentation of exposure pathways and receptors. Complete exposure pathways are identified in the CSM figure, and these pathways are assessed in detail in the sections that follow.

6.1 Baseline Human Health Risk Assessment

The HHRA identifies COPCs in soil, evaluates exposure pathways by which people may contact these COPCs, identifies toxicity criteria for use in quantifying potential risks associated with exposure to the COPCs, and characterizes possible cancer risks and non-cancer health hazards associated with potential current and future exposures. Uncertainties in the risk assessment process are also discussed to provide an appropriate perspective for interpreting and using the results of the quantitative analysis.

The HHRA is developed according to guidance presented in the EPA Region 10 risk assessment staff memorandum dated April 17, 2007, as well as general EPA risk assessment guidance. Specifically, this assessment was prepared using guidance set forth in the following documents and reference materials:

- Risk Assessment Guidance for Superfund (RAGS): Human Health Evaluation Manual, Part A (EPA 1989);
- RAGS: Human Health Evaluation Manual, Part D, Standardized Planning, Reporting, and Review of Superfund Risk Assessments (EPA 2001);
- RAGS: Human Health Evaluation Manual, Part E, Supplemental Guidance for Dermal Risk Assessment. Final (EPA 2004b);
- RAGS: Human Health Evaluation Manual, Part F, Supplemental Guidance for Inhalation Risk Assessment. Final (EPA 2009d);
- Supplemental Guidance for Developing Soil Screening-Levels (SSLs) for Superfund Sites (EPA 2002);
- Regional Screening Levels (RSLs) (EPA 2010b);
- Integrated Risk Information System (IRIS) (on-line database of toxicity information) (EPA 2010c); and
- ProUCL Version 4.00.05 User's Guide (EPA 2010d).

The scope of this HHRA is OU1, and addresses mine material and soil contamination at the Site. This HHRA quantifies health risks associated with direct exposure to these materials. Note that for the HHRA, both mine materials and soils are referred to as 'soils' herein to simplify the assessment. Although contaminants from impacted soils may migrate to groundwater and surface water where humans can subsequently encounter them, consideration of these pathways is reserved for the OU2 HHRA which will address these media.

The remainder of this HHRA is organized according to the steps of the risk assessment, as follows:

- Section 6.1.1 presents Hazard Identification (Data Summary and Selection of COPCs);
- Section 6.1.2 presents the Exposure Assessment;
- Section 6.1.3 presents the Toxicity Assessment;
- Section 6.1.4 presents the Risk Characterization;
- Section 6.1.5 presents the Uncertainty Analysis; and
- Section 6.1.6 presents Conclusions.

6.1.1 Hazard Identification

6.1.1.1 Data Summary

Site characterization activities and data collected to support this risk assessment are discussed in earlier sections of this report. Analytical samples used for risk assessment purposes are shown in Tables 6.1-1 through 6.1-5 and described below. Analysis of pH of soils was also undertaken. There are no criteria with which to evaluate the health effects of soil pH directly; however, acidic water allows dissolution of higher concentrations of metals which can then be ingested by humans through drinking water. This method of exposure will be evaluated in the assessment for OU2.

Soil

EA-1. A total of 50 surface soil (0-6 in) samples and 42 subsurface soil (> 6 in) samples (excluding field duplicates) are utilized to define EA-1 for the HHRA. All soils were analyzed for inorganic constituents. Surface and subsurface sampling locations for EA-1 are shown on Figures 2.3-1 and 2.3-3 and analytical results employed in the HHRA are presented in Tables 6.1-1 (surface) and 6.1-4 (mixed surface and subsurface).

EA-2. A total of 11 surface soil (0-6 in) samples are utilized to characterize the contamination in soils from the area designated as EA-2. Sampling locations for EA-2 are shown on Figures 2.3-1 and 2.3-2 and analytical results employed in the HHRA are presented in Table 6.1-2. EA-2 is composed of 11 DUs as shown on Figure 2.3-4, and three replicate incremental samples were taken from each DU. Each replicate incremental sample is comprised of subsamples taken from 30 or more distinct locations within the DU. Analytical results from the three replicate incremental samples from each DU were averaged to get the mean concentration for that DU.

EA-3. A total of 5 surface soil (0-6 in) samples (excluding field duplicates) were collected to characterize contamination in soils from the area designated as EA-3. All soils were analyzed for

inorganic constituents. Sampling locations for EA-3 are shown on Figure 2.3-4 and analytical results employed in the HHRA are presented in Table 6.1-3.

Surface Water and Groundwater

Some constituents in soils from the Site have migrated to groundwater and surface water. Characterization activities at the Site have been undertaken to examine groundwater and surface impacts. However, the scope of the current risk assessment is limited to human health risks associated with direct contact with OU1 soils. Indirect contact with soil constituents via exposure to groundwater and surface water are to be addressed in a subsequent risk assessment directed at OU2. Therefore, other than a cursory screen to ascertain whether soils have impacted water to an extent necessary for further consideration, groundwater is not quantitatively considered further in this assessment. Sampling locations for water are shown on Figures 2.3-5a through c and 2.3-6. A screening comparison for select surface water locations is presented in Table 6.1-5 showing comparisons to several drinking water standards and if standards are not available, to risk-based criteria.

6.1.1.2 Selection of Contaminants of Potential Concern

COPCs are chemicals detected in Site media at concentrations that could pose a health risk. Identification of a chemical as a COPC does not indicate that such a health risk exists. Instead, identification as a COPC indicates that additional analysis in a quantitative risk assessment is needed.

Current Scenarios

To select COPCs for surface soil, maximum detected concentrations from surface soil samples collected from each of the EAs were screened against EPA's RSLs for industrial soil (EPA 2010b). Industrial screening levels were selected because residential use is not expected at this location, and recreational screening levels are not available. The frequency and duration of exposure for industrial users is expected to be greater than that for recreational users or trespassers; therefore, the use of industrial screening levels should be protective for these populations. The comparisons are shown in Tables 6.1-1 through 6.1-3. The resulting COPCs are examined in greater detail in the remainder of this risk assessment to assess possible hazards associated with exposure to these chemicals via direct contact for current site workers (such as forestry workers or fire lookouts), current trespassers or other visitors, and the indirect exposure of offsite residents via inhalation of windblown dust. Offsite residents are located approximately 3 miles away from the mine impacted areas and are likely unaffected by windblown dust but have been included in this assessment for completeness and protectiveness.

Future Scenarios

Future development of the Site while unlikely because of factors such as lack of power and winter access, is plausible. This development may be as simple as installing a fire watch tower or forestry worker cabin, or as involved as reopening mining activities. During this development phase, future construction workers may be exposed to surface and subsurface site soils. Also, following construction activities, site workers, trespassers, or other visitors may be exposed to disrupted site soils, and offsite residents may be exposed to windblown dust. To evaluate these potential exposures, maximum detected concentrations of samples from 0 in to 10 ft in depth were

screened against EPA's RSLs for industrial soil (EPA 2010b). This comparison is shown in Table 6.1-4.

Summary of COPCs

In surface soils, antimony, arsenic, copper, iron, lead, and mercury were selected as COPCs in EA-1 (Table 6.1-1); arsenic and manganese were selected as COPCs in EA-2 (Table 6.1-2); and antimony, arsenic, and iron were selected as COPCs in EA-3 (Table 6.1-3). In mixed surface/subsurface soil, antimony, arsenic, chromium, cobalt, copper, iron, lead, manganese, and mercury were selected as COPCs in EA-1 (Table 6.1-4).

6.1.2 Exposure Assessment

An exposure assessment describes the type and magnitude of possible current and future exposures to the COPCs for people that live, work, or visit a site. The results of the exposure assessment are later combined with chemical-specific toxicity criteria to characterize possible risks associated with these exposures. Presently, the site is used occasionally by forestry workers. In the future, limited use by forestry workers or fire lookouts may continue, or although there are challenges such as no power and limited winter access, the site may be developed for other uses, including continuation of mining activities. Because of lack of specific development plans, this HHRA evaluates possible risks a generic worker that may occupy the site on a limited basis as well as others that may occasionally visit there. Several categories of visitors were considered, including trespassers, hikers, campers, ATV riders, and hunters. Additionally, this HHRA considers possible exposures via windblown dust to residents that do not occupy the property but may live nearby. Presently, residents live approximately three miles from the mine impacted areas and as mentioned previously, are likely unaffected by windblown dust but have been included to err on the site of protectiveness.

Plausible routes of exposure for these populations to site-related contaminants were investigated. First, exposure pathways were identified by assessing the various ways in which receptors could be exposed to COPCs. Second, exposure scenarios were developed based on exposure pathways identified to be important for defining human health risk. Next, concentrations to which the populations may be exposed to each COPC via each potentially complete pathway were estimated. These concentrations are referred to as exposure point concentrations (EPCs). Finally, from estimated EPCs, potential average daily doses (ADDs) via ingestion and dermal contact were calculated. The ADD is expressed in terms of the mass of a substance in contact with the body per unit body weight per unit time, i.e., milligrams of a chemical per kilogram of body weight per day (mg/kg-day). Inhalation exposures were evaluated somewhat differently according to recent EPA guidance (EPA 2009d). For these pathways, exposure concentrations (ECs) were estimated. ECs are expressed in units of micrograms per cubic meter ($\mu g/m^3$) in air. ECs are then compared to acceptable air concentrations (UIRs and reference concentrations [RfCs]) published by EPA.

Each of these steps is presented in the sections below. The exposure pathways selected for evaluation are summarized in Figure 6.1-1. Assumptions used to estimate the extent of each receptor's exposure to soil are summarized in Table 6.1-6. The EPCs estimated for each COPC in site soil are summarized in Tables 6.1-7 through 6.1-10, and the values and equations for calculating ADDs are summarized in Tables 6.1-11 and 6.1-12a through 6.1-12c.

6.1.2.1 Exposure Pathways

An exposure pathway defines a unique mechanism by which receptors may be exposed to contamination. Each pathway consists of the following four primary components:

- A source and mechanism of chemical release to the environment;
- An environmental transport medium (e.g., surface soil);
- A point of potential human contact with the contaminated medium (exposure point); and
- An exposure route at the exposure point (e.g., dermal contact with surface soil).

If all four components are present, the pathway is considered complete. Both current and possible future exposures are considered. The CSM presents complete exposure pathways evaluated in this HHRA in graphical format (Figure 6.1-1). These pathways are discussed below.

Contaminants associated with historical operations at the Site may have been released to surface soil and subsequently leached to subsurface soil and groundwater. Under current conditions, occasional workers such as forestry workers or fire lookouts, as well as visitors that may frequent the property may come in direct contact with surface soils as well as inhale fugitive dust. Therefore, these populations were quantitatively evaluated for exposure via incidental ingestion of soil, dermal contact with soil and inhalation of dust particulates. In addition, exposure of an off-site resident to windblown dust particulates was examined. As mentioned previously, residents presently live approximately three miles from the mine impacted areas and are likely unaffected by windblown dust but have been included to err on the site of protectiveness.

In the future, if the Site were to undergo development from simply installing a forestry worker cabin or a fire watch tower to the more complicated task of reinstating the mining activities, construction workers involved in excavating activities may come in direct contact with contaminants in surface as well as subsurface soil. Therefore, a future construction worker exposure scenario was quantitatively evaluated. This scenario assumes that workers contact contaminants in surface and subsurface soils via incidental ingestion, dermal contact, and inhalation of fugitive dust.

If the Site undergoes development, future users of the Site, such as site workers and the visitor populations considered under current use scenarios may come in contact with mixed site soils and fugitive dust. Therefore, these populations were quantitatively evaluated for exposure via incidental ingestion of soil, dermal contact with soil, and inhalation of dust particulates from mixed surface and subsurface soils brought to the surface during redevelopment. As before, exposure of an offsite resident to windblown dust particulates was also examined to err on the side of protectiveness.

Soil contaminants may leach to groundwater or be transported overland to surface water which is subsequently used as a potable source. Groundwater is not currently used as a potable water source at the Site. However, downstream residents that use surface water as their potable water supply may be exposed to site related COPCs via ingestion. Therefore, this assessment includes a screening level evaluation of this exposure pathway and if appropriate, recommends surface water exposures be examined quantitatively in the OU2 risk assessment.

6.1.2.2 Exposure Scenarios

For a baseline HHRA, receptor populations of concern are characterized by individuals, whose activities represent full and unrestricted use of the Site assuming appropriate site land use. Quantitative estimation of exposure to such individuals should be conservative, meaning it should estimate exposures at the high end of those possible for the population. If such individuals are protected, the rest of the population will be protected as well. Therefore, reasonable maximum exposure (RME) scenarios were developed for current workers, visitors, and offsite residents as well as future construction workers, workers, visitors, and offsite residents to evaluate current and future exposures to Site soils.

In addition, more moderate estimates of exposure can be calculated and used for informational purposes in the discussion of uncertainties. Therefore, for this assessment, central tendency exposure (CTE) scenarios were also developed for the current worker, visitor, and offsite resident scenarios as well as future construction worker, site worker, visitor, and offsite resident scenarios. Exposure assumptions for the RME and CTE evaluation of the receptors' exposure to soil are summarized in Table 6.1-6.

As presented in Table 6.1-6, for a current outdoor worker such as a forestry worker or fire lookout, the RME scenario assumes a soil ingestion rate of 100 milligrams per day (mg/day) for 40 days per year for 25 years. The CTE scenario assumes the same soil ingestion rate but for 20 days per year for 7 years. Both scenarios assume for the assessment of dermal contact with soil that workers have an exposed skin surface area of 3,300 square centimeters (cm^2) but the RME assumes a soil adherence factor of 0.2 milligrams per square centimeter (mg/cm^2) while the CTE scenario assumes a soil adherence factor of 0.02 (EPA 2004b).

For current site visitors, the RME scenario assumes a soil ingestion rate of 100 mg/day for 14 days per year (2 weeks per year). The CTE scenario assumes the same soil ingestion rate but for 7 days per year (one week per year). Both scenarios assume for the assessment of dermal contact with soil that adults have an exposed skin surface area of 5,700 cm^2 but the RME scenario assumes a soil adherence factor of 0.07 mg/cm^2 while the CTE scenario assumes a soil adherence factor of 0.01 mg/cm^2. Both scenarios assume children 7-16 years old have an exposed skin surface area of 4,000 cm^2 and a soil adherence factor of 0.3 mg/cm^2 (EPA 1997 and EPA 2004b, respectively).

For current offsite residents, the RME scenario assumes an inhalation exposure 24 hours per day for 350 days per year for 30 years (24 years as an adult plus 6 years as a child))(EPA 2002). The CTE scenario assumes an inhalation exposure 24 hours per day for 234 days per year for 11 years for adults (9 years as an adult plus 2 years as a child)(EPA 1997).

For the future construction worker scenario, a soil ingestion rate of 330 mg/day was assumed. This rate is relative high, but appropriate for short term and potentially intense soil exposure. For assessment of dermal contact with contaminated soil, an exposed skin surface area of 3,300 cm^2 and a soil adherence factor of 0.3 mg/cm^2 were used according to assumptions presented in Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites (EPA 2002). The RME scenario assumed an exposure frequency of 250 days per year for one year while the CTE scenario assumed an exposure frequency of 130 days per year for one year.

For the future site workers, visitors, and offsite resident, the RME and CTE exposure assumptions are the same as those listed for the current exposure scenarios.

6.1.2.3 Exposure Point Concentrations

EPCs represent concentrations of COPCs to which receptors may be exposed. EPCs are a critical input factor to calculations of chemical exposure. Typically, EPCs are estimated as the upper one-sided 95 percent confidence limit of the arithmetic mean (95 percent UCL) to help reduce the chance that the actual average concentration is underestimated. For this assessment EPCs were UCLs as calculated by EPA Software ProUCL version 4.0.05 (EPA 2010d) for data sets with 10 or more data points. For smaller data sets, the maximum detected concentration for each COPC was selected as the EPC.

Antimony, arsenic, copper, iron, lead, and mercury were selected as COPCs in surface soil in EA-1 where 50 samples were collected (Table 6.1-1). ProUCL was used to calculate surface soil EPCs for these COPCs (Table 6.1-7).

Arsenic and manganese were selected as COPCs in surface soil in EA-2 where 11 samples were collected (Table 6.1-2). ProUCL was used to calculate surface soil EPCs for these COPCs. Specifically, the three incremental samples from each of the 11 areas were averaged and the UCL was calculated on the 11 results. If the chemical was reported as all non-detect in an area but detected in other areas the average of the quantitation limit for the non-detect was used in the EPC calculation (Table 6.1-8). In the Uncertainty Analysis Section 6.1.5, the areas are examined individually.

Antimony, arsenic, and iron were selected as COPCs in surface soil in EA-3 where five samples were collected (Table 6.1-3). Because of the small sample size (less than 10), the maximum detection was taken as the EPC for these COPCs (Table 6.1-9).

For the future scenarios, it was assumed the receptors could be exposed to surface as well as newly excavated subsurface soils in EA-1. EPCs, therefore, were calculated for COPCs in mixed surface soil and subsurface soil. Antimony, arsenic, chromium, cobalt, copper, iron, lead, manganese, and mercury were selected as COPCs in the mixed surface/subsurface soils (Table 6.1-4). ProUCL was used to calculate EPCs for these chemicals (Table 6.1-10).

Because no quantitative risk evaluation is performed for impacts to groundwater, EPCs were not calculated.

6.1.3 Toxicity Assessment

This section provides the scientific information that correlates chemical intake (dose) to expected health effects (response) for both noncarcinogens and carcinogens. This information is generally summarized in the form of toxicity criteria that are used in risk assessments. The following presents the recommended EPA hierarchy of toxicity values used in this risk characterization:

1. Tier 1 – EPA's IRIS (EPA 2010c);
2. Tier 2 – EPA's Provisional Peer Reviewed Toxicity Values (PPRTVs) – Office of Research and Development/National Center for Environmental Assessment/Superfund Health Risk

Technical Support Center develops PPRTVs on a chemical-specific basis when requested by EPA's Superfund program; and

3. Tier 3 – Other Toxicity Values – includes additional EPA and non-EPA sources of toxicity information. Priority is given to those sources of information that are most current, the basis for which is transparent and publicly available and which has been peer reviewed. For this assessment, in addition to the Tier 1 and Tier 2 sources above, toxicity values developed by the California Protection Agency were employed in this HHRA.

6.1.3.1 Health Effects Criteria for Potential Carcinogens

For chemicals that exhibit carcinogenic effects, EPA recognizes that more than one molecular event must occur to transform a cell from its normal state into a cancerous one. However, EPA regulates carcinogens using a non-threshold concept that assumes that a single change to the genome of a cell can initiate the carcinogenesis process. This non-threshold theory of carcinogenesis therefore assumes that any level of exposure to a carcinogen is associated with some finite possibility of causing cancer. Generally, regulatory agencies assume that the non-threshold hypothesis for carcinogens holds regardless of information concerning mechanisms of carcinogenic action for the chemical.

The carcinogenic potential of a chemical is expressed as a cancer slope factor (CSF) (in units of inverse milligrams chemical per kilogram body weight per day [mg/kg body weight-day)]-1), which estimates the risk of cancer per unit dose. When a slope factor is multiplied by an estimate of lifetime ADD of a potential carcinogen (in milligrams chemical per kilogram body weight per day [mg/kg body weight-day]), the result is an estimate of the excess lifetime cancer risk (ELCR) associated with exposure at that dose. ELCR is generally expressed in scientific notation and as a probability. An ELCR of 1×10-6 (one in one million), for example, represents the incremental probability that an individual will develop cancer as a result of exposure to a carcinogen over a 70 year lifetime under specified exposure conditions.

Carcinogens are also categorized with respect to the strength of the evidence of carcinogenicity. Three major factors are considered in characterizing the overall weight of evidence for human carcinogenicity: (1) the availability and quality of evidence from human studies, (2) the availability and quality of evidence from animal studies, and (3) other supportive information which is assessed to determine whether the overall weight of evidence should be modified. Carcinogens have often been grouped into the following five categories based on strength of this evidence:

- Group A- Human Carcinogen: There is at least sufficient evidence from human epidemiological studies to support a causal association between an agent and cancer.
- Group B - Probable Human Carcinogen: There is at least limited evidence from epidemiological studies of carcinogenicity in humans or, in the absence of adequate data in humans, there is sufficient evidence of carcinogenicity in animals.
- Group C - Possible Human Carcinogen: There is inadequate evidence of carcinogenicity in humans.

- Group D - Not Classified: There is inadequate data or no existing data for the chemical.
- Group E - No Evidence of Carcinogenicity in Humans: There is no evidence of carcinogenicity in at least two adequate animal tests in different species or in both epidemiological and animal studies.

The EPA 2005 Cancer Guidelines (EPA 2005) update previous versions and suggest a slightly different approach to categorizing carcinogens. These guidelines emphasize the value of understanding the biological changes a chemical can cause and how these changes might lead to the development of cancer. They also discuss methods to evaluate and use such information, including information about an agent's postulated *mode-of-action*. Mode-of-action data, when available and of sufficient quality, may be useful in drawing conclusions about the potency of an agent, its potential effects at low doses, whether findings in animals are relevant to humans, and which populations or life stages may be particularly susceptible. In the absence of mode-of-action information, default options are available to allow the risk assessment to proceed.

The EPA cancer guidelines (EPA 2005) recommend an agent's human carcinogenic potential be described in a *weight-of-evidence narrative* rather than the previously identified categories. The narrative summarizes the full range of available evidence and describes any conditions associated with conclusions about an agent's hazard potential. For example, the narrative may explain that an agent appears to be carcinogenic by some routes of exposure but not others (e.g., by inhalation but not ingestion). Similarly, a hazard may be attributed to exposures during sensitive life stages of development but not at other times. The narrative also summarizes uncertainties and key default options that have been invoked.

The following five standard hazard descriptors are still used in the newest guidelines:

- Carcinogenic to humans;
- Likely to be carcinogenic to humans;
- Suggestive evidence of carcinogenic potential;
- Inadequate information to assess carcinogenic potential; and
- Not likely to be carcinogenic to humans.

However, requirements for in-depth analysis of mode-of-action data and other modifying information preclude the use of these descriptors to place chemicals into categories as was done previously.

6.1.3.2 Health Effects Criteria for Non-carcinogens

For chemicals that exhibit non-carcinogenic (e.g., systemic) effects, organisms have repair and detoxification capabilities that must be exceeded by some critical concentration (threshold) before the health effect is manifested. This threshold view holds that a range of exposures from just above zero to some finite value can be tolerated by the organism without an appreciable hazard of adverse effects.

Health criteria for chemicals exhibiting non-carcinogenic effects for use in risk assessment are generally EPA-derived reference doses (RfDs) and RfCs. The RfD or RfC is an estimate of average daily exposure or exposure concentration to an individual (including sensitive individuals) that is likely to be without appreciable risk of deleterious effects during a lifetime. The RfD is expressed in units of mg/kg-day, while the RfC is expressed in units of milligrams chemical per cubic meter of air (mg/m^3). RfDs and RfCs are usually derived either from human studies involving workplace exposures or from animal studies and are adjusted using uncertainty factors to ensure that they are unlikely to underestimate the potential for adverse non-carcinogenic effects to occur.

Uncertainty factors reflect scientific judgment regarding the various types of data used to estimate the RfD/RfC and generally consist of multiples of factors ranging from 1 to 10. For example, a factor of 10 may be introduced to account for possible differences in response between humans and animals in prolonged exposure studies. Other factors may be used to account for variation in susceptibility among individuals in the human population, use of data from a study with less-than-lifetime exposure, and/or use of data from a study that did not identify a no-observed-adverse-effect level (NOAEL).

RfDs and RfCs provide benchmarks against which estimated doses (i.e., those projected from human exposures to various environmental conditions) are compared. Specifically, EPA uses the benchmark of a hazard quotient (HQ) and/or hazard index (HI) =1 as the point of departure for non-cancer risks. Doses that are significantly higher than the RfD/RfC may indicate an increased potential of hazard from the exposure (that is, HQ and/or HI greater than one), while doses that are less than the RfD/RfC are unlikely to be associated with adverse health effects. It should be noted that an exceedance of the RfD/RfC does not provide an accurate estimate of the likelihood of adverse effects. It only reflects an increased potential hazard for non-cancer health effects.

6.1.3.3 Summary of Toxicity Criteria

Tables 6.1-13 and 6.1-14, respectively, summarize the oral and dermal CSFs and inhalation unit risk values used to estimate cancer risks for the COPCs, and Tables 6.1-15 and 6.1-16a, b, and c, respectively, summarize the RfDs and RfCs used to estimate non-carcinogenic effects for the COPCs. These criteria are the most current data, obtained from the November 2010 online version of IRIS and sources listed in EPA RSL table (www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/index.htm).

6.1.4 Risk Characterization

Risk characterization is the final quantitative step in the risk assessment process. In this step, the results of the hazard identification, exposure assessment, and toxicity assessment are integrated to yield quantitative measures of cancer and non-cancer (threshold) risk.

6.1.4.1 Carcinogenic Risk Characterization

For potential carcinogens via the oral/dermal route of exposure, ELCR are obtained by the following equation:

ELCR = LADD x CSF

where:

ELCR = Excess lifetime cancer risk associated with exposure to the chemical via the specified route of exposure (unitless)

LADD = Lifetime average daily dose (mg/kg-day)

CSF = Cancer slope factor (mg/kg-day)-1

In evaluating the potential cancer risks, it is assumed that the potential toxicity of chemicals is additive. Thus, cancer risks attributable to each chemical are summed for each receptor to obtain an estimate of total ELCR.

The ELCR is a unitless probability of an excess cancer rate due to contamination from the Site. Since EPA values for CSFs are calculated at a 95 percent upper confidence level, risks are likely fall in the upper range of those possible. Thus, risks associated with exposure to a potential carcinogen are not likely to be underestimated by use of CSF, and could be overestimated.

6.1.4.2 Non-carcinogenic Risk Characterization

Non-carcinogenic risk is measured in terms of an HQ for exposure to a single chemical and an HI for exposure to multiple chemicals. The HQ for oral/dermal exposures is defined by the equation:

HQ = ADD/ RfD

where:

HQ= Hazard quotient associated with the exposure via the specified exposure route (unitless)

ADD = Average daily dose (mg/kg-day)

RfD = Reference dose (mg/kg-day)

In evaluating non-carcinogenic risk, it is assumed that potential toxicity of chemical mixtures is additive. Thus, HQs attributable to each chemical are summed for each receptor to obtain a cumulative HI. A cumulative HI represents the cumulative non-carcinogenic impact that the Site has on a particular receptor group. The cumulative HI accounts for exposures that a receptor may receive from multiple chemicals and multiple exposure routes.

The HI is a unitless ratio of a receptor's exposure level (or dose) to the "acceptable" or allowable exposure level. EPA uses a benchmark HI of 1 as a point of departure for non-cancer risk. A HI of 1 or less indicates that the receptor's exposure is equal to or less than the allowable exposure level, and it is considered unlikely that adverse health effects will occur. When the cumulative HI is less than or equal to 1, a conclusion of "no significant risk" of harm to human health based on non-cancer effects is appropriate. An exceedance of the RfD/RfC reflects an increased potential hazard for non-cancer health effects but does not provide an accurate estimate of the likelihood of adverse effects. Futhermore, the level of concern does not increase linearly as the RfD/RfC is approached or exceeded because these values do not have equal accuracy or precision and are not based on the same severity of toxic effects. Thus, the slopes of the dose-response curves in excess of the toxicity value can range widely depending on the substance.

6.1.4.3 Summary of Carcinogenic and Non-carcinogenic Risk

Total risks are shown in Table 6.1-17 through Table 6.1-32 and summarized in Table 6.1-33 through Table 6.1-36 for each of the receptors currently or potentially exposed to COPCs in the soils at the Site. The risk calculations for each exposure scenario are discussed further below.

Current Outdoor Worker Scenario

EA-1. Total ELCR from exposure to surface soils for the outdoor worker in EA-1 in the RME case is 1E-05 (Tables 6.1-17 and 6.1-20). In the CTE case, the risk is reduced to 1E-06. Both of these values fall within the risk range of 1E-06 to 1E-04. The risk is solely due to arsenic and primarily due to oral exposure.

Total HI associated with exposure to surface soils for the outdoor worker in EA-1 in the RME case is 0.1 (Tables 6.1-23 and 6.1-26). In the CTE case, the total HI was 0.04. Both of these values are below the acceptable HI limit of 1.

EA-2. Total ELCR from exposure to surface soils for the outdoor worker in EA-2 in the RME case is 2E-06 (Tables 6.1-18 and 6.1-21). In the CTE case, the risk is reduced to 2E-07. These values fall within or below the risk range of 1E-06 to 1E-04. The risk is solely due to arsenic and primarily due to oral exposure.

Total HI associated with exposure to surface soils for the outdoor worker in EA-2 in the RME case is 0.02 (Tables 6.1-24 and 6.1-27). In the CTE case, the total HI was 0.01. Both of these values are below the acceptable HI limit of 1.

EA-3. Total ELCR from exposure to surface soils for the outdoor worker in EA-3 in the RME case is 6E-05 (Tables 6.1-19 and 6.1-22). In the CTE case, the risk is reduced to 7E-06. These values fall within or below the risk range of 1E-06 to 1E-04. The risk is solely due to arsenic and primarily due to oral exposure.

Total HI associated with exposure to surface soils for the outdoor worker in EA-1 in the RME case is 0.48 (Tables 6.1-25 and 6.1-28). In the CTE case, the total HI was 0.21. Both of these values are below the acceptable HI limit of 1.

Current Visitor Scenario

EA-1. Total ELCR from exposure to surface soils for the adult and child visitor in EA-1 in the RME case are 4E-06 and 3E-06, respectively (Tables 6.1-17 and 6.1-20). If the visitor also participated in ATV riding activities, the inhalation risk increased but the overall risk remained 4E-6. In the CTE case, risks for the adult and child visitor are 2E-06 and 1E-06, respectively. Again, if the visitor also participated in ATV riding activities, the inhalation risk increased but the overall risk remained 2E-06. These risks fall within the range of 1E-06 to 1E-04. The risk is solely due to arsenic and primarily due to oral exposure.

Total hazard indices for the adult and child visitor in the RME case are 0.03 and 0.06, respectively (Tables 6.1-23 and 6.1-26). If the visitor also participated in ATV riding activities, the inhalation HI increased but the overall hazard remained 0.03. In the CTE case, the total hazard indices are 0.02, 0.03, and 0.2, respectively. All of these values are below the acceptable HI limit of 1.

EA-2. Total ELCR from exposure to surface soils for the adult and child visitor in EA-2 in the RME case are 6E-07 and 4E-07, respectively (Tables 6.1-18 and 6.1-21). In the CTE case, risks for the adult and child visitor are 3E-07 and 2E-07, respectively. These risks fall below the range of 1E-06 to 1E-04. The risk is solely due to arsenic and primarily due to oral exposure.

Total hazard indices for the adult and child visitor in the RME case are 0.01 and 0.01, respectively (Tables 6.1-24 and 6.1-27). In the CTE case, the total hazard indices are 0.004 and 0.006, respectively. All of these values are below the acceptable HI limit of 1.

EA-3. Total ELCR from exposure to surface soils for the adult and child visitor in EA-3 in the RME case are 2E-05 and 1E-05, respectively (Tables 6.1-19 and 6.1-22). In the CTE case, risks for the adult and child visitor are 1E-05 and 7E-06, respectively. These risks fall within or below the range of 1E-06 to 1E-04. The risk is solely due to arsenic and primarily due to oral exposure.

Total hazard indices for the adult and child visitor in the RME case are 0.16 and 0.3, respectively (Tables 6.1-25 and 6.1-28). In the CTE case, the total hazard indices are 0.08 and 0.15, respectively. All of these values are below the acceptable HI limit of 1.

Current Offsite Resident Scenario

EA-1. Total ELCR from exposure to windblown dust from EA-1 for the offsite resident in the RME case is 7E-07 and in the CTE case is 2E-07 (Tables 6.1-17 and 6.1-20). These values are below the risk benchmark of 1E-06.

Total HI for the offsite resident from exposure to dust from EA-1 in the RME case is 0.025 and in the CTE case is 0.016 (Tables 6.1-23 and 6.1-26). These values are below the acceptable HI limit of 1.

EA-2. Total ELCR from exposure to windblown dust from EA-2 for the offsite resident in the RME case is 8E-08 and in the CTE case is 2E-08 (Tables 6.1-18 and 6.1-21). These values are below the risk benchmark of 1E-06.

Total HI for the offsite resident from exposure to dust from EA-2 in the RME case is 0.11 and in the CTE case is 0.08 (Tables 6.1-24 and 6.1-27). These values are below the acceptable HI limit of 1.

EA-3. Total ELCR from exposure to windblown dust from EA-3 for the offsite resident in the RME case is 2E-06 and in the CTE case is 5E-07 (Tables 6.1-19 and 6.1-22). These values are within or below the risk range of 1E-06 to 1E-04.

Total HI for the offsite resident from exposure to dust from EA-3 in the RME case is 0.07 and in the CTE case is 0.05 (Tables 6.1-25 and 6.1-27). These values are below the acceptable HI limit of 1.

Future Construction Worker Scenario

Total ELCR for the exposure of a future construction worker to surface/ subsurface soils in EA-1 in the RME case is 7E-06 and in the CTE case is 4E-06 (Tables 6.1-29 and 6.1-30). These values are within the risk range of 1E-06 to 1E-04.

Total hazard indices for the exposure of a future construction worker to surface/subsurface soils in EA-1 in the RME case is 2 and in the CTE case is 0.9 (Tables 6.1-31 and 6.1-32). The RME value exceeds the acceptable HI limit of 1. The hazard is associated with oral exposure and primarily due to arsenic (61 percent), iron (16 percent), and to a lesser extent copper, cobalt, and antimony (less than 7 percent each). The hazard indices segregated by target organ are all below 1.

Future Outdoor Worker Scenario

Total ELCR from exposure to surface soils for the outdoor worker in EA-1 in the RME case is 9E-06 (Tables 6.1-29 and 6.1-30). In the CTE case, the risk is reduced to 1E-06. Both of these values fall within the risk range of 1E-06 to 1E-04. The risk is solely due to arsenic and primarily due to oral exposure.

Total HI associated with exposure to surface soils for the outdoor worker in EA-1 in the RME case is 0.09 (Tables 6.1-31 and 6.1-32). In the CTE case, the total HI was 0.04. Both of these values are below the acceptable HI limit of 1.

Future Visitor Scenario

Total ELCR from exposure to surface soils for the future adult and child visitor in EA-1 in the RME case are 4E-06 and 2E-06, respectively (Tables 6.1-29 and 6.1-30). If the visitor also participated in ATV riding activities, the inhalation risk increased but the overall risk remained 4E-6. In the CTE case, risks for the adult and child visitor are 2E-06 and 1E-06, respectively. Again, if the visitor also participated in ATV riding activities, the inhalation risk increased but the overall risk remained 2E-06. These risks fall within the range of 1E-06 to 1E-04. The risk is solely due to arsenic and primarily due to oral exposure.

Total hazard indices for the future adult and child visitor in the RME case are 0.03 and 0.06, respectively (Tables 6.1-31 and 6.1-32). If the visitor also participated in ATV riding activities, the inhalation HI increased but the overall hazard remained 0.03. In the CTE case, the total hazard indices are 0.01, 0.03, and 0.2, respectively. All of these values are below the acceptable HI limit of 1.

Future Offsite Resident Scenario

Total ELCR from exposure to windblown dust from EA-1 for the offsite resident in the RME case is 7E-07 and in the CTE case is 2E-07 (Tables 6.1-29 and 6.1-30). These values are below the risk benchmark of 1E-06.

Total HI for the offsite resident from exposure to dust from EA-1 in the RME case is 0.07 and in the CTE case is 0.05 (Tables 6.1-31 and 6.1-32). These values are below the acceptable HI limit of 1.

6.1.5 Uncertainty Analysis

Methods used and assumptions made in assessing potential human health risks are subject to a certain degree of uncertainty. Each step in the risk characterization process has associated uncertainties as described below. Site specific uncertainties are also discussed.

6.1.5.1 Data Evaluation and Sample Representativeness

Soil sampling locations were distributed throughout the Site. In EA-1, surface soil samples were collected from 50 locations and subsurface soils were collected from 42 locations. In EA-2, samples were collected from 11 DUs and at least 30 locations in each DU were sampled. Therefore, the sampling in these areas likely captured representative concentrations of the COPCs. However, for completeness and to address uncertainty, the concentrations and risk estimates by sampling unit are provided in Table 6.1-35. In EA-3, five samples were collected and showed little variability. However, the sampling was concentrated within the visibly impacted adit drainfield areas and as pH changes with distance other metals may precipitate father from the source. Additional sampling may be needed in areas downgradient of EA-3 and/or in the subsurface soils and groundwater below EA-3. Greatest contributors to risk and hazard estimates in all three EAs were arsenic and iron.

Current investigations described impacts to groundwater and surface water. It is likely that some constituents reported in surface and subsurface soils represent a threat to groundwater. While some data are available to address such impacts, doing so is outside the scope of the assessment of OU1. These impacts will be addressed in the assessment for OU2.

6.1.5.2 Exposure Assessment

Exposure assumptions for each exposure scenario are provided with the intention of reflecting reasonable maximum exposure (RME case). It is unlikely exposures would exceed exposures based on these assumptions.

EPCs are also calculated to reflect reasonable maximum exposures. In cases where more than 10 samples are available, the EPC is based on a 95th UCL estimate of the mean. However, in cases where fewer than 10 samples are available the EPC is the maximum measured concentration. Generally use of maximum detected concentrations and the assumption that the concentrations are widespread are factors likely to overestimate the risk associated with exposure to soils. However, in this assessment, the maximum concentrations were used only for EA-3 where five samples were available but little variability was observed. The lowest concentration of arsenic among the five samples was 247 mg/kg, only two-fold less than the maximum. The five sample results seem likely to have adequately characterized typical arsenic concentrations in the immediate vicinity of the adit outfall. Because pH changes downslope from the outfall may cause increased precipitation of metals, more characterization of this area may be needed.

EPCs for arsenic used to evaluate both cancer and non-cancer health effects associated with exposure assume a bioavailability of 100 percent. However, a number of studies suggest arsenic from soil is less available for gastrointestinal and dermal absorption than previously assumed. Relative bioavailability values for 14 soil samples obtained from 12 different contaminated sites as measured in nonhuman primates (cynomolgus monkeys) ranged from 0.05 to 0.31 (5-31 percent), with most values in the 0.1-0.2 (10-20 percent) range (Roberts, et. al. 2007). Estimates based on data from soluble forms of arsenic freshly mixed with soil indicate that percutaneous absorption of arsenic from soil ranges from 3.2 to 4.5 percent of the dermally applied dose. Additionally, the solubility of arsenic in soil varies, depending on the provenance of the soil, the source of the arsenic, and the chemical interaction of arsenic with other minerals present within the soil matrix. Weathering produces forms of arsenic that are more tightly bound within the soil

and less available for absorption. These findings are consistent with current understanding of the environmental chemistry of arsenic, wherein arsenic can be present in soils in complexed mineral forms. As the arsenic present at the Site is weathered, the bioavailability and hence the EPCs for arsenic are likely overestimated.

EPA Region 10 has issued a policy statement regarding arsenic bioavailability (EPA, 2000). This statement suggests the use of default bioavailability for arsenic of 60 percent. While this may be a reasonable estimate for the Formosa site, there is some uncertainty due to the high acidic nature of the soil. Therefore, to err on the side of public health, a bioavailability of 100 percent is assumed in this assessment as a conservative measure and is expected to overestimate the risk associated with arsenic exposure.

EPCs for indirect exposure such as dust inhalation are estimated by modeling. It should be noted this type of modeling is uncertain and hence contributes uncertainty to the risk estimates. In the case of offsite residents, a screening level assessment was performed to determine if adverse health effects were predicted. More detailed modeling could then be undertaken to refine the risk estimates. However, as adverse health effects were not expected, no refinement in the modeling was considered necessary.

In this assessment, cancer risk estimated for all receptors is due to arsenic. In EA-1, the arsenic concentrations ranged from 0.41 to 778 mg/kg and the EPC used was 105 mg/kg. The majority of the samples had arsenic concentrations between 50 and 200 so it is unlikely the EPC drastically over or under estimated the mean concentration. In EA-2, incremental sampling was conducted. Again, while some locations may have arsenic concentrations higher or lower than those evaluated, it is unlikely the EPC drastically over or under estimated the mean concentrations. Table 6.1-35 shows the cancer risks for each incremental sampling area within EA-2. As discussed above, in EA-3 where only five samples were available, the arsenic concentrations varied less than three fold. Therefore, it is unlikely the EPC drastically over or underestimated the mean concentration.

In this assessment, unacceptable non-cancer exceedances are limited to the RME case of the future construction worker scenario and are due primarily to arsenic (61 percent) and iron (16 percent). As discussed previously, arsenic is likely less bioavailable than the 100 percent assumed for this assessment, further lowering the expected health effects. The iron concentration evaluated (56,000 mg/kg) is similar to that reported for background concentrations in Oregon (50,000 mg/kg; EPA 2003). Moreover, hazard indices when segregated by target organ are less than 1.0 for all tissues and organs. Therefore, site-related exposures seem unlikely to be associated with non-cancer hazards for any receptors evaluated.

In this assessment, soil influence on groundwater/surface water and subsequent exposure of receptors was not quantitatively assessed. A comparison of surface water concentrations to health based criteria and regulatory criteria indicate surface water is affected by site-related releases. Groundwater and surface water exposures will be addressed in the risk assessment conducted for OU2.

6.1.5.3 Dose Response Assessment

The dose-response assessment step of a risk characterization involves the estimation of the toxicological effects of a chemical on humans and is often based on quantitative laboratory studies. Two potentially significant sources of uncertainty are animal to human extrapolation and high dose to low dose extrapolation. As an example, CSF estimates are derived from the results of human epidemiology studies or chronic animal bioassays. The animal studies are conducted for a range of doses, including a high dose, to detect possible adverse effects. Since humans are expected to be exposed at lower doses than those used in animal studies, the data are adjusted via mathematical models. Data from animal studies are typically fitted using a linearized multistage model to obtain a dose-response curve at low levels of exposure. EPA evaluates a range of possible models based on the available data before conducting the extrapolation. The most appropriate model to reflect the data is selected based on an analysis of the data set. The 95 percent UCL slope of the dose-response curve, subject to various adjustments and an inter-species scaling factor, is usually applied to derive a health protective CSF estimate for humans. For human epidemiological studies, dose-response data are fitted to dose-time-response curves. These models provide rough, but reasonable, estimates of the upper limits on lifetime risk. Overall, assumptions are made using best professional judgment and scientific literature on toxicity assessment. Toxicological criteria are derived with margins of safety relative to the degree of uncertainty in the value. Risk estimates based on these criteria are likely to be conservative; that is, they will tend to err on the side of protection of public health. Therefore, actual hazards and/or risks associated with exposures to chemicals in the environment are unlikely to be higher than those calculated using the toxicity values in this assessment, and they could be considerably lower.

In addition, there is a degree of uncertainty due to fact that some chemicals do not have toxicity data for the assessment of risk. For example, limited information is available for some chemicals and EPA does not recommend assessing dermal exposure for those chemicals. Therefore, the lack of a dermal assessment for some chemicals may underestimate the exposure via this pathway. Conversely, as mentioned previously, because of reduced bioavailability, the dermal exposure for arsenic is likely overestimated.

6.1.5.4 Risk Characterization

In general, uncertainty is inherent in the risk characterization step by adding hazard indices and cancer risks across chemicals and media for each receptor. This assumption of additive risk from multiple chemical exposures may overestimate or underestimate risk since actual interactions among chemicals may be synergistic or antagonistic rather than additive.

6.1.6 Conclusions

Current workers, visitors, and possible offsite residents were quantitatively evaluated for exposure to surface soils at the Site. Future construction workers, workers, visitors, and offsite residents were quantitatively evaluated for risks to surface and subsurface soils. Estimated cancer risks for all populations both current and future, fall within or below the EPA acceptable risk range of 10-4 to 10-6. Estimated non-cancer hazards segregated by target organ are below the acceptable hazard benchmark of 1.0.

6.1.6.1 Current Condition Assessment

EA-1 is the primary mine disturbance area which represents the main area of mining impacts at the Site. Estimated cancer risks for current onsite workers in EA-1 are equal to 1E-05 or less. Estimated cancer risks for current visitors (adult and child) in EA-1 are equal to 4E-06 or less. Estimated risks for offsite residents exposed via inhalation to windblown dusts from EA-1 are below the risk benchmark of 1E-06. In all cases, the risks are due to arsenic and the estimated site related risks for all populations fall within or below the EPA acceptable risk range of 10-4 to 10-6. Estimated non-cancer hazards for these populations are below the acceptable hazard benchmark of 1.0.

EA-2 represents the areas downslope of mine materials in EA-1. Estimated cancer risks for current onsite workers in EA-2 are equal to 2E-06 or less. Estimated cancer risks for current visitors (adult and child) in EA-2 and offsite residents exposed via inhalation to windblown dusts from EA-2 are below the risk benchmark of 1E-06. In all cases, the risks are due to arsenic and the estimated site related risks for all populations fall within or below the EPA acceptable risk range of 10-4 to 10-6. Estimated non-cancer hazards for these populations are below the acceptable hazard benchmark of 1.0.

EA-3 represents the visibly impacted areas (e.g., visible iron precipitates) of the historic and current adit water diversion system pipelines and drainfields. Estimated cancer risks for onsite workers in EA-3 are equal to 6E-05 or less. Estimated cancer risks for visitors (adult and child) in EA-3 are equal to 2E-05 or less. Estimated risks for offsite residents exposed via inhalation to windblown dust from EA-3 are 2E-06 or less. In all cases, the risks are due to arsenic and the estimated site related risks for all populations fall within or below the EPA acceptable risk range of 10-4 to 10-6. Estimated non-cancer hazards for these populations are below the acceptable hazard benchmark of 1.0.

6.1.6.2 Future Condition Assessment

Estimated cancer risks for future construction workers exposed to surface as well as subsurface soils in EA-1 are equal to 7E-06 or less. Estimated cancer risks for future onsite workers in EA-1 are equal to 9E-06 or less. Estimated cancer risks for future visitors (adult and child) in EA-1 are equal to 4E-06 or less. Estimated risks for offsite residents are below the risk benchmark of 1E-06. Therefore, the estimated site related risks for all populations fall within or below the EPA acceptable risk range of 10-4 to 10-6. In all cases, the risks above 1E-06 were due to arsenic.

Estimated non-cancer hazard for future construction workers exposed to surface as well as subsurface soils in EA-1 in the RME case is 2; however, when segregated by target organ, individual hazard indices are all below the acceptable hazard benchmark of 1.0. In the CTE case, the hazard is below the acceptable hazard benchmark of 1.0. Estimated non-cancer hazards for future onsite workers and future visitors (adult and child) exposed to surface/subsurface soils and offsite residents exposed via inhalation of windblown dust from EA-1are all below the acceptable hazard benchmark of 1.0.

In summary, human health risks greater than 10-6 because of exposure to soils are likely site related but limited to arsenic. All estimated excess cancer risks fall within EPA's acceptable risk range of 10-4 to 1 0-6. All estimated non-cancer hazards segregated by target organ fall below

EPA's benchmark of 1.0. Groundwater and surface water exposures may contribute to human health risk and will be examined quantitatively in the risk assessment conducted for OU2.

6.2 Ecological Risk Assessment

ERAs evaluate the likelihood that adverse ecological effects may occur or are occurring at a site as a result of exposure to single or multiple chemical stressors. Risk of such effects result from *contact* between ecological receptors (e.g., plants and animals) and stressors (e.g., mining-related contaminants) that are of sufficiently long duration and of sufficient intensity to elicit adverse effects. The primary purpose of an ERA is to identify and describe actual or potential onsite conditions stemming from releases of chemical contaminants that can result in adverse effects to existing or future ecological receptors.

Following EPA Superfund Guidance (EPA 1997), ERAs may be comprised of a screening level ERA (SLERA) and, where indicated, a baseline ERA (BERA). SLERAs are used to evaluate chemicals of interest (COI) to preliminarily identify COPCs and receptors, and to estimate risks using a conservative approach. COIs include all potentially hazardous chemicals detected, while COPCs include a subset of COIs associated with potential to contribute to adverse ecological effects, based on comparisons to ecological screening levels (ESLs). For this ERA, COPCs with the greatest potential to cause or contribute to ecologically significant adverse effects are termed chemicals of concern (COCs) (EPA 1997).

Where risks appear likely, based on the results of the SLERA, a BERA is often warranted. According to EPA (EPA 1997), the BERA is a more detailed effort that:

1. Refines the list of SLERA COPCs to identify final COCs;
2. Refines EPCs and in some cases effects data;
3. Identifies ecological receptors and selects a subset of representative receptors for full assessment; and
4. Estimates risks to representative ecological receptors using a less conservative approach than the SLERA based on multiple lines of evidence.

The ERA for OU1 includes the SLERA and the initial step of the BERA process, commonly referred to as Step 3a. Step 3a of the ERA process for Superfund sites is a refinement step of the ERA that reduces uncertainties and the level of conservatism in exposure data and assumptions to provide more realistic estimates of risk.

The magnitude and extent of mining-related contamination of OU1 surface soil and mine materials, the types of contaminants, and the likelihood of exposure for some ecological receptors clearly support conclusions of ecological risk for OU1. Although this ERA identifies elevated risk estimates based on preliminary and conservative data evaluations, it is assumed that the decision to terminate the ERA process for OU1 at the SLERA/ERA Step 3a stage and that a BERA need not be performed for OU1 will be supported by the following reasons:

- Limited Habit Quality and Quantity in OU1: Exposures for terrestrial ecological receptors associated with OU1 are likely limited by the disturbed and generally unsuitable habitats.

- Limited Exposure Potential in OU1 and Planned Remedial Action for OU1: Remedial actions are currently planned to reduce exposures to OU1 surface soils and mine materials, and such actions will substantially change conditions in OU1 such that current assessments will not reflect near future conditions.
- Characterization of the Contamination of OU1: OU1 surface soil and mine materials serve as potential sources of risk to terrestrial and especially aquatic ecological receptors associated with downgradient environments in OU2 (defined as the terrestrial and aquatic environments (surface water and sediment) immediately downgradient of OU1), primarily via migration of contaminants from OU1 to these environments.
- Ecological Significance of Identified Risks: Ecological risks associated with site-related contamination of OU2 abiotic and biological media will be addressed by conducting a BERA for OU2, likely after remedial actions for OU1 have been completed.

This ERA is organized as follows:

- Section 6.2.1 presents the Screening Level Problem Formulation;
- Section 6.2.2 presents the Screening Level Exposure Assessment;
- Section 6.2.3 presents the Screening Level Effects Assessment;
- Section 6.2.4 presents the Screening Level Risk Characterization; and
- Section 6.2.5 presents the Recommendations.

6.2.1 Screening Level Problem Formulation

OU1 includes the primary mine disturbance area and a buffer zone around this area, as identified on Figure 1.3-2. Potential impacts to surface waters, sediments, aquatic and terrestrial habitats, and ecological receptors downgradient of established OU1 boundaries are not fully addressed in this OU1 ERA. However, OU1 soil and mine materials as well as groundwater and runoff of surface water are recognized as potential sources of impacts to these downgradient resources, which will be addressed in a future BERA to be conducted for OU2.

The screening level problem formulation typically includes the following elements:

- Environmental setting;
- Exposure areas;
- Media and chemicals of interest;
- Ecological receptors;
- Exposure pathways and receptors;
- Assessment endpoints;
- Measurement endpoints;

- CSM; and
- Risk questions.

The environmental setting is presented in detail in Sections 3 through 5 and is not repeated herein. The EAs were presented in the introduction above and are the same as for the HHRA. Section 6.2.1.1 describes the media of interest and COI for the ERA. Section 6.2.1.2 identifies the potential (known and expected) ecological receptors, and selects representative receptors and/or receptor groups for more detailed analyses. Section 6.2.1.3 describes the major exposure pathways. Assessment endpoints are described in Section 6.2.1.4 and measurement endpoints are discussed in Section 6.2.1.5. Contaminant sources, media of concern, release mechanisms, exposure pathways, routes of exposure, and representative receptors are identified and integrated to produce a CSM (Figure 6.1-1), described in Section 6.2.1.6. Finally, as presented in Section 6.2.1.7, the problem formulation integrates this information to derive a list of hypotheses or risk questions to focus and guide the ERA. Responses to risk questions are included in Risk Characterization, Section 6.2.4.

6.2.1.1 Media and Chemicals of Interest

Media of Interest

The primary abiotic media of interest for this ERA are surface soil and mine materials that may serve as surface soil from a terrestrial ecological exposure perspective. These media are considered important for two reasons. First, they can serve as exposure media for terrestrial ecological receptors occurring in or using OU1. Such exposures are considered limited given the disturbed nature of OU1, which leads to assumptions of infrequent exposures, exposures of short duration, and exposures for only a limited suite of ecological receptors tolerant of marginal habitat quality. Second and probably most important is the identification of these materials as potential sources of contamination downgradient into OU2 groundwater, surface waters, sediments, and possibly other media associated with the terrestrial environment.

The second type of abiotic medium of interest for this ERA is surface water in the upper reaches of OU2, immediately downgradient of OU1. Upper reaches of surface waters of OU2 are briefly evaluated here only to support the preliminary assumption that OU1 surface soil and mine materials and other abiotic media (e.g., groundwater) appear to be adversely impact OU2 surface waters and related media (e.g., sediment and biota). Evaluations of surface water in this document are therefore limited in scope, with the objective being confirmation that upgradient reaches of OU2 creeks and streams are contaminated with COPCs originating in OU1. Confirmation of this assumption is used in part to generally support likely remedial actions associated with OU1 soil and mine materials.

Chemicals of Interest

COIs for this ERA include all potentially hazardous inorganic chemicals detected in OU1 surface soils and surficial mine materials, except certain essential nutrients and electrolytes (calcium, magnesium, sodium, potassium). COIs for surface soils and mines materials include the following:

- *Aluminum, antimony, arsenic, barium, beryllium, boron, cadmium, chromium, cobalt, copper, iron, lead, lithium, manganese, mercury, molybdenum, nickel, selenium, silver, thallium, thorium, uranium, vanadium, and zinc*

Also of interest are dissolved metals in the upper reaches of OU2 surface waters. For the limited objectives described above, a small suite of metals are identified in OU2 surface waters. These are used to generally evaluate surface water quality at locations near OU1 and include the following:

- *Cadmium, copper, lead, nickel, and zinc*

Other potentially hazardous chemicals may be identified in OU2 surface waters, but a finding of elevated concentrations of these metals in the upper reaches of OU2 surface waters is sufficient to support the need to address source materials in OU1.

6.2.1.2 Ecological Receptors

Ecological receptors for the OU1 ERA include terrestrial and in a limited manner, aquatic receptors. Terrestrial receptors include those of the onsite and adjacent Douglas fir (*Pseudotsuga menziesii*) dominated forest habitats as well as the disturbed areas of the Site. Aquatic receptors include those found in the upper reaches of streams such as Upper Middle Creek and South Fork Middle Creek found in OU2. These streams are within the Upper Middle Creek and South Fork Middle Creek drainages of the Upper Middle Creek subwatershed. Aquatic receptors are included in the OU1 ERA for the specific purpose of performing a screening level assessment on potential impacts of mine-related solid media and groundwater on downgradient (OU2) surface water bodies. Although aquatic receptors are located in OU2, OU1 source materials (including secondary media such as groundwater linked to primary sources) have impacted the surface water bodies and resulted in detrimental affects to aquatic receptors. Terrestrial and aquatic receptors with potential to occur within OU1 or immediately downgradient of OU1 are described below, and Tables 6.2-1 through 6.2-3 provide additional information on various receptor groups potentially linked to the Site area. Such information includes an evaluation of potential to occur onsite, listed and special concern species, and scientific names of species known or potentially occurring onsite. It should be noted that wildlife and plant habitat quality is poor and quantity of suitable habitat is limited within or near OU1.

Terrestrial Receptors

Vegetation: Detailed descriptions of upland vegetation are provided in Section 3.7. Table 6.2-1 provides a list of wildlife and plants found at the Site.

Wildlife: Descriptions of terrestrial wildlife species are provided in Section 3.7. Table 6.2-1 provides a list of wildlife and plants found at the Site. To provide additional information for the ERA, the Atlas of Oregon Wildlife (Csuti et al. 1997) and other information sources indicate that a number of vertebrate species have potential to occur within the range of the Site. These include salamanders, anurans (frogs and toads), lizards, snakes, birds, and mammals, including bats (Table 6.2-2). A number of these species would likely use the coniferous forest ecosystems within OU1 occasionally or infrequently, given the nearby disturbed areas. Some species more tolerant of disturbed conditions can occur within OU1 more frequently. Probably more suitable for many of these species are the less disturbed coniferous and mixed forests adjacent to OU1. A full list of species with ranges that could include the Site is provided in Table 6.2-2.

Aquatic/Riparian Receptors

Risks to aquatic ecological receptors will be fully addressed in a forthcoming OU2 BERA. For this focused OU1 ERA, aquatic ecological receptors of interest include species and/or groups

considered to be linked to water quality criteria and are often referred to as aquatic life. For the purposes of this OU1 ERA, aquatic life are defined as aquatic plants, water column invertebrates, fish, and larval amphibians underlying the derivation of chronic water quality criteria for the selected metals of concern for the upper reaches of OU2 surface waters, just downgradient of the OU1 boundaries. Specifically, these species include those reported to occur in OU2 surface waters, and others that may occur in such waters but for which site-specific observations are lacking. Among the aquatic receptors considered most important are salmonid fish and the invertebrates and fish that serve as prey for salmonid fish.

Vegetation: Detailed descriptions of riparian vegetation species are provided in Section 3.7. Table 6.2-1 provides a list of wildlife and plants found at the Site and Table 6.2-2 provides a further list based on Csuti et al. 1997.

Wildlife: Detailed descriptions of aquatic wildlife species are provided in Section 3.7. Table 6.2-1 provides a list of wildlife and plants found at the Site and Table 6.2-2 provides a further list based on Csuti et al. 1997.

Listed Species and Species of Special Concern

Federally Threatened and Endangered Species: Detailed information on threatened and endangered species is provided in Section 3.7. These species are listed in Table 6.2-3.

State Special Concern Species: There are a number of species listed as "special concern" for Douglas County. "Special concern" species have a conservation status that is of concern to the USFWS (many previously known as Category 2 candidates), but for which further information is still needed. For Douglas County there are 13 birds, 10 mammals, 5 fish, 10 reptiles and amphibians, 5 invertebrates, and 17 plants that are listed as special concern. All special concern species for Douglas County are provided in Table 6.2-3.

6.2.1.3 Exposure Pathways and Receptors

Terrestrial

Exposure pathways and receptor groups of potential interest for terrestrial ecological receptors include the following:

- Complete and significant exposure pathways:
    - Direct contact/dermal exposure:
        - Soil-associated invertebrates;
        - Terrestrial amphibians and reptiles;
        - Soil-associated birds; and
        - Small mammals.
    - Direct contact/uptake:
        - Terrestrial plants.

- Complete but insignificant pathways or pathways for which risks cannot be quantified:
    - Inhalation:
        - Small burrowing mammals.
- Incomplete or minor exposure pathways:
    - Dietary:
        - Birds and mammals with large foraging ranges.

The ERA for OU1 is focused on the complete and significant exposure pathways and receptor categories listed above. Risks to small burrowing mammals via the inhalation pathway are not evaluated in this ERA, because the COIs (metals) are not volatile and because data are lacking to quantify inhalation exposures. Site-related risks to birds and mammals with large foraging ranges are also not quantified in this ERA because OU1 is 1) relatively small compared to the large amount of more suitable foraging areas adjacent to OU1, and 2) is associated with degraded habitats that limit foraging opportunities and the likelihood of onsite foraging. Bioaccumulation of some metals (e.g., cadmium and mercury) is a concern for upper trophic level receptors that forage within OU1 for a significant duration and/or with sufficient frequency. Such risks are assessed in this ERA by comparing exposure concentrations of bioaccumulative COIs to soil screening levels based on bioaccumulation and dietary food web transfer to upper trophic level birds and mammals.

Aquatic

Exposure pathways and receptor groups of potential interest for aquatic ecological receptors are included here to document potential site-related contamination in surface waters within OU2 downgradient of OU1. Strong evidence of site-related contamination of such surface waters is assumed if upper reaches of OU2 surface waters contain dissolved contaminants at concentrations exceeding chronic EPA National Recommended Water Quality Criteria (NRWQC) for protection of aquatic life (EPA 2009). Because chronic standards are used to confirm site-related contamination of surface waters immediately downgradient of OU1, the exposure pathways and receptors associated with such use include the following:

- Complete and significant exposure pathways
    - Direct contact/ingestion
        - Water column and benthic aquatic invertebrates
        - Fish
        - Larval amphibians
    - Direct contact/uptake
        - Aquatic plants

The ERA for OU1 is focused on the complete and significant exposure pathways and receptor categories listed above. Risks to other receptors such as water-associated reptiles (e.g., garter snakes), water-associated birds (e.g., kingfisher), and water-associated mammals (e.g., mink) are not addressed in this OU1 ERA but will be addressed in a forthcoming OU2 ERA.

6.2.1.4 Assessment Endpoints

Assessment endpoints identify the ecological values to be protected (e.g., abundance and diversity of aquatic macroinvertebrates or fish). Assessment endpoints are directly related to remedial action goals and objectives determined for the Site, in this case OU1 of the Site. Appropriate assessment endpoints are developed and consider guidance from relevant regulatory agencies. Formosa OU1-related PRAOs are presented in Section 7.2.2. With respect to the ERA, these PRAOs should consider the following components:

- The establishment and maintenance of healthy and diverse aquatic and riparian ecosystems downstream of OU1;
- Reductions in concentrations of site-related COPCs in aquatic biota such that upper trophic level consumers (e.g., piscivorous birds and mammals) are not adversely affected at the population or community level; and
- The establishment and maintenance of a healthy and diverse terrestrial ecosystem within OU1 where possible, given the primary objective of eliminating or reducing potential site-related contamination to areas downgradient of OU1 (e.g., to surface waters of OU2).

This ERA is designed to support decisions related to PRAOs and ultimately numerical remedial action goals for OU1. This support consists of selecting appropriate assessment endpoints and evaluating risks related to these endpoints. The characteristics of the Site, COI, toxic mechanisms, and exposure pathways were used to select the following assessment endpoints:

Surface Water-Based Assessment Endpoints

Surface water-based assessment endpoints are primarily associated with OU2 evaluations, but are presented here to support the limited evaluation of surface waters with regard to potential OU1 sources of contamination. These assessment endpoints include the following:

- Protection of water-column and benthic invertebrate receptors from the toxic effects (on survival, growth, and reproduction) of site-related chemicals present in sediment and surface water;
- Protection of fish from the toxic effects (on survival, growth, and reproduction) of site-related chemicals present in surface water;
- Protection of insectivorous, piscivorous, and carnivorous avian receptors (e.g., belted kingfisher) from the toxic effects (on survival, growth, and reproduction) of site-related chemicals present in prey, sediment, and surface water; and
- Protection of omnivorous and piscivorous mammalian receptors (e.g., raccoon and mink) from the toxic effects (on survival, growth, and reproduction) of site-related chemicals present in prey, sediment, and surface water.

Soil-Based Assessment Endpoints

Soil-based assessment endpoints are directly linked to OU1 evaluations and such assessment endpoints will likely be associated with future OU2 evaluations as well. These assessment endpoints include the following:

- Protection of terrestrial plants (including individuals of special status species) and soil-associated invertebrate communities from the toxic effects (on survival, growth, or reproduction) of site-related chemicals present in surface soil;
- Protection of terrestrial amphibians (e.g., toads) and reptiles from the toxic effects (on survival, growth, or reproduction) of site-related chemicals present in surface soil;
- Protection of omnivorous, herbivorous, invertivorous, and carnivorous avian receptors with small foraging ranges from the toxic effects (on survival, growth, or reproduction) of site-related chemicals present in prey (e.g., earthworms) and soil. This assessment endpoint also considers certain species of special concern, including individual Northern Spotted Owls, based on the assumption that protection of species with small foraging ranges ensures protection of other species with larger foraging ranges; and
- Protection of herbivorous, omnivorous, and insectivorous mammalian receptors with small foraging ranges (e.g., cottontail, deer mouse, and shrew) from the toxic effects (on survival, growth, or reproduction) of site-related chemicals present in food items and soil.

6.2.1.5 Measurement Endpoints

Assessment endpoints are often difficult to measure or evaluate directly. For example, we cannot predict with certainty the conditions necessary to ensure the survival and successful reproduction of earthworms in OU1 surface soil and mine materials. Such critical concentrations are site-specific and depend on innumerable factors related to chemical characteristics (e.g., chemical form, bioavailability, soil moisture, and pH) and biological factors (e.g., sensitivity of resident earthworms to site-related contaminants). However, toxicity data based on experimental studies or those designated as critical thresholds by regulatory agencies can often help predict the likely outcome of expected exposures.

Measurement endpoints selected for use in this ERA are for the most part chemical specific ESLs selected from or based on accepted sources, such as EPA and other relevant regulatory agencies. Measurement endpoints are used where assessment endpoints cannot be directly measured or evaluated, and are defined as quantitative expressions of observed or measured biological responses to stressors relevant to selected assessment endpoints. For example, protection of the survival, growth, and reproduction of soil-associated invertebrates (an assessment endpoint) can be evaluated using earthworm toxicity data that can serve as an appropriate measurement endpoint. As a more specific example, concentrations of metals in surface soil and mine materials can be compared to concentrations in soil-based laboratory tests that result in observed ecologically significant effects to sensitive and relevant test species (i.e., earthworm). This example expresses the relationship between a relevant measurement endpoint (chronic effects concentration of metals in soil) directly related to the assessment endpoints of terrestrial invertebrate survival, growth, and reproduction.

For this ERA, ecologically significant effects are defined as those affecting survival, growth, or reproduction of selected receptors. Other endpoints such as effects on behavior or histopathological effects are not considered because these cannot be easily linked to ecologically significant endpoints that can impair populations or communities. Protection of populations and communities is a major goal of the ERA, while protection of individual organisms is warranted for species of special concern (e.g., threatened or endangered species). Four such species are identified as State Special Concern Species for Douglas County, Oregon (Table 6.2-3), and one or more of these may occur near the Site. Because of the potential for certain metals to accumulate in biological tissues and exert adverse effects in upper trophic level biota, this ERA also considers bioaccumulation and associated food web effects. However, these exposure scenarios and associated risks are not quantitatively evaluated in the OU1 ERA for the reasons cited previously, but will be fully evaluated in a future OU2 assessment.

6.2.1.6 Conceptual Site Model

The CSM for the ERA (Figure 6.1-1) is a visual presentation that summarizes key components related to potential ecological exposures resulting from site-related chemical contamination. The CSM is an important output of the problem formulation phase of the ERA, and summarizes exposure scenarios and is used to help develop a series of testable risk questions or hypotheses, as presented below. In addition, the CSM is used to guide and support the selection of appropriate assessment and measurement endpoints.

The CSM presents the potential exposure pathways for representative ecological receptors exposed to site-related contaminants. These potential pathways indicate how the ecological resources can co-occur or come in contact with contaminants, and include contaminant sources, fate and transport processes, and exposure routes. Figure 6.1-1, the CSM for both of this ERA and the associated HHRA presents all the components of the OU1 and OU2 CSM (e.g., contaminant sources, transport processes, exposure routes, potential receptors), with emphasis on OU1 exposure scenarios. Components of exposure scenarios associated with OU2 are shown on this figure as shaded cells. Remedial objectives for OU1, information presented in the OU1 CSM, and preliminary selection of ERA assessment and measurement endpoints are all used to guide derivation of risk questions or hypotheses. These risk questions, presented below, help guide the ERA towards compilation, evaluation, and interpretation of critical information. Risk questions for a particular receptor category are assumed to address potential hazards to individual organisms for special status species.

6.2.1.7 Risk Questions

The following are risk questions developed based on information presented above to focus the ERA approach:

- Are the concentrations of COPCs in surface soil and/or surficial mine materials sufficiently elevated to cause or contribute to adverse effects related to the survival, growth, or reproduction of terrestrial plants?
- Are the concentrations of COPCs in surface soil and/or surficial mine materials sufficiently elevated to cause or contribute to adverse effects related to the survival, growth, or reproduction of soil-associated invertebrates?

- Are the concentrations of COPCs in surface soil and/or surficial mine materials sufficiently elevated to cause or contribute to adverse effects related to the survival, growth, or reproduction of soil-associated birds with small foraging ranges?
- Are the concentrations of COPCs in surface soil and/or surficial mine materials sufficiently elevated to cause or contribute to adverse effects related to the survival, growth, or reproduction of soil-associated mammals with small foraging ranges?
- Are the concentrations of COPCs in surface water from selected upper reaches of OU2 surface water bodies sufficiently elevated to cause or contribute to adverse effects related to the survival, growth, or reproduction of aquatic life (i.e., aquatic receptors underlying the derivation of the chronic EPA NRWQC (EPA 2009c)?

6.2.2 Screening Level Exposure Assessment

This section of the ERA discusses chemical properties of identified COIs (Section 6.2.2.1) and presents screening level EPCs for COIs by EA (Section 6.2.2.2). Section 6.2.2.3 describes terrestrial and aquatic exposure scenarios.

6.2.2.1 Chemical Properties of COIs

This section of the ERA presents chemical properties for the major chemical stressors identified at OU1. Each of these properties is discussed below.

Environmental Persistence

Environmental persistence indicates whether a chemical is likely to be long-lasting in the environment or, alternatively, be degraded by natural processes. Degradation is also limited for many organics and metals are not degraded. Of concern to this ERA is the persistence of metals in the environment. Metals are not significantly degraded by any biological or abiotic process, so reductions in concentrations over time are not expected.

Bioavailability

Bioavailable chemicals are defined as those that exist in a form that have the ability to be assimilated and cause adverse ecological effects or bioaccumulate. As stated previously, bioaccumulation may not in itself constitute a significant ecological effect, but provides important evidence of both exposure and potential for causing adverse effects to multiple trophic levels under certain conditions. For example, some lipophilic chemicals, such as dichlorodipenyltrichloroethane (DDT), are taken up by biota and are stored in fatty tissues with no apparent ill effects. However, under stressful conditions, such as during winter when only poor quality foods are available, these fats are metabolized and the contaminants can then cause adverse effects.

For some contaminants, chemical form and thus toxicity can change rather rapidly under changing environmental conditions. For example, fluctuations in pH or other conditions related to seasonal conditions such as snowmelt can affect to surface water quality and bioavailability of metals. Also, low pH soils can increase the bioavailability of some metals, such as aluminum, and can also be an independent stressor to soil-dwelling invertebrates and terrestrial plants. Measurements of total organic carbon (TOC) in soil can be used to generally describe the

bioavailable portion of some inorganic chemicals. Higher levels of TOC in soil can reduce bioavailability and toxicity due to binding of contaminants with organic carbon. It is expected that some if not all COIs are bioavailable. This would not be surprising for some COIs, since they are essential elements and uptake is required. For others, uptake and accumulation may pose a hazard worth investigating.

Similarly, chemicals found in surface waters can vary with regard to bioavailability and toxicity depending on chemical form and water quality characteristics. Factors affecting contaminant bioavailability and toxicity in surface water can include the following:

- Hardness (primarily calcium and magnesium concentrations);
- Alkalinity;
- Salinity;
- Sulfate (affects selenium toxicity);
- Temperature;
- DO;
- TDS and TSS;
- TOC; and
- pH (independent stressor and source of increased metal bioavailability).

Of these, hardness (measured as calcium carbonate [$CaCO_3$] is most important for affecting the toxicity of certain metals (cadmium, trivalent chromium, copper, lead, nickel, silver, and zinc). Current information suggests that hardness may not in fact affect the toxicity of silver, but that issue has not been fully finalized. Higher hardness levels in surface water decrease bioavailability and toxicity of these metals.

The location-specific hardness (expressed as mg/L $CaCO_3$) of each of the surface water sampling locations within each of the four surface water bodies subject to screening level evaluation (Middle Creek, South Fork Middle Creek, Formosa 1 adit, and the 404 adit) is used to evaluate bioavailability and toxicity, primarily through adjusting ESLs for hardness-dependent metals detected in surface water. Hardness values greater than 400 mg/L are set to 400 mg/L per EPA guidance for adjusting water quality criteria for hardness-dependent metals. The average hardness values for the selected sampling locations for each of the three water bodies are shown below:

- Upper Middle Creek sampling locations (hardness): A4 (120 mg/L), A6 (59 mg/L), and MXR (170 mg/L);
- South Fork Middle Creek sampling locations (hardness): SFA4 (768 mg/L, set to 400 mg/L), SFA2 (486 mg/L, set to 400 mg/L), and SF1.0 (88 mg/L); and
- Adit sampling locations (hardness): 404 adit (82 mg/L) and Formosa 1 adit (451 mg/L).

Organic carbon content and the presence of particulates in surface water can substantially affect the bioavailability and toxicity of contaminants. Increases in organic carbon and particulates in surface water reduce the bioavailability of some chemicals, but particulates can also adversely affect filter feeding aquatic receptors. The other factors listed above can also affect the toxicity of inorganic and organic chemicals in surface water to varying degrees.

The bioavailability and toxicity of metals can be further affected by the chemical form of the metal. For example, dissolved metals in surface water are frequently implicated in toxic effects while metals bound to particulate matter are generally less bioavailable and exhibit lower toxicity to aquatic life. The aquatic toxicity of other metals, such as aluminum, is most influenced by water pH. In soils, increased acidity (lower pH) often increases the bioavailability of metals. The variable toxicity of metals can be revealed by comparing accepted criteria, benchmark concentrations, or screening levels for individual metals.

Bioconcentration and Bioaccumulation

Bioconcentration potential indicates whether a chemical is likely to be retained in biological tissues after it is taken in by ingestion or other means. Retention of chemicals is not in itself an appropriate measurement endpoint unless it is associated with adverse ecological effects. Retention is, however, useful for verifying exposure and for evaluating bioavailability and the potential for food web effects.

There are differences in the ability of different types of biota to detoxify and/or eliminate certain chemicals following initial uptake. For example, inorganic COI include those that are essential for life and therefore are physiologically regulated (e.g., copper and zinc), as well as those with no known biological function (e.g., mercury). Whether a metal is accumulated and retained in biological tissues depends on the metal, the receptor, and the chemical form in which the metal occurs. Some metals, such as cadmium, mercury, and arsenic, are not essential for life and, in fact, can be highly toxic at very low exposure concentrations. Some of the most toxic metals like mercury and cadmium also accumulate in biological tissues (i.e., are considered bioaccumulative). Mercury is known to biomagnify, resulting in adverse effects in upper trophic level receptors.

Retention of metals in biological tissues can be a necessary function for essential elements but, for other non-essential metals, can cause adverse effects. Accumulation of metals in biological tissues (bioaccumulation) is, therefore, important to ERA. Bioaccumulative COI have been identified in surface soil and surface waters. These include cadmium, chromium, copper, lead, mercury, nickel, selenium, and zinc in surface soil and cadmium, copper, lead, nickel, and zinc in surface waters. Some of these (e.g., selenium, copper, and zinc) are necessary elements and concentrations in organisms are biologically regulated. Others, such as lead and mercury, have no known function and accumulation is not regulated. All can be toxic at concentrations exceeding safe or regulated thresholds.

6.2.2.2 Magnitude and Distribution of COIs

This section of the ERA presents a summary of the magnitude and distribution of chemicals identified in OU1 as COIs. The ranges of concentrations of COIs detected in OU1 surface soil and mine materials and upper OU2 surface water near OU1 are shown in Tables 6.2-4 through 6.2-11 (soils) and Table 6.2-12 (surface water).

Data collected to support the RI for OU1 are used to describe the magnitude and distribution of chemicals in surface soil and mine materials for each EA at OU1. Although no single concentration value can truly represent the variability of chemical concentrations measured in each medium of concern, EPA guidance (1997) for conducting ERAs recommends using the maximum detected value of each chemical to initially assess risk. Therefore, for this ERA, the maximum detected concentration for each detected chemical within each medium of concern at EA-1 and EA-3 was compared to conservative ESLs to select preliminary COPCs for that medium in the EA. In contrast, the EA-2 surface soils were characterized by incremental sampling and collection of triplicate samples, which generates a confident arithmetic mean concentration of the triplicate samples for each DU. Therefore, the arithmetic mean for each DU was used for EA-2 to select COPCs.

Maximum detected chemical concentrations for each medium of concern at each EA are presented in Tables 6.2-4 through 6.2-12. Following EPA guidance, if the maximum detected concentration of a chemical exceeds its respective selected ESL, then a potential for adverse ecological effects may exist. Tables 6.2-4 and 6.2-11 also list the location where the maximum concentration of each chemical was measured and the frequency of detection for each chemical detected in EA-1 and EA-3.

At the conclusion of the SLERA step of this ERA, several chemicals are identified as preliminary COPCs and retained for further evaluation. Since individual organisms within a population would not routinely be exposed to maximum surface soil concentrations, a more realistic estimate of exposure is used to evaluate risks to ecological receptors at EA-1 and EA-3. Thus, in Step 3a of the ERA process, potential threats associated with those preliminary COPCs are re-evaluated using less conservative exposure assumptions. The streamlined Step 3a evaluation for OU1 includes refinement of EPCs, which entails substituting the maximum detected concentration with the 95 percent upper confidence limit of the arithmetic mean (95 percent UCL) or the average (arithmetic mean) concentration as the EPC for each chemical retained for further evaluation at the conclusion of the SLERA in the applicable media at each EA. The refined EPC differs by EA and medium, and reflects the most appropriate EPC based on data quantity for a given combination of exposure medium, chemical, and location. Refined EPCs are discussed below and are shown in the tables referenced below:

- 95 percent UCL:
    - EA-1 surface soil and mine materials.
- Arithmetic mean:
    - EA-2 surface soil (incremental sampling data) as described above;
    - EA-3 surface soil; and
    - Surface Water (single measurements or means of up to three values).

The arithmetic mean for EA-3 surface soil and surface water is selected as the refined EPC because 95 percent UCLs could not be confidently derived for these combinations of location, exposure medium, and chemical because of lack of a sufficient number of samples. Concentrations

are set to half the reporting limit for those location-specific values associated with non-detected results. Arithmetic mean concentrations therefore include all detected concentrations and non-detect data set to half the detection limit.

EA-1 Assessment

Surface Soil/Mine Materials – Maximum concentrations of chemicals detected in EA-1 surface soils mine materials serve as the preliminary EPCs for EA-1 surface materials. For chemicals retained following comparisons of maximum detected concentrations to conservative ESLs, maximum detected concentrations are replaced with 95 percent UCLs to provide less conservative risk estimates (Table 6.2-4).

Surface Water – Surface water quality is evaluated on a screening level by determining recently measured concentrations of dissolved chemicals in selected OU1 (adits) and OU2 surface water bodies and sampling locations associated with (i.e., in or near) OU1. These measured values are compared to a limited set of chronic water quality criteria derived for the protection of aquatic life (Table 6.2-12). Selected surface water bodies and sampling locations include the following:

- Middle Creek sampling locations A4, A6, and MXR;
- South Fork Middle Creek sampling locations SFA4, SFA2, and SF1.0; and
- Adit sampling locations Formosa 1 adit and 404 adit.

EA-2 Assessment

Surface Soil – Average (arithmetic mean) concentrations of chemicals detected in EA-2 surface soils serve as EPCs for each of the unique DUs evaluated within EA-2. These DUs are described in detail in Section 2, but can be briefly described as relatively long, narrow areas comprised of an upper and lower components situated downgradient of EA-1, as shown on Figure 2.3-4. In addition, some of the sampled areas only had single DUs, and no upper and lower areas were sampled. The term 'upper' refers to the more upgradient DU and 'lower' refers to the DU immediately downgradient of the 'upper' area. Average concentrations of the triplicate samples for each DU are used as EPCs for this EA (Tables 6.2-5 though 6.2-10).

EA-3 Assessment

Surface Soil – Average (arithmetic mean) and maximum concentrations of metals detected in EA-3 surface soils serve as EPCs for EA-3. As for EA-1 soils and mine materials, maximum detected concentrations are used as preliminary EPCs for this EA. In contrast to EA-1, however, arithmetic mean concentrations are used as refined EPCs rather than 95 percent UCLs, because the number of soil samples (five or fewer) does not allow for calculation of confident 95 percent UCLs (Table 6.2-11).

6.2.2.3 Terrestrial and Aquatic Exposure Scenarios

The primary exposure scenarios of interest for OU1 are those based on direct contact, uptake (plants), and ingestion (incidental) of metals in surface soils and mine materials. Such exposure scenarios are most likely for terrestrial plants and soil-associated invertebrates tolerant of disturbed conditions. Also of interest are direct contact/ingestion exposures for birds and mammals with small home or foraging ranges that find suitable habitat within OU1. Avian and

mammalian exposures are expected, however, to be limited because of the degraded habitats that dominate OU1.

The focused evaluation of downgradient surface waters is based primarily on comparing dissolved concentrations of selected chemicals to concentrations intended to protect a wide variety of freshwater aquatic life. Included in this category are aquatic plants (including algae), benthic and water column aquatic invertebrates, fish, and larval amphibians. Based on these receptor categories, the primary exposure scenarios of interest for this assessment include direct contact with and uptake of dissolved chemicals by plants and direct contact with and ingestion of dissolved chemicals by aquatic animals.

6.2.3 Screening Level Effects Assessment

Screening level effects data are compiled and evaluated for use as ESLs. Selected ESLs are compared to EPCs for each COI by medium in each EA. The results of these comparisons are presented in Section 6.2.4 Risk Characterization as HQs. ESLs are selected from multiple sources and in many cases are applicable to specific receptor categories or groups. No single source of ESLs provides suitable ESLs for all COIs. ESL sources and order of preference where multiple ESLs are considered are presented below for each abiotic medium. ESLs for surface soil (Section 6.2.3.1) are the primary ESLs used in this focused ERA, but ESLs for surface water (Section 6.2.3.2) are used specifically to reveal the need to address contaminants linked to surface soils and mine materials in OU1 to protect downgradient aquatic resources, which will be addressed in an ERA for OU2.

6.2.3.1 Ecological Screening Levels for Surface Soil and Mine Materials

ESLs for surface soil and mine materials for all three EAs are compiled for four ecological receptor categories. These are terrestrial plants, soil invertebrates, birds, and mammals. The preferred ESL for all four receptor categories is the receptor-specific Eco-SSL (EPA 2008c). Eco-SSLs for birds and mammals are based on dietary exposures (i.e., exposures via food ingestion) and do not consider direct contact exposures. Where Eco-SSLs have not been derived, alternative ESLs are selected. These are provided below, by receptor category:

- Terrestrial Plants:
    - Oak Ridge National Laboratory Benchmark for Terrestrial Plants (Efroymson et al. 1997a).
- Soil Invertebrates:
    - Oak Ridge National Laboratory Benchmark for Soil and Litter Invertebrates (Efroymson et al. 1997b).

Where none of these sources provides an acceptable ESL for a particular receptor category, alternative ESLs are selected from multiple sources. These sources include site-specific values from other mining-related projects, more general ESLs applicable to a wide range of receptor types or generally applicable to ecological receptors (but undefined), or ESLs recommended by EPA regions. The selection of ESLs from these alternative ESL sources are chemical-specific and are shown as footnotes on Tables 6.2-4 through 6.2-9, and Table 6.2-11. In all cases the ESLs for

terrestrial plants and soil invertebrates are given highest priority and level of importance given the limited habitat suitability for birds and mammals using OU1.

6.2.3.2 Ecological Screening Levels for Surface Water

Preferred ESLs for surface water are the chronic EPA NRWQC (EPA 2009c), adjusted for hardness where applicable. These are derived for the limited set of chemicals subject to surface water screening (cadmium, copper, lead, nickel, and zinc). Table 6.2-12 presents the surface water ESLs used to screening chemicals detected in surface water.

6.2.4 Screening Level Risk Characterization

Following EPA guidance, screening level risk estimates are quantified first by comparing preliminary EPCs (e.g., maximum detected concentration of COIs in surface soil for EA-1 or EA-3) to one or more ESLs (e.g., Eco-SSL for multiple receptor groups). These comparisons result in the derivation of screening level HQs, as shown below:

Screening Level HQ = Maximum Detected Concentration / ESL

HQs equal to or greater than 1.0 identify, at this stage of the ERA process, preliminary COPCs. ESLs are by design conservative values, and HQs based on such ESLs are likely to be overestimated to some degree, assuring that no potentially important contaminant is prematurely eliminated at this stage of the ERA process. Quantitative risk estimates in the form of screening level HQs are presented in Section 6.2.4.1 of this SLERA.

Refined HQs used in Step 3a of this ERA are based on a similar approach as that used to derive screening level HQs, differing only in the substitution of the maximum detected concentration by a less conservative EPC. The EPC selected for this step of the process is either the 95 percent UCL or the arithmetic mean, depending on the quantity of data available, as previously described. The refined HQ is based on the following:

Refined HQ = 95 percent UCL or Arithmetic Mean Concentration / ESL

Refined HQs associated with Step 3a of the ERA are presented in Section 6.2.4.2. Refined HQs are supplemented by other lines of evidence (Section 6.2.4.3). In addition to the HQ calculations, lines of evidence used to interpret the results of the SLERA/Step 3a include site-related biological information, such as habitat quality, habitat quantity, and presence or absence of sensitive habitats or suitable habitats located in or near OU1. Risk characterization for OU1 also includes responses to the risk questions posed in Problem Formulation (Section 6.2.4.4) and a discussion of the ecological significance of risk estimates (Section 6.2.4.5). This important component considers the likelihood that observable adverse effects are in fact expected where quantitative risk estimates exceed the threshold of acceptability (i.e., HQs equal to or exceed 1). For example, high HQs might suggest likelihood of adverse effects; yet, measurable population level or community level effects may be unlikely given site-specific considerations. Uncertainties related to the risk characterization process are presented in Section 6.2.4.7. Finally, the risk characterization conclusions, which incorporate all lines of evidence and the ecological significance of the HQ calculations, are presented in Section 6.2.4.7.

6.2.4.1 Screening Level Risk Estimates

As discussed above, two main lines of evidence are used in risk characterization. The first line of evidence includes the derivation of screening level HQs based primarily on direct contact/ingestion exposure scenarios for all COIs. These risk estimates are derived from comparisons of maximum detected concentrations of COIs in surface soil and mine materials serving as surface soil from an exposure viewpoint to ESLs for soil-associated receptors, such as terrestrial plants and soil invertebrates.

Risks to upper trophic level receptors (e.g., omnivorous and carnivorous birds and mammals) from bioaccumulative COIs via ingestion of food items are also considered for some chemicals because the preferred ESLs consider this exposure pathway. Food web modeling is not performed for upper trophic level receptors in this ERA for two reasons. First, site-specific data are unavailable to support food web modeling, and results of such modeling based on literature-based inputs are highly uncertain. Second, and most importantly, the size and quality of terrestrial habitats in the mine-affected portions of OU1 suggest that upper trophic level receptors have low potential to be significantly exposed to surface soil and mine materials contaminated with potentially bioaccumulative COIs.

Following refinement of the screening level HQ presentation (Step 3a) is the second line of evidence, which are evaluations of OU1-specific supporting information related to potential for exposure, including comparisons of OU1 terrestrial habitat quality and quantity to surrounding terrestrial habitats. As stated previously, it is anticipated that the ERA will result in HQs greater than 1 for several COIs, which were then selected as preliminary COPCs in surface soil and mine materials. Although such findings generally indicate a need to conduct a BERA, it is expected that a BERA is not warranted for OU1 based on likely remedial actions and the recognition that potential source control of OU1 contamination is planned, allowing for future risk evaluations for other OUs. Screening level HQs for surface soil and mine materials are presented on Tables 6.2-4 (EA-1), 6.2-5 through 6.2-10 (EA-2), and 6.2-11 (EA-3) and summarized below. Screening level risk estimates for surface water are presented in Table 6.2-12, and these are also summarized below.

EA-1 Surface Soil HQs (Screening Level)

Twenty-eight inorganic chemicals were detected in the surface soils and mine materials of EA-1. Calcium, magnesium, potassium, and sodium are essential nutrients or electrolytes and are eliminated from further evaluation. Of the 24 remaining chemicals, most were frequently detected but boron was detected in only 2 of 50 samples. All 24 were retained for additional evaluation in Step 3a because the maximum detected concentration exceeded one or more ESLs or because an ESL for one or more of the four receptor categories (plants, invertebrates, birds, mammals) was unavailable. The 24 chemicals retained are at this phase of the process termed preliminary COPCs and are shown on Table 6.2-4.

Screening level HQs for preliminary COPCs range from less than 1 to 1,730 (iron). Higher HQs do not necessarily identify risk drivers, because some of the higher HQs (e.g., those calculated for iron) are based on ESLs with low confidence. In other cases, ESLs are below concentrations commonly found in uncontaminated soils (i.e., near or below background). In any case, all 24

chemicals are retained at this stage of the process and Table 6.2-4 reveals the screening level HQs for each of the 24 chemicals for all receptor categories for which ESLs are available.

EA-2 Surface Soil HQs (Screening Level)

EA-2 is divided into several unique DUs located immediately downgradient or beyond the boundaries of EA-1. These unique areas include the Encapsulation Mound East, Encapsulation Mound South East, Encapsulation Mound West, Formosa Adit, Encapsulation Mound West Drainage 1, Encapsulation Mound West Drainage 2, and Silver Butte. All but the last three areas are again divided into upper and lower sections.

The evaluation of surface soils within EA-2 includes independent evaluations of each of the areas identified, and also includes a comparison of upper and lower DUs for those areas paired as such. Screening level HQs based on maximum detected concentrations are not calculated for EA-2 soils, but instead arithmetic mean concentrations are used to evaluate EA-2 soils. HQs based on mean values are considered refined (Step 3a) HQs, and the results of these evaluations are presented on Table 6.2-5 through 6.2-10, and summarized in Section 6.2.4.2.

EA-3 Surface Soil HQs (Screening Level)

Twenty-six inorganic chemicals were detected in the surface soils of EA-3. Calcium, magnesium, potassium, and sodium are essential nutrients or electrolytes and are eliminated from further evaluation. Cadmium, manganese, and nickel were eliminated from further investigation because HQs for all four receptor categories did not exceed the threshold of one. Twenty one chemicals were retained for additional evaluation (Step 3a) because the maximum detected concentration exceeded one or more ESLs or because an ESL for one or more of the four receptor categories (plants, invertebrates, birds, mammals) was unavailable. The 21 chemicals retained are at this phase of the process termed preliminary COPCs) and are shown on Table 6.2-11.

Screening level HQs for preliminary COPCs range from less than 1 to 2,490 (iron). As discussed for EA-1, higher HQs do not necessarily identify risk drivers, because some of the higher HQs (e.g., those calculated for iron) are based on ESLs with low confidence. In other cases, ESLs are below concentrations commonly found in uncontaminated soils (i.e., near or below background). All 21 chemicals are retained at this stage of the process and Table 6.2-11 reveals the screening level HQs for each of the 21 chemicals for all receptor categories for which ESLs are available.

Surface Water HQs associated with EA-1 (Screening Level)

Screening level HQs for selected metals (cadmium, copper, lead, nickel, and zinc) in surface water are based on comparisons of dissolved concentrations recently measured at locations near OU1 to chronic hardness-adjusted (where applicable) EPA NRWQC (EPA 2009c). The resulting HQs are presented in Table 6.2-12, and combinations of water bodies, sampling locations, and metals associated with elevated HQs (i.e., equal to or exceeding 1) are summarized below, with HQs shown in parentheses. All HQs for dissolved nickel remained below 1.

- Middle Creek:
    - A4 – Elevated HQs calculated for cadmium (219), copper (427), and zinc (104);
    - A6 – Elevated HQs calculated for cadmium (129), copper (353), and zinc (59); and

  - MXR – Elevated HQs calculated for cadmium (41), copper (38), and zinc (18).

- South Fork Middle Creek:
  - SF A4 – Elevated HQs calculated for cadmium (286), copper (648), and zinc (120);
  - SF A2 – Elevated HQs calculated for cadmium (247), copper (552), and zinc (109); and
  - SF 1.0 – Elevated HQs calculated for cadmium (35), copper (36), and zinc (21).

- Adits:
  - Formosa 1 adit – Elevated HQs calculated for copper (1,476), zinc (382), cadmium (1,041), and lead (7.2), based on comparison of maximum detected concentrations of dissolved metals to chronic criteria for protection of aquatic life (hardness-adjusted where applicable). Also, the low pH of adit water (approximately 2.1 to 3.3) precludes survival, growth, and reproduction of all or nearly all aquatic receptors.
  - 404 adit – Marginally elevated HQs calculated for cadmium (3.2), copper (5.9), lead (3.0), and zinc (1.8). In addition, the low pH of the 404 adit (approximately 2.5 to 3.5) indicates hazardous conditions for directly exposed aquatic life regardless of metals concentrations.

6.2.4.2 Refined (Step 3a) Risk Estimates

Chemicals associated with screening level HQs equal to or exceeding the threshold of one are retained for further evaluation, and this evaluation is defined as Step 3a of the BERA process. Step 3a consists of refinement of input parameters used to derive HQs. In this ERA, Step 3a includes refinement of screening level EPCs but retention of the initial ESLs (i.e., ESLs are not refined or changed from the screening level step). The refined EPC replaces the maximum detected concentration used in the screening level derivation of HQs, and is either the 95 percent UCL or arithmetic mean concentration, depending on data availability.

As discussed previously, 95 percent UCLs are used for EA-1 surface soil HQs, and arithmetic means are used for EA-2 and EA-3 surface soil HQs. Focused evaluations of surface water are limited to the screening level step and refinement (Step 3a) is not performed because of a limited number of surface water samples. Screening level HQs for surface soil are presented on Tables 6.2-4 (EA-1), 6.2-5 through 6.2-10 (EA-2), and 6.2-11 (EA-3) and summarized below.

EA-1 Refined Surface Soil HQs

As stated above, 24 inorganic chemicals detected in EA-1 surface soil and surficial mine materials are subjected to further investigation in Step 3a. For EA-1, this refinement is based on comparing the same ESLs used in the screening level risk estimation to 95 percent UCL concentrations. The resulting HQs are termed refined HQs, and these are presented on Table 6.2-4.

Refined HQs for the 24 preliminary COPCs range from less than 1 to 480 (iron). Chemicals with refined HQs equal to or exceeding the threshold of one or lacking an ESL for one or more receptor

groups but occurring at concentrations below local background include aluminum, beryllium, boron, chromium, cobalt, lithium, manganese, thorium, uranium, and vanadium. Chemicals of most concern from an ecological risk viewpoint are those with refined HQs equal to or exceeding the threshold of one and occurring at concentrations exceeding local background. These are designated as final COPCs and include antimony, arsenic, barium, cadmium, copper, iron, lead, mercury, molybdenum, nickel, selenium, silver, thallium, and zinc.

EA-2 Refined Surface Soil HQs

Refined HQs for EA-2 surface soils by location are presented on Tables 6.2-5 through 6.2-10. Table 6.2-10 presents a summary of the evaluation of EA-2 surface soils. The presentation below includes identification of chemicals as COPCs by location. Designation as a COPC is based on elevated HQs (derived from comparisons of arithmetic mean concentrations to conservative ESLs), comparison to local background, or on the unavailability of ESLs for one or more receptor categories (plants, invertebrates, birds, mammals).

Designation as a COPC based on lack of an ESL is a conservative approach that recognizes an important source of uncertainty at this stage of the assessment. Chemicals eliminated from further consideration and not included in the presentations below include those for which all HQs remain below the threshold of one and those measured at concentrations remaining below those of local background.

<u>Encapsulation Mound East (Table 6.2-5 and Table 6.2-10)</u>

In general, metals concentrations within the upper and lower DUs are similar, with no consistent pattern of one DU being more contaminated than the other. One exception is that the average and maximum concentrations of zinc in the upper DU are approximately two-fold higher than those in the lower DU.

Upper DU – Nineteen inorganic chemicals were detected in surface soils collected from this DU. Selenium and silver were not detected, and thorium was not analyzed. Of these, nine are selected as COPCs based on comparison of mean detected concentration to conservative ESLs for surface soil. These nine chemicals are arsenic, barium, beryllium, cadmium, copper, lead, mercury, molybdenum, and zinc.

Lower DU – The same nineteen inorganic chemicals were detected in surface soils collected from this DU. The same nine chemicals are identified as COPCs for the lower DU (arsenic, barium, beryllium, cadmium, copper, lead, mercury, molybdenum, and zinc).

<u>Encapsulation Mound South East (Table 6.2-6 and Table 6.2-10)</u>

For most metals, concentrations in the upper DU are higher than those of the lower DU. Concentrations are generally similar between the two DUs for beryllium, cadmium, cobalt, lithium, uranium, vanadium, and zinc.

Upper DU – Eighteen inorganic chemicals were detected in surface soils collected from this DU. Molybdenum, selenium, and silver were not detected, and thorium was not analyzed. Of these, five are selected as COPCs based on comparison of mean detected concentration to conservative ESLs for surface soil. These five chemicals are barium, beryllium, cadmium, copper, and zinc.

Lower DU – The same eighteen inorganic chemicals were detected in surface soils collected from this DU. Of these, four are selected as COPCs based on comparison of mean detected concentration to conservative ESLs for surface soil. The selected COPCs (barium, beryllium, cadmium, and zinc) are similar to the Upper DU, except copper.

Encapsulation Mound West (Table 6.2-7 and Table 6.2-10)

For most metals, concentrations in the upper DU exceed those of the lower DU. Concentrations are generally similar between the two DUs for beryllium, cobalt, lead, lithium, manganese, mercury, uranium, and vanadium.

Upper DU – Twenty-one inorganic chemicals were detected in surface soils collected from this DU. Molybdenum was not detected. Six chemicals are selected as COPCs (beryllium, cadmium, selenium, thorium, uranium, and zinc). Most of these are identified as COPCs because one or more of the four preferred ESLs are unavailable. No ESLs are available for thorium.

Lower DU – Nineteen inorganic chemicals were detected in surface soils collected from this DU. Cadmium, molybdenum, and selenium were not detected. Only beryllium is identified as a COPC, based on the unavailability of an avian ESL. HQs for beryllium are below one for terrestrial plants, soil invertebrates, and mammals.

Formosa adit (Table 6.2-8 and Table 6.2-10)

Metals concentrations within the upper and lower DUs are generally similar, with no consistent pattern of one DU being more contaminated than the other. Exceptions include cadmium, manganese, vanadium, and zinc. Concentrations of these metals in the upper DU exceed those of the lower DU.

Upper DU – Twenty inorganic chemicals were detected in surface soils collected from this DU. Molybdenum and selenium were not detected. Six chemicals are selected as COPCs (barium, cadmium, copper, lithium, silver, and zinc). Most of these are identified as COPCs because HQs for one or more of the four receptor categories exceed the threshold of one. Silver is identified as a COPC only because an ESL for soil invertebrates is lacking (HQs for plants, birds, and mammals are below one).

Lower DU – The same 20 inorganic chemicals were detected in surface soils collected from this DU. Six chemicals are selected as COPCs (barium, beryllium, cadmium, copper, silver, and zinc). Most of these are identified as COPCs because HQs for one or more of the four receptor categories exceed the threshold of one. Beryllium and silver are identified as a COPC only because an ESL for soil invertebrates is lacking. HQs for plants, birds, and mammals remain below one for beryllium and silver.

Encapsulation Mound West Drainage 1 (Table 6.2-9 and Table 6.2-10)

Eighteen inorganic chemicals were detected in surface soils collected from this DU. Molybdenum, selenium, and silver were not detected. Soils were not analyzed for thorium. Six chemicals are selected as COPCs (barium, beryllium, cadmium, manganese, mercury, and zinc). Most of these are identified as COPCs because HQs for one or more of the four receptor categories exceed the threshold of one. Barium and beryllium are identified as COPCs only because an avian ESL is

lacking. HQs for plants, invertebrates, and mammals are below one for both barium and beryllium.

Encapsulation Mound West Drainage 2 (Table 6.2-9 and Table 6.2-10)

Eighteen inorganic chemicals were detected in surface soils collected from this DU. Cadmium, molybdenum, and silver were not detected. Soils were not analyzed for thorium. Only beryllium and mercury are selected as COPCs. Beryllium is identified as COPCs only because an avian ESL is lacking. Mercury is identified as a COPC because of the elevated HQ for invertebrates, and because ESLs are lacking for birds and mammals.

Silver Butte (Table 6.2-9 and Table 6.2-10)

Twenty inorganic chemicals were detected in surface soils collected from this DU. Silver was not detected and soils were not analyzed for thorium. Eight chemicals are selected as COPCs (arsenic, barium, cadmium, copper, lead, mercury, molybdenum, and zinc). Most of these are identified as COPCs because, HQs for one or more of the four receptor categories exceed the threshold of one. Molybdenum is identified as a COPC only because an invertebrate ESL is lacking. HQs for plants, birds, and mammals are below one for molybdenum.

EA-3 Refined Surface Soil HQs

As stated above, 21 inorganic chemicals detected in EA-3 surface soils are subjected to further investigation in Step 3a. For EA-3, this refinement is based on comparing the same ESLs used in the screening level risk estimation to arithmetic mean (average) concentrations. The resulting HQs are termed refined HQs, and these are presented on Table 6.2-11.

Refined HQs for the 21 preliminary COPCs range from less than 1 to 2,024 (iron). Chemicals with refined HQs equal to or exceeding the threshold of one or lacking one or more ESLs but occurring at concentrations below local background include aluminum, barium, beryllium, chromium, cobalt, lithium, mercury, thorium, uranium, and vanadium. Chemicals of most concern from an ecological risk viewpoint are those with refined HQs equal to or exceeding the threshold of one and occurring at concentrations exceeding local background. These include antimony, arsenic, copper, iron, lead, molybdenum, selenium, and zinc. These, along with boron, silver, and thallium, are identified as final COPCs. Boron is designated as such only because ESLs are unavailable and risk estimates cannot be calculated. Silver and thallium were selected based on a lack of one or more ESLs or elevated detection limits.

6.2.4.3 Supporting Lines of Evidence

The habitats of OU1 have been highly disturbed from past mine related activities. Mining has degraded the forest habitats within the primary mine disturbance area and immediately adjacent to this area. The degree of disturbance has resulted in these habitats becoming less attractive and usable for resident and migratory wildlife. The primary mine disturbance area (i.e., the majority of OU1) covers approximately 25 acres of land. This area is dominated by mine materials, which results in habitats that are mostly unsuitable for wildlife. Wildlife associated with the fir-dominated forests of the area surrounding the Site will not find suitable habitats for either foraging or breeding. There are a few patches of good quality forest within the primary mine disturbance area, and the estimated acreage of these forest patches is less than a half acre. Small patches of forest provide habitats for species that can adapt to the types and degrees of

disturbance currently associated with OU1, but species dependent on contiguous fir forests would not be expected in these areas.

6.2.4.4 Responses to Risk Questions

Responses to risk questions are used to help interpret the results of refined (Step 3a) risk estimation and reach conclusions regarding ecological risks associated with OU1 exposures. Risk questions and responses are presented below:

- Are the concentrations of COPCs in surface soil and/or surficial mine materials sufficiently elevated to cause or contribute to adverse effects related to the survival, growth, or reproduction of terrestrial plants?

  a. YES – Seventeen chemicals in EA-1 surface soil and mine materials, up to 12 chemicals in EA-2 surface soils, and 9 chemicals in EA-3 surface soils have been measured at concentrations exceeding selected ESLs for terrestrial plants.

- Are the concentrations of COPCs in surface soil and/or surficial mine materials sufficiently elevated to cause or contribute to adverse effects related to the survival, growth, or reproduction of soil-associated invertebrates?

  a. YES – Seven chemicals in EA-1 surface soil and mine materials, up to seven chemicals in EA-2 surface soils, and six chemicals in EA-3 surface soils have been measured at concentrations exceeding selected ESLs for soil-associated invertebrates.

- Are the concentrations of COPCs in surface soil and/or surficial mine materials sufficiently elevated to cause or contribute to adverse effects related to the survival, growth, or reproduction of soil-associated birds with small foraging ranges?

  a. YES / CONDITIONAL – Nine chemicals in EA-1 surface soil and mine materials, up to six in EA-2 surface soils, and six chemicals in EA-3 surface soils have been measured at concentrations exceeding selected ESLs for avian receptors. The elevated risk estimates for these chemicals include some based on ESLs with low confidence, and most are applicable to avian receptors exposed via the dietary pathway. Foraging opportunities for avian receptors are likely limited within OU1, so these elevated risk estimates likely overestimate actual risks. Finally, ESLs specific to avian receptors are lacking for several chemicals identified as final COPCs.

- Are the concentrations of COPCs in surface soil and/or surficial mine materials sufficiently elevated to cause or contribute to adverse effects related to the survival, growth, or reproduction of soil-associated mammals with small foraging ranges?

  a. YES / CONDITIONAL - Nine chemicals in EA-1 surface soil and mine materials, up to four in EA-2 surface soils, and six chemicals in EA-3 surface soils have been measured at concentrations exceeding selected ESLs for mammalian receptors. The elevated risk estimates for these chemicals include some based on ESLs with low confidence, and most are applicable to mammalian receptors exposed via the dietary pathway. Foraging opportunities for mammalian receptors are likely limited within OU1, so these elevated

risk estimates likely overestimate actual risks. Finally, ESLs specific to mammalian receptors are lacking for several chemicals identified as final COPCs.

- Are the concentrations of COPCs in surface water from selected reaches of OU2 surface water bodies sufficiently elevated to cause or contribute to adverse effects related to the survival, growth, or reproduction of aquatic life (i.e., aquatic receptors underlying the derivation of EPA chronic criteria).

  a. YES – Concentrations of dissolved cadmium, copper, lead, and zinc have been measured recently in one or more water bodies evaluated at concentrations exceeding EPA chronic NRWQC for the protection of aquatic life. Concentrations of nickel were measured at concentrations below EPA chronic criterion (EPA 2009c). Also, the pH of the 404 adit water ranged from approximately 2.5 to 3.5, while that of the Formosa 1 adit water ranged from about 2.1 to 3.3, indicating hazardous conditions for aquatic life if exposed to adit water regardless of metals concentrations.

6.2.4.5 Ecological Significance

As discussed above, several chemicals in OU1 surface soils and OU1 (adit) nearby (OU2) surface waters have been measured at concentrations exceeding ESLs intended as thresholds for adverse effects in terrestrial (soil) and aquatic (surface water) ecological receptors. Exceedance of such thresholds does not equate to confirmation of ecologically significant adverse effects. Even very high HQs, such as those calculated for iron in surface soils, do not necessarily suggest adverse effects are inevitable. The potential for ecological receptors exposed to mining-related chemicals to suffer adverse effects related to survival, growth, or reproduction is based only partly on exposure concentration and associated HQs. Also important to consider are the following:

- Receptor Behavior and Exposure – non-mobile receptors (e.g., terrestrial plants) and receptors with limited mobility (e.g., soil invertebrates) have an increased potential to suffer adverse effects, because exposure to OU1 soil and mine materials are more likely for these organisms than highly mobile receptors and those with large foraging ranges.

- Habitat Quality and Quantity – poor quality or disturbed habitat such as that dominating the primary mine disturbance area in OU1, is unlikely to support abundant and diverse ecological communities. A large amount of higher quality habitat is found adjacent to the primary mine disturbance area, which probably results in exposures that are comparatively more infrequent and of shorter duration than those associated with offsite habitats.

- Chemical Concentration, Chemical Form, and Data Availability – Some of the elevated HQs associated with OU1 surface soil and mine materials do not consider the form of chemical likely occurring in OU1 surface soil and mine materials. Some chemicals are found in forms that reduce toxicity compared to the forms on which the ESLs are based. For example, EPCs based on total chromium are in some cases compared to ESLs based on either trivalent or hexavalent chromium. Comparisons to ESLs based on hexavalent chromium probably overestimate risks because most chromium in soils is expected to occur in the less toxic trivalent form. Other inorganic chemicals often occur in forms that are generally considered toxic or have reasonable potential be toxic under commonly encountered conditions.

For this reason it is expected that arsenic, cadmium, copper, lead, and zinc are more ecologically significant (regardless of HQs) than chemicals that are less well-studied, those with low confidence ESLs, and those for which toxicity data are generally lacking. Arsenic, cadmium, copper, lead, and zinc are, therefore, designated as final COCs for this ERA. Copper (dissolved) is designated as the single most hazardous chemical for surface water downgradient of OU1. Chemicals designated as final COCs can be viewed as risk drivers or chemicals with the greatest potential to cause or contribute to ecologically significant adverse effects in exposed receptors.

- Population vs. Individual Effects – Calculated HQs primarily reflect potential for adverse effects to individual organisms. In some cases these HQs can infer potential for population level effects because effects underlying the ESLs include reduced survival or impaired reproduction, both of which can affect population status. Most HQs, however, are best viewed as indicating potential for adverse effects at the organism and not the population or community level.

- Representative Receptors vs. Species of Concern – Calculated HQs and qualitative discussions of risk are based primarily on receptor categories (e.g., terrestrial plants) and not on any particular species. Threatened or endangered species, or species of special concern, are not evaluated individually in this ERA because data are lacking to make such evaluations. It is reasonable, however, to conclude that special concern species have potential to be adversely affected if risks to representatives of the receptor category are at risk. Whether a particular species is actually at risk because of exposure to site-related contamination is best considered from a likelihood of exposure viewpoint. For the most part, OU1 does not provide habitat suitable for plant or animal species of special concern.

6.2.4.6 Uncertainty Analysis

This section presents the uncertainty analysis related to exposure, effects, and risk characterization.

Uncertainties Related to Exposure

All exposure assessments have a degree of uncertainty because of necessary simplifications and assumptions that must be made as part of the evaluation. Major sources of uncertainty in the exposure assessment include the values used to represent the magnitude and distribution of media-specific contamination. Obviously, all media cannot be sampled at all locations, and data interpolation and/or extrapolation is necessary. The most likely causes of uncertainty in the exposure portion of this assessment are the chemical concentrations selected as EPCs for risk estimation. Contaminants in soils are most often unevenly distributed, and there are uncertainties in the mean, maximum, and 95 percent UCL values derived from soil sampling. It is believed, however, that sufficient samples have been collected and appropriately analyzed to adequately describe the nature and extent of chemical contamination within OU1 of the Site.

Where potential levels of uncertainty could adversely affect the results of the assessment, conservative approaches were taken that may result in over-protection of some local species. For example, commonly applied exposure assumptions often lead to predictions of risk, especially where receptors with large foraging ranges are assumed to forage predominately on site. The foraging behavior of individual organisms and even populations are sufficiently unknown to

warrant a more conservative or protective approach. To err on the side of over-protection is considered prudent and follows regulatory guidance. This ERA, therefore, evaluates risks to birds and mammals even though exposures for most avian and mammalian receptors are likely to be minimal given the degraded habitat within OU1, and may also be influenced by other variables such as bioavailability or pH.

Uncertainties Related to Effects

Medium- and chemical-specific ESLs used in this ERA to screen COIs and to derive screening level HQs are probably the primary source of uncertainty in the effects analysis. ESLs are by design conservative values that likely overestimate risk when used as thresholds for adverse effects. The degree of conservatism and the confidence in the HQs linked to ESLs depends on the selected ESL. Some ESLs are highly confident because they are based on appropriately derived toxicity data for receptors of interest. Others are more general and less applicable to specific receptors or even receptor categories.

Toxicity data and other information providing the basis for the majority of accepted ESLs are commonly based on effects experienced by individual organisms under controlled laboratory conditions. There is, therefore, considerable concern regarding the ability of these data to reflect or predict population-level or community-level effects in the field. Adequate field data are lacking for most chemical stressors and receptor species, and laboratory-based data are therefore used and accepted in most cases to estimate effects in the field. Effects to individuals in the laboratory may or may not be representative of effects that may be seen in populations and communities in the field.

ESLs for surface water are considered to be associated with low levels of uncertainty, while soil ESLs are likely more uncertain. This is especially true for chemicals for which Eco-SSLs have not been derived. Eco-SSLs are assumed to be associated with low uncertainty for most receptor categories, especially those linked to direct contact exposures. Because site-specific effects or toxicity-based biological data are unavailable, a weight-of-evidence approach is used to assess potential for ecological effects. This ERA relies on ESLs from a large variety of appropriate and relevant data sources, which should decrease the overall uncertainty compared to assessments based on only one or a few data sources.

Uncertainties Related to Risk Characterization

By definition, uncertainties in risk characterization are influenced by uncertainties in exposure assessment and effects assessment. Uncertainties in exposure assessment are considered to be minimized by the extensive recent sampling and analysis of surface soil and to a lesser degree, of surface water. Descriptions of the magnitude and distribution of COPCs within OU1 are considered to be reasonably representative of actual conditions to which ecological receptors may be exposed. This ERA relies on maximum detected COPC concentrations to preliminarily identify COPCs and to describe risks using a conservative approach. These risk estimates are further refined using arithmetic mean or 95 percent UCL concentrations of COPCs as EPCs. It is assumed that the risk estimates based on the refined EPCs more closely reflect actual or potential exposures for organisms with small home or foraging ranges.

Specific areas of concern with regard to uncertainties in this ERA include the lack of useful ESLs or other ecotoxicity data for certain potential chemical stressors, limited data for other chemical stressors, and the impact of exposure to multiple chemical stressors. For example, ecotoxicity data are lacking for several frequently detected metals in surface soil. The impact of cumulative risks or effects from exposure to multiple chemical stressors is another area of uncertainty in the ERA. It is generally assumed that risks from individual chemical stressors are additive. This assumption is based on limited data where the effects of exposures to multiple chemicals were investigated. The actual impact of exposure to multiple chemical stressors on ecological receptors is unknown because additive toxicity has not been confirmed for most chemical combinations.

Finally, the risk characterization method itself can contribute to uncertainties in this ERA. These uncertainties are reduced in this ERA by not relying only on a single EPC or receptor category. The simple HQ method of expressing risk is a useful screening-level approach that may not be appropriate for more complete investigations. The HQ method is, however, considered appropriate as a primary line of evidence for this screening level ERA. The quantitative HQs are supplemented by site-specific observations and general habitat descriptions. Together, these quantitative and qualitative data support a multiple line of evidence approach that provides a more meaningful and realistic evaluation of ecological conditions within OU1.

6.2.4.7 Risk Summary and Conclusions

This section summarizes ecological risks and presents related conclusions regarding ecologically significant results of the ERA. This ERA identified several COPCs in surface soil and mine materials occurring at elevated concentrations potentially linked to adverse effects in exposed terrestrial receptors. A subset of these chemicals are identified as final COCs based on measured concentrations in surface soil and mine materials, the form of these chemicals likely occurring in these media, the potential for toxicity, the confidence in the quantitative risk estimates (reflecting the confidence in the EPCs and ESLs underlying these estimates), and best professional judgment. Final COCs for OU1 surface soil and surface mine materials by EA are presented below:

- EA-1 – Arsenic, cadmium, copper, lead, mercury, nickel, selenium, and zinc;
- EA -2 – Cadmium, copper, manganese, and zinc (location-specific); and
- EA-3 – Arsenic, copper, vanadium, and zinc.

In addition, the ERA concluded that surface soil and mine materials in OU1 (as well as groundwater underlying OU1) are potentially adversely affecting downgradient aquatic resources. Contributing to these surface water-related risks are concentrations of cadmium, copper, lead (marginally), and zinc in surface water. The source of elevated concentrations of these chemicals in surface water is expected to include solid materials transported from OU1 and surface water and groundwater discharge from OU1/OU2. The Formosa 1 adit water was found to be highly acidic (pH about 2.1 to 3.3) and contained greatly elevated concentrations of several dissolved metals (copper, zinc, cadmium, and, to a lesser degree, lead). The 404 adit water was found to contain comparatively low metals concentrations, but is also highly acidic and likely hazardous to aquatic life (and unsuitable for drinking by wildlife) as evidenced by the low pH (approximately 2.5 to 3.5).

6.2.5 Recommendations

This SLERA identified several COPCs in surface soil and mine materials occurring at elevated concentrations that have potential to adversely affect exposed terrestrial receptors. In addition, the SLERA and Step 3a concluded that surface soil and mine materials in OU1 (as well as groundwater underlying OU1) have potential to adversely affect downgradient aquatic resources. Although such findings generally indicate a need to conduct a BERA, it is expected that a BERA is not warranted for OU1 based on likely remedial actions and the recognition that source control of OU1contamination is planned, allowing for future risk evaluations for other OUs. Based on these findings, the following recommendations are presented.

- Evaluate remedial action of OU1 surface soil and mine materials during the FS;
- Terminate the ERA process for OU1; and
- Initiate a BERA for OU2 after:
    - Completion of OU1 remedial actions; and
    - Data for evaluation of OU2 becomes available.

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Section 7
Summary and Conclusions

This section summarizes preceding sections of the RI and presents conclusions. Data limitations and recommendations for future work, as well as PRAOs are also discussed. This section is organized as follows:

- Summary and conclusions (Section 7.1);
- Data limitations and recommendations for future work (Section 7.2); and
- Recommended preliminary remedial action objectives (Section 7.3).

7.1 Summary and Conclusions

The following section presents the summary and conclusions in relation to the major sections of the RI.

7.1.1 Introduction

7.1.1.1 Purpose

The purpose of the RI is to understand the nature and extent of contamination, evaluate risks to human health and the environment, and present sufficient information to support FS and remedial action decisions for OU1. The Site is divided into two OUs:

- ***OU1*** includes all surface and subsurface mine materials and potentially contaminated soils deposited outside of the underground mine workings. These mine materials are defined as OU1 mine materials and generally include materials that were excavated during construction and operation of the mine, such as waste rock, ore, tailings, construction rock, road surfaces, and natural soils co-mingled with waste rock. Potentially contaminated soils are natural soils that may be affected by dispersion of contaminants from mine materials or from MIW.
- ***OU2*** includes all remaining media and site contamination areas, including surface water, stream sediment, groundwater, underground workings, and adit water drainage. Mine materials present within the underground workings are defined as OU2 mine materials.

The EPA-led RI activities were initiated in October 2009. The initial sampling event was conducted to study the Site as a whole and following this event, preliminary OU definitions were developed. After development of the OU definitions, further sampling activities were focused on OU1 characterization to complete the RI/FS process for this OU more quickly rather than the Site as a whole. This will enable remedial action for OU1 source materials to move forward sooner and result in improvement of surface

water and groundwater quality. Data collected for both OUs is presented in this RI report to document the basis for the current CSM for the Site and support FS and ROD development for OU1.

7.1.1.2 Site Description

The Site is an abandoned mine located in southwest Oregon in Douglas County, approximately 25 miles south of Roseburg, Oregon, and 7 miles south of Riddle, Oregon, within Sections 23, 26, and 27, Township 31 South, Range 6 West Willamette Meridian. The Site is located in the Coast Range Klamath Mountains at elevations between 3,200 and 3,700 ft amsl near Silver Butte Peak (3,973 ft amsl). The primary environmental issue is ARD, which is acidic and metal-laden water produced through interaction of precipitation and oxygen with sulfide minerals. ARD is generated within the underground mine and discharges from the Formosa 1 adit on a perennial basis. ARD is also generated by surface and near-surface mine materials, and at a reclamation structure called the encapsulation mound. As ARD is transported through the environment via surface water and groundwater pathways, the pH generally increases through interactions with soils and mixing with neutral-pH waters. The general term MIW is used to describe this water as it continues to move through the watershed, because the pH of the water gradually becomes near-neutral, and the COPC concentrations in MIW gradually decrease. However, this process sequesters COPCs from MIW into sediments and soils.

MIW has severely contaminated surface water and groundwater at the Site. Adverse effects to surface water are observed on an intermittent basis up to 13 miles downstream from the primary mine disturbance area at the confluence of Middle Creek with Cow Creek, but the most severe effects occur in close proximity to the primary mine disturbance area where surface water is virtually devoid of all aquatic life. Effects to groundwater are not well-defined to date, but several areas of strongly acidic and metal-laden groundwater have been identified. Discharge of MIW from groundwater to surface water occurs within both the Upper Middle Creek and South Fork drainages. Effects to soils downslope from ARD-generating mine materials have also been characterized. This work suggests that physical and/or hydrogeochemical dispersion of COPCs has occurred. Effects to sediments within Upper Middle Creek and South Fork Middle Creek are significant based on visual observations, but the nature and extent of contamination in sediments has not yet been assessed.

7.1.1.3 Site History

The mine produced primarily copper and zinc with byproduct silver and gold. Mining was conducted intermittently by several operators over a period of approximately 80 years, with the most recent period of operation occurring from approximately 1990 to 1993. Mine reclamation was conducted after the most recent period of mining. However, mine reclamation was not successful in mitigating problems related to ARD generation.

In the late 1990s and early 2000s, ODEQ and BLM recognized the severity of mine effects to aquatic life in Upper Middle Creek and South Fork Middle Creek. The state of Oregon formerly listed the Site as a State Orphan Site in 2000, and ODEQ conducted remedial measures to mitigate MIW discharge. In 2005, citizens petitioned EPA to consider adding the Site to the NPL. The Site was added to the NPL in 2007.

7.1.2 Study Area Investigations

7.1.2.1 Study Area

The overall study area is focused on the abandoned Formosa Mine Superfund Site. The study area for OU1 is focused on the primary disturbance area of the mine; including surface mine material WRDs, encapsulation mound, other relic mine features, and also includes potentially affected soils down slope of mine materials. The RI sampling activities were conducted from October 2009 through September 2011.

Some previous investigation data collected by others before NPL listing is presented in the RI report. This data is presented to understand historic data trends and describe the physical characteristics of the Site. All previous investigation data are summarized in the data summary report which is provided in Appendix A.

Two SAPs were prepared for the RI. These SAPs were developed before definition of the current Site OU's and therefore were focused on overall Site characterization. As the RI sampling was prioritized to characterize OU1, those portions of the SAPs were completed. The two SAPs were designed as follows:

- SAP1 addresses surface mine materials and contaminated soil sampling, monthly/quarterly surface water and groundwater sampling, seep and spring surveys, and installation of flow rate and water quality instrumentation.
- SAP2 addresses subsurface mine materials and contaminated soil sampling, groundwater monitoring well installation, groundwater sampling, hydrogeologic characterization using down-hole geophysical methods, pumping tests, and well data loggers, background soil sampling, and soil sampling of areas downslope of mine materials.

All sampling activities defined in the SAPs that were related to OU1 sampling were completed by September 2011. Several activities related to OU2 were also defined in the SAPs; however, not all of these activities have been completed. Sampling activities related to OU2 are ongoing and will be completed during a later project phase. Also, it is likely that as remedial action on OU1 is completed, Site conditions will change, which will require development of additional SAPs and/or revisions to existing SAPs.

QA/QC requirements for field and analytical methods as defined by the SAPs were achieved for all sampling activities, except where noted as deviations to these requirements in Section 2. All DQOs relevant to OU1 were achieved. Although there were some unusable rejected data, the data collected is overall of sufficient quality and quantity to define the nature and extent of contamination and support the HHRA and ERA for OU1.

7.1.2.2 Sampling Activities

Surface and Subsurface Mine Materials

Surface and subsurface OU1 mine materials were characterized using a combination of field and laboratory analysis methods. Field methods included paste pH and conductivity measurements, lithologic logging, and other visual observations. Laboratory methods included total metals, SPLP, ABA, and mineralogical analyses. A summary of the samples collected are as follows:

- A total of 398 surface field samples were collected, with 60 of these field samples analyzed by the laboratory for total metals, SPLP, and ABA. A small fraction of these samples were studied for mineralogical analysis.
- A total of 184 subsurface locations were either excavated or advanced using a DPT Geoprobe rig. At these locations, a total of 323 field samples were collected, with 47 of these field samples analyzed by the laboratory for total metals, SPLP, and ABA.
- A total of 202 FPXRF samples were collected, with 52 of these field samples analyzed by the laboratory for total metals.

Soils

Background soils and potentially affected soils downslope of OU1 mine materials were sampled using incremental sampling methods and field sampling methods that included FPXRF, paste pH and conductivity, and lithologic logging. As described above, a total of 202 FPXRF samples were collected. Some of these samples were from locations at the toe of WRDs and some of these samples were from locations in soils downslope of WRDs.

Background soil incremental samples were collected from two different areas; however, only one of the background sample data sets was used for screening and evaluation of Site risks. This background area, BKG1, was located along the general trend of the sulfide mineralized ore bodies. Screening criteria were developed based on data from BKG1, because OU1 is located in areas of known natural outcrops of massive sulfides and other strongly mineralized rocks. It should be noted that no massive sulfide outcrops or weathering products of massive sulfide outcrops were observed in or near the BKG1 sample area; however, this area is located along the general mineralized trend and has greater potential to contain natural concentrations of elevated metals and metalloids compared to non-mineralized areas. However, natural background concentrations in OU1 may have been higher than represented by sample BKG1, because mineralized outcrops are present within OU1.

Incremental samples collected downslope from mine materials were focused on select areas associated with the major WRDs. Four of these incremental sample locations were sampled with two distinct DUs: 1) an upper DU located just below the downslope extent of mine materials, and 2) a lower DU located immediately below the upper DU. Three other downslope incremental samples were collected as a single DU only. These samples were located within major drainage valley areas downslope from the WRDs where the pathways of contaminant dispersion by erosion and hydrogeochemical processes are strongly controlled by topography.

Surface Water

Several historic and new surface water locations have been sampled for the RI. A comprehensive sampling event was conducted in October 2009 that established an understanding of the Site at that time, since infrequent sampling had been conducted at the Site since 2002. A dry season seep and spring survey was conducted during this initial sampling event. A wet season seep and spring survey was also conducted in January/February 2010. After these initial surface water sampling events and the decision to focus the RI on OU1, surface water sampling was focused on a small group of locations as part of a biannual sampling program. The biannual sampling program included five sites located within the Upper Middle Creek, South Fork Middle Creek, and Lower

Middle Creek areas. The surface water samples provide further evidence of COPC migration throughout the Site.

Groundwater

The initial groundwater sampling event in October 2009 identified that only two of the five original bedrock groundwater wells were functioning or had water present. These wells were then sampled at that time. These wells were also sampled during biannual sampling conducted between January 2010 and September 2011. A series of shallow wells and piezometers were installed in August 2010 using a DPT Geoprobe rig. After installation, wells that had water present were sampled. Additional samples and water levels have been collected at these new wells and the existing bedrock wells during biannual sampling conducted between January 2010 and September 2011. In November 2010, water level transducers were installed in all functioning wells at the Site. Water level data available through September 2011 is included in this RI.

7.1.3 Physical Characteristics

Physical characteristics are evaluated to characterize the environmental setting at the Site, including features such as soils, geology, hydrology, and climate. Developing an adequate understanding of site physical characteristics is vital to understanding the nature and extent of contamination, fate and transport, and risk.

7.1.3.1 Site Features

The Site is accessible by improved gravel and natural surface roads, which are maintained by BLM and private timber companies. The majority of the Site can be accessed off of Shoestring Road using Silver Butte Road (Road 30-6-35.1) and is readily accessible by vehicle throughout the year, with the exception of winter months when snow may hinder vehicular travel.

Major Site features include:

- **Surface piles of OU1 mine materials** are predominantly waste rock and construction rock, which have been comingled in many areas. OU1 mine materials are present at all adit portals, on the east and west sides of the encapsulation mound, on road surfaces, and in other areas disturbed by mining.
- The **encapsulation mound** was constructed from a former water and tailings storage pond during mine reclamation. This facility contains tailings and low grade ore.
- The **underground mine and associated mine portals** were constructed over various periods of operation. Currently all underground mine workings are inaccessible, because portals were reclaimed during the early 1990s. ARD discharges from the Formosa 1 adit on a perennial basis. Four additional reclaimed portals formerly accessed the underground mine, but do not generally discharge ARD. Two small isolated adits (404 and K1G) are also present south of the Site.
- The **adit water diversion system** has been reconstructed several times since mine reclamation. This facility is designed to collect MIW discharging from the Formosa 1 and Silver Butte 1 adits and divert this water in a pipeline to a discharge point located just north of the Silver Butte WRD.

7.1.3.2 Surface Water

The Site is located near the top of Silver Butte at the drainage divide among four major drainages. The west and south east portions of the Site are drained by Upper Middle Creek and South Fork Middle Creek, perennial streams that are tributaries to Middle Creek. These streams are severely affected by the mine. The north and northeast portions of Silver Butte are drained by Russell Creek and Upper West Fork Canyon Creek respectively.

Russell Creek, West Fork Canyon Creek, and Middle Creek all drain into Cow Creek, a major regional watershed which supplies municipal drinking water to the town of Riddle, as well as several private drinking and irrigation water intakes. Flow in Cow Creek is significantly higher than the tributary drainages of Russell Creek, Canyon Creek, and Middle Creek.

7.1.3.3 Geology

The geology of the Site is characterized by weakly metamorphosed mafic volcanic rocks, which lie within an accommodation zone between two regional thrust faults, the Silver Butte Thrust and the Coast Range Thrust. The rocks strike generally northeast and dip towards the east. The volcanic rock units include a variety of basaltic to dacitic flows and tuffs. A thin veneer of unconsolidated colluvial and alluvial sediments overlies the metavolcanic bedrock.

A series of massive sulfide lenses are present within the metavolcanic rocks. These massive sulfide lenses are concordant with bedding of the metavolcanic rocks and crop out along a northeastern trend extending from the encapsulation mound area towards the Formosa 2 and 3 adits. Natural enrichment of metals and metalloids including arsenic, cadmium, copper, lead, and zinc are associated with these massive sulfide deposits. Massive sulfide deposits containing economic concentrations of copper and zinc were the target of mining activities at Formosa. The massive sulfide deposits and surrounding rocks contain high concentrations of pyrite, an ARD-generating mineral, and other sulfide, sulfosalt, and sulfate minerals.

7.1.3.4 Groundwater

Although groundwater has not been fully characterized to date, available information regarding groundwater is presented to support: 1) assessment of effects to groundwater caused by OU1 mine materials, 2) understanding of fate and transport processes relevant to both OUs, and 3) facilitate evaluation of additional groundwater characterization activities during a later phase of the project. The groundwater system at the Site is differentiated into two groundwater systems: the alluvial system and the bedrock system.

The importance of the alluvial groundwater system in transporting MIW to surface water was recognized during detailed seep and spring surveys on and around Site. Alluvial aquifers are present within unconsolidated alluvial and colluvial sediments located within tributary drainages. These aquifers coalesce in the downstream direction and convey water to the major drainages of Upper Middle Creek, South Fork Middle Creek, Russell Creek, and West Fork Canyon Creek.

The bedrock aquifer is located within metavolcanic rocks, which exhibit relatively lower permeability as compared to unconsolidated sediments that host the alluvial groundwater system. Observation of bedrock outcrops and water movement through those outcrops during

spring and seep surveys shows that the primary porosity of the bedrock rock units is low, and that groundwater is conveyed predominantly through fractures and other discontinuities. The overall permeability of the bedrock aquifer and the degree of inter-connectedness of individual fracture zones within the bedrock aquifer is unknown.

7.1.3.5 Surface Water-Groundwater Interactions

Discharge of groundwater to surface water was observed in many tributary drainage during the wet season seep and spring survey. Most of the observed locations were areas where groundwater discharges to surface water from alluvial aquifers. Discharge areas were commonly located at intersections of roads with the tributary drainages, where the road cut excavation truncated the alluvial aquifer forcing groundwater to the surface. Often this water flowed over the surface for a short distance downstream of the road before re-infiltrating into the alluvial groundwater system within undisturbed portions of the tributary drainages.

Discharge of MIW to surface water was observed within both the Upper Middle Creek and South Fork Middle Creek drainages. Within Upper Middle Creek, discharge of MIW from groundwater to surface water is extensive in a tributary located approximately 300 ft downgradient from the Formosa 1 adit. This discharge causes severe effects to surface water quality, and was observed during both the wet season and dry season spring and seep surveys suggesting that MIW discharge in this area is perennial. Discharge from the alluvial aquifer system is thought to be a major contributor to MIW discharge from groundwater to surface water in the Upper Middle Creek drainage; however, discharges from the bedrock aquifer to surface water may also occur. MIW was also observed to be discharging from the alluvial aquifer to the South Fork Middle Creek drainage. These discharges occur where road cuts truncate the alluvial groundwater system, and MIW re-infiltrated downstream of the road cuts. The observed discharges were intermittent and may be associated with both the alluvial and/or bedrock groundwater systems.

7.1.3.6 Climate

The climate of the Klamath Mountains is characterized by hot dry summers followed by wet winters of low to moderate temperatures. Precipitation varies between 15 and 70 inches per year. November through March are the wettest months of the year, with median precipitation of 4.48, 5.75, 5.02, 3.58, and 3.35 inches, respectively. The higher precipitation during these months causes high surface water flow in area streams that generally peaks in March and declines during spring, summer, and fall. Precipitation during winter may fall as snow in higher elevations, especially above 3,200 ft amsl. The warmest months are July and August, when the high temperatures average around 76 degrees Fahrenheit. The coldest month is January, when the high averages around 41 degrees Fahrenheit and a low of 31 degrees Fahrenheit.

7.1.3.7 Ecology

The primary mine disturbance area is largely devoid of vegetation in many areas. However, thick vegetative cover is located in areas surrounding the Site. Upland vegetation in and around the Site consists primarily of coniferous forest dominated by Douglas-fir. Golden chinkapin and Pacific madrone also commonly occur in drier areas, while western red cedar and western hemlock occur in wetter areas or on north aspects. Canyon live oak is occasionally found in open, drier areas on rocky soils. Forest age in and around the Site varies from old-growth stands to younger

successional forest and areas of recent timber harvest. Old growth forest is present on BLM managed land located near the Formosa adits.

The areas surrounding the mine provide habitat for a variety of wildlife including Roosevelt elk, black tailed deer, coyote, western grey squirrel, black bear, and numerous bird species. Upper Middle Creek and South Fork Middle Creek are adversely affected by MIW discharge from the Site. Winter steelhead and resident rainbow trout, fall and spring chinook salmon, coho salmon, and cutthroat trout have been documented by the ODFW using the Lower Cow Creek Watershed Analysis Unit (BLM 2002), which includes unaffected portions of the watershed. The old growth forest associated with the Site is potential habitat for the Northern Spotted Owl, a federally listed endangered species.

7.1.3.8 Land Use and Demographics

The Site area for OU1 includes the 25 acres of contaminated mine materials (i.e., OU1 mine materials), as well as potentially contaminated soils outside this area. The majority of this area is located on private land owned by FEI, with some areas managed by BLM. Timber harvest is the predominant land use in the area, with the majority of land surrounding the OU1 Site area is either owned by private timber companies, chiefly Silver Butte Timber Company and Roseburg Resources, or is federal land managed by BLM. The BLM land in the area is designated using one of two land use allocations, either as a General Forest management Area or Connectivity/Diversity Block. In both cases the land is available for timber harvest at varying frequencies, with the Connectivity/Diversity Block being more restrictive in terms of potential land use.

7.1.4 Nature and Extent of Contamination

A major facet of the RI is characterizing nature and extent of contamination to facilitate informed decisions regarding the level of risk at the Site and the appropriate type of remedial response (EPA 1988). Characterizing “nature” of contamination consists of identifying contaminants and measuring the concentrations of those contaminants in various Site media. Evaluating “extent” consists of delineating the contamination to identify the geographic extent, depth, and volume of Site media, which may require remediation to protect human health or the environment.

The RI focuses on OU1; therefore, geochemical characteristics of OU1 source materials are examined in detail, and the geographic extent, depth and volume of the OU1 source materials are defined. The RI work to date has also evaluated nature and extent of contamination in surface water and groundwater, components of OU2, but these media have not yet been fully characterized. Data collected from these media are presented in this RI, but these data are analyzed in less detail pending completion of RA activities for OU1.

7.1.4.1 OU1 Mine Materials and Soils

OU1 mine materials are primary source materials, which are causing deleterious effects to surface water and groundwater. Soils located downslope from mine materials, or in areas that are affected by ARD discharge or seeps are potential secondary sources of contamination.

OU1 Mine Materials

OU1 mine materials consist of waste rock, ore, tailings, construction rock, road construction material, and contaminated soils. Waste rock, ore, and tailings are the primary source materials that contain natural enrichments of various metals and metalloids have the potential to generate ARD. Tailings are present in the encapsulation mound and within the underground mine, but are generally not observed on the surface. Waste rock is common within OU1 mine materials, and unfortunately waste rock management practices during mining and reclamation resulted in extensive comingling of waste rock with construction rock, road surfaces, and other soils. As a result of this extensive comingling of these materials, they are evaluated together and referred to as "OU1 mine materials."

OU1 mine materials were characterized using a weight of evidence approach by comparing data to several different screening criteria. The screening criteria include:

- TAL metals screening criteria based on background incremental soil sample data;
- SPLP screening criteria based on State of Oregon groundwater and surface water standards;
- ABA screening criteria based on the metrics defined by the laboratory method;
- Lithology screening criteria indicative of ARD generating materials;
- Field paste pH screening criteria based on paired comparison of field paste pH and SPLP data; and
- FPXRF screening criteria based on statistical evaluation of the FPXRF data populations.

OU1 mine materials were evaluated for these criteria to identify materials that may require mitigation based on the presence of COPCs that exceed the screening criteria (TAL metals, SPLP metals, and FPXRF metals), the potential to generate ARD, and the potential to leach COPCs to surface water and groundwater.

Mine materials are commonly strongly ARD-generating, as shown by field paste PH data, laboratory acid base accounting data, and lithological data. Modified SPLP data show that dissolved metals and acidity leaches from mine materials at concentrations exceeding screening criteria. The SPLP extract solutions contain high concentrations of cadmium, copper and zinc, which are indicators for MIW-affected waters. These indicators are also found in surface water and groundwater in close proximity to the mine materials. Evaluations of the maturity of the OU1 mine materials indicates that these materials are not yet mature, and that the materials would be expected to generate ARD with lower pH and higher concentrations of COPCs in the future. This indicates that the downstream extent of affects to Upper Middle Creek and South Fork Middle Creek would be expected to increase in the future if the OU1 mine materials are not remediated.

It is estimated that the process of infiltration of precipitation into OU1 mine materials, ARD generation as the water percolates through the mine materials, and subsequent ARD discharge produces 4 to 13 million gallons of ARD in an average year. During particularly high-precipitation years, this volume is estimated to be between 9 and 15 million gallons per year. In contrast, a

previous estimate of the volume ARD that discharges from the Formosa 1 adit is 5 million gallons per year (HartCrowser 2004b). This illustrates the relative importance of OU1 mine materials in overall ARD generation at the Site. ARD produced by OU1 mine materials discharges to both groundwater and surface water. The dominant COPC transport pathway is discharge of ARD to groundwater, COPC migration in groundwater, and subsequent discharge of MIW from groundwater to surface water in Upper Middle Creek and South Fork Middle Creek.

OU1 mine materials are present in WRDs located at the portals of all former openings into the underground mine, and in piles on the east and west side of the encapsulation mound. The areal extent of mine materials is delineated as shown previously on Figure 4.1-17. The depth of OU1 mine materials was delineated based on surface borings and excavator trenches. The thickness of OU1 mine materials averages 9.5 ft based on this subsurface data. Information regarding the variation in OU1 mine materials thickness across the Site is compiled into a thickness isopach map, which was shown previously as Figure 4.1-20. The estimated volume of OU1 mine materials is 317,000 BCY.

Potential Contaminated Soils

Soils located downslope from the mine materials are subject to both physical and hydrogeochemical dispersion of COPCs from the mine materials. Soils in these areas were evaluated using several methods to: 1) further define the downslope boundary of the OU1 mine materials, and 2) characterize soils downslope from that boundary, which may be affected by COPC dispersion. The downslope boundary of mine materials was delineated using a weight of evidence approach that incorporated visual observation, lithological logging, field paste pH/conductivity, and FPXRF. The downslope boundary of mine materials includes the visual extent of the mine materials, and a narrow band of affected soils that was delineated based on paste pH/conductivity and FPXRF data.

Natural soils downslope from this delineated boundary may be affected by either physical dispersion or hydrogeochemical dispersion of contaminants. Hydrogeochemical dispersion is a broad term that relates to leaching of metals and acidity from mine materials through ARD generation, and sequestration of dissolved metals and acidity in soils as the ARD migrates downslope. These soils are located within vegetated areas including some old-growth forest on BLM land. COPC concentrations in these soils were evaluated by incremental sampling methods. Two areas of background soils were also sampled by incremental sampling to provide screening criteria to compare with the downslope soils. Comparison of the background data with the downslope data shows that the downslope soils are enriched in numerous COPCs as compared to background. However, it is unknown if the relatively higher metal concentrations in the downslope soils reflect natural variability in background in this strongly mineralized area, or if these relatively higher values result from downslope dispersion from mining–related contamination.

Several areas were identified in the downslope soils where hydrogeochemical dispersion was clearly responsible for metals enrichment. The most pronounced effects are present within the discharge areas for the adit water diversion system. Although delineation of contamination associated with the adit water diversion system discharge was not a DQO for the RI, opportunity samples of affected soils and general observations were completed in the area visibly affected by

adit water discharge. Thick accumulations of iron precipitates and anomalous arsenic concentrations are present in the direct vicinity discharge area. Although not delineated to date, it is thought that effects of contaminant dispersion for COPCs such as cadmium, copper and zinc, which precipitate and/or adsorb at higher pH, may be present downgradient from the adit diversion discharge point. These effects of COPC dispersion may be present within soil, subsoil, or groundwater.

Several relatively small areas were also identified where MIW was discharging to soils from groundwater as seeps. These seep-affected soils exhibit high copper and zinc concentrations, which may be caused by adsorption of dissolved copper and zinc by organic matter in the soil. The sources for the seeps have not been identified and may relate to discharge of MIW from OU1 mine materials and from the alluvial and/or bedrock groundwater systems.

7.1.4.2 Surface Water

The nature and extent of contamination in surface water have not been fully characterized to date. Available data regarding surface water are described to support analysis of the effects of OU1 mine materials on surface water, document effects of MIW discharge in the Middle Creek watershed, monitor for potential effects to Russell Creek and West Fork Canyon Creek, and evaluate water quality downstream in Cow Creek where water is withdrawn for uses including irrigation and municipal drinking water. Wet and dry season seep and spring surveys were also conducted to evaluate the effect of groundwater discharge on surface water quality.

Surface water quality data collected from the upper reaches of Upper Middle Creek and South Fork Middle Creek is strongly affected by MIW. This water is calcium–sulfate type water, with high TDS and high concentrations of cadmium, copper, and zinc, indicator parameters for ARD generation. The water is strongly acidic near the primary mine disturbance area, and the pH gradually increases as the surface water flows downstream. COPC concentrations also decrease as the water flows downstream as a result of various attenuation processes including precipitation, adsorption, and dilution.

Surface water in Upper Middle Creek is thought to be affected by ARD discharge from both OU1 mine materials and leakage of the adit water diversion system at the portal of the Formosa 1 adit (from OU2 mine materials). Discharge from the adit water diversion system near the Silver Butte WRD may also affect Upper Middle Creek surface water. MIW contamination in South Fork Middle Creek is thought to be caused primarily by ARD generation from OU1 mine materials. It is possible that some unknown hydraulic connection is present between the underground mine and South Fork Middle Creek. However, available data indicate that OU1 mine materials are the dominant contributor to MIW water in South Fork Middle Creek including: 1) the lack of any underground workings within the South Fork Middle Creek watershed; 2) the presence of MIW seeps in South Fork Middle Creek at elevations above the Formosa 1 adit (i.e., the discharge point for the underground mine); 3) the presence of severe groundwater contamination in the headwaters area of South Fork Middle Creek measured at MW-5; and 4) the presence of strongly ARD-generating OU1 mine materials in the South Fork Middle Creek watershed.

Surface water quality within Russell Creek and West Fork Canyon Creek is not affected by the mine, based on samples collected during a wet season and dry season seep and spring survey.

This water is neutral pH, calcium-bicarbonate type water with low TDS, and low concentrations of indicator parameters for MIW.

MIW that discharges from Middle Creek enters Cow Creek, where significant dilution occurs. Water within Cow Creek was sampled to evaluate if the dilution resulted in attenuation of dissolved contaminant loads to a point that would not present risks to either human or ecological receptors. Surface water in Cow Creek was sampled above the confluence with Middle Creek and at three locations downstream from the confluence where surface water is used. Comparison of the surface water quality data from upstream of Middle Creek to the three downstream locations indicate that the Site is not causing adverse effects to surface water quality within Cow Creek, and that drinking water intakes are not affected by the mine discharge.

7.1.4.3 Groundwater

Preliminary evaluation of nature and extent of contamination in the bedrock and alluvial groundwater systems has been conducted. Two existing bedrock wells were sampled in the wet a dry seasons between October 2009 and January 2011. MW-2 is a bedrock monitoring well located near the Formosa 1 adit. MW-5 is an existing bedrock monitoring well located on the east side of the encapsulation mound. In addition, five alluvial monitoring wells were installed and sampled during 2010 and 2011. Additional characterization of groundwater may be necessary as components of future work focused on OU2.

Water quality in the bedrock aquifer near the Formosa 1 adit is circumneutral pH calcium-sulfate type water with low concentrations of cadmium, copper, and zinc, indicator parameters for MIW. The presence of sulfate as the predominant anion suggests that this water may be slightly affected by either the underground mine or OU1 mine materials. However, the circumneutral pH and relatively low concentration of indicator parameters for MIW suggest that effects to bedrock groundwater quality at this location are not severe. The bedrock groundwater system is fracture controlled, and the possible presence of an unknown fracture-controlled connection between the underground mine and Upper Middle Creek cannot be entirely ruled out. However, the available data do not support a hypothesis that ARD inflows to Upper Middle Creek are caused by discharge of MIW from the bedrock aquifer.

Alluvial monitoring well MW-7A is located close to the Formosa 1 adit, in a perched alluvial aquifer that extends downgradient to major areas of MIW discharge from groundwater to surface water in Upper Middle Creek. Field and laboratory data collected from this well indicates this perched aquifer is strongly acidic with high conductivity, which indicates that the aquifer is affected by MIW. These data support the current hypothesis that some portion of the MIW discharged from the Formosa 1 adit bypasses the collection facility and leaks into the perched alluvial aquifer at this location. This may be a significant source of metals loading to Upper Middle Creek.

Water quality within the bedrock aquifer on the east side of the encapsulation mound is monitored at MW-5. In contrast to the relatively good water quality at MW-2, water quality at MW-5 is severely affected by MIW. This water is strongly acidic calcium-sulfate type water, with high concentrations of cadmium, copper, and zinc. It is unknown if this water has been contaminated by ARD generated in surface mine materials piles or by leakage from the encapsulation mound. However, it is unlikely that groundwater contamination at MW-5 is caused

by the underground mine as described above. Numerous seeps and springs located in South Fork Middle Creek watershed show similar water chemistry and may be related to discharge of MIW from this bedrock aquifer to surface water.

Water quality within the encapsulation mound has also been evaluated based on data collected from piezometers MW-22 and MW-23 installed in August 2010. The data collected indicate that the former pond is saturated for nearly the entire depth with severally affected MIW. Over the 11-month monitoring period, transducer data show an increase and decrease in water level of approximately 1.5 ft following the seasonal changes in precipitation. This data indicates that the encapsulation mound cover system is leaking and that the former pond liner is leaking at some point. Based on this data and historical information regarding pond construction, the estimated leakage of MIW during 2011 is approximately 103,000 gal.

7.1.5 Fate and Transport

Evaluation of contaminant fate and transport considers the processes that contribute to contaminant generation, transport and fate in the environment. Schematic diagrams of contaminant fate and transport processes were developed to provide a conceptual framework describing how mining-related contamination located near the top of Silver Butte has contaminated 18 miles of aquatic habitat within the Middle Creek and South Fork Middle Creek. Current Site conditions are a result of numerous factors discussed previously in this RI report including mining and reclamation practices, geology and mineralogy, topography, climate, and surface water and groundwater hydrogeology. The schematic diagrams provide a conceptual framework, which combines historical information, and data collected during the RI into a coherent model to support future Site remedial action decisions. This model was presented initially in Figures 1.3-3 and 1.3-4, and is described in detail in Section 5.1.

Primary contaminant sources at the Site are natural materials that contain sulfide minerals, which generate ARD when exposed to precipitation and oxygen, and natural enrichments of COPCs. These include OU1 mine materials at the surface and OU2 mine materials within the underground workings. The process of sulfide oxidation and subsequent release of dissolved metals in ARD is the dominant contaminant release mechanism at the Site. Products of ARD generation such as acidity and dissolved metals are transported through the environment. This process leads to attenuation of COPC concentrations in MIW through precipitation and adsorption. However, the COPCs that are attenuated in MIW are deposited in soil and sediment through precipitation and adsorption. These mineral precipitates and associated contaminated sediments and soils represent secondary sources within the Upper Middle Creek and South Fork Middle Creek watersheds, which may be re-dissolved or further mobilized as suspended sediments.

Contaminant fate and persistence in the environment is controlled by changes in mineral solubility and adsorption processes. The highest dissolved contaminant concentrations occur in strongly acidic water discharge from the adits and groundwater seeps. pH is a dominant control on both mineral solubility and adsorption. As this water moves downstream through the watershed the pH increases through dilution, mixing with buffered surface waters, and water-rock interactions. This gradual increase in pH results in sequestration of COPCs from MIW to stream sediments as the MIW flows downstream. Within approximately one mile of the Site,

mineral precipitates are commonly observed, although there composition and extent vary temporally.

Important routes of pollutant migration include runoff, percolation into the alluvial and bedrock groundwater systems, and physical dispersion through erosion and downslope movement. Highly soluble secondary products of ARD generation build up within mine materials as a result of sulfide oxidation. During major precipitation events, these secondary products of ARD generation readily dissolve and release dissolved metals and acidity from OU1 mine materials. During some periods, overland flow may be an important route of pollutant migration; however, percolation to groundwater is thought to be a more important route of pollutant migration. ARD percolates through mine materials, infiltrates into groundwater, and flows towards discharge points located within South Fork Middle Creek and Upper Middle Creek.

Physical dispersion of mine materials is also active in the very steep areas of the Site. Numerous areas of large-scale downslope movement of mine materials are present as a result of the topography and relatively high precipitation rates during some periods of the year. Slope failure of mine materials piles is possible based on observation of a major tension crack along the road across the Silver Butte WRD. Numerous areas of smaller scale slope-movement and erosion were also observed during RI sampling.

7.1.6 Risk Assessment

An evaluation of potential human health and ecological risks associated with exposure to materials in OU1 has been conducted. OU1 was divided into the following three EAs:

- *EA-1* – this exposure area represents the primary mine disturbance area of the Site, as defined by the OU1 mine materials boundary delineated and described in detail in Section 4.1.
- *EA-2* – this exposure area represents the area of potentially affected soils located immediately downslope of mine materials defined as EA-1. The area was characterized to determine whether impacts are present beyond the mine materials boundary, and was sampled using an incremental sampling approach.
- *EA*-3 – This exposure area represents the visibly affected areas resulting from the adit water diversion system pipeline and drainfields. This EA includes discharge areas associated with both the current pipeline and previous pipelines which discharged ARD in a drainfield further upgradient from the current pipeline. Human and ecological populations may additionally be exposed to contaminants migrating from mine materials and soils to groundwater and surface water. Exposures to these media are addressed more qualitatively in this risk assessment for OU1; detailed evaluations will be addressed in the risk assessment for OU2.

7.1.6.1 Human Health Risk Assessment

Current workers, visitors, and possible offsite residents were quantitatively evaluated for exposure to surface soils. Future construction workers, workers, visitors and offsite residents were quantitatively evaluated for risks to surface as well as subsurface soils. Visitors included trespassers, hikers, campers, ATV riders, and hunters. Estimated cancer risks for all populations

both current and future, fall within or below the EPA acceptable risk range of 10-4 to 10-6. Estimated noncancer hazards segregated by target organ are below the acceptable hazard benchmark of 1.0.

- EA-1. Estimated cancer risks for current and future onsite workers and construction workers in EA-1 are equal to 1E-05 or less. Estimated cancer risks for current and future visitors (adult and child) in EA-1 are equal to 4E-06 or less. Estimated risks for offsite residents exposed via inhalation to windblown dusts from EA-1 are below the risk benchmark of 1E-06. In all cases, the risks greater than 1E-06 were due to arsenic.
- EA-1. Estimated noncancer hazards for current and future onsite workers, visitors and offsite residents are below the acceptable hazard benchmark of 1.0. Estimated noncancer hazard for future construction workers in the RME case is 2; however, when segregated by target organ, the individual hazard indices for each organ are below 1. In the CTE case, the hazard is below the acceptable hazard benchmark of 1.0.
- EA-2. Estimated cancer risks for current visitors (adult and child) in EA-2 and offsite residents exposed via inhalation to windblown dusts from EA-2 are below the risk benchmark of 1E-06. In all cases, the risks were due to arsenic. Estimated noncancer hazards for these populations are below the acceptable hazard benchmark of 1.0
- EA-3. Estimated cancer risks for onsite workers in EA-3 are equal to 6E-05 or less. Estimated cancer risks for visitors (adult and child) in EA-3 are equal to 2E-05 or less. Estimated risks for offsite residents exposed via inhalation to windblown dust from EA-3 are 2E-06 or less. In all cases, the risks were due to arsenic. Estimated noncancer hazards for these populations are below the acceptable hazard benchmark of 1.0.

In summary, human health risks greater than 1E-6 due to exposure to mine materials and soils are likely site-related, but limited to arsenic. All estimated excess cancer risks fall within EPA's acceptable risk range of 10-4 to 1 0-6. All estimated noncancer hazards segregated by target organ fall below EPA's benchmark of 1.0. Groundwater and surface water exposures may also contribute to human health risk and will be examined quantitatively in the risk assessment conducted for OU2.

7.1.6.2 Ecological Risk Assessment

The ERA identified several COPCs in surface soil and mine materials occurring at elevated concentrations potentially linked to adverse effects in exposed terrestrial receptors. A subset of these chemicals are identified as final COCs based on measured concentrations in surface soils and mine materials, the form of these chemicals likely occurring in these media, the potential for toxicity, the confidence in the quantitative risk estimates (reflecting the confidence in the EPCs and ESLs underlying these estimates), and best professional judgment. Final COCs for OU1 by EA are presented below:

- EA-1 – Arsenic, cadmium, copper, lead, mercury, nickel, selenium, and zinc;
- EA -2 – Cadmium, copper, manganese, and zinc (location-specific); and
- EA-3 – Arsenic, copper, vanadium, and zinc.

In addition, the ERA concluded that OU1 mine materials are adversely affecting downgradient aquatic resources. Contributing to these surface water-related risks are concentrations of cadmium, copper, lead (marginally), and zinc in surface water. The source of elevated concentrations of these chemicals in surface water includes solid materials transported from OU1 and surface water and groundwater discharge.

7.2 Data Limitations and Recommendations for Future Work

Data developed during this RI are sufficient to support the OU1 FS. OU1 mine materials are well characterized and delineated. Potentially affected soils downslope from OU1 mine materials are defined in less detail, but COPC concentrations in the sampled areas are known, and these conditions are thought to be generally representative of soils downslope from mine materials that were not sampled. Characterization and delineation of contamination in the area of the adit water diversion system outfall has been evaluated based on five opportunity samples, which supports risk assessment for these affected soils. After completion of the OU1 FS, pre-design investigations may be necessary in soils downslope of mine materials, and in the adit diversion system outfall area to support detailed remedial designs, if remediation is deemed necessary in these areas.

During the OU1 FS, it is recommended that mine material volumes be further reviewed and assessed as necessary. In particular, further refinement of the volume of mine materials within the encapsulation mound is recommended using existing as-built data, and 3-dimensional computer volumetric modeling approaches. It is also recommended that the content of potentially beneficial metals and other constituents be assessed further during the FS. For example, tailings currently stored within the encapsulation mound may represent a potential source of beneficial materials. Both the metal content and the pyrite content of the tailings should be evaluated for potential beneficial use (pyrite is used in manufacture of sulfuric acid; metals such as copper, silver, and zinc may be recoverable if the material is shipped to a smelter). After remedial alternatives have been selected, it is recommend that the need for pre-design investigations be assessed for downslope soils and soils affected by the adit water diversion system.

Work conducted to date shows that the aquatic habitat in Upper Middle Creek is adversely affected by both OU1 mine materials and water discharging from the underground mine at the Formosa 1 adit. Evaluation and interpretation of RI data indicates that leakage from the Formosa 1 adit is being transported through the subsurface via an alluvial aquifer, and that this water is discharging from the alluvial aquifer into Upper Middle Creek between the confluence of the MA and MB tributaries and a resistant rock outcrop at Raymond Bear Falls. This source of COPCs to Upper Middle Creek may be a major source of metals loading to the stream. It is therefore recommended that work commence to evaluate and improve the performance of the MIW collection system at the portal of the Formosa 1 adit.

Complete mitigation of strongly ARD-generating mines such as Formosa often requires a combination of short-term expenditures for source control and long-term expenditures for water treatment (Nelson et al. 2010). Mitigation of OU1 mine materials through actions such as excavation and placement in a low-permeability repository would limit MIW release from surface

and near surface source materials. However, long-term mitigation of MIW discharge from the Formosa 1 adit will likely include some form of water treatment, which could consist of in situ or ex situ passive treatment, or active treatment. Long-term active treatment is a presumptive remedy for treatment of MIW. The economic liabilities to fund long-term active treatment are significant, and project stakeholders have discussed the need to thoroughly investigate the potential to utilize passive treatment options to reduce these long-term liabilities. The various in situ and ex situ passive treatment technologies require site-specific bench-scale and/or pilot scale assessment to support detailed analysis of remedial alternatives for long-term water treatment in the FS. Therefore, it is recommended that treatability testing of MIW generated within the underground mine commence in the near future to provide full consideration of potential in situ or ex situ passive treatment approaches, and thereby reduce long-term economic liabilities for project stakeholders. These activities should be considered as planning commences for future OU2 activities.

7.3 Recommended Preliminary Remedial Action Objectives

RAOs are medium-specific and operable unit-specific goals for protecting human health and the environment (EPA 1988). In accordance with EPA RI/FS guidance, this section presents recommended PRAOs for OU1 based on results of the RI:

1. Manage OU1 mine materials to prevent COPC migration into surface or groundwater, and to protect aquatic and riparian ecosystems downgradient of OU1;
2. Implement land-use controls to provide for land uses that will be protective of the remedy;
3. Ensure that users of private or BLM lands have no more than a 1×10^{-6} chance of contracting cancer from ingestion of mine materials or contaminated soils; and
4. Reduce risks to ecological receptors at the population or community level through management of mine materials and contaminated soils;

These recommended PRAOs are described further below.

Manage OU1 mine materials to prevent COPC migration into surface or groundwater, and to protect aquatic and riparian ecosystems downgradient of OU1

As discussed in section 4, identification of mine materials is based on a weight of evidence approach, because there is no test than can fully define the propensity for a rock to generate ARD. Using this weight of evidence approach, mine materials in OU1 have been characterized and delineated. Mine materials are primary source materials and the process of ARD generation causes ongoing releases of COPCs from mine materials into the environment. These COPCs are subsequently transported via groundwater and surface water pathways to downstream ecosystems, where they cause adverse effects to aquatic biota and potentially to other upper trophic level consumers [e.g., piscivorous (fish eating) birds and mammals]. Managing mine materials in a manner that prevents ARD generation and subsequent transport of the COPCs via groundwater and surface water, will prevent ongoing releases of COPCs from mine materials, and the associated deleterious effects to downstream ecosystems.

Implement land-use controls to provide for land uses that will be protective of the remedy

Management of OU1 source materials may require excavation and placement of the ARD-generating source materials in a repository with a low-permeability cover system, liner, and leachate collection system. Potential future land uses could potentially damage or degrade this cover system or restored areas where mine materials were excavated. This recommended PRAO would protect the repository and restored areas, and thereby provide for long-term protection of downstream resources.

Ensure that users of private or BLM lands have no more than a 1 x 10^{-6} chance of contracting cancer from ingestion of mine materials or contaminated soils

Evaluation of human health risks related to incidental ingestion and inhalation of arsenic indicate that under some land uses and in some exposures, the cancer risk exceeds 1 x 10^{-6}. The exposure areas that pose potential cancer risks to human receptors of greater than 1 x 10^{-6} are EA-1 and EA-3. OU1 mine materials that pose cancer risks in EA-1 are those materials that have been determined to also be sources of ARD generation and associated deleterious effects to downstream ecosystems. It is expected that management of mine materials to meet the goals set forth in PRAO 1 and PRAO 2 would also address the requirements of this PRAO. Contaminated soils that pose potential cancer risks in EA-3 are associated with the adit water diversion system discharge. This PRAO would require management or mitigation of contaminated soils in EA-3 to protect human health.

Reduce risks to ecological receptors at the population or community level through management of mine materials and contaminated soils

The ecological risk assessment shows that mine materials in EA-1, potentially contaminated soils in EA-2, and contaminated soils in EA-3 have the potential to cause risks to various ecological receptors. This recommended PRAO is expected to provide protection of most ecological receptors at the population or community level through appropriate management or mitigation, which would be analyzed in the FS. This recommended PRAO may not, however, provide protection of sensitive ecological receptors at the individual level (i.e., individual organisms may suffer adverse effects).

Section 8
References

Baron, D. and Palmer, C.D. 1996. *Solubility of Jarosite at 4-35°C*. Geochimica et Cosmochimica Acta, Vol. 60, No. 2, pp. 185 – 195.

BLM. 2000. *Action Memorandum – Request for Approval of Time-Critical Removal Action at the Formosa Abandoned Mine Land Site, Douglas County, Oregon*. September.

BLM. 2002. *Lower Cow Creek Watershed Analysis and Water Quality Restoration Plan. Roseburg District, South River Resource Area*. November.

Caterpillar Inc. 2006 Caterpillar Performance Handbook, Edition 36. April.

CDM. 2009a. *Final Sampling and Analysis Plan for Surface Water, Groundwater, and Surface Soil and Waste Rock Sampling*. September.

___. 2009b. *Final Data Summary Report, Formosa Mine Site, Douglas County, Oregon.* June.

___. 2010. *Final Sampling and Analysis Plan for Subsurface Mine Waste Sampling, Hydrogeologic Characterization, and Risk Assessment Sampling, Formosa Mine Superfund Site, Douglass County Oregon.* July.

Csuti, B., T. A. O'Neil, [M. M. Shaughnessy, E. P. Gaines, and J. C. Hak.] 1997. *Atlas of Oregon Wildlife*. Oregon State University Press, Corvallis, Oregon. 492p. September.

Derkey, R.E. 1981. *The Silver Peak Volcanogenic Massive Sulfide, Northern Klamath Mountains, Oregon*, U.S. Geological Survey Open File Report, 81-355, 213-222.

___. 1982. *Geology of the Silver Peak Mine, Douglas County, Oregon*. A Dissertation Presented in Partial Fulfillment of the Requirement for the Degree of Doctor of Philosophy, Major in Geology. University of Idaho. August.

Derkey, R.E. and Matsueda, H.M. 1989. *Geology of the Silver Peak Mine, A Kuroko-Type Deposit in Jurassic Volcanic Rocks, Oregon*, U.S.A., J. Min. Coll. Akita Univ., Ser. A, Vol. VII, No. 2, pp. 99-123, March.

DOGAMI. 1990 – 1999. *Onsite Inspection Reports*. Series of Reports on inspections of the Formosa Mine by DOGAMI personnel.

___. 1993. *Closure Order, RE: 10-0169*. Memorandum issued to FEI. August 3.

___. 1994. *Silver Butte Mine Acid Rock Drainage- Formation and Future*. DOGAMI report by A.H. Throop. March.

___. 1995. *Reclamation of Formosa Exploration's Silver Butte Mine as of December 1994*. By A.H. Throop. January.

___. 1996. *Formosa Exploration's Silver Butte Mine Status Update – April 1996*. By A.H. Throop. April.

Duex, T.A., 2000, *Reclamation at the Richmond Hill Mine, Lawrence County, South Dakota*, in Proceeding from the Fifth International Conference on Acid Rock Drainage, Society for Mining Metallurgy and Exploration Inc, Littleton, Colorado.

Efroymson, R.A., M.E. Will, G.W. Suter II, and A.C. Wooten. 1997a. *Toxicological Benchmarks for Screening Contaminants of Potential Concern for Effects on Terrestrial Plants*: 1997 Revision. Oak Ridge National Laboratory, Oak Ridge, TN. 128 pp. ES/ER/TM-85/R3.

Efroymson, R.A., M.E Will, and G.W. Suter II. 1997b. *Toxicological Benchmarks for Contaminants of Potential Concern for Effects on Soil and Litter Invertebrates and Heterotrophic Processes*: 1997 Revision. Oak Ridge National Laboratory, Oak Ridge TN. ES/ER/TM-126/R2.

EPA. 1986. *Quality Criteria for Water*. (Goldbook) water.epa.gov/scitech/swguidance/standards/criteria/aqlife/upload/2009_01_13_criteria_goldbook.pdf.

__. 1988. *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA, Interim Final,* Office of Emergency and Remedial Response. Publication Number 9285.7-15-1. EPA/540/G-89/004.

__. 1989. *Risk Assessment Guidance for Superfund: Human Health Evaluation Manual Part A*. U.S. Environmental Protection Agency, Office of Emergency and Remedial Response, Washington DC. EPA/540/1-89/002. OSWER Directive 9285.701A. NTIS PB90-155581.

___. 1991. *"Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual, Supplemental Guidance, Standard Default Exposure Factors,"* Interim Final, OSWER Directive: 9285.6-03, Office of Emergency and Remedial Response Toxics Integration Branch, USEPA, Washington, D. C., March 25, 1991.

__. 1997. *Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessments*, Interim Final. EPA/540/R-97/006. OSWER 9285.7-25. June.

__. 2000a. *Guidance for the Data Quality Objectives Process, Final*. EPA QA/G-4. August.

__. 2000b. *Guidance for Region 10 human health risk assessments regarding bioavailability of arsenic contaminated soil.* Interim Report, EPA Region 10 guidance for Superfund human health risk assessment, September.

__. 2001. *Risk Assessment Guidance For Superfund: Volume I: Human Health Evaluation Manual (Part D, Standardized Planning, Reporting, and Review of Superfund Risk Assessments)*. Office of Solid Waste and Emergency Response. Publication 9285.7-47. December.

__. 2002. *Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites*. Office of Emergency and Remedial Response. OSWER 9355.4-24. December.

__. 2003. *Guidance for Developing Ecological Soil Screening Levels*. Office of Solid Waste and Emergency Response. OSWER 9285.7-55. February.

__. 2004a. *CLP NFGs for Inorganic Review*.

__. 2004b. *Risk Assessment Guidance for Superfund: Volume I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment) Final*. Office of Emergency and Remedial Response. OSWER 9285.7-02EP. EPA/540/R/99/005. July.

__. 2005. *Guidelines for Carcinogen Risk Assessment*. Risk Assessment Forum. EPA 630/P-03/001F. March.

__. 2007. Method 6200 *Field Portable X-Ray Fluorescence Spectrometry for the Determination of Elemental Concentrations in Soil and Sediment*. Revision 0. February.

__. 2008a. *Region 10 Emergency Response Unit Site Specific Sampling Plan, Formosa Mine Site*. June.

__. 2008b. *Demonstrations of Method Applicability under a Triad Approach for Site Assessment and Cleanup — Technology Bulletin*. August.

__. 2008c. *Ecological Soil Screening Levels* (Eco-SSLs). Last updated December 9. Accessed at: http://www.epa.gov/ecotox/ecossl/.

__. 2009a. *Action Memorandum for Emergency Removal Action, Formosa Mine.* June.

__. 2009b. *Amendment to Action Memorandum for Emergency Removal Action, Formosa Mine.* June.

__. 2009c. *National Recommended Water Quality Criteria*. water.epa.gov/scitech/swguidance/standards/current/index.cfm.

__. 2009d. RAGS *Risk Assessment Guidance for Superfund: Volume I: Human Health Evaluation Manual (Part F, Supplemental Guidance for Inhalation Risk Assessment) Final*. Office of Solid Waste and Emergency Response. OSWER 9285.7-82. EPA/540/R/070/002. January.

__. 2010a. *CLP NFGs for Inorganic Data Review.* January.

__. 2010b. Human Health Medium Specific Screening Levels. November. Accessed at: http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/Generic_Tables/index.htm

__. 2010c. *Integrated Risk Information System (on-line database of toxicity measures)*. http://www.epa.gov/iris.

__. 2010d. *ProUCL Version 4.0 (Version 4.00.04) User's Guide*. February.

FEI. 1995. *Formosa Exploration, Incorporated, Silver Butte Mine, Douglas County, Oregon*. January.

FRC. 1988. *Formosa/Silver Butte Project (Kuroko), Douglas County, Oregon, Exploration, 1988 – 1989*. Unpublished prepared by Lu, K.I. for the Formosa Resources Corporation. April.

___. 1987. *Summary Report on the 1986 Exploration Work at the Silver Peak Kuroko Project, Douglass County, Oregon*. Unpublished prepared by Lu, K.I., Chernavska, A., Madeisky, H.E. for the Formosa Resources Corporation. February.

Freeze, R.A., and Cherry, J.A. 1979. *Groundwater*, Prentice Hall, Englewood Cliffs.

Jambor, et. al. 2003. *Environmental Aspects of MINE WASTES, Short Course Series Volume 31*. Prepared by the Mineralogical Association of Canada.

Guilbert, J.M., and Park, C.F. 1985. *The Geology of Ore Deposits*, W.H. Freeman.

HC. 2000. *Removal Assessment: Focused Engineering Evaluation and Cost Analysis, Formosa Abandoned Mine Land Site, Douglas County, Oregon*. Prepared by HC for ODEQ. September.

___. 2001a. *Interim Remedial Action Measure Report, Formosa Abandoned Mine Land Site, Douglas County, Oregon*. Prepared by HC for ODEQ. March.

___. 2001b. *Data Evaluation Report, Formosa Abandoned Mine Land Site, Douglas County, Oregon*. Prepared by HC for ODEQ. September.

___. 2002. *Supplemental Remedial Investigation Report, Formosa Abandoned Mine Land Site, Douglas County, Oregon*. Prepared by HC for ODEQ. December.

___. 2004a. *Human Health and Ecological Baseline Risk Assessment, Former Formosa Abandoned Mine Land Site, Douglas County, Oregon*. Prepared by HC for ODEQ. January.

___. 2004b. *Feasibility Study, Formosa Abandoned Mine Site, Douglas County, Oregon.* Prepared by HC for ODEQ. Prepared by HC for ODEQ. December.

HDOH. 2008. *Technical Guidance Manual for the Implementation of the Hawaii State Contingency Plan*, Section 4 Soil Sample Collection Approaches, Interim Final.

Heenan, E. 2000. *Summary of Significant Events at the Formosa Mine AML Site*. Unpublished internal BLM document provided by E. Heenan. March.

Jambor, et. al. 2003. *Environmental Aspects of Mine Wastes, Short Course Series Volume 31*. Prepared by the Mineralogical Association of Canada.

Koch, G.S., Link, R.F. 1980. Statistical Analysis of Geological Data, Dover Publications, New York.

Langmuir, D. 1997. *Aqueous Environmental Geochemistry*, Prentice Hall, Upper Saddle River.

Nelson, M., Hazen, G, and Fundingsland, S. *Mine Water Remediation at Large-Scale Metal Mines: Balancing Near-Term Expenditures for Source Control with Long-Term Expenditures for Collection*

and Treatment. 2010 Proceedings, Mine Water and Innovative Thinking, International Mine Water Association, September 5-9, 2010, Cape Briton University Press, Sydney, Nova Scotia.

Nelson, M.R. 2003. *Circumneutral pH Contaminant Mobility at Black Hills Gold Mines: Environmental Concerns and Long-Term Closure Liability, Preprint*. Annual Meeting of the Society for Mining, Metallurgy, and Exploration, Cincinnati, Ohio.

Nordstrom, D.K., Alpers, C.N. 1999. *Geochemistry of Acid Mine Waters, in the Environmental Geochemistry of Mineral Deposits, Part A: Processes, Techniques, and Health Issues*. Plumlee, G.S., and Logsden, M.J., editors, Reviews in Economic Geology Volume 6A, Society of Economic Geologists.

Norecol. 1989. *Formosa Exploration Inc. - Silver Butte Project Baseline Environmental Studies Report*. Prepared for FEI. November.

Northwest Environmental Resources. 2003. *Proposal to Remedy Metals Contamination in Middle Creek, Phase 1.* March.

ODEQ. 2003 – 2006. *Time Critical Removal Incident Orders*. Internal ODEQ files.

Plumlee, G.S. 1999. *The Environmental Geology of Mineral deposits,* in the Environmental Geochemistry of Mineral Deposits, Part A: Processes, Techniques, and Health Issues. Plumlee, G.S., and Logsden, M.J., editors, Reviews in Economic Geology Volume 6A, Society of Economic Geologists, Littleton, CO., p. 133-154.

Ramp, L. 1972. *Geology and Mineral Resources of Douglas County, Oregon*. DOGAMI, Bulletin 75, p. 106.

Ramsey, C. 2007. *Sampling for Defensible Environmental Decisions,* Short course manual presented April 30 to May 3, 2007, Envirostat.

Reimann, C., Filzmoser, P. and Garrett, R.G. 2005. *Background and Threshold: Critical Comparison of Methods of Determination*. Science of the Total Environment, vol. 346, no. 1/3, pp. 1-16.

Roberts, Stephen M.; Munson, John W.; Lowney, Yvette W.; and Ruby, Michael V. 2007. *Relative Oral Bioavailability of Arsenic from Contaminated Soils Measured in the Cynomolgus Monkey.* Toxicological Sciences 95(1) 281-288.Rose, A.W., Hawkes, H.E., Webb, J.S. 1979. *Geochemistry in Mineral Exploration*. Academic Press, Harcourt Brace Jovanovich Publishers, London, p. 549-581.

Rose, A.W. and Cravotta, C.A. 1994. *Geochemistry of Coal Mine Drainage, Coal Mine Pollution Prevention on Pennsylvania, Pennsylvania Department of Environmental Quality*.

Schafer, W.M. and Benowitz, S. 2000, Performance-Based Closure and Preliminary Remedial Action Goals, unpublished presentation, Gilt Edge Mine Superfund Site, Lawrence County, South Dakota.

Seal, R.R., and Hammarstrom, J.M. 2003. *Geoenvironmental Models of Mineral Deposits: Examples from Massive Sulfides and Gold Deposits*, in Jambor, J.J., Blowes, D.W., and Ritchie, A.I.M. eds.,

Environmental Aspects of Mine Wastes, Mineralogical Associateion of Canada, Short Course Volume 31.

Shenon, P.J. 1933. *Copper Deposits in the Squaw Creek and Silver Peak Districts and at the Almeda Mine, Southwestern Oregon with Notes on the Pennell & Farmer and Banfield Prospects*. U.S. Department of Interior Geological Survey, Circular 2.

Smith, K.S., 1999. *Metal Sorption on Mineral Surfaces: An Overview with Examples Relating to Mineral Deposits, in The Environmental Geochemistry of Mineral Deposits Part A: Processes, Techniques, and Health Issues*. Plumlee, G.S. and Logsdon, M.J., Editors, Reviews in Economic Geology, Volume 6A, Society of Economic Geologists, Inc., Littleton, Colorado, p. 161-176.

Stumm, W. and Morgan, J.J. 1996. Aquatic Chemistry, Chemical Equilibria and Rates in Natural Waters. Third Edition. John Wiley and Sons, Inc.

Thermo Scientific. 2008. Chemical Analysis of Copper and Cobalt with the Thermo Scientific NITON® XL3t 500 Series.

Tukey, J.W. 1977. *Exploratory Data Analysis*, Reading, Addison-Wesley.

U.S. Census Bureau; American Community Survey. 2005-2009. Summary Tables ; generated by Matt Hewitt; using American FactFinder; <http://factfinder.census.gov>.

USFWS. 2008a. *Final Revised Critical Habitat for the Northern Spotted Owl*. Maps available at: http://www.fws.gov/pacific/ecoservices/nsofch.html.

__. 2008b. *Revised Designation of Critical Habitat for the Northern Spotted Owl*; Final Rule. Federal Register (73):47326-47522.

__. 2008c. *Recovery Plan for the Northern Spotted Owl* (Strix occidentalis caurina). U.S. Fish and Wildlife Service, Portland, Oregon.

__. 2010. *Species Fact Sheet. Northern Spotted Owl*; Strix occidentalis caurina. Oregon Fish and Wildlife Office. Available on line at: http://www.fws.gov/oregonfwo/Species/Data/NorthernSpottedOwl/ .

__. 2011a. *Federally Listed, Proposed, Candidate Species and Species of Concern under the Jurisdiction of the Fish and Wildlife Service which may occur within Douglas County, Oregon*. Oregon Fish and Wildlife Office Available on line at: http://www.fws.gov/oregonfwo/Species/Lists/.

__. 2011b. *Species Fact Sheet, Fisher; Martes pennant*. Oregon Fish and Wildlife Office. Available on line at: http://www.fws.gov/oregonfwo/Species/Data/Fisher/.

__. 2011c. *Species Fact Sheet, Columbian white-tailed deer*; Odocoileus virginianus leucurus. Oregon Fish and Wildlife Office. Available on line at: http://www.fws.gov/oregonfwo/Species/Data/ColumbianWhiteTailedDeer/ .

White W.W., Lapakko, K.A., Cox, R.L. 1999. *Static-Test Methods Most Commonly Used to Predict Acid- Mine Drainage: Practical Guidelines for Use and Interpretation*. Plumlee, G.S., and Logsden, M.J., editors, Reviews in Economic Geology Volume 6A, Society of Economic Geologists, Littleton, Colorado, p. 325-338.

Wilson, J. 2009. Personal Communication, Interview.

Younger P.L., Banwart, S.A., Hedin, R.S. 2002. *Mine Water, Hydrology, Pollution, Remediation*, Kluer Academic Publishers, Dordrecht.

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