Response Action Contract for
Remedial, Enforcement Oversight, and Non-time Critical
Removal Activities at Sites of Release or Threatened Release of
Hazardous Substances in EPA Region 8

Final

Remedial Investigation Report for the Gilt Edge Superfund Site Lawrence County, South Dakota

U.S. EPA Contract No. 68-W-05-049
Work Assignment No.: 214- RICO-087T

February 1, 2008

Prepared for:
U.S. Environmental Protection Agency, Region VIII
1595 Wynkoop
Denver, Colorado 80202

Prepared by:
CDM Federal Programs Corporation
1331 17th Street, Suite 1100
Denver, CO 80202

Contents

Section 1 Introduction

1.1 Purpose 1-1
1.2 RI Organization 1-1
1.3 Site Description 1-2
1.3.1 Site Location 1-2
1.3.2 Site Contamination 1-3
1.3.3 Operable Units 1-5
1.3.4 General Site Features 1-6
1.3.4.1 Open Pits 1-6
1.3.4.2 Waste Rock Dumps 1-7
1.3.4.3 Underground Mine Workings 1-8
1.3.4.4 Heap Leach Pad 1-8
1.3.4.5 Mineral Processing Facilities 1-9
1.3.4.6 Water Treatment Plant and ARD Collection and Conveyance System 1-10
1.3.5 Site Conceptual Model 1-10
1.3.6 Remediation Subareas 1-13
1.3.6.1 Anchor Hill Pit Remediation Subarea 1-14
1.3.6.2 Dakota Maid Pit Remediation Subarea 1-15
1.3.6.3 Hoodoo Fill Remediation Subarea 1-15
1.3.6.4 Heap Leach Pad Remediation Subarea 1-15
1.3.6.5 Langley Benches Remediation Subarea 1-16
1.3.6.6 Process Plant Remediation Subarea 1-16
1.3.6.7 Ruby Repository Remediation Subarea 1-17
1.3.6.8 Lower Strawberry Creek Remediation Subarea 1-17
1.3.6.9 Strawberry Gulch Remediation Subarea 1-17
1.3.6.10 Stormwater Pond Remediation Subarea 1-18
1.3.6.11 Sunday Pit Remediation Subarea 1-18
1.3.6.12 Union Hill Upland Remediation Subarea 1-19
1.3.6.13 Upper South Ruby Remediation Subarea 1-19
1.3.6.14 Water Treatment Plant Operations Remediation Subarea 1-19
1.3.6.15 Groundwater Remediation Subarea 1-20
1.4 Site History 1-20
1.4.1 Early Mining and Mineral Processing 1-20
1.4.1.1 Early Owners/Operators 1-20
1.4.1.2 BMC Operations 1-22
1.4.2 Regulatory Activities 1-24
1.4.3 Emergency Responses 1-25
1.4.3.1 State of South Dakota Emergency Response 1-25

1.4.3.2 EPA Response 1-26
1.4.4 Remedial Actions at OU2 and OU3 1-26
1.4.4.1 OU2, Water Treatment, Early Action Interim ROD, April 2001 1-26
1.4.4.2 OU2, Water Treatment, Interim ROD, November 2001 1-27
1.4.4.3 OU3, Ruby Gulch Waste Rock Dump, Interim ROD, August 2001 1-27

Section 2 Data Collection, Evaluation, and Usability

2.1 Data Quality Objectives 2-2
2.2 Quality Assurance/Quality Control Summary 2-3
2.3 Data Usability Evaluation 2-6
2.4 Data Sources and Their Evaluation 2-6
2.4.1 Historical Data from Previous Investigations. 2-6
2.4.1.1 HISTORIC DATA 2-6
2.4.1.2 PM DEDYCKER & ASSOC. 2-7
2.4.2 EPA Superfund Technical Assessment and Response Team 2 (START2) Data 2-7
2.4.2.1 URS Operating Services, Inc. 2-7
2.4.2.2 Robertson GeoConsultants, Inc. 2-8
2.4.3 EPA RAC Data – CDM Investigations 2-8
2.4.3.1 Fill Material Sampling – Fall 2001 2-8
2.4.3.2 Subsurface Soils Investigation to Support Human Health Risk Assessment (HHRA) 2-9
2.4.3.3 Heap Leach Pad Investigation 2-10
2.4.3.4 Soil and Vegetation Investigation 2-12
2.4.3.5 Supplemental Feasibility Study Investigation 2-13
2.4.3.6 Site-Wide Sludge Investigation 2-16
2.4.3.7 Groundwater Investigation 2-22
2.4.3.8 Low/High Flow Synoptic Surface Water and Sediment Sampling 2-33
2.4.3.9 Quarterly Surface Water Groundwater, and Sediment Sampling 2-35
2.4.3.10 Surface Water Investigation (O&M) 2-37
2.4.3.11 Tailings Present in Strawberry Creek 2-39
2.4.3.12 Merrill-Crowe and Process Plant Equipment 2-39
2.4.4 EPA RAC Data – Treatability Studies 2-41
2.4.4.1 Anchor Hill Pit Treatability Study 2-41
2.4.4.2 Bauxsol Treatability Study 2-41
2.4.4.3 Multi-Cell Treatability Study 2-42
2.4.5 EPA RAC Data – Pilot Studies 2-43
2.4.5.1 Lime-Based High-Density Sludge (HDS) Pilot Study 2-43

2.4.5.2 Metals Coordination Pilot Study 2-43
2.4.6 Investigations Performed by Others 2-43
2.4.6.1 Geologic Reconnaissance Mapping Investigations 2-43
2.4.6.2 Quantification of Mass Loading to Strawberry Creek near the Gilt Edge Mine 2-43
2.4.6.3 Climatic Evaluation for the Gilt Edge NPL Site 2-44
2.5 Laboratory Method and Analysis 2-44
2.5.1 Total Analysis 2-44
2.5.2 Paste pH 2-45
2.5.3 Extraction Test 2-45
2.5.4 Acid Base Accounting 2-47
2.5.5 Inorganic Carbon Analysis 2-50

Section 3 Physical Characteristics

3.1 Remediation Subareas 3-5
3.1.1 Anchor Hill Pit Remediation Subarea 3-5
3.1.1.1 Anchor Hill Pit 3-5
3.1.1.2 Stored Water and ARD Neutralization Sludge 3-6
3.1.1.3 Unconsolidated Rock Piles 3-6
3.1.1.4 Soil Stockpile 3-6
3.1.1.5 EPA Treatability Tests 3-7
3.1.1.6 Stockpiled Alkaline Waste Products 3-7
3.1.2 Dakota Maid Pit Remediation Subarea 3-8
3.1.2.1 Dakota Maid Pit 3-8
3.1.2.2 Stored ARD and Water Treatment Plant Sludge 3-9
3.1.2.3 Underground Workings 3-9
3.1.2.4 Bunny Ear Pit Backfill 3-11
3.1.2.5 Tailings Repository 3-11
3.1.2.6 Soil Stockpile 3-11
3.1.3 Hoodoo Fill Remediation Subarea 3-11
3.1.3.1 Hoodoo Fill 3-12
3.1.3.2 Hoodoo Mine 3-12
3.1.3.3 Hoodoo Road Slope Soil Stockpile 3-12
3.1.3.4 Hoodoo Riprap Stockpile 3-13
3.1.4 Heap Leach Pad Remediation Subarea 3-13
3.1.4.1 Heap Leach Pad Liner System 3-13
3.1.4.2 Fills Placed During Heap Leach Pad Construction 3-15
3.1.4.3 Spent Ore Located on the Heap Leach Pad 3-16
3.1.4.4 Construction Rock Stockpiles 3-18
3.1.4.5 Water Treatment Plant Sludge 3-18
3.1.5 Langley Benches Remediation Subarea 3-18
3.1.5.1 Mine Pits 3-18
3.1.5.2 Access Roads and Waste Rock Fills 3-19

3.1.6 Process Plant Remediation Subarea 3-19
3.1.6.1 Merrill-Crowe Gold Processing Plant 3-19
3.1.6.2 Assay Laboratory 3-21
3.1.6.3 Waste Rock Fills 3-21
3.1.6.4 EPA Treatability Investigations 3-21
3.1.6.5 Storage Areas 3-21
3.1.7 Ruby Repository Remediation Subarea 3-22
3.1.7.1 Ruby Repository 3-22
3.1.7.2 Rock Borrow Area 3-23
3.1.8 Lower Strawberry Creek Remediation Subarea 3-23
3.1.8.1 Relic Mine Tailings 3-24
3.1.8.2 Stream Sediments 3-24
3.1.9 Strawberry Gulch Remediation Subarea 3-24
3.1.9.1 Fill Rock in Strawberry Gulch Remediation Subarea 3-24
3.1.9.2 Components of Site ARD Collection, Conveyance, and Treatment Infrastructure 3-25
3.1.9.3 Site Infrastructure 3-25
3.1.10 Stormwater Pond Remediation Subarea 3-25
3.1.10.1 Stormwater Pond 3-25
3.1.10.2 Stored Water Treatment Plant Sludge and ARD 3-25
3.1.10.3 Rock Fills 3-26
3.1.10.4 Soil Stockpiles 3-26
3.1.11 Sunday Pit Remediation Subarea 3-26
3.1.11.1 Sunday Pit and Rattlesnake Workings 3-26
3.1.11.2 Stored ARD and Water Treatment Plant Sludge 3-27
3.1.11.3 South Sunday Reclamation Backfill 3-28
3.1.11.4 Sunday Tailings Repository 3-28
3.1.12 Union Hill Upland Remediation Subarea 3-28
3.1.12.1 Rubble Storage Area 3-28
3.1.12.2 Former Contractor's Staging Area 3-29
3.1.12.3 Former Crusher Area 3-29
3.1.12.4 Crusher Area Soil Stockpile 3-29
3.1.13 Upper South Ruby Remediation Subarea 3-30
3.1.14 Water Treatment Plant Operations Remediation Subarea 3-30
3.1.15 Groundwater Remediation Subarea 3-31
3.2 ARD Collection and Conveyance Facilities 3-31
3.2.1 Sunday Pit 3-31
3.2.2 Strawberry Gulch Facilities 3-32
3.2.3 Hoodoo Gulch Facilities 3-33
3.2.4 Ruby Gulch Facilities 3-33
3.2.5 Heap Leach Pad Facilities 3-34
3.2.6 Dakota Maid Pit 3-34
3.2.7 Anchor Hill Pit 3-34

3.2.8 Stormwater Pond 3-34
3.3 Climate 3-35
3.4 Geology 3-36
3.4.1 Lithology and Stratigraphy 3-37
3.4.2 Structural Geology 3-39
3.5 Surface Water 3-41
3.5.1 Perennial Streams 3-41
3.5.1.1 Bear Butte Creek 3-41
3.5.1.2 Strawberry Creek 3-42
3.5.2 Intermittent Streams 3-43
3.5.3 Ephemeral Streams 3-44
3.6 Groundwater 3-45
3.6.1 Regional Hydrogeology 3-45
3.6.2 Site Hydrogeology 3-47
3.6.2.1 Site Groundwater Monitoring Network 3-47
3.6.2.2 Site Aquifers 3-47
3.6.2.3 Potentiometric Surface/Hydraulic Gradient 3-56
3.6.2.4 Groundwater Linear Velocity 3-57
3.7 Groundwater-Surface Water Interactions 3-58
3.7.1 Regional Groundwater-Surface Water Interactions 3-58
3.7.2 Local Groundwater-Surface Water Interactions 3-59
3.7.2.1 Groundwater-Surface Water Interactions in Lower Strawberry Creek 3-59
3.7.2.2 Groundwater-Surface Water Interactions in Upper Strawberry Creek 3-61
3.7.2.3 Groundwater-Surface Water Interactions in Hoodoo Gulch 3-62
3.7.2.4 Groundwater-Surface Water Interactions in Upper Ruby Gulch 3-62
3.7.2.5 Hydraulic Communication between Pit Lakes and Groundwater 3-62
3.8 Site Water Balance 3-65
3.8.1 Site Groundwater Budget 3-65
3.8.2 Site Hydrologic Budget 3-68
3.8.3 ARD Water Balance 3-69
3.8.4 Components of Annual ARD Yield 3-71
3.8.4.1 Estimated Ruby Repository Water Budget 3-72
3.8.4.2 Wet Well Collection System 3-72
3.8.4.3 Pond C Collection System 3-73
3.8.4.4 Heap Leach Pad 3-74
3.8.4.5 Hoodoo Gulch 3-74
3.8.4.6 Other Inflows 3-74
3.9 Land Use and Demographics 3-74

3.9.1 Demographics 3-74
3.9.2 Land Status of Site 3-75

Section 4 Nature and Extent of Contamination

4.1 Comparison Criteria 4-3
4.1.1 Contaminant Sources 4-4
4.1.2 Groundwater 4-5
4.1.3 Surface Water 4-5
4.2 Contaminant Sources 4-5
4.2.1 Waste Rock Fill Material 4-6
4.2.1.1 General Fills 4-7
4.2.1.2 Reclamation Fills 4-11
4.2.1.3 2007 Stormwater Pond Reclamation Fill Sampling 4-16
4.2.1.4 Fill Rock Located in Ruby Gulch Waste Rock Dump 4-18
4.2.2 Heap Leach Pad Spent Ore 4-20
4.2.2.1 Total Metals with the Potential to Impact Human Health 4-20
4.2.2.2 Load of Stored Water-Soluble Contaminants 4-21
4.2.2.3 Future Potential to Generate Acid 4-26
4.2.2.4 Summary of Heap Leach Pad Geochemical Characteristics 4-28
4.2.3 Exposed Rock Surfaces 4-29
4.2.3.1 Dakota Maid Pit 4-30
4.2.3.2 Sunday Pit 4-32
4.2.3.3 Southeast Langley Pit 4-34
4.2.3.4 Anchor Hill Pit 4-35
4.2.4 Underground Mine Workings 4-38
4.2.4.1 Upper and Lower King Workings 4-38
4.2.4.2 Rattlesnake Workings 4-39
4.2.4.3 Langley Adit 4-39
4.2.4.4 Hoodoo Workings 4-39
4.2.5 Amended Tailings 4-39
4.2.5.1 Total Metals with Potential to Impact Human Health 4-40
4.2.5.2 Load of Water Soluble Contaminants 4-40
4.2.5.3 Future Potential to Generate Acid 4-41
4.2.6 Soil Stockpiles 4-41
4.2.6.1 Total Metals with Potential to Impact Human Health 4-42
4.2.6.2 Load of Water Soluble Contaminants 4-42
4.2.6.3 Future Potential to Generate Acid 4-43
4.2.7 Sludge 4-43
4.2.7.1 Total Metals with Potential to Impact Human Health 4-45
4.2.7.2 Load of Water Soluble Contaminants 4-46
4.2.7.3 Stability of ARD Neutralization Sludge 4-48

4.3 Nature and Extent of Contamination in Groundwater 4-51
4.3.1 Background Groundwater Quality 4-52
4.3.1.1 Background Water Quality in Bedrock Wells 4-52
4.3.1.2 Background Water Quality in Alluvial Wells 4-52
4.3.2 Ambient Groundwater Quality 4-52
4.3.3 Nature and Extent of Contamination within Bedrock Aquifers 4-53
4.3.3.1 Aerial Extent of Individual Constituent Concentrations Exceeding Site-Specific Groundwater Standards 4-53
4.3.3.2 Evaluation of Temporal Trends in Groundwater Quality of Bedrock Wells 4-53
4.3.3.3 Evaluation of Major Ion Concentrations 4-59
4.3.4 Nature and Extent of Contamination within Alluvial Aquifers and the Waste Dump Water Bearing Unit 4-62
4.3.4.1 Current Extent of Contamination in Alluvial Aquifers 4-63
4.4 Acid Rock Drainage 4-67
4.4.1 ARD Sources 4-68
4.4.1.1 Heap Leach Pad 4-68
4.4.1.2 Ruby Repository 4-70
4.4.1.3 Hoodoo Gulch 4-72
4.4.1.4 Pond C 4-73
4.4.1.5 Langley Adit 4-73
4.4.1.6 King Adit 4-74
4.4.1.7 Wood Weir 4-74
4.4.1.8 Other Sources 4-75
4.4.2 Stored ARD 4-75
4.4.2.1 Sunday Pit 4-75
4.4.2.2 Dakota Maid Pit 4-77
4.4.2.3 Anchor Hill Pit 4-77
4.4.2.4 Stormwater Pond 4-79
4.5 Strawberry Creek Area 4-79
4.5.1 Surface Water 4-79
4.5.1.1 Water Treatment Plant Effluent 4-80
4.5.1.2 Compliance Point CP001 4-82
4.5.1.3 Synoptic Sampling Investigations and 2002 Quarterly Monitoring 4-84
4.5.1.4 2003 through 2006 Quarterly Operational Monitoring 4-89
4.5.2 Stream Sediments 4-93
4.5.2.1 Synoptic Sampling and May 2002 Quarterly Sampling 4-93
4.5.2.2 Sediment Acid-Base Accounting Results 4-94
4.5.3 Relic Tailings 4-94
4.5.3.1 Total Metals with Potential to Impact Human Health 4-96
4.5.3.2 Load of Water Soluble Contaminants 4-96
4.5.3.3 Future Potential to Generate Acid 4-97

4.5.4 Groundwater-Surface Water Interactions 4-98
4.5.4.1 Summary of USGS Investigation 4-99
4.5.4.2 Evaluation of Identified Groundwater-Surface Water Interactions 4-100
4.6 Bear Butte Creek 4-104
4.6.1 Synoptic Sampling Investigations and 2002 Quarterly Monitoring 4-105
4.6.2 2003 through 2006 Quarterly Operational Monitoring 4-107
4.6.2.1 SWCDM33 Water Quality 4-107
4.6.2.2 SWCDM34 Water Quality 4-108
4.6.2.3 SWCDM35 Water Quality 4-109
4.6.2.4 SWCDM37 Water Quality 4-109

Section 5 Fate and Transport

5.1 Site Conditions 5-2
5.2 Potential Routes of Migration 5-5
5.3 Contaminant Release Mechanisms 5-5
5.3.1 Primary Occurrence of Metals and Metalloids 5-6
5.3.2 Sulfide Oxidation and Acid Generation 5-6
5.3.3 Residual Processing Reagents 5-9
5.3.4 Water Treatment Plant Sludge 5-9
5.4 Contaminant Fate and Persistence 5-10
5.4.1 Metal and Metalloid Mobility 5-10
5.4.1.1 Development of Secondary Acidity 5-10
5.4.1.2 Metal Solubility 5-12
5.4.1.3 Adsorption 5-13
5.4.2 Cyanide Degradation 5-15
5.4.2.1 Hydrolysis and Volatilization 5-15
5.4.2.2 Oxidation of HCN and CN- 5-16
5.4.2.3 Hydrolysis/Saponification 5-16
5.4.2.4 Aerobic Biodegradation 5-16
5.4.2.5 Thiocyanate Formation 5-16
5.4.2.6 Cyanide Compound Dissociation 5-17
5.4.2.7 Metal-Cyanide Complexation 5-17

Section 6 Risk Assessment

6.1 Baseline Human Health Risk Assessment 6-2
6.1.1 Identification of Chemicals of Potential Concern 6-3
6.1.2 Exposure Assessment 6-4
6.1.2.1 Soil 6-4
6.1.2.2 Groundwater 6-4
6.1.2.3 Surface Water, Sediment, and Fish Tissue 6-4
6.1.2.4 Potential Receptors 6-4

6.1.3 Toxicity Assessment 6-5
6.1.3.1 Non-Cancer Effects 6-5
6.1.3.2 Cancer Effects 6-6
6.1.3.3 Toxicity Values 6-6
6.1.3.4 Adjustments for Relative Bioavailability 6-6
6.1.4 Risk Characterization 6-7
6.1.4.1 Basic Approach for Characterizing Non-Cancer Risks 6-7
6.1.4.2 Basic Approach for Characterizing Cancer Risks 6-8
6.1.4.3 Risk Estimates for Onsite ATV Riders 6-8
6.1.4.4 Risk Estimates for Onsite Hikers 6-8
6.1.4.5 Risk Estimates for Onsite Residents 6-9
6.1.4.6 Risk Estimates for Onsite Commercial Workers 6-9
6.1.4.7 Risk Estimates for Onsite Construction Workers 6-10
6.1.4.8 Risk Estimates for Offsite Children 6-10
6.1.4.9 Risk Estimates for Offsite Recreational Fishermen 6-10
6.1.4.10 Risk Estimates for Offsite Residents 6-10
6.1.5 Uncertainties 6-11
6.1.6 Preliminary Remediation Goals and Remedial Action Levels 6-11
6.1.6.1 Preliminary Remediation Goals 6-12
6.1.6.2 Remedial Action Levels 6-12
6.2 Ecological Risk Assessment 6-12
6.2.1 Identification of Chemicals of Concern 6-13
6.2.2 Exposure Assessment 6-13
6.2.3 Risk to Aquatic Receptors 6-14
6.2.3.1 Direct Contact with Contaminants in Surface Water 6-14
6.2.3.2 Direct Contact with Contaminants in Sediment 6-17
6.2.3.3 Exposure of Fish by All Pathways (based on tissue levels of contaminants in fish tissue) 6-18
6.2.3.4 Overall Conclusion Regarding Risks to Aquatic Receptors 6-18
6.2.4 Risk to Terrestrial Plants and Soil Organisms 6-18
6.2.5 Risk to Wildlife Receptors 6-19
6.2.6 Uncertainties 6-23
6.2.6.1 Uncertainty in the Nature and Extent of Contamination 6-23
6.2.6.2 Uncertainty in Exposure Assessment 6-23
6.2.6.3 Uncertainties in Effects (Toxicity) Assessment 6-25
6.2.6.4 Uncertainties in Risk Characterization 6-26
6.2.6.5 Summary of Uncertainties 6-27
6.2.7 Biological Monitoring Report 6-27
6.2.8 Ecological Preliminary Remediation Goals 6-28

Section 7 Summary and Conclusions

7.1 Purpose and Background 7-1
7.2 Site Physical Characteristics 7-2
7.3 Nature and Extent of Contamination 7-5
7.4 Fate and Transport 7-7
7.5 Risk Assessments 7-8
7.6 Summary of Site Conceptual Model 7-9
7.7 Summary of Source Materials and Contamination within Remediation Subareas 7-13

Section 8 References

Appendices

Appendix A First Five-Year Review Report
Appendix B DVD of Gilt Edge Database

Figures

Figures

1.3-1 Site Location Map

3-1 Site Boundary
3.1-1 Remediation Subarea Location Map
3.1-2 Stockpile Locations
3.1-3 Underground Mine Workings
3.1-4 Heap Leach Pad Cell Locations
3.1-5 Groundwater Remediation Subarea
3.2-1 Schematic Diagram of ARD Collection and Conveyance Facilities
3.3-1 Isohyetal Map Showing Distribution of Annual Precipitation in Black Hills, South Dakota, Water Years 1961 to 1990 (from Driscoll et al, 2000)
3.3-2 Box Plot Showing Monthly Precipitation Summary Statistics Lead, South Dakota
3.3-3 Total Annual Precipitation Lead, South Dakota
3.3-4 Annual Departure from Long-Term Average Precipitation Lead, South Dakota
3.3-5 Cumulative Departure from Long-Term Average Precipitation Lead, South Dakota
3.3-6 Estimation of 24-hour Storm Event Frequency Lead, South Dakota
3.4-1 Site Geology
3.5-1 Perennial, Intermittent, and Ephemeral Streams
3.5-2 Box Plot Showing Summary Statistics at USGS Flow Monitoring Station on Bear Butte Creek near Galena
3.5-3 Box Plot Showing Summary Statistics for Compliance Point 001 Flow on Strawberry Creek Below Boomer Gulch
3.5-4 Flow Data for Hoodoo Gulch after Completion of New Collection Facility
3.5-5 Flow Data in Lower Ruby Gulch (Compliance Point 003) after Completion of New Wet Well
3.6-1 Well Locations
3.6-2 Locations of Alluvial Aquifers
3.6-3 Hydrogeologic Units with Major Fracture Zones
3.6-4 Schematic Diagram of Hydrogelogic Framework
3.6-5 Schematic Diagrams of Alluvial Aquifers and Waste Dump Water Bearing Unit
3.6-6 Hydraulic Conductivity of Alluvial Wells
3.6-7 Comparison of Water Level in GW-6 and GW-7
3.6-8 Comparison of Water Level in BES-11 and BED-11
3.6-9 Comparison of Water Level in GWCDM09 and GWCDM10
3.6-10 Hoodoo Pumpback Rate
3.6-11 Ruby Repository Toe Flow Data Compared to Lead, SD Precipitation Data
3.6-12 Schematic Diagram Depicting Inflows at Ruby Repository
3.6-13 Comparison of Water Level in GW-8 and GW-9

3.6-14 Comparison of Water Level in GW-8A and GW-9A
3.6-15 August 2002 Potentiometric Surface Bedrock Wells
3.6-16 Potentiometric Surface April 2007
3.7-1 Comparison of Wood Weir Flow Rate to Sunday Pit Lake Elevation
3.7-2 Comparison of GE-MW-07 Water Level with Sunday Pit
3.7-3 Comparison of GE-MW-06 Water Level With Sunday Pit
3.7-4 Comparison of BED-8 Water Level With Anchor Hill Pit
3.7-5 Comparison of GE-MW-08 Water Level with Anchor Hill Pit
3.8-1 Strawberry Gulch Freshwater Diversion Hydrograph
3.9-1 Location of Residential Structures
3.9-2 Mine Claims and Property Ownership

4.2-1 Fill Zone Location Map
4.2-2 Histogram Showing Paste pH Distribution for General Fills
4.2-3 Paste pH Data within Fill Zones
4.2-4 Sulfide Sulfur versus Paste pH in General Fill Samples
4.2-5 Comparison of NP to AP for General Fills
4.2-6 Comparison of NP:AP Ratio to Sulfide Sulfur for General Fills
4.2-7 Potential Maturation Pathways of General Fill Based on Total Sulfur and Paste pH
4.2-8 Potential Maturation Pathways of General Fill Based on NP:AP Ratio and Paste pH
4.2-9 Histogram Showing Paste pH Distribution of Reclamation Fills
4.2-10 Comparison of NP to AP for Reclamation Fills
4.2-11 Comparison of NP:AP Ratio to Sulfide Sulfur for Reclamation Fills
4.2-12 Potential Maturation Pathways of Reclamation Fill Based on Total Sulfur and Paste pH
4.2-13 Potential Maturation Pathways of Reclamation Fills Based on NP:AP Ratio and Paste pH
4.2-14 Comparison of NP to AP for 2007 Stormwater Pond Reclamation Fill Samples
4.2-15 Comparison of NP:AP Ratio to Sulfide Sulfur for 2007 Stormwater Pond Reclamation Fill Samples
4.2-16 Histogram Showing Paste pH Distribution of Ruby Gulch Waste Rock Dump Samples
4.2-17 Comparison of NP to AP for Ruby Gulch Waste Rock Dump Samples
4.2-18 Comparison of NP:AP Ratio to Sulfide Sulfur for Ruby Gulch Waste Rock Dump Samples
4.2-19 Paste pH Summary Statistics for Heap Leach Pad Samples
4.2-20 Photo of East Side of HLP
4.2-21 Comparison of NP to AP for Heap Leach Pad Samples
4.2-22 Comparison of NP:AP Ratio to Sulfide Sulfur for Heap Leach Pad Samples
4.2-23 Acid Potential of Exposed Bedrock Areas
4.2-24 Histograms Showing Paste pH Distribution at Pit Highwalls
4.2-25 Locations and Volumes of Soil Resources

4.2-26 Comparison of NP to AP for Soil Stockpiles
4.2-27 Comparison of NP:AP Ratio to Sulfide Sulfur for Soil Stockpile Samples
4.2-28 Sludge Locations and Volumes
4.2-29 Sludge Sampling Locations
4.2-30 Pit Lake Sludge Thickness
4.2-31 Comparison of NP to AP for Sludge
4.2-32 Comparison of NP:AP Ratio to Sulfide Sulfur for Sludge
4.2-33 Strong Acid Leach Test Results for Aluminum
4.2-34 Strong Acid Leach Test Results for Cadmium
4.2-35 Strong Acid Leach Test Results for Copper
4.2-36 Strong Acid Leach Test Results for Iron
4.2-37 Strong Acid Leach Test Results for Zinc
4.3-1 Interpretive Extent of Contamination and Potential Migration Direction
4.3-2 Interpretive Extent of Manganese Concentrations Exceeding Comparison Criteria
4.3-3 Interpretive Extent of Sulfate Concentrations Exceeding Comparison Criteria
4.3-4 Interpretive Extent of Aluminum Concentrations Exceeding Comparison Criteria
4.3-5 Interpretive Extent of pH Exceeding Comparison Criteria
4.3-6 Total Dissolved Solids and pH in GW-4
4.3-7 Arsenic, Cadmium, Copper and Zinc Concentrations in GW-4
4.3-8 Total Dissolved Solids and pH in GW-5
4.3-9 Arsenic, Cadmium, Copper and Zinc Concentrations in GW-5
4.3-10 Total Dissolved Solids and pH in GW-6
4.3-11 Arsenic, Cadmium, Copper and Zinc Concentrations in GW-6
4.3-12 Total Dissolved Solids and pH in GWCDM10
4.3-13 Arsenic, Cadmium, Copper and Zinc Concentrations in GWCDM10
4.3-14 Total Dissolved Solids and pH in GE-MW-08
4.3-15 Arsenic, Cadmium, Copper and Zinc Concentrations in GE-MW-08
4.3-16 Total Dissolved Solids and pH in GWCDM03
4.3-17 Arsenic, Cadmium, Copper and Zinc Concentrations in GWCDM03
4.3-18 Total Dissolved Solids and pH in GWCDM02
4.3-19 Arsenic, Cadmium, Copper and Zinc Concentrations in GWCDM02
4.3-20 Total Dissolved Solids and pH in GE-MW-16
4.3-21 Arsenic, Cadmium, Copper and Zinc Concentrations in GE-MW-16
4.3-22 Total Dissolved Solids and pH in GWCDM14
4.3-23 Arsenic, Cadmium, Copper and Zinc Concentrations in GWCDM14
4.3-24a Piper Diagram Showing Major Ion Concentrations in Background Bedrock Well GWCDM28, April 2007
4.3-24b Piper Diagram Showing Major Ion Concentrations in Wells Impacted by ARD, April 2007
4.3-25 Piper Diagram Showing Major Ion Concentrations in Bedrock Wells Located on the North End of the Site, April 2007

4.3-26 Piper Diagram Showing Major Ion Concentrations in Anchor Hill Pit Area Bedrock Wells, April 2007
4.3-27 Piper Diagram Showing Major Ion Concentrations in Sunday/Dakota Maid Pit Area Bedrock Wells, April 2007
4.3-28 Piper Diagram Showing Major Ion Concentrations in Strawberry Gulch Bedrock Wells, April 2007
4.3-29 Piper Diagram Showing Major Ion Concentrations in Hoodoo Gulch Bedrock Wells, April 2007
4.3-30 Piper Diagram Showing Major Ion Concentrations in Strawberry Creek Bedrock Wells, April 2007
4.3-31 Piper Diagram Showing Major Ion Concentrations in Bedrock Wells in Ruby Gulch, April 2007
4.3-32 Extent of Contamination in Alluvial Aquifers Exceeding Comparison Criteria
4.3-33 Piper Diagram Showing Major Ion Concentrations in Strawberry Gulch Alluvial Wells, April 2007
4.3-34 Total Dissolved Solids and pH in GW-2A
4.3-35 Arsenic, Cadmium, Copper and Zinc Concentrations in GW-2A
4.3-36 Total Dissolved Solids and pH in GW-3
4.3-37 Arsenic, Cadmium, Copper and Zinc Concentrations in GW-3
4.3-38 Total Dissolved Solids and pH in GWCDM11
4.3-39 Arsenic, Cadmium, Copper and Zinc Concentrations in GWCDM11
4.3-40 Total Dissolved Solids and pH in GWCDM12
4.3-41 Arsenic, Cadmium, Copper and Zinc Concentrations in GWCDM12
4.3-42 Total Dissolved Solids and pH in GW-7
4.3-43 Arsenic, Cadmium, Copper and Zinc Concentrations in GW-7
4.3-44 Piper Diagram Showing Major Ion Concentrations in Strawberry Creek Alluvial Wells, April 2007
4.3-45 Total Dissolved Solids and pH in BES-11
4.3-46 Arsenic, Cadmium, Copper and Zinc Concentrations in BES-11
4.3-47 Total Dissolved Solids and pH in BES-14
4.3-48 Arsenic, Cadmium, Copper and Zinc Concentrations in BES-14
4.3-49 Piper Diagram Showing Major Ion Concentrations in Hoodoo Gulch Alluvial Wells, April 2007
4.3-50 Total Dissolved Solids and pH in GWCDM09
4.3-51 Arsenic, Cadmium, Copper and Zinc Concentrations in GWCDM09
4.3-52 Total Dissolved Solids and pH in BES-17
4.3-53 Arsenic, Cadmium, Copper and Zinc Concentrations in BES-17
4.3-54 Piper Diagram Showing Major Ion Concentrations in Ruby Repository and Ruby Gulch Alluvial Wells, April 2007
4.3-55 Total Dissolved Solids and pH in GW-8
4.3-56 Arsenic, Cadmium, Copper and Zinc Concentrations in GW-8
4.3-57 Total Dissolved Solids and pH in GW-8A
4.3-58 Arsenic, Cadmium, Copper and Zinc Concentrations in GW-8A
4.4-1 Surface Water Sampling Locations

4.4-2 pH Values at Sampling Location 003
4.4-3 Cadmium Concentrations at Sampling Location 003
4.4-4 Copper Concentrations at Sampling Location 003
4.4-5 Zinc Concentrations at Sampling Location 003
4.4-6 Stratification of Sunday Pit Lake Based on Sulfate Concentrations
4.4-7 Anchor Hill Pit Lake Profile Charts Showing Chemocline Location
4.5-1 Total and Dissolved Copper Concentrations Water Treatment Plant Effluent
4.5-2 Total and Dissolved Selenium Concentrations Water Treatment Plant Effluent
4.5-3 Total Suspended Solids Concentrations Water Treatment Plant Effluent
4.5-4 Daily Harness and WTP Discharge Volume Strawberry Creek – Compliance Point 001
4.5-5 Total and Dissolved Cadmium Concentrations Strawberry Creek – Compliance Point 001
4.5-6 Total and Dissolved Copper Concentrations Strawberry Creek- Compliance Point 001
4.5-7 Total and Dissolved Selenium Concentrations Strawberry Creek- Compliance Point 001
4.5-8 Total and Dissolved Zinc Concentrations Strawberry Creek – Compliance Point 001
4.5-9 Total Suspended Solids Concentrations Strawberry Creek – Compliance Point 001
4.5-10 pH Results Strawberry Creek Synoptic Sampling and 2002 Quarterly Operational Monitoring
4.5-11 Conductivity Results Strawberry Creek Synoptic Sampling and 2002 Quarterly Operational Monitoring
4.5-12 Oxidation-Reduction Potential Strawberry Creek Synoptic Sampling and 2002 Quarterly Operational Monitoring
4.5-13 Cation Concentrations Strawberry Creek Synoptic Sampling and 2002 Quarterly Operational Monitoring
4.5-14 Anion Concentrations Strawberry Creek Synoptic Sampling and 2002 Quarterly Operational Monitoring
4.5-15 Piper Diagram for SWCDM32 or CP-001 Strawberry Creek Synoptic Sampling and 2002 Quarterly Operational Monitoring
4.5-16 Total and Dissolved Aluminum Concentrations Strawberry Creek Synoptic Sampling and 2002 Quarterly Operational Monitoring
4.5-17 Total and Dissolved Cadmium Concentrations Strawberry Creek Synoptic Sampling and 2002 Quarterly Operational Monitoring
4.5-18 Total and Dissolved Copper Concentrations Strawberry Creek Synoptic Sampling and 2002 Quarterly Operational Monitoring
4.5-19 Total and Dissolved Manganese Concentrations Strawberry Creek Synoptic Sampling and 2002 Quarterly Operational Monitoring
4.5-20 Total and Dissolved Zinc Concentrations Strawberry Creek Synoptic Sampling and 2002 Quarterly Operational Monitoring

4.5-21 Total Dissolved Solids Concentrations Strawberry Creek Synoptic Sampling and 2002 Quarterly Operational Monitoring
4.5-22 Total Suspended Solids Concentrations Strawberry Creek Synoptic Sampling and 2002 Quarterly Operational Monitoring
4.5-23 Nitrate + Nitrite Concentrations Strawberry Creek Synoptic Sampling and 2002 Quarterly Operational Monitoring
4.5-24 Total and Dissolved Aluminum Concentrations Strawberry Creek 2003 Quarterly Operational Monitoring
4.5-25 Total and Dissolved Iron Concentrations Strawberry Creek 2003 Quarterly Operational Monitoring
4.5-26 Total and Dissolved Cadmium Concentrations Strawberry Creek 2003 Quarterly Operational Monitoring
4.5-27 Total and Dissolved Copper Concentrations Strawberry Creek 2003 Quarterly Operational Monitoring
4.5-28 Total and Dissolved Manganese Concentrations Strawberry Creek 2003 Quarterly Operational Monitoring
4.5-29 Total and Dissolved Zinc Concentrations Strawberry Creek 2003 Quarterly Operational Monitoring
4.5-30 pH Values CLVT01 2003 - 2006 Quarterly Operational Monitoring
4.5-31 Hardness and Sulfate Concentrations CLVT01 2003 - 2006 Quarterly Operational Monitoring
4.5-32 Total and Dissolved and Aluminum/Iron Concentrations CLVT01 2003 - 2006 Quarterly Operational Monitoring
4.5-33 Total and Dissolved Cadmium Concentrations CLVT01 2003 - 2006 Quarterly Operational Monitoring
4.5-34 Total and Dissolved Copper Concentrations CLVT01 2003 - 2006 Quarterly Operational Monitoring
4.5-35 Total and Dissolved Selenium Concentrations CLVT01 2003 - 2006 Quarterly Operational Monitoring
4.5-36 Total and Dissolved Zinc Concentrations CLVT01 2003 - 2006 Quarterly Operational Monitoring
4.5-37 pH Values HD01 2003 - 2006 Quarterly Operational Monitoring
4.5-38 Hardness and Sulfate Concentrations HD01 2003 - 2006 Quarterly Operational Monitoring
4.5-39 Total and Dissolved Aluminum/Iron Concentrations HD01 2003 - 2006 Quarterly Operational Monitoring
4.5-40 Total and Dissolved Cadmium Concentrations HD01 2003 - 2006 Quarterly Operational Monitoring
4.5-41 Total and Dissolved Copper Concentrations HD01 2003 - 2006 Quarterly Operational Monitoring
4.5-42 Total and Dissolved Zinc Concentrations HD01 2003 - 2006 Quarterly Operational Monitoring
4.5-43 Hardness and Sulfate Concentrations BMRCK01 2003 - 2006 Quarterly Operational Monitoring

4.5-44 Total and Dissolved Aluminum/Iron Concentrations BMRCK01 2003 - 2006 Quarterly Operational Monitoring
4.5-45 Hardness and Sulfate Concentrations SWCDM32 2004-2006 Quarterly Operational Monitoring
4.5-46 Total and Dissolved Aluminum/Iron Concentrations SWCDM32 2004-2006 Quarterly Operational Monitoring
4.5-47 Strawberry Creek Sediment Arsenic, Cadmium, Copper, Lead, Mercury, And Zinc Concentrations
4.5-48 Strawberry Creek Sediment (Fall 2000) Sulfur Composition Results
4.5-49 Comparison of NP:AP Ratio to Sulfide Sulfur for Strawberry Creek Sediment (Fall 2000)
4.5-50 Strawberry Creek Transect Sample Locations (October 2003) and Bank Material Sample Locations (October 2000)
4.5-51 Strawberry Creek Bank Sediment Paste pH Histograms
4.5-52 Approximate Extent of Exposed Tailings In Strawberry Creek between Last Chance Pond and Hoodoo Gulch
4.5-53a Approximate Extent of Exposed Tailings and Paste pH
4.5-53b Approximate Extent of Exposed Tailings and Paste pH
4.5-53c Approximate Extent of Exposed Tailings and Paste pH
4.5-54 SPLP Results for Strawberry Creek Tailings and Bank Material
4.5-55 Comparison of NP to AP for Strawberry Creek Tailings and Bank Material
4.5-56 Percent Sulfur Results for Strawberry Creek Tailings and Bank Material
4.5-57 Relative Water Table Elevation at BES-11 and BED-11
4.5-58 Dissolved Iron and pH Trends in Well GWCDM14
4.6-1 pH Measurements within Bear Butte Creek
4.6-2 Conductivity Measurements within Bear Butte Creek
4.6-3 Oxidation-Reduction Potentials within Bear Butte Creek
4.6-4 Major Cation Concentrations within Bear Butte Creek
4.6-5 Major Anion Concentrations within Bear Butte Creek
4.6-6 Piper Diagram Bear Butte Creek Above and Below the Confluence with Strawberry Creek
4.6-7 Total and Dissolved Manganese Concentrations in Bear Butte Creek
4.6-8 TDS Concentrations within Bear Butte Creek
4.6-9 Nitrate + Nitrite Concentrations within Bear Butte Creek
4.6-10 Sulfate and Hardness Concentrations at SWCDM34
4.6-11 Cadmium Concentrations at SWCDM34
4.6-12 Copper Concentrations at SWCDM34
4.6-13 Zinc Concentrations at SWCDM34
4.6-14 Iron and Aluminum Concentrations at SWCDM34
4.6-15 Iron and Aluminum Concentrations at SWCDM35
4.6-16 Iron and Aluminum Concentrations at SWCDM37
4.6-17 Cadmium Concentrations at SWCDM37
4.6-18 Copper Concentrations at SWCDM37
4.6-19 Zinc Concentrations at SWCDM37

4.6-20 Sulfate and Hardness Concentrations at SWCDM37

5.1-1 Schematic Diagram of Contaminant Fate and Transport Mechanisms in Union Hill, Dakota Maid Pit and Strawberry Gulch Remediation Subareas
5.1-2 Schematic Diagram of Contaminant Fate and Transport Mechanisms in Heap Leach Pad, Union Hill Upland, Sunday Pit, Langley Benches, and Lower Strawberry Creek Remediation Subareas
5.4-1 pH Dependence of Solubility for Iron and Aluminum Hydroxides
5.4-2 Solubility of Several Metals with Oxide or Hydroxide Phases
5.4-3 pH Dependence of Adsorption for Several Cations
5.4-4 pH Dependence of Adsorption for Several Anions

6-1 COPC Selection Procedure
6-2 Site Conceptual Model for Human Exposure
6-3 Soil Exposure Units
6-4 Ecological Site Conceptual Model

This page left intentionally blank.

Tables

Tables

2.3-1 Summary of QC Samples
2.3-2 Summary of the Rejected and Estimated Data by Investigation
2.5-1 Summary of Sample Collection, Evaluation, and Usability

3.1-1 Soil Stockpile Physical Parameters
3.3-1 Comparison of Site Precipitation Data to Lead, South Dakota Data Weather Station
3.3-2 Monthly Precipitation Data from Water Year 1949 to Water Year 2006
3.6-1 Transmissivity Data for Bedrock Wells
3.6-2 Aquifer Characteristics of Alluvial Wells
3.8-1 Estimated Groundwater Budget
3.8-2 Estimated Annual Inflow for Water Years 2000 to 2006
3.8-3 Normalized ARD Yield for Water Years 2000 to 2006
3.8-4 Estimate of Other Inflows
3.9-1 Land Parcels Located Within Site Boundary

4.1-1 Site Specific Groundwater Quality Standards
4.1-2 South Dakota Surface Water Quality Standards in Vicinity of Site
4.2-1 Total Metals and Cyanide Results for General Fills from Human Health Risk Assessment Investigation
4.2-2 Total Metals and Cyanide Results for General Fills from CDM Fills Investigation
4.2-3 Synthetic Precipitation Leaching Procedure Results for General Fills
4.2-4 Acid Base Accounting Results for General Fills
4.2-5 Total Metals and Cyanide Results for Reclamation Fills from Human Health Risk Assessment
4.2-6 Total Metals and Cyanide Results for Reclamation Fills From CDM Fills Investigation
4.2-7 Synthetic Precipitation Leaching Procedure Results for Reclamation Fills
4.2-8 Acid Base Accounting Results for Reclamation Fills
4.2-9a Paste pH Results for Stormwater Pond Reclamation Fills - 2007 Investigation
4.2-9b Acid Base Accounting Results for Stormwater Pond Reclamation Fills - 2007 Investigation
4.2-10 Total Metals Results for Ruby Waste Rock Dump
4.2-11 Modified SPLP Results for Rudy Gulch Waste Rock Dump
4.2-12 Acid Base Accounting Results for Ruby Gulch Waste Rock Dump
4.2-13 Total Metals and Cyanide Results for Heap Leach Pad Spent Ore from Human Health Risk Assessment

4.2-14 Total Metals and Cyanide Results for Heap Leach Pad Spent Ore from CDM fills Investigation
4.2-15 Modified SPLP Test Results for Heap Leach Pad Spent Ore
4.2-16 Acid Base Accounting Results for Heap Leach Pad Spent Ore
4.2-17 Total Metals Results for Pit Highwalls
4.2-18 Modified SPLP Results for Pit Highwalls
4.2-19 Acid Base Accounting Results for Pit Highwalls
4.2-20 Total Metals and Cyanide Results for Amended Tailings from CDM Fills Investigation
4.2-21 SPLP Results for Amended Tailings
4.2-22 Acid Base Accounting Results for Amended Tailings
4.2-23 Total Metals and Cyanide Results for Soil Stockpiles from Human Health Risk Assessment Investigation
4.2-24 Total Metals and Cyanide Results for Soil Stockpiles from CDM Soil Investigation
4.2-25 Paste pH Results for Soil Stockpiles
4.2-26 SPLP Data for Soil Stockpiles
4.2-27 Acid Base Accounting Results for Soil Stockpiles
4.2-28 Total Metals and Cyanide Results for Sludge
4.2-29 SPLP and TCLP Results for Sludge
4.2-30 ABA Results for Sludge
4.2-31 Strong Acid Leach Test Results For Site Sludge
4.3-1 Groundwater Sampling Locations 1990 – Spring 2007
4.3-2 Groundwater Sampling Data from April and May, 2007 Sampling Programs
4.4-1 Pit Lake Chemical Analyses
4.5-1 Strawberry Creek and Tributary Sampling Locations 2000 - 2006
4.5-2(a) Total Metals and Cyanide Results for Sediment within Strawberry Creek (Fall 2000)
4.5-2(b) Total Metals and Cyanide Results for Sediment within Strawberry Creek (Spring 2001)
4.5-2(c) Total Metals and Cyanide Results for Sediment within Strawberry Creek (Fall 2001)
4.5-2(d) Total Metals and Cyanide Results for Sediment within Strawberry Creek (May 2002)
4.5-3 Total Metals and Cyanide Results for Sediment within Tributaries to Strawberry Creek
4.5-4 Acid Base Accounting Results for Sediment within Strawberry Creek
4.5-5 Total Metals and Cyanide Results for Strawberry Creek Bank Material – October 2000
4.5-6 Total and SPLP Metals Results for Strawberry Creek Bank Tailings Samples – October 2003

4-5-7 Acid Base Accounting Results for Strawberry Creek Bank Tailings Samples - October 2003
4.5-8 Acid Base Accounting Results for Strawberry Creek Bank Material - October 2000
4.6-1 Bear Butte Creek and Tributary Sampling Locations 2000 – 2006

5.3-1 Estimate of concentration of aqueous complexes present in ARD stored within Sunday Pit at a depth of approximately 50 feet based on geochemical equilibrium modeling using PREEQC software
5.4-1 The pH of the Point of Zero Charge for Several Adsorbent Species, Data compiled from Langmuir (1987)

6-1 Quantitative Chemicals of Potential Concern for Human Health Risk Assessment
6-2 Qualitative Chemicals of Potential Concern for Human Health Risk Assessment
6-3 On-Site Exposure Units
6-4 Off-Site Exposure Units
6-5 Risks to Recreational Visitors (ATV Riders) from Incidental Ingestion and Inhalation of On-Site Soils
6-6 Total Risks to Hikers from On-Site Surface Water, Sediment, and Soil
6-7 Risks to Hypothetical Future Residents from Ingestion of On-Site Groundwater and Soil
6-8 Total Risks to Hypothetical Future Commercial Workers from Ingestion of On-Site Groundwater and Surface Soil
6-9 Risks to Hypothetical Future Construction Workers from Incidental Ingestion and Inhalation of On-Site Soils
6-10 Risks to Children from Surface Water and Sediment in Off-Site Drainages
6-11 Risks to Recreational Fishermen from Surface Water, Sediment, and Fish in Off-Site Drainages
6-12 Risks to Residents from Ingestion of Groundwater Along Off-Site Drainages
6-13 Preliminary Remediation Goals (PRGs) and Remedial Action Levels (RALs) for Recreational Visitors at the Site
6-14 Surface Soil Remedial Action Levels (RALs)
6-15 Summary of Assessment and Measurement Endpoints
6-16 Summary of Uncertainties in the Ecological Risk Assessment

Acronyms

Acronyms

ABA	acid base accounting
AH&P	Anchor Hill and Ponds
ANFO	ammonium nitrate fuel oil
AP	acid potential
ARAR	applicable or relevant and appropriate requirement
ARD	acid rock drainage
ARSD	Administrative Rules of South Dakota
ATV	all-terrain vehicle
bgs	below ground surface
BMC	Brohm Mining Corporation
BOR	U.S. Bureau of Reclamation
BRA	baseline human health risk assessment
CCV	continuing calibration verification
CDM	CDM Federal Programs Corporation
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CFS	cubic feet per second
CLP	Contract Laboratory Program
cm/sec	centimeters per second
COC	contaminant of concern
COPC	contaminant of potential concern
CSM	conceptual site model
CTE	central tendency exposure
cy	cubic yards
DENR	South Dakota Department of Environment and Natural Resources
DI	daily intake
DIL	daily intake lifetime
DQO	data quality objective
Eco-SSL	ecological soil screening level
EPA	U.S. Environmental Protection Agency
ERA	ecological risk assessment
ET	evapotranspiration
FS	feasibility study
ft	feet
ft/day	feet per day
ft^2/day	feet squared per day
GCL	geosynthetic clay liner
gpm	gallon per minute
gw	groundwater
GWS	Green World Science Inc.
HDPE	high density polyethylene
HDS	high-density sludge
HEAST	Health Effects Assessment Summary Tables

HHRA	human health risk assessment
HI	hazard index
HLP	Heap Leach Pad
hp	horsepower
HQ	hazard quotient
ICP-AES	inductively coupled plasma atomic emission spectroscopy
ICP	inductively coupled plasma
ICS	interference check standard
ICV	initial calibration verification
in.	inch(es)
IRIS	Integrated Risk Information System
km^2	square kilometer
KVA	kilo volt amp
LCS/LCSD	laboratory control sample/laboratory control sample duplicate
LDCRS	leak detection, collection, recovery system
LDPE	low-density polyethylene
LOAEL	Lowest Observed Adverse Effect Level
LP	Langley Pit
MCGRC	Merrill-Crowe Gold Recovery Circuit
Mgal	million gallons
mg/kg	milligram per kilogram
mg/L	milligram per liter
mi^2	square mile
ml	milliliter
mm Hg	millimeter of mercury
MSE	MSE Technology Applications, Inc.
MS/MSD	matrix spike/matrix spike duplicate
mV	millivolt
MWMP	meteoric water mobility procedure
MWTP	Mine Waste Technology Program
NAG	net acid generation
NCEA	National Center for Environmental Assessment
NFG	National Functional Guidelines
NNP	net neutralization potential
NOAEL	No Observed Adverse Effect Level
NOV	Notice of Violation
NP:AP	neutralization potential to acid potential ratio
NP	neutralization potential
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
O&M	operation and maintenance
ORD	Office of Research and Development's
ORP	oxidation-reduction potential
OSHA	Occupational Safety and Health Administration
OU	operable unit
oz	ounce
PCA	Pits and Crusher Area
PCOC	potential contaminant of concern

PRG	preliminary remediation goal
QA	quality assurance
QA/QC	quality assurance/quality control
QC	quality control
QAPP	quality assurance project plan
RAC	Response Action Contract
RAL	remedial action level
RAM	Risk Assessment Model for Human Exposure
RBA	relative bioavailability
RBC	risk-based concentration
RCRA	Resource Conservation and Recovery Act
RfD	reference dose
RGC	Robertson Geoconsultants, Inc.
RGWRD	Ruby Gulch waste rock dump
RI	remedial investigation
RMB	redox-mediated biotransformations
RME	reasonable maximum exposure
ROD	record of decision
RPD	relative percent difference
RPM	remedial project manager
SALT	strong acid leach test
SAP	sampling and analysis plan
SAR	site activities report
SCM	site conceptual model
SERA	screening level ecological risk assessment
SF	slope factor
SM	Sheperd-Miller Inc.
SPLP	synthetic precipitation leaching procedure
SRC	Syracuse Research Corporation
SSTT	site-specific toxicity test
START2	Superfund Technical Assessment and Response Team 2
su	standard unit
TAL	target analyte list
TCLP	toxicity characteristic leaching procedure
TDS	total dissolved solids
TRV	toxicity reference value
TSS	total suspended solids
t/kt $CaCO_3$ eq	tons per kiloton calcium carbonate equivalent
UCL	upper confidence limit
ULSA	unique laboratory service analysis
UOS	URS Operating Services
USCS	Unified Soil Classification System
USDA	U.S. Department of Agriculture
USFS	U.S. Forest Service
USGS	U.S. Geological Survey
Virotec	Virotec International Ltd
VLDPE	very low-density polyethylene
WAD	weak acid dissociable

WTP	water treatment plant
µg/dL	micrograms per deciliter
µg/L	microgram per liter
µm	micron
µS/cm	microsiemens per centimeter
%R	percent recovery

$Al_4(SO_4)(OH)_{10} \cdot 5H_2O$	basaluminite
$AsFeS_2$	arsenopyrite
$BaSO_4$	barite
$Ca(OH)_2$	hydrated lime
$CaCO_3$	calcium carbonate or calcite
$CaMg(CO_3)_2$	dolomite
CNS^-	thiocyanate ions
CO_2	carbon dioxide
$CuFeS_2$	chalcopyrite
CN	cyanide
CN^-	cyanide ion
CNO^-	cyanite ion
$Fe(OH)_3$	iron hydroxide
$Fe^{2+}Fe^{3+}{}_2(SO_4)_4 \cdot 14H_2O$	roemerite
$Fe^{2+}SO_4 \cdot 7H_2O$	melanterite
Fe_2O_3	hematite
$Fe^{3+}{}_2(SO_4)_3 \cdot 9H_2O$	coquimbite
$Fe_5HO_8 \cdot 4H_2O$	ferrihydrite
$Fe_8O_8(SO_4)(OH)_6$	schwertmannite
FeOOH	goethite
FeS_2	pyrite mineral lattice
$(H_3O)Fe^{3+}(SO_4)_2 \cdot 3H_20$	rhomboclase
H_2SO_4	sulfuric acid
HCl	hydrochloric acid
HCN	hydrogen cyanide
HCNO	hydrogen cyanate
$KAlSi_3O_8$	feldspar
$KFe_3(SO_4)_2(OH)_6$	jarosite
NaOH	sodium hydroxide
NO_3	nitrate
PbS	galena
S_2	polysulfides
S_2O_3	thiosulfate
SO_3^{2-}	sulfite
SO_4^{2-}	sulfate
ZnS	sphalerite

This page left intentionally blank.

Section 1
Introduction

1.1 Purpose

The purpose of this remedial investigation (RI) report is to present sufficient information to support feasibility study (FS) and remedial action decisions at the Gilt Edge Mine National Priorities List (NPL) site located in Lawrence County, South Dakota (the site). The RI report is an important resource for citizens, regulators, scientists, and others who may have an interest in the site.

This report documents the history of the site, summarizes remedial investigations completed, describes physical characteristics of the site, characterizes nature and extent of contamination, describes the fate and transport of contaminants, and summarizes baseline human health (BRA) and ecological risk assessments.

The RI report includes a comprehensive description of the nature and extent of contamination in Operable Unit 1 (OU1), Operable Unit 2 (OU2), and Operable Unit 3 (OU3) and, along with the risk assessments, presents estimates of the risks to human health and the environment posed by the contamination. The subsequent FS report takes the data from the RI and performs a systematic analysis of OU1 to determine the need for, and scope of, remedial action. It presents an analysis of how the risks identified in the RI can be managed.

The U.S. Environmental Protection Agency (EPA) is currently preparing the FS for OU1. After it is completed, EPA will issue a proposed plan that describes a proposed approach for managing risks in OU1. When the 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 plan and to take comment. Comments may also be provided in writing via mail or email. This process is designed to allow the public adequate opportunity to provide formal input before a final decision is made. EPA will read and consider all public comments. The comments and EPA's response to them will be compiled into a document known as a response comment summary report. EPA will then make its final risk management and cleanup decisions and will publish them in a record of decision (ROD).

1.2 RI Organization

The RI is organized in a manner that conforms to EPA guidance (EPA 1988). Additionally, it has been formatted to facilitate easy access by a variety of readers.

The RI includes seven sections (not including references):

- **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 – Data Collection, Evaluation, and Usability**. Provides an overview of site investigations completed by EPA. Includes discussions of data quality objectives, data usability, previous studies performed by others, EPA treatability studies, laboratory methods and analysis, and quality assurance/quality control.

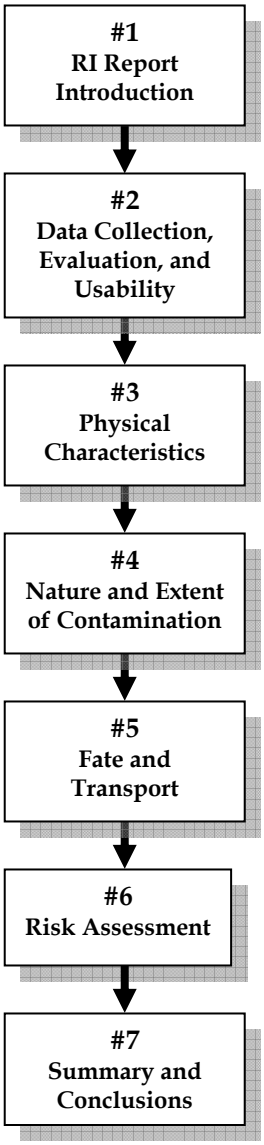
- **Section 3 – Physical Characteristics**. Provides a description of the physical characteristics of the site. Includes discussion of acid rock drainage (ARD) collection and conveyance infrastructure, climate, surface water, geology, groundwater, groundwater-surface water interactions, site water balance, land use, and demographics.

- **Section 4 – Nature and Extent of Contamination**. Describes the nature and extent of contamination in source materials, 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 the site.

- **Section 7 – Summary and Conclusions**. Summarizes the material in the previous sections and provides conclusions drawn from that work.



1.3 Site Description

1.3.1 Site Location

The site is located in the Black Hills of South Dakota (Figure 1.3-1) - specifically, in Sections 4, 5, 6, 7, 8, and 9, T4N, R4E, Black Hills Meridian, Lawrence County, South Dakota. Site coordinates are 44° 19' 43" north latitude and 103° 44' 28" west longitude. The mine is approximately 4.5 miles south-southeast from Lead, South Dakota on Highway 385, then approximately 2 miles northeast on Gilt Edge Road. The historic address is 2 Gilt Edge Road, Deadwood, South Dakota, and the current mailing address is 11898 Gilt Edge Road, Deadwood, South Dakota 57732.

The site boundary encompasses an area of 1,516 acres. The primary mine disturbance area is the portion of the site that contains the largest accumulation of contaminant sources. The primary mine disturbance area encompasses approximately 316 acres within the site boundary.

1.3.2 Site Contamination

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) program is designed to address abandoned hazardous waste sites that have had a release or pose an imminent threat of release of hazardous substances into the environment. Hazardous substance releases at the site are caused by 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 excavation (open pits), particle size reduction (crushing), and mine waste management (waste rock dumps).

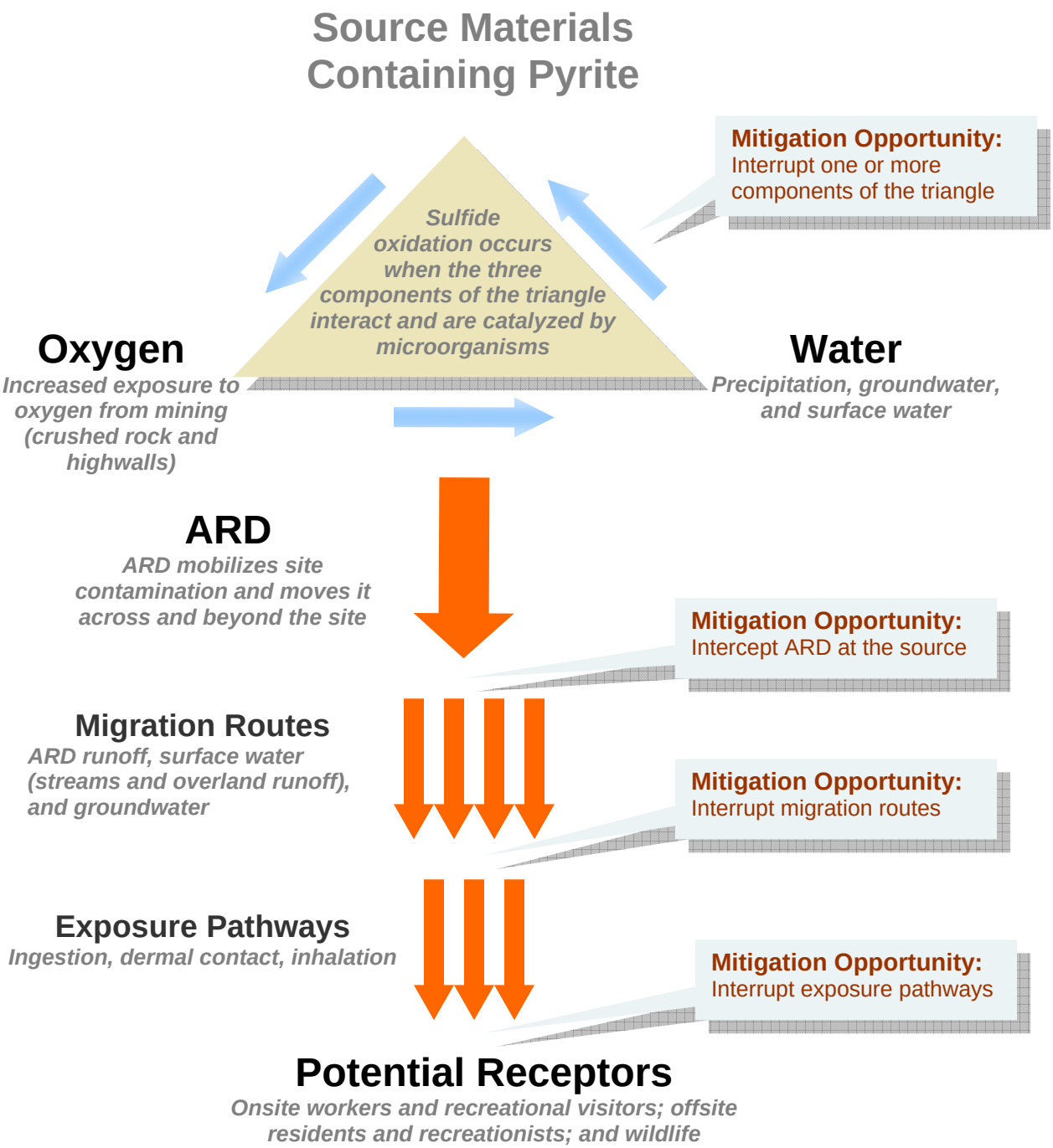
At the Gilt Edge gold deposit, the natural gold enrichment was concentrated enough to render mining and mineral processing economic. Natural enrichments of metals, such as cadmium, copper, and zinc, and metalloids, such as arsenic and selenium, are associated with the gold enrichment. Site contaminants are attributable to natural enrichments of metals and metalloids in the rock. The process of acid generation results in mobilization of these naturally occurring metals and metalloids into surface water and groundwater at the site.

The primary cause of acid generation at the site is oxidation of the mineral pyrite (FeS_2). 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 toxic metals. Pyrite is widespread in rock exposed by mining at the site, and acid generation occurs from numerous sources that are widespread over the primary mine disturbance area.

Acid generation at the site requires three primary components, oxygen, water, and pyrite. 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 acid 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 100s to 1000s of times. This strongly acid drainage containing elevated metal/metalloid concentrations is referred to as ARD. This process is represented schematically by the triangle shown on the top of Exhibit 1-1.

The site produces about 103 million gallons of ARD in an average year. The quantity of ARD produced is dependant on the timing and amount of precipitation received. It is estimated that approximately 3.6 million gallons of ARD are produced at the site per inch of rainfall. This ARD must be collected from the numerous source areas and

Exhibit 1-1. ARD Generation, Migration, and Mitigation



be treated prior to discharge into the cold water fishery at Strawberry Creek.

The existing ARD collection systems at the site are not 100 percent effective at preventing migration of ARD in surface water and groundwater. Migration in surface water and groundwater are examples of potential *migration routes* for contamination. These are shown schematically on Exhibit 1-1.

Contamination that migrates from the site has the potential to impact human or ecological receptors. The means by which a potential receptor may become exposed to contamination is referred to as an exposure pathway. An example of an exposure pathway for humans is ingestion of groundwater contaminated by ARD. *Exposure pathways* and potential receptors are also shown schematically on Exhibit 1-1.

CERCLA terms used in this RI report are provided in Exhibit 1-2.

Exhibit 1-2. CERCLA Terms Used at the Gilt Edge Mine Site

Term	Definition
Sources	Site materials that generate ARD in significant quantities (i.e., waste rock and fills, exposed rock surfaces, Heap Leach Pad (HLP) spent ore, soil stockpiles, and tailings)
Migration Routes	Routes by which ARD and other contaminants can travel from the source areas to receptors (i.e., ARD runoff, surface water, and groundwater)
Exposure Pathways	Pathways by which individual receptors can come in contact with the ARD and other contaminants (i.e., ingestion, dermal contact, and inhalation)
Receptors	Individuals who may have significant exposure to ARD and other contaminants generated by the source areas (i.e., onsite workers, residents, and recreational visitors and offsite residents and recreationists). Wildlife are also receptors.

1.3.3 Operable Units

Superfund sites are often divided into OUs in order to expedite actions at discrete areas or for cost accounting purposes. Due to the complex nature of the site, EPA has organized the work into three OUs.

- **OU1, Primary Mine Disturbance Area**. Addresses existing contaminant sources within the primary mine disturbance area such as acid generating waste rock and fills, spent ore, exposed acid generating bedrock, and sludge.

- **OU2, Water Treatment, Groundwater, and Lower Strawberry Creek**. Addresses 1) management of ARD generated at the site including ARD collection systems, pumping stations, pipelines, water treatment, and management of ARD treatment sludge generated in the future; 2) groundwater contamination associated with the site; and 3) contaminant sources, surface water, and sediments in the Lower Strawberry Creek area.

- **OU3, Ruby Gulch Waste Rock Dump**. Addresses contaminant sources located within the Ruby Gulch waste rock dump.

This RI report addresses the entire Superfund site, which is comprised of the three operable units listed above.

1.3.4 General Site Features

The site has been extensively disturbed by mining and mineral processing operations, and many features associated with development remain, including open pits, waste rock dumps, underground mine workings, a heap leach pad, and mineral processing facilities. Other important features include piping, storage locations, and equipment associated with ARD management at the site.

The nomenclature adopted to describe general site features and remediation subareas discussed in Section 1.3.6 is provided in Exhibit 1-3. Site features are discussed in greater detail in Section 3 - Physical Characteristics.

Five specific types of mining features have a significant impact at the site:

- Open pits
- Waste rock dumps
- Underground mine workings
- Heap Leach Pad
- Mineral processing facilities

These site features are described in greater detail in the following sections.

1.3.4.1 Open Pits

The dominant type of mining excavation present at the site is open pit. These pits were excavated in order to extract rock that contained enough gold to make extraction and mineral processing economic. Rock that contains enough gold to make extraction and mineral processing economic is referred to in mining terms as *ore*. Extracting ore from open pits requires excavation of ore as well as excavation of rock that does not contain enough gold to make extraction and mineral processing economic (*waste rock)*.

Waste rock is mined along with ore in order to create excavations that will be stable enough for personnel and equipment to work within the pits. The waste rock to ore ratio is an inherent characteristic of any gold deposit that will be mined by open pit methods. Profit is only developed from mining and processing ore, so a mine operator attempts to minimize the amount of waste rock that must be removed to access the ore. This results in construction of excavations with slopes that are as steep as possible. These slopes are termed *highwalls*. All highwalls contain *safety benches*, which are approximately horizontal benches constructed along highwalls at discrete vertical intervals. The purpose of these benches is to reduce the safety risks associated with rocks falling from the steep highwalls and improve the stability of the highwall.

The cost of excavating waste rock is dependant on the distance that it must be hauled. In order to minimize these costs, waste rock is placed as close to the open pit as

possible. Open pit mining produces large quantities of waste rock. At the site, available disposal areas are constrained by the site topography. The steep topography required placement of waste rock within gulches located nearby the open pits. These create waste rock dumps, which are a second major feature of the site.

Exhibit 1-3. Mining Terms Used at the Gilt Edge Site

Term	Definition
Ore	Rock that contains enough gold to make extraction and mineral processing economic
Spent Ore	The material remaining after crushed ore is processed and the gold is removed from the rock
Waste Rock	Rock that does not contain sufficient gold to be economically extracted and processed
Highwall	The steeply sloped rock walls of an excavated open-pit mine
Safety Bench	Approximately horizontal benches constructed along all highwalls at discrete vertical intervals to reduce the risk of falling rock
Waste Rock Dump	Areas where waste rock is placed in order to allow continued mining within the open pit
Fill	Waste rock placed at various locations to create a flat area for construction of infrastructure or to dispose of material as close to the open pit as possible
Heap Leach Pad	A large, lined facility where ore is piled to facilitate leaching with a dilute cyanide solution percolated through the ore
Merrill-Crow Gold Recovery Circuit	Mineral processing equipment used on the Heap Leach Pad ore to recover gold from solution and produce a solid mass containing gold, silver, and copper that was shipped off site for refining
Tailings	The fine sand left after ore is crushed and milled prior to treatment to remove the gold
Water Treatment Plant	The facility constructed in 2003 for treatment of ARD collected at various locations on the site
ARD Collection and Conveyance System	A complex system of collection facilities and conveyance mechanisms (pumping stations, pipelines and ARD storage locations) developed on site over the last 15 years to facilitate ARD treatment and discharge
Sludge	Metals-laden, semi-solid material produced in the clarifier of the water treatment plant after metals are precipitated out of solution by increasing the pH of the ARD
Underground Workings	Features created by the process of underground mining (i.e., tunnels, drifts, shafts, stopes, etc.)

1.3.4.2 Waste Rock Dumps

Mine *waste rock dumps* are areas where waste rock was placed in order to allow continued mining within the open pit. Moving waste rock from a waste rock dump back into open pits after mining essentially doubles the cost of mining waste rock,

which is a critical economic factor for overall mine profitability. As a result, removing waste rock from waste rock dumps and placing it back into open pits was not required in state mining permits for the site.

The primary type of waste rock dump at the site is the valley fill waste rock dump. This type of waste rock dump is constructed by end dumping mine haul trucks and/or bulldozing waste rock into a valley, which fills in the valley with rock and creates an approximately horizontal surface. There is one large valley fill waste rock dump present at the site, which is located in the headwaters area of Ruby Gulch and named the Ruby Gulch waste rock dump.

There are numerous areas on the site where mine waste rock was placed in convenient areas either to create a flat area for construction of mine infrastructure or simply to dispose of waste rock as close to the open pit as possible. These areas are referred to in this report as *fill* areas. Also present are fill areas created by initial mine construction, which cut rock from topographically higher areas of the site and placed this rock into topographical depressions in order to prepare areas for construction of mine facilities, such as the Heap Leach Pad and the mineral processing plant. This type of construction is referred to as cut and fill.

1.3.4.3 Underground Mine Workings

Prior to the development of large earth moving equipment, such as mine haul trucks, bulldozers, and front end loaders, gold mining was more commonly accomplished by underground mining. This type of mining required a relatively small capital expense as compared to open pit mining. It was also very labor intensive. Underground mining remains an important mining method in modern time, but it is generally only used for ore deposits too deep to be mined economically by open pit methods. Most mining at the site prior to the mid 1980s was underground mining.

This underground mining involved excavation of adits (approximately horizontal openings into the side of a hill) and shafts (approximately vertical openings into subsurface ore bodies). These are connected by underground tunnels referred to as drifts, which access the underground ore zones. When an ore zone is mined out, the opening in the rock is referred to as a stope. Collectively, all of these features are referred to in this document as *underground workings*.

The “old timers” did an effective job of locating the ore, and several of the large open pits at the site were excavated in areas that contain underground workings. These workings were partially excavated during construction of the open pits, which created new openings into the workings, primarily in the open pit highwalls.

1.3.4.4 Heap Leach Pad

The gold recovery process used in conjunction with open pit mining operations incorporates a dilute cyanide solution which was percolated through crushed ore on an HLP. The HLP is a large, lined facility where ore was piled to facilitate leaching with cyanide. The cyanide solution percolated through the ore and was collected in a

sump. The cyanide solution was pumped from the HLP sump into the gold processing circuit.

After crushed ore was processed and the gold was removed from the rock, the rock is called *spent ore*. The geochemical characteristics of spent ore are similar in many ways to geochemical characteristics of rock that has not been processed to remove gold with several important exceptions. Spent ore contains residual mineral processing reagents, such as cyanide and lime. These reagents affect the types of contaminants present in the rock as well as the mobility of contaminants. The particle size of spent ore is generally smaller than waste rock due to crushing and ranges from a sandy gravel to coarse boulders.

1.3.4.5 Mineral Processing Facilities

Mineral processing facilities used in open pit mining operations at the site consist of two major groups of mineral processing equipment: that used prior to placement of ore on the HLP and that used after the ore was placed on the HLP. The equipment used prior to ore placement on the HLP includes a rock crushing plant and ancillary conveyors, electrical infrastructure, and crushed rock storage areas. The rock crushing plant and most electrical control equipment has been removed from the site and was sold during a site auction by one of the mine creditors. Some components of the system remain, such as crusher foundations and the crushed rock storage area.

Mineral processing equipment used after the ore was placed on the HLP primarily consists of the *Merrill-Crow Gold Recovery Circuit* (MCGRC). This circuit included the gold processing plant as well as several lined ponds that were used for storage of solutions containing cyanide and/or gold in solution. The MCGRC was used to recover gold from solution and produce gold doré, which was produced as a solid mass containing gold, silver, and copper. This was shipped off site for the final step of the process, which is refining. Numerous components of the MCGRC remain on site, although interim remedial actions have largely removed the gold processing equipment and converted the processing plant to support ongoing ARD management activities.

Mineral processing methods used by the old timers during underground mining operations at the site differed from the processes utilized in recent mine operations. An important difference was the extent of crushing and grinding that was completed prior to ore treatment to remove the gold. The old timers used crushers and mills to pulverize the ore to a fine sand. After the ore was processed to remove the gold, the fine sand was discharged directly into Strawberry Creek. This sand-sized processed ore is called *tailings*. The primary difference between spent ore and tailings is the grain size. At the site, the spent ore versus tailings designation also describes the period in which the ore was mined and processed. Spent ore was produced during the most recent stage of mining at the site between the mid 1980s and 1997. Most tailings were produced at the site between 1938 and 1941.

1.3.4.6 Water Treatment Plant and ARD Collection and Conveyance System

A complex system of collection facilities, pumping stations, pipelines, and ARD storage areas have been developed on the site over the last 15 years. The site produces approximately 95 million gallons of ARD from a variety of sources each year. This contaminated water must be collected, pumped to central storage facilities, and treated prior to discharge from the site.

A high-density sludge (HDS) *water treatment plant* was constructed and began treatment of ARD in 2003. This water treatment plant uses lime to increase pH of the ARD and precipitate metals into a *sludge*. The plant has a design treatment rate of 250 gallons per minute (gpm). The high-density sludge generated in the water treatment plant clarifier is disposed of on the HLP Extension.

Numerous ARD collection and conveyance facilities are present at the site and use various methods to collect ARD from surface water and alluvial groundwater, pump this water into pipelines, and store the water prior to treatment. Current ARD storage facilities include a lined pond that was formerly used as a contingency pond for gold processing solutions and three open pits.

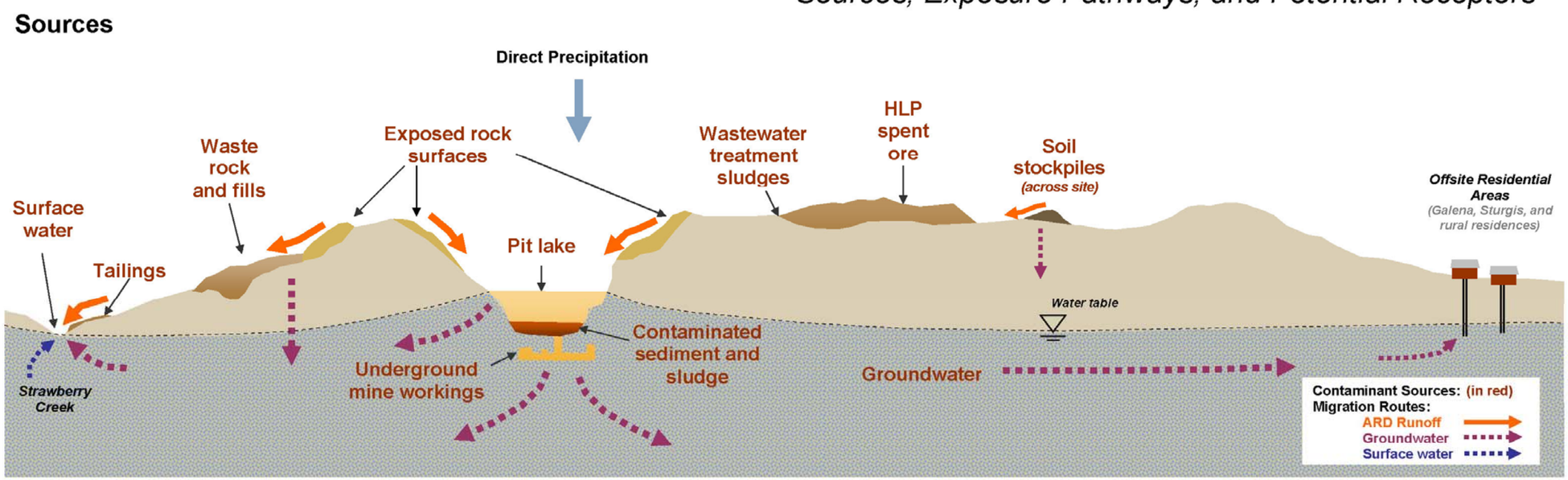
Previous water treatment processes at the site used sodium hydroxide to increase the pH of the ARD and precipitate metals into sludge. The sodium hydroxide sludge is similar to the HDS sludge but contains about 95 percent water. Sludge generated by past water treatment at the site is present in numerous areas, including all pit lakes and several surface impoundments.

1.3.5 Site Conceptual Model

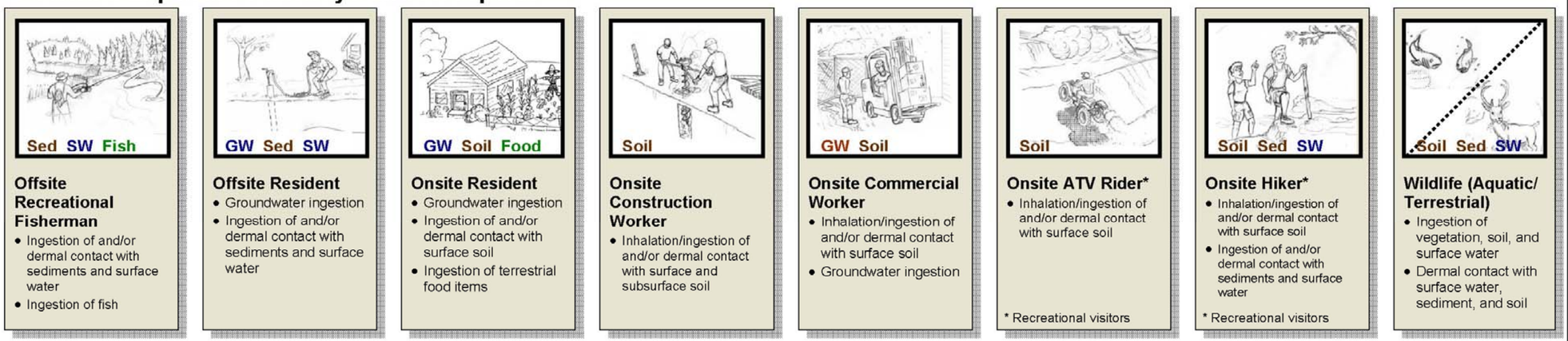
The site conceptual model (SCM) is used in development of a conceptual understanding of the site in order to evaluate risks to human health and the environment. The SCM is developed in the scoping phase of the RI/FS and refined and expanded, as necessary, to incorporate added information developed in the RI and risk assessments. The SCM includes sources of contamination, affected media, such as surface water and groundwater, potential migration routes for contamination, and potential human and environmental receptors.

The current SCM incorporates components of a fate and transport model that is presented in Section 5, and components of a risk assessment model that is presented in Section 6. A graphical representation of the current SCM is presented in Exhibit 1-4. This model incorporates the current understanding of the contaminant sources, migration routes, exposure pathways, and potential receptors.

Exhibit 1-4
Gilt Edge Site Conceptual Model
Sources, Exposure Pathways, and Potential Receptors



Potential Exposure Pathways and Receptors



CDM

Source materials shown on Exhibit 1-4 are primarily sources of contaminants that interact with oxygen and water to form ARD. These sources consist of the following:

- **Waste Rock and Fills** are waste rock dumps and other fills that contain broken unconsolidated rock that forms ARD at the site. The broken and unconsolidated nature of the waste rock and fills exacerbates ARD generation because of the large amount of surface area that is exposed to weathering.

- **Exposed Rock Surfaces** are rock surfaces that are exposed in highwalls, safety benches, and other rock exposures (bedrock) at the sites. The reduced surface area of exposed rock surfaces as compared to waste rock and fills decreases the relative potential for ARD generation. However, exposed rock surfaces remain an important source of ARD on the site.

- **HLP Spent Ore** is spent ore that is present on the HLP. ARD generated by spent ore on the HLP is contained by the liner system that was originally used to contain cyanide solutions used in the gold extraction process.

- **Soil Stockpiles** are piles of stockpiled topsoil and subsoil that are a resource for reclamation. These piles are potentially acid generating as a result of the widespread occurrence of the mineral pyrite at the site.

- **Tailings** are the sand textured mine wastes left on the site by the old timers. Some of the tailings on the site have been remediated by previous actions, although some ARD generating tailings remain on the site.

One additional source material is present on the site, which does not have the potential to generate ARD.

- **ARD treatment sludge** contains the toxic metals that have been removed from ARD during treatment. ARD treatment sludge is a potential source of contaminants depending on the environment in which it is stored.

Migration routes included in the SCM consist of ARD runoff, surface water migration, and groundwater migration.

- **ARD runoff** occurs when precipitation interacts with ARD source materials. The runoff dissolves secondary acidity and metals that were released from the rock by acid generation and transports these contaminants as ARD.

- **Surface water migration** occurs when ARD reaches area streams and contaminants are transported by surface water in either the dissolved or particulate form.

- **Groundwater migration** occurs when the ARD is transported along with groundwater through site aquifers.

The final components of the SCM are potential exposure pathways and receptors. Exposure pathways describe the processes by which a potential receptor could contact contaminated media, such as surface water or groundwater. Receptors define groups of humans (or other organisms) that could be impacted by site contaminants via one of the exposure pathways. The SCM evaluates eight receptors:

- Offsite recreational fisherman
- Offsite resident
- Onsite resident
- Onsite construction worker
- Onsite commercial worker
- Onsite all-terrain vehicle rider
- Onsite hiker
- Wildlife

One to three exposure pathways are evaluated for each receptor. The exposure pathways include ingestion, inhalation, and dermal contact of various types of contaminated media, such as surface water, groundwater, soil, contaminated sediments, and contaminated fish.

- **Incidental ingestion** could result from small amounts of soil, dust or water that adheres to hands and is incidentally ingested through hand to mouth activities.
- **Ingestion** could also occur if groundwater was used as a source of drinking water in the future.
- **Inhalation** could occur if dust is incidentally inhaled during activities such as recreation or construction.
- **Dermal contact** could occur if dust or water containing metals adheres to skin and is absorbed.

1.3.6 Remediation Subareas

As investigations were completed and data became available for the RI report, EPA developed several FS-type documents and work products that were used to assist in remedy screening and preliminary cost estimates. Certain categorizing methods and nomenclature were developed in this process. For example, contaminated media of concern and site features were categorized by geographic location.

In 2004, the primary mine disturbance area was divided into geographic regions or *remediation subareas* that included multiple media of concern and covered large expanses of the site. To manage these remediation subareas, an integrated remedial strategy was developed for each remediation subarea. This organizational approach has been adopted for this RI and the accompanying FS for OU-1.

The remediation subareas are summarized in the following section and are discussed in greater detail in Section 3. Exhibit 1-5 presents a site map depicting the various remediation subareas.

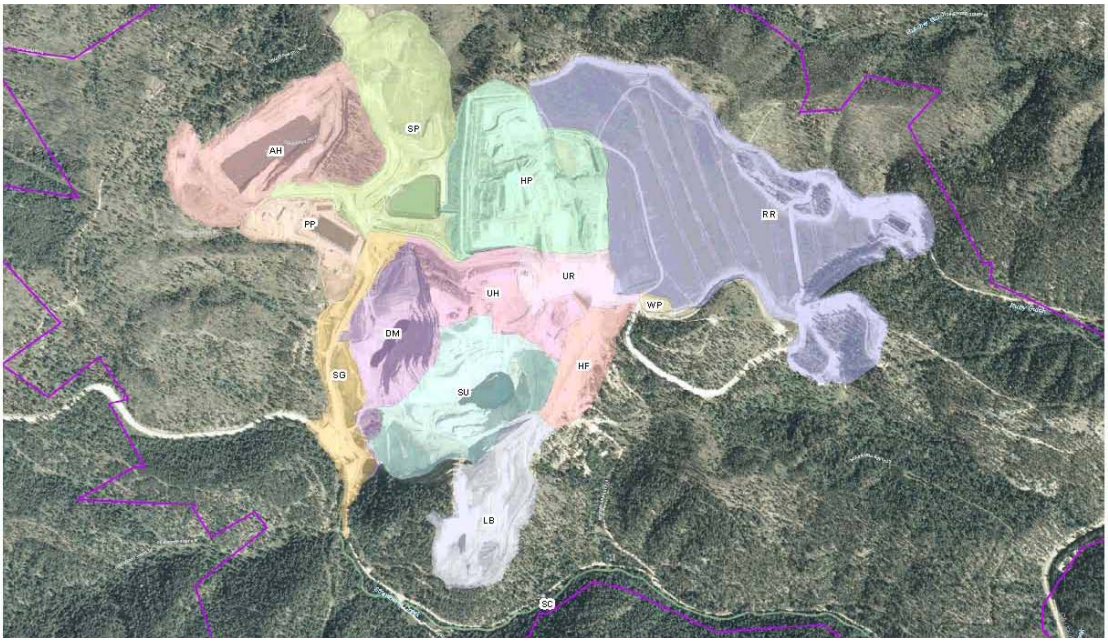


Exhibit 1-5. Aerial Photograph Depicting Remediation Subareas

1.3.6.1 Anchor Hill Pit Remediation Subarea

The primary feature of the Anchor Hill Pit Remediation Subarea is the Anchor Hill Pit. The pit is long and narrow, 1,200 feet by 600 feet. The highwall on the northwest side rises 300 feet above the pit floor, and the upper 100 feet of the highwall projects above the surrounding area as the remnant of Anchor Hill. Contaminated media of concern are acid-generating waste rock and fills, exposed acid-generating bedrock, contaminated sediment and sludge, and ARD.

Exhibit 1-6. Anchor Hill Pit Remediation Subarea

1.3.6.2 Dakota Maid Pit Remediation Subarea

The Dakota Maid Pit Remediation Subarea is asymmetrically shaped, has varied and complex geology, is connected with underground workings, and has close proximity to the Strawberry Gulch drainage. Exposed bedrock contains pyrite and deeply penetrating fracture zones. On the northwest side of the remediation subarea, part of the pit has been backfilled with reclamation fills. Unconsolidated fill and acid-contaminated colluvium form a small berm on the south end of the pit. Early water-treatment sludges, comingled with sediments carried off the highwalls during storms, are deposited into the bottom of the pit.

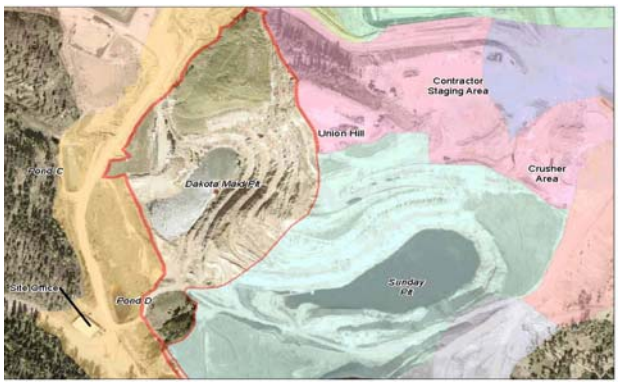


Exhibit 1-7. Dakota Maid Pit Remediation Subarea

Underground mine workings complicate the groundwater hydrology system, and the ARD waters in the pit and mine workings are connected via bedrock fractures with the Strawberry Creek alluvium and regional groundwater. Contaminated media of concern are acid-generating waste rock and fills, exposed acid-generating bedrock, contaminated sediment and sludge, and ARD.

1.3.6.3 Hoodoo Fill Remediation Subarea

The Hoodoo Fill Remediation Subarea is located adjacent to the east rim of the Sunday Pit near the top of Hoodoo Gulch. An acid-generating fill embankment was placed in this location to establish a haul road to transport ore and waste rock to the crusher and Ruby Gulch waste rock dump. The fill embankment is up to 80 feet tall. Underground mine workings are buried beneath the Hoodoo Fill. Contaminated media of concern are acid-generating waste rock and fills, exposed acid-generating bedrock, and ARD.

Exhibit 1-8. Hoodoo Fill Remediation Subarea

1.3.6.4 Heap Leach Pad Remediation Subarea

The Heap Leach Pad Remediation Subarea includes the HLP, spent ore located in the HLP, stockpiles of construction material, and a sludge storage area. The HLP contains 2.1 million cubic yards of spent ore. The leach pad was initially constructed using a cut and fill method, and later expansions were constructed on fills constructed with spent ore and waste rock. A multi-layer liner system is present at the base of the HLP, which was designed to contain and collect gold processing solutions. The HLP liner system currently collects ARD that is generated by the spent ore.

The southeastern portion of the leach pad is currently being used to stockpile construction materials imported to the site. The northeastern portion of the extension area is used for storage of sludge generated at the HDS water treatment plant. Contaminated media of concern are acid-generating waste rock and fills, exposed acid-generating bedrock, contaminated sediment and sludge, and contaminated surface water.

Exhibit 1-9. Heap Leach Pad Remediation Subarea

1.3.6.5 Langley Benches Remediation Subarea

The Langley Benches Remediation Subarea includes benched areas to the south and east of Langley Peak, two open pits, and the fills used to construct the access roads to the pits. The pits in the Langley Benches Remediation Subarea are called the North Langley and the Southeast Langley pits. The pits have been partially backfilled with waste rock, and ARD generating exposed bedrock remains above the backfill. The North Langley Pit was backfilled, covered with soil, and revegetated by the Brohm Mining Company (BMC).

Exhibit 1-10. Langley Benches Remediation Subarea

The area is impacted by acid-generating fills and exposed acid-generating bedrock. Contaminated media of concern are ARD generating waste rock and fills and ARD generating exposed bedrock.

1.3.6.6 Process Plant Remediation Subarea

The Process Plant Remediation Subarea is located southeast of the Anchor Hill Pit where a gulch was filled in to create two level terraces used as construction areas. The upper terrace contains the Process Plant Building, the Assay Laboratory Building, the Process Pump House, and several outdoor storage areas. Tanks and vessels removed from the former sodium hydroxide water treatment process are stored in the yard area south of the Assay Laboratory Building.

The lower terrace contains several lined ponds, which was a part of the site's former mineral processing circuit. Terrace fills are ARD generating, and ARD seepage flows from the Process Plant Remediation Subarea into the Strawberry Gulch Remediation Subarea where it is captured for treatment. Contaminated media of concern are acid-generating waste rock and fills.

Exhibit 1-11. Process Plant Remediation Subarea

1.3.6.7 Ruby Repository Remediation Subarea

This Ruby Repository Remediation Subarea is located east of the Heap Leach Pad Remediation Subarea. It was constructed as part of OU3 to contain acid-generating waste rock and spent ore within the Ruby Gulch waste rock dump. The repository covers approximately 75 acres of the Ruby Gulch waste rock dump. The remainder of the Ruby Gulch waste rock dump has not been capped and is included in the Upper South Ruby Remediation Subarea.

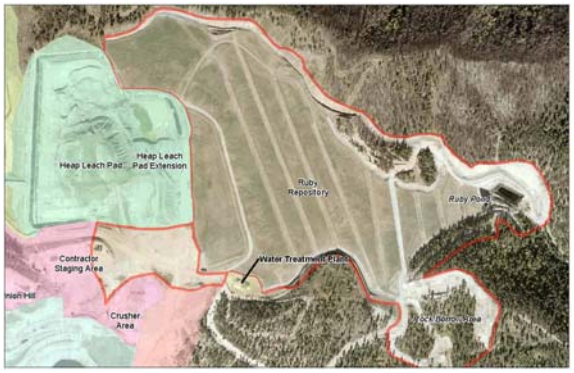


Exhibit 1-12. Ruby Repository Remediation Subarea

The lower portion of the repository includes an internal cutoff wall and outfall pipe that collect ARD seepage and convey it to a subsurface collection gallery for temporary storage prior to transfer to the Sunday Pit for storage. Contaminated media of concern are acid-generating waste rock and fills, exposed acid-generating bedrock, contaminated sediment and sludge, and ARD.

Exhibit 1-13. Lower Strawberry Creek Remediation Subarea

1.3.6.8 Lower Strawberry Creek Remediation Subarea

This subarea includes the lower section of Strawberry Creek from the water treatment plant discharge outlet to the confluence with Boomer Gulch. It has been impacted by tailings derived from historic mining operations. In addition, water treatment sludge inadvertently deposited along the streambed has become embedded in the stream channel substrate, adversely impacting the benthic zone. Contaminated media of concern are streamside tailings, contaminated streambed sludges, and ARD.

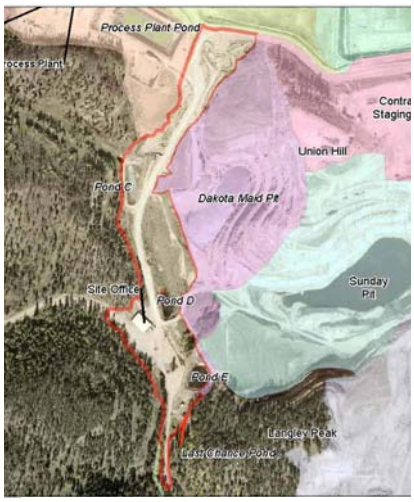


Exhibit 1-14. Strawberry Gulch Remediation Subarea

1.3.6.9 Strawberry Gulch Remediation Subarea

This subarea is the portion of the pre-mining drainage located south of the Process Plant and Stormwater Pond remediation subareas and west of the Dakota Maid Pit Remediation Subarea. It includes fills that form the main roadway along the

former stream corridor of upper Strawberry Creek, a series of water diversion channels and culverts, and ARD-conveyance culverts with flow regulation ponds. The ponds function as ARD capture and conveyance locations for site-wide water treatment. The area also includes infrastructure left from BMCs operations, including the mine office, parking lot, septic system, entrance gate, and a power line. Contaminated media of concern are acid-generating waste rock and fills, exposed acid-generating bedrock, contaminated sediment and sludge, and ARD.

1.3.6.10 Stormwater Pond Remediation Subarea

This subarea is located west of the Heap Leach Pad Remediation Subarea and east of the Anchor Hill Pit Remediation Subarea. It includes the Stormwater Pond, adjacent road and embankment fills, a road cut excavation, and topsoil stockpiles. The pond was lined as a precaution to contain flow from the Heap Leach Pad in the event of a large precipitation event. The Stormwater Pond is currently used for storage of ARD treatment sludge and ARD collected from the HLP.

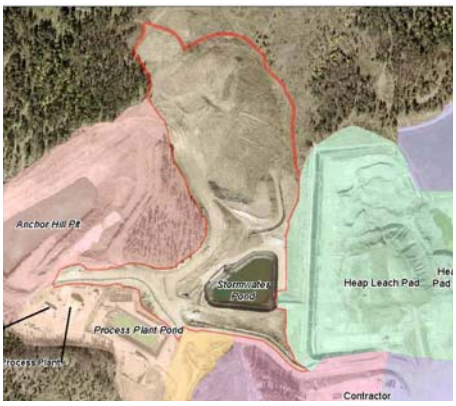


Exhibit 1-15. Stormwater Pond Remediation Subarea

The upper reaches of the Strawberry Creek watershed drain through this area via the Strawberry Creek Diversion. The pipe captures and conveys surface water runoff to the lower end of Strawberry Gulch where it discharges below the mine office. Contaminated media of concern are acid-generating waste rock and fills, sludge, and ARD.

1.3.6.11 Sunday Pit Remediation Subarea

This subarea includes the Sunday Pit, underground mine workings, stored ARD, water treatment plant sludge, Surge Pond sludge, reclamation fill, and a tailings repository. The pit is the primary ARD storage facility on site and is an integral part of the site ARD collection, conveyance, and treatment system. Exposed bedrock on pit highwalls is strongly ARD generating. The upper east end of the pit contains a backfilled zone of amended tailings that have been capped with a low-permeability clay layer, covered with topsoil and revegetated. An area on the southwest side of the pit has been backfilled with waste rock and has been reclaimed. Underground mine workings are present underneath and adjacent to the Sunday Pit. Contaminated media of concern are acid-generating waste rock and fills, exposed acid-generating bedrock, contaminated sediment and sludge, and ARD.

Exhibit 1-16. Sunday Pit Remediation Subarea

1.3.6.12 Union Hill Upland Remediation Subarea

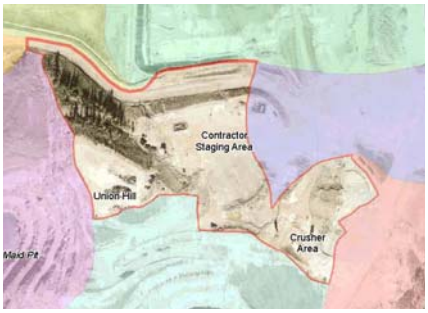


Exhibit 1-17. Union Hill Upland Remediation Subarea

This subarea is located east of the Dakota Maid Pit Remediation Subarea, north of the Sunday Pit Remediation Subarea, and south of the Heap Leach Pad Remediation Subarea. It includes remnants of Union Hill and the adjacent upland surfaces, including the undisturbed northwest slope. The top of the hill was used for material storage and a contractor staging area, and the eastern slope was used as the crusher area. An onsite fueling station used for current site operations is located in the contractor staging area. This area also includes ancillary structures remaining from the ore processing operations, including a retaining wall and foundations from the former crusher. The crusher and lime silo have been removed. Contaminated media of concern are acid-generating waste rock and fill and exposed acid-generating bedrock.

1.3.6.13 Upper South Ruby Remediation Subarea

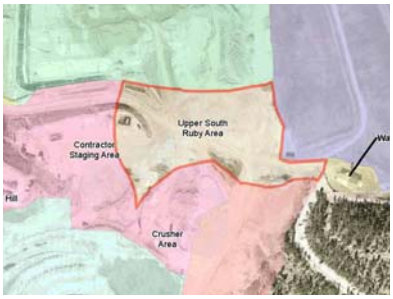


Exhibit 1-18. Upper South Ruby Remediation Subarea

The Upper South Ruby Remediation Subarea is located south of the Heap Leach Pad Remediation Subarea, north of the Hoodoo Fill Remediation Subarea, and west of the Ruby Repository Remediation Subarea. It includes the portion of the Ruby Gulch waste rock dump that was not covered during construction of Ruby Repository. Contaminated media of concern are acid-generating waste rock and fills.

1.3.6.14 Water Treatment Plant Remediation Subarea

This subarea is located on the southwestern corner of the Ruby Repository Remediation Subarea. It was constructed as a component of OU2 to provide for more efficient and cost-effective treatment of ARD and to minimize impacts to lower Strawberry Creek caused by the former water treatment plant. A complex site-wide ARD collection, conveyance, and treatment system was assembled by BMC during mining operations to collect and transfer site waters between storage impoundments and the water treatment plant. This system has been modified during implementation of OU2 to capture ARD for treatment within Strawberry Gulch and Hoodoo Gulch.

Exhibit 1-19. Water Treatment Plant Remediation Subarea

The interim ROD recognized that further remedial strategies would be needed for ARD treatment. Additional water treatment plant modifications will be evaluated in the future. Contaminated media of concern are ARD and sludge generated from treating ARD.

1.3.6.15 Groundwater Remediation Subarea

A Groundwater Remediation Subarea has been developed for use in the future. Groundwater contamination crosses boundaries of the previously defined remediation subareas and extends out of the primary mine disturbance area encompassed by the remediation subareas. Further definition of the aerial extent of the Groundwater Remediation Subarea will be provided in Section 3.1.15.

1.4 Site History

Mining and mineral processing have been conducted at the site on an intermittent basis since the late 1800s. Major periods of activity occurred from 1938 to 1941 and during a period extending from the mid-1980s to approximately 1997. Environmental degradation began with the careless disposal of tailings and other mined materials into gulches and streams, as was common in that era. The impact of these disposal methods continues to the present day.

The vast majority of disturbance at the site occurred during the later stage when large-scale open pit mining occurred at the site. The site operator, BMC, abandoned the site in July 1999. At that time, there was an imminent risk of uncontrolled discharges of acid rock drainage from the site. The State of South Dakota immediately responded and took responsibility for collection and treatment of ARD. In 2000, the EPA took over primary site responsibilities.

The following subsections discuss:

- Early mining and mineral processing activities that caused the contamination
- State and federal regulatory activities undertaken to address the contamination

Exhibit 1-20 depicts a brief summary of those activities.

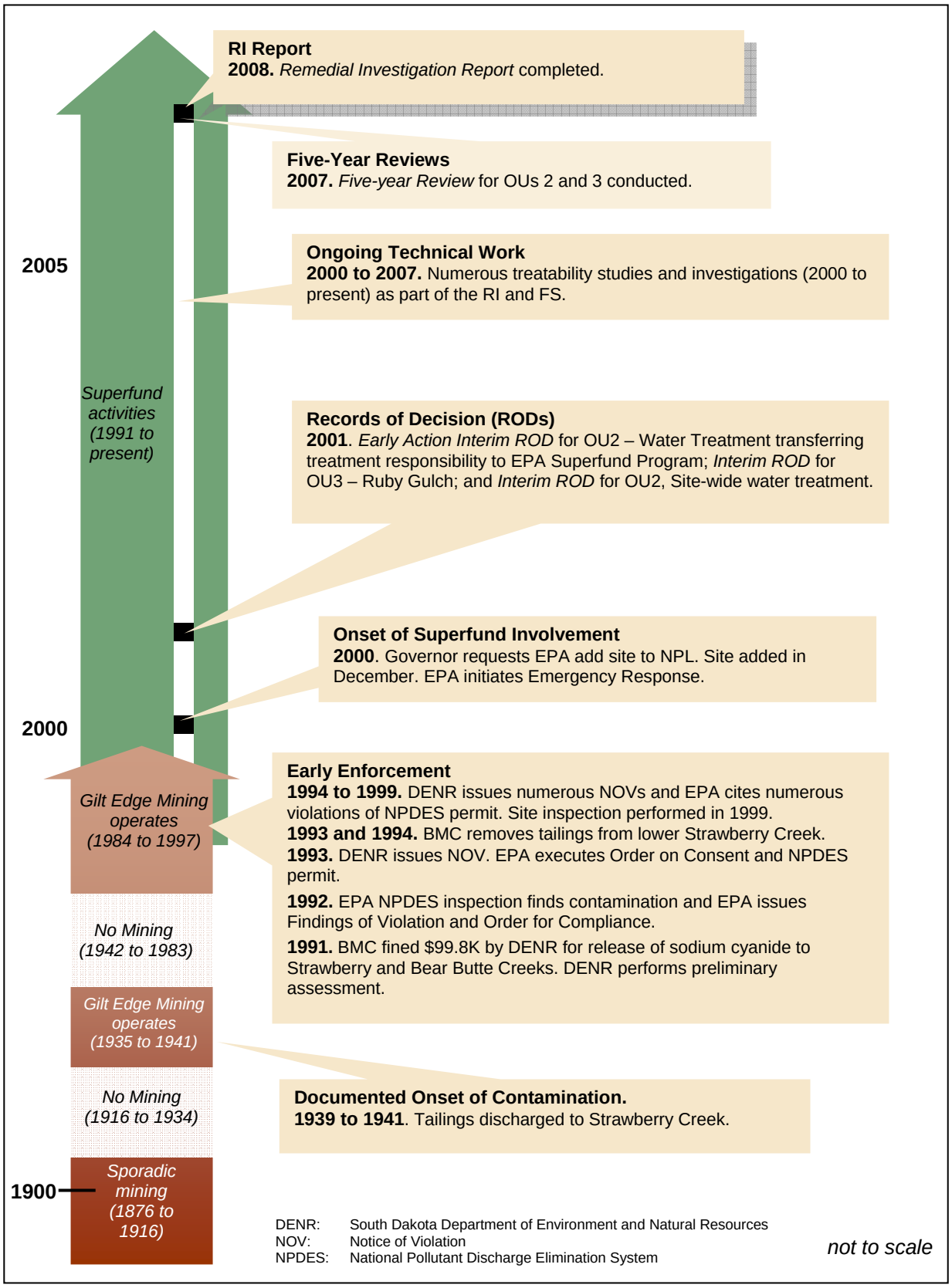
1.4.1 Early Mining and Mineral Processing

Mining activities began at the site in 1876 when the Gilt Edge and Dakota Maid claims were founded. Historical underground mining operations extracted sulfide-bearing gold ores from irregular deposits in veins and fracture zones in the igneous rocks. Over the past century, a number of owners and operators have established mining operations at the site.

1.4.1.1 Early Owners/Operators

The Oro Fino Mine, which is located next to Strawberry Creek, was operated in 1893. From 1893 to 1900, no mining activity was conducted at the site. The Hoodoo-Union

Exhibit 1-20. Timeline of Mining and Regulatory Activities at the Site



Group reactivated operations in 1900. The Gilt Edge Mining Company operated at the site from 1900 to 1902. No mining was conducted between 1902 and 1905.

From 1905 to 1916, sporadic mining operations were carried out by the Gilt Edge Maid Gold Mining Company. During that time, gold, silver, and small amounts of copper, lead, and zinc were reportedly extracted and processed from claims at the site. No mining occurred at the Gilt Edge Mine between 1916 and 1935.

In 1935, the Gilt Edge Mining Company incorporated in South Dakota, with mining operations subsequently being reestablished at the site in 1937 and continuing until 1941 (URS Operating Services [UOS] 1999). In 1938, the milling operation used a cyanidization gold extraction process that was capable of processing 125 tons of ore per day. Mercury amalgamation was reportedly used on the jig concentrate while zinc precipitation was used on the flotation solids (UOS 1999).

Gilt Edge Mining Company metal production included gold, silver, and minor amounts of copper, lead, and zinc. In 1940, the presence of copper within the ore body resulted in losses of cyanide and inefficient recovery of gold. As a result, flotation cells were installed and copper concentrates recovered. Copper concentrates were transported and sold to Montana smelters. Mines at the site reportedly produced a small amount of tungsten in 1941. During that time, underground operating mines included the Gilt Edge, the Pyrite, the Rattlesnake Jack, and the Hoodoo-Union Hill. Underground mining operations broke through to the surface leaving glory hole openings (UOS 1999).

Beginning in 1938, mill tailings were discharged directly into Strawberry Creek. This discharge continued for 3 years until the mine closed in 1941. Over time, oxidation and erosion of the tailings severely affected water quality in Strawberry Creek, causing acidic pH, increased heavy metal/metalloid concentrations, increased suspended solids concentrations, and the absence of any aquatic life. In the early 1980s, South Dakota Department of Environment and Natural Resources (DENR) observed and quantified several tens of thousands of tons of acid-generating tailings within the upper reaches of the Strawberry Creek drainage. A spring at the base of these tailings was recorded as having a pH of 1.9 standard units (DENR unpublished files). Underground shafts and mine entrances were also observed to discharge acidic water and metals into the surrounding environment (UOS 1999).

1.4.1.2 BMC Operations

In 1984, Gilt Edge, Inc. applied for a permit to begin an open pit mining operation at the site. Gilt Edge, Inc. had acquired claims formerly held by the Hoodoo-Union Hill and Anchor Hill Mining companies. Prior to a permit being issued by the State of South Dakota, Gilt Edge, Inc. was acquired by BMC.

The South Dakota Board of Minerals and Environment issued Large Scale Mine Permit No. 439 in 1986, approving the open pit mining operation. Initial development included construction of a heap leach pad, a Merrill-Crowe gold processing plant,

process solution ponds, and ancillary mine infrastructure. The Sunday and Dakota Maid pits were mined from 1986 through 1992. Several conditions of the permit addressed mitigation of relic mine tailings. For instance, a portion of the residual tailings was used in construction of mineral processing facilities at the mine during the mid-1980s, and a pump back system designed to prevent onsite acidic discharges from entering Strawberry Creek was installed.

In 1991, cyanide leaked from the mineral processing circuit and impacted Strawberry and Bear Butte creeks. During an EPA inspection in 1992, unpermitted discharges of acidic and metal-laden waters containing aluminum, cadmium, copper, lead, and zinc were observed and recorded. As a result, in 1993 EPA issued a National Pollutant Discharge Elimination System (NPDES) permit to BMC addressing surface water discharges. Three NPDES compliance points were designated, including one in Strawberry Creek and two in Ruby Gulch, an intermittent tributary to Bear Butte Creek. NPDES permit violations (based on low pH and elevated levels of cadmium, copper, and zinc relative to permitted concentrations) have occurred on several occasions since the permit was issued.

Work done by BMC documents impacts to benthic macro-invertebrate communities along Strawberry Creek, as well as downstream of the confluence of Strawberry Creek with Bear Butte Creek (UOS 1999). ARD from the Ruby Gulch waste rock dump was first detected in 1993. In 1993 and 1994, historic mine tailings were removed from lower Strawberry Creek. This project removed a major portion of the historic tailings from the creek bed along a slot excavated to bedrock aligned along the creek bed. The excavated tailings were amended with fly ash from a local coal-fired power plant, placed on upper portions of pit benches, and top soiled in 1994 (Durkin 1994).

Subsequent operations by BMC developed the North and Southeast Langley pits and the Anchor Hill Pit. A large-scale mining permit for the Anchor Hill deposit was issued by the South Dakota Board of Minerals and Environment in January 1996. The project was split into Phase I (on private land) and Phase II (mostly on U.S. Forest Service [USFS] land). Mining of the Phase I deposit and the portions of the Phase II deposit on private land was initiated in May of 1996 and completed by August of 1997. The Langley pit area was mined between the first and third quarters of 1997.

Mining of the portion of Phase II located on USFS land was delayed because of the need for an environmental impact statement. A USFS decision approving the mine was issued for Phase II in November 1997. However, in response to appeals, the USFS withdrew its approval in February 1998. On May 21, 1998, BMC reported that it would abandon the mine in 1 week. The state filed for a temporary restraining order to prevent the abandonment. The order was granted on May 29, 1998 and was followed by a preliminary injunction on June 5, 1998. BMC's parent company, Dakota Mining Corporation, filed for bankruptcy in Canada in July 1999. As a result, DENR assumed water treatment operations using the South Dakota Regulated Substance Response Fund.

1.4.2 Regulatory Activities

Enforcement actions and the history of documented releases of hazardous substances into surface water are illustrated in Exhibit 1-20 and briefly described below:

- **December 1939 through September 1941.** Mine tailings were discharged down Strawberry Creek and into Bear Butte Creek. When the mine closed in 1941, piles of acidic tailings were left along Strawberry Creek. These tailings continually discharged acid and metal-laden water into the creek until they were removed by BMC (U.S. Bureau of Reclamation [BOR] 2000a).

- **June 20 to 21, 1991.** Sodium cyanide used in the heap leach process to extract gold from crushed ore leaked and was discharged into Strawberry Creek and Bear Butte Creek (EPA 2000a). BMC was fined $99,800 and issued a Notice of Violation (NOV) and Order by DENR.

- **1991.** A preliminary assessment of the site was prepared by DENR.

- **May 19, 1992.** EPA conducted an NPDES inspection and found contaminated water was discharging from two areas without a permit. This included water seeping from the toe of Ruby Gulch waste rock dump and pollutants from several point sources entering the Strawberry Creek diversion culvert through sedimentation ponds. The pH of Ruby Gulch waste rock dump water was acidic and contained aluminum, cadmium, copper, lead, and zinc. Discharges to Strawberry Creek were acidic and contained elevated aluminum, cadmium, copper, iron, lead, and zinc (EPA 2000a).

- **August 10, 1992.** EPA transmitted an inspection report to BMC requiring application for an NPDES permit (EPA 2000a).

- **November 24, 1992.** EPA issued a Findings of Violation and Order for Compliance, setting forth monitoring requirements and interim performance standards for Strawberry Creek and Ruby Gulch (EPA 2000a).

- **April 19, 1993.** Based on low pH and elevated concentrations of sulfate, aluminum, copper, iron, manganese, and zinc in Ruby Gulch discharge, an NOV was issued by DENR (EPA 2000a).

- **September 14, 1993.** EPA executed an Order for Compliance on Consent, superseding the November 24, 1992 Order (EPA 2000a).

- **September 15, 1993.** EPA issued NPDES Permit Number SD-0026891 to BMC (EPA 2000a).

- **February 15, 1994.** DENR issued a letter regarding NPDES permit violations at Compliance Point 002 in Ruby Gulch for pH, cadmium, copper, and zinc (EPA 2000a).

- **March 31, 1994.** EPA issued a Notice of Proposed Assessment of Class II Civil Penalty on NPDES Permit Number SD-0026891 (EPA 2000a).
- **August 25, 1994.** EPA issued a Consent Order based on permit violations, including February 1994 violations in Ruby Gulch (EPA 2000a).
- **February 20, 1997.** DENR issued an NOV for the discharge of acid mine drainage into Strawberry Creek. BMC paid a total penalty of $5,400.
- **September 15, 1997.** DENR issued an NOV for two discharges of acid mine drainage into Strawberry Creek. BMC paid a total penalty of $18,000.
- **September 5, 1998.** DENR issued an NOV and Order for Compliance for NPDES permit violations (including cadmium, copper, and zinc) at Strawberry Creek Compliance Point 001 in 1996, 1997, and 1998 (EPA 2000a).
- **March 31, 1994 through January 31, 2000.** Numerous violations of NPDES permit limits at Compliance Points 001 and 002 (EPA 2000a).
- **1999.** UOS prepared the site inspection. Soil, sediment, and surface water samples were collected and analyzed for heavy metals and cyanide (UOS 1999).
- **February 2000.** The governor of South Dakota requested that EPA propose the site for the Superfund NPL listing and provide emergency response, as well as long-term remedial cleanup.
- **May 2000.** Site proposed for NPL listing.
- **July 2000.** Robertson GeoConsultants, Inc. (RGC) conducted a reconnaissance of the site, which included geochemical characterization of surficial materials.
- **December 2000.** Site placed on NPL.

1.4.3 Emergency Responses

Both the State of South Dakota and EPA have had to conduct Emergency Response activities at the site in order to prevent or mitigate imminent environmental threats.

1.4.3.1 State of South Dakota Emergency Response

After BMC declared bankruptcy and abandoned the mine, the state immediately assumed site maintenance and water treatment activities using the South Dakota Regulated Substance Response Fund. The primary requirements were retaining critical staff to operate and maintain ARD collection, conveyance, and treatment systems; procuring reagents necessary for operation of the water treatment systems; and purchasing electrical power to run the ARD collection, conveyance, and treatment systems.

At that time, there was an imminent danger of an uncontrolled release of ARD into Strawberry Creek and Ruby Gulch. The volume of stored ARD in Sunday Pit was 81 million gallons in September 1999 (only 13 million gallons below maximum capacity), and the site was generating ARD at a rate of approximately 3.3 million gallons per inch of precipitation (CDM Federal Programs Corporation [CDM] 2007a). The capacity of the ARD collection pond at the toe of the Ruby Gulch waste rock dump was 1.4 million gallons, which was sufficient to prevent a direct discharge from the waste rock dump into Ruby Gulch for less than 2 weeks in the event that the water was not pumped into storage at Sunday Pit. Cessation of active collection of ARD from numerous sources at the mine *or* cessation of active water treatment would have lead to direct discharges of ARD into Strawberry Creek or Ruby Gulch, both tributaries of Bear Butte Creek.

1.4.3.2 EPA Response

In early 2000, EPA initiated emergency response activities and assumed primary responsibility for ARD collection, conveyance, and treatment, as well as general site operation and maintenance. This work was conducted by EPA's Region 8 Emergency Response Team. An Early Action Interim ROD was completed in 2001, which transferred responsibilities for ARD collection, conveyance, and treatment as well as general site operations and maintenance from the Region 8 Emergency Response Team to the Superfund Remedial Program.

A ROD for OU3 was completed in 2001 to address acid generation at Ruby Gulch waste rock dump (Section 1.4.4). In early 2002, EPA completed a second Early Action ROD addressing OU2 site-wide water treatment. Since 2000, EPA has conducted numerous investigations and treatability studies in order to provide sufficient information to select appropriate remedial alternatives. These investigations are described in later sections within this report.

1.4.4 Remedial Actions at OU2 and OU3

Since Gilt Edge became a Superfund site, EPA and DENR have entered into three interim RODs for the site, which are protective of human health and environment in the short term and were intended to provide protection until final actions are completed. These interim remedial actions are summarized below.

1.4.4.1 OU2, Water Treatment, Early Action Interim ROD, April 2001

This early action interim remedial action had four main objectives:

- Maintain site control and operational infrastructures
- Collect and treat ARD in the existing water treatment plant
- Upgrade the water treatment plant with a ferric iron addition to increase precipitation and co-precipitation of metals in the sodium hydroxide sludge

- Implement an optimized onsite sludge management using onsite storage basins or sludge filtering equipment

Needed repairs to the administrative building were also performed. The ROD was signed by Max H. Dodson, EPA assistant regional administrator, and Tim Tollefsrud, DENR director, Division of Environmental Services, on April 23, 2001 and April 5, 2001, respectively.

1.4.4.2 OU2, Water Treatment, Interim ROD, November 2001

The primary requirements of the interim remedial action under this Interim ROD are:

- Collection and diversion of ARD seep flows for treatment
- Conversion of the existing sodium hydroxide water treatment plant to a less costly lime-based or metals-coordination treatment/filtration system

The results of the interim action were:

- Reduced migration of metal contaminants and acid water to Strawberry Creek from Hoodoo Gulch and Pond C
- Reduced metals-contamination concentrations in surface water discharge to Strawberry Creek
- Increased net amount of ARD treatment through the current water treatment plant system to 250 gpm, thereby, reducing the threat of contaminant release to downgradient water consumers
- Reduced operating costs of the water treatment system

Under this interim action, a collection and conveyance system to transport ARD flows in Hoodoo Gulch and the ponds to the water treatment plant was constructed. The existing sodium hydroxide water treatment plant was converted to a lime-based neutralization/precipitation process, which was selected following pilot testing on site.

As recognized in the ROD, the ability of the water treatment plant to meet total dissolved solids (TDS) and selenium water quality standards is uncertain. Because of the uncertainty, EPA waived these standards for the short term with the understanding that they will be part of the final site remedial objectives. The ROD was signed by Max H. Dodson, EPA assistant regional administrator, and Tim Tollefsrud, DENR director, Division of Environmental Services, on November 30, 2001.

1.4.4.3 OU3, Ruby Gulch Waste Rock Dump, Interim ROD, August 2001

This interim remedial action addressed contamination associated with the largest ARD source on the site, the Ruby Gulch waste rock dump, by:

- Reducing the volume of contaminated materials exposed at OU3
- Reducing infiltration that produces large quantities of ARD
- Containing the materials of the Ruby Gulch waste rock dump

The remedy selected by EPA and DENR for this interim remedial action was:

- Regrading of waste rock, including placement in the upper Ruby Gulch drainage
- Construction of a composite cap using a geomembrane liner
- Installation of lateral drainage structures to limit erosion and convey runoff
- Construction of a protective layer for the liner and surface water controls using materials consisting of the Highway 385 project rock and growth materials from onsite sources
- Construction of surface water run-on diversion channels

The results of the interim action were:

- Controlled erosion of mine waste into local water courses
- Controlled formation of ARD and leaching and migration of contaminants from mine waste into surface water
- Controlled formation of ARD and leaching and migration of contaminants from mine waste into local groundwater
- Significantly reduced quantity of ARD requiring containment and treatment
- Reduced threat of release to downgradient water users

This ROD was signed by Max H. Dodson, EPA assistant regional administrator, and Tim Tollefsrud, DENR director, Division of Environmental Services, on August 30, 2001 and August 9, 2001, respectively.

Since OU2 and OU3 remedial actions resulted in hazardous substances remaining on site above the health-based levels, a review will be conducted to ensure that the remedy continues to provide protection of human health and the environment within 5 years after commencement of the remedial action. As stated in the First Five-Year Review Report for Gilt Edge Superfund Site Operable Unit 2 and 3 (EPA 2007a), the purpose of the 5-year review is to determine whether the site remedy is protective of human health and the environment. The trigger action for this review is the August 2001 OU3 ROD. Because hazardous substances, pollutants, or contaminants remain at the site above levels that allow for unrestricted use and unlimited exposure, a 5-year review is required by statute. The 5-year review report is included in Appendix A.

Section 2
Data Collection, Evaluation, and Usability

This section discusses the sources for the data used in the RI, how they were collected, how they were evaluated for quality, and whether or not they are useable for the purposes of the RI and FS. The RI objectives were to determine the nature and extent of contamination at the site, determine the impact to surface water, groundwater, and sediment, and evaluate risk to human health and the environment.

Where possible, the RI made use of field investigations and studies already performed by others, including BMC, DENR, and federal agencies. This maximized the use of historic data and minimized the need to collect new data. The term "recent data" applies only to data collected by CDM under the EPA Response Action Contact (RAC). All evaluations of data quality and usability were conducted using EPA protocols.

This section includes the following topics by media of concern:

- Data quality objectives (DQOs) (Section 2.1)
- Quality assurance/quality control summary (Section 2.2)
- Data usability evaluation (Section 2.3)
- Data source (historical data, Superfund Technical Assessment and Response Team 2 (START2) data, RAC data, EPA treatability and pilot studies) (Section 2.4)
- Laboratory methods and analysis (Section 2.5)

The key points for each of these topics are:

<u>Data Quality Objectives</u>

- DQOs were established for all of CDM's investigations and some of the other investigations after site historical data were screened for usability and data gaps were identified.
- Their purpose was to determine 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.
- They were developed for site fills and soils, Heap Leach Pad, groundwater, surface water, groundwater-surface water interactions, tailings, sediment and stream bank material, sludges, and Merrill-Crowe and process plant equipment.

Quality Assurance/Quality Control (QA/QC) Evaluation

- The precision and representativeness in the field processes and the laboratory analytical process were evaluated to ensure the data used were of high quality and useable for the RI.

- Generally, sample duplicates were collected at a frequency of 10 percent of total samples by medium and analyses, and equipment rinsates were submitted at a frequency of 20 percent.

- For some data, the validation/evaluation procedure was modified to include additional information about the primary qualifier (National Functional Guidelines [NFG]) that can be used to determine applicability of data to specific study objectives.

Data Usability Evaluation

- All data were evaluated for the RI and FS to determine whether data were acceptable for all purposes, selected purposes, or were unusable.

- Most data were determined to be usable for its intended purpose.

Data Sources

- Data sources include historic analytical data collected by the agencies and consultants for BMC, analytical data collected for the RI by EPA's contractor, and analytical and non-analytical data collected tangential to the RI by other entities that are useful to the RI.

- A description of the DQOs, QA/QC evaluations performed, and data usability is provided.

Laboratory Analysis

- Evaluation of ARD involves the use of specialized analytical methods (total analysis, paste pH, extraction tests, acid base accounting, and inorganic carbon testing).

- Specifics of and modifications to this testing are provided herein.

2.1 Data Quality Objectives

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 2000b)

DQOs were developed in accordance with EPA's seven step DQO process after the historical data for the site were screened for usability and the data gaps identified. As a result, specific DQOs were developed for the following previously identified media:

- Site fills
- Heap Leach Pad
- Groundwater
- Surface water
- Groundwater-surface water interactions
- Tailings, sediment, and stream bank material
- Sludges
- Merrill-Crowe and process plant equipment

Although each investigation had a media-specific DQO(s), all DQOs work toward the goal of understanding the characteristics of the media and the impact to the area of investigation. DQOs for each investigation can be found in the sampling and analysis plan (SAP) that was used to direct the investigation.

Investigations and studies not directly related to nature and extent of contamination have also been performed at the site. For example, plant growth trials of potassium permanganate treated waste rock were performed. Although this study furthered scientific understanding of the remedial technology, the direct application to the nature and extent of contamination at the site is limited and is not discussed in detail in this report.

2.2 Quality Assurance/Quality Control Summary

During the RI, QA/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 rinsates consisted of the final rinse water (deionized water) after it had been in contact with a sampling tool and were also submitted at a frequency of 20 percent of the total samples collected by medium and analyses. Quality control (QC) samples (i.e., duplicates and equipment rinse blanks) collected and analyzed are summarized in Table 2.3-1. A summary of rejected and estimated data for each investigation is provided in Table 2.3-2.

All field measurement equipment were calibrated daily prior to use. An equipment calibration log or other documentation was kept for each piece of equipment requiring calibration. If the equipment or instruments could not be properly calibrated, that specific piece of equipment was not used.

Laboratory data were validated at a frequency of 10 percent. EPA's Contract Laboratory Program National Functional Guidelines for Inorganic Data Review (EPA 1994a) were used for data evaluation and validation. For validation, all items presented in the guidelines were reviewed, if available in the data packages.

For evaluation of data, the following were reviewed (where applicable):

- Matrix spike/ matrix spike duplicate (MS/MSD) relative percent differences (RPDs)
- Laboratory control sample/ laboratory control sample duplicate (LCS/LCSD) RPDs
- Laboratory duplicate RPDs
- MS/MSD percent recoveries (%Rs)
- LCS/LCSD %Rs
- Holding times
- Preservation
- Laboratory preparation blanks

For some data, the data validation/evaluation procedure was modified to include additional information about the primary qualifier (i.e., NFG qualifier) that can be used by the data user to determine the applicability of data to their specific study objective. The data were assigned the primary data qualifier per NFG protocol, then a secondary data qualifier was assigned to the data which either identified the reason for the primary data qualifier and/or specified potential bias (i.e., a high or low designation). This bias qualifier reflected whether the data may be either above or below the true concentration.

The following primary qualifiers (defined below) were used:

U The material was analyzed for, but was not detected above, the level of the associated value.

J The associated value is an estimated quantity.

R Result is unusable. (Note: Analyte may or may not be present)

UJ The material was analyzed for but was not detected. The associated value is an estimate and may be inaccurate or imprecise.

The following secondary qualifiers to identify qualification reasons (defined below) were used:

H Result was qualified due to a holding time exceedance.

I Result was qualified due to an unacceptable initial calibration verification (ICV) %R.

C Result was qualified due to an unacceptable continuing calibration verification (CCV) %R.

M Result was qualified due to an unacceptable MS and/or MSD%R.

S Result was qualified due to an unacceptable interference check standard (ICS) %R.

L Result was qualified due to an unacceptable LCS%R.

G Result was qualified due to an unacceptable post-digestion spike %R.

The following bias qualifiers (defined below) were used:

^ High bias. Actual concentration may be lower than the concentration reported.

v Low bias. Actual concentration may be higher than the concentration reported.

Note: Bias qualification was addressed for all data that are qualified with a J, UJ, or R. There are situations when the bias cannot be determined (e.g., one unacceptable %R is above criteria and another below). In these instances, no bias qualifier was assigned.

A DVD containing the site database, including sample results, qualifiers, and bias, is provided in Appendix B. It contains the following investigations that pertain to the RI. Data from EPA treatability studies and internal studies have not been included.

Investigation Nomenclature used in Database (nomenclature shown as capitalized text)

BANK MATERIAL STUDY
COMPLIANCE MONITORING
CYANIDE NEUTRALIZATION SLUDGE
DRUM AND BAG
ERT/REAC SEP 2000
GROUNDWATER STUDY
HEAP LEACH PAD
HHRA SUPPORT
HISTORIC DATA
MERRILL-CROWE
O&M
PM DEDYCKER & ASSOC
RGC GEOCHEMICAL FIELD RECON SURVEY 2000
SEDIMENT STUDY
SITE WIDE FILL MATERIAL
SITE WIDE SLUDGE
SITE WIDE SLUDGE STUDY
SITE WIDE VEGETATION

STRAWBERRY CREEK TAILINGS
SURFACE WATER STUDY

These investigations are described in detail in the following sections.

2.3 Data Usability Evaluation

Historical and recently collected data were evaluated to determine their usability for the RI and FS. To maximize the use of historic data, data adequacy was evaluated along with the QA/QC. For example, the BMC data were used to identify chemical trends over time, and an individual measurement may be suspect because the collection method, custody chain, or analytical QA/QC documentation can not be recreated. However, the data can be used to support general trends and impacts of changing site conditions over time and are presented as part of this RI. This approach was approved by the EPA remedial project manager (RPM), and the usability of the data is described herein. The results of the usability evaluation are presented in Section 2.5.

2.4 Data Sources and Their Evaluation

Relevant information about the sources of data used in the RI is summarized below and in Table 2.5-1. This includes name of investigation, organization responsible for investigation, date, the applicable SAP, database identification, and usability.

2.4.1 Historical Data from Previous Investigations

Two important data sets were loaded into the Gilt Edge database and used in this RI. They are (database nomenclature shown as capitalized text):

- HISTORIC DATA
- PM DEDYCKER & ASSOC

These data sets are discussed in the following sections.

2.4.1.1 HISTORIC DATA

The HISTORIC DATA are data from the mine site as compiled by the State of South Dakota. This set represents environmental samples collected during mine permitting and/or mining operations.

In September 1993, EPA issued an NPDES surface water discharge permit to BMC (Permit number: SD-0026891) to become effective November 1, 1993. Two NPDES compliance points were designated, including one in Strawberry Creek (CP001) and one in Ruby Gulch (CP002), an intermittent tributary to Bear Butte Creek. In 1996, NPDES compliance point 002 was replaced by downstream compliance point CP003 due to construction of the Ruby Repository and Ruby Pond located within Ruby Gulch.

When using this data, it should be noted that water quality exceedances may not coincide with the official South Dakota record. Discrepancies between the data reported here and the South Dakota official compliance record may be explained for the following reasons:

- There are multiple sampling events within the database that were not required by permit but were collected to better understand the geochemical condition of the site by BMC.
- The database also includes information collected to optimize site operations (e.g., the mine collected additional water quality data following an upset of the water treatment plant to assure permit compliance).
- Multiple samples and duplicates were not removed from the database.
- There may be missing data from the database.

The data are presented in the RI to illustrate the impact of mining activities and subsequent remedial efforts on area surface waters and to substantiate the need to treat the surface waters using water treatment technologies. No additional evaluation or validation of the data was performed by CDM.

2.4.1.2 PM DEDYCKER & ASSOC

The PM DEDYCKER & ASSOC are data from the Strawberry Creek Loading Evaluation Report performed by P.M. De Dycker & Associates, Inc. and Water, Waste & Land, Inc. The field investigation was conducted on May 18 and August 24, 1993. The study commissioned by BMC evaluated the magnitude of metal concentrations and loads in Strawberry Creek to identify and quantify point and non-point sources of metal loading and to identify reaches in the creek where loads are gained or lost.

Data for the Strawberry Creek load evaluation are used in the RI as a baseline for metal concentrations present in the creek. No additional evaluation or validation of the data was performed by CDM.

2.4.2 EPA Superfund Technical Assessment and Response Team 2 (START2) Data

Under EPA START2, URS Operating Services, Inc. completed the site activities report (SAR). UOS also subcontracted with RGC to perform a rock geochemical analysis at the site.

2.4.2.1 URS Operating Services, Inc.

Tasks managed or performed by UOS under the START2 included:

- General site discovery surveys
- Several water sampling events

- Aerial photography of the site
- Monitoring well drilling and installation
- Site-wide rock geochemical sampling (discussed in next section)
- Land surveying

Surface and groundwater samples were collected from May 30 through June 28, 2000 and from September 19 through 22, 2000. Specifics with respect to this investigation can be found in the field sampling plan (CDM 2000a) and the quality assurance project plan (QAPP) (CDM 2000b). The results of this investigation are compiled in the August 17, 2001 SAR. The data were used in the RI to assist in the determination of nature and extent of contamination. Data collected were subject to the START2 QA/QC procedures. No additional evaluation or validation of the data was performed. These data are presented in the database as ERT/REAC SEP 2000.

2.4.2.2 Robertson GeoConsultants, Inc.

RGC performed a rock geochemical analysis of each reclamation unit. The study evaluated the geochemical characteristics and the "evolutionary states" of the rock present at the site. Field sampling was performed from July 10 to 21, 2000 and included the collection of 620 samples analyzed for field paste pH and TDS. A percentage (126 of 620 samples) were subject to analysis in the laboratory for rinse pH, conductivity, modified acid base accounting (ABA), inorganic carbon, leach extraction, forward acid titration, multi-element inductively coupled plasma (ICP), and net acid generation (NAG) tests. These data are used in the RI to assist in the determination of nature and extent of contamination at the site. The data were subject to the START2 QA/QC procedures, and no additional evaluation or validation of the data was performed. The data are presented in the database as RGC GEOCHEMICAL FIELD RECON SURVEY 2000.

2.4.3 EPA RAC Data – CDM Investigations

On behalf of EPA, CDM conducted several investigations of multiple mine waste units. A summary of each investigation is described below and includes the study objective, when the investigation was performed, number and type of analysis performed, deviations from the SAP, quality control summary, assessment of DQOs, and database nomenclature.

2.4.3.1 Fill Material Sampling – Fall 2001

As stated in the SAP (CDM 2001a), the objective of this investigation was to collect the data necessary to characterize 15 zones of fill material throughout the site in order to determine the remedial alternative. The investigation was conducted August 12 through 19, 2001. Samples were analyzed for paste pH, paste TDS, ABA, standard 20:1 synthetic precipitation leaching procedure (SPLP) (EPA Method 1312), and meteoric water mobility procedure (MWMP).

Deviations from the SAP were due to constraints encountered in the field, specifically:

- No samples were collected from the Strawberry Creek Road/Tailings fill material as telephone lines buried under the road could not be located prior to fieldwork.
- Only one sample was collected from the Hoodoo Fill because no substantial amount of fill material could be identified in this area (this location had less than 4 feet (ft) of fill above native material).
- Subsamples collected in each test pit were not always collected at a distance of 4 vertical ft apart, primarily because some pits were less than 12 ft deep, but five sub-samples were always collected at vertical intervals appropriate for the total depth of the test pit.
- The toxicity characteristic leaching procedure (TCLP) was not completed; rather, an aliquot of each composite sample was sent to a laboratory for completion of the MWMP leaching test.
- For each test pit completed, a composite of the upper 2 inches of the material was created by collecting five grab samples in the vicinity of the test pit, and the composite was archived for possible future analyses, specifically for addressing risk assessment.

The QC activities completed during this investigation included the collection of field duplicates, MS/MSDs, calibration of field instruments, and decontamination of equipment used. A total of 3 field duplicates were collected and 2 MS/MSDs were submitted for a total of 28 samples. The field instruments were calibrated on a daily basis, and the calibration was checked at the end of each day of use. The decontamination procedures required by the SAP were adhered to throughout the investigation. All QC activities for this investigation were in accordance with the SAP. All data were evaluated and determined usable, except for the weak acid dissociable (WAD) cyanide, bicarbonate, and carbonate results from the MWMP leachate.

The principal study question as stated in the SAP was "What are the physical and chemical characteristics of the 15 fill material zones?" This DQO was achieved. The physical and chemical characteristics of interest (except for WAD cyanide, bicarbonate, and carbonate within a MWMP leachate) are known. These data are presented in the database as SITE WIDE FILL MATERIAL.

2.4.3.2 Subsurface Soils Investigation to Support Human Health Risk Assessment (HHRA)

The objective of this investigation was to prepare fill material samples previously collected by sieving the samples to particles less than or equal to 250 microns (µm) and submit for total metals analysis to provide data for the HHRA. These data provided metal/metalloid concentrations of the ingestible portion of the surface soil (i.e., less than 250 µm) with respect to the screening levels for the preliminary review during the HHRA. This work was performed in accordance with the SAP (CDM 2002a).

The collection of the fill material samples occurred in August 2001. Preparation and analysis of HHRA samples occurred in March 2002. Thirty-one composite surface soil samples and seven grab surface soil samples were collected and were archived at CDM's Denver laboratory under chain-of-custody protocol. The 38 upper 2-inch surface soil samples were removed from the CDM laboratory archive for total metals analysis. Each surface soil sample was prepared by sieving the sample to particles less than or equal to 250 µm and submitted for total metals analysis.

There were no deviations from the surface soil investigation to support the HHRA SAP. The QC activities completed during the HHRA investigation included field duplicates, MS/MSDs, calibration of field instruments, and decontamination of equipment used. During the surface soil investigation to support the HHRA, 4 duplicates were collected and 3 MS/MSDs were submitted for a total of 45 samples analyzed during the investigation. The decontamination procedures described in each SAP were adhered to throughout the investigations. Two equipment rinsate blanks were collected from decontaminated equipment during the investigation. All QC activities for this investigation were in accordance with their respective SAP. All data were evaluated and determined usable except mercury and cyanide.

The principal study question as stated in the SAP (CDM 2002a) was "Are the concentrations of metals/metalloids in the less than or equal to 250 µm portion of the surface soil samples known either as non-detected results at or below the screening levels or as positive results?" This DQO established for the surface soil investigation to support the HHRA was achieved. Total metals concentration of the sampled material is believed to be known except for mercury and cyanide. These data are presented in the database as HHRA SUPPORT.

2.4.3.3 Heap Leach Pad Investigation

The objectives of this investigation were to:

- Investigate spent ore located on the HLP in more detail than the initial RGC reconnaissance, including collection of sub-surface samples
- Assess variability of spent ore geochemical characteristics, as well as the potential to release potential contaminants of concern (PCOCs) both immediately and in the future
- Assess potential suitability of spent ore to be used as cover material for waste rock repositories as fill or as construction materials

Specifics with respect to this investigation are detailed in the SAP (CDM 2001b).

CDM conducted a field investigation of the HLP from March 6 to March 13, 2001. Field measurements performed by CDM on all samples collected included paste pH and paste conductivity. Analytical tests performed on the samples collected during the field investigation were total metals analyses, total cyanide, and ABA. Additional analyses were planned for a subset of samples that would be representative of

lithogeochemical sub-units within the overall spent ore pile. The additional analyses were not completed and represent a deviation from the SAP. Additional analyses planned in the SAP consisted of SPLP tests, sequential extraction/microprobe analyses, MWMP tests, humidity cell tests, saturated column tests, and nine tests to evaluate the suitability of the spent ore for use as a plant growth medium.

Per direction from EPA, these additional analyses were not completed for the following reasons.

- HLP spent ore was included in a site-wide saturated column test program initiated in 2001 to evaluate potential deposition of various fill materials in saturated pit backfills obviating the need for saturated column tests of HLP spent ore.

- Although the potential for HLP spent ore to be used as a plant growth medium during reclamation was considered as an initial objective, RGC and CDM investigations identified soluble contaminants, and Syracuse Research Corporation (SRC) (EPA 2006a) identified human health risk associated with surface exposure as a result of direct ingestion/inhalation hazards. This precluded consideration of spent ore as a vegetative growth medium, and the planned soil characteristic analyses were not done.

- Sequential extraction/microprobe analyses and humidity cell tests were not determined to be necessary to understand geochemical characteristics of HLP spent ore for the purposes of this study. Humidity cell tests are primarily used for pre-mining geochemical analyses to estimate future geochemical conditions. In this study, paste pH and ABA data were determined to be adequate to evaluate current and future acid potential of the HLP spent ore.

- MWMP and SPLP tests are similar methods to estimate the potential for spent ore to leach contaminants in response to infiltrating precipitation. Based on previous SPLP data, coupled with paste pH and total metals data, the additional MWMP and SPLP analyses were not considered necessary to meet the objectives of this investigation.

The QC activities completed during this investigation included the collection of field duplicates, MS/MSDs, calibration of field instruments, and decontamination of equipment used. A total of 7 field duplicates were collected and 7 MS/MSDs were submitted for a total of 140 samples. The field instruments were calibrated on a daily basis, and the calibration was checked at the end of each day of use. The decontamination procedures required by the SAP were adhered to throughout the investigation. All QC activities for this investigation were in accordance with the SAP. All data were evaluated and determined usable except total selenium and total mercury in the HLP spent ore.

The principal study questions as stated in the SAP are:

(1) How spatially variable is the material within the HLP with respect to geochemical and soil characteristics?

(2) Is the HLP material suitable for sustaining vegetative growth, either with or without amendment?

(3) What is the potential of the HLP material to release only target analyte list (TAL) metals—as well as acid—both immediately and in the future; also, is the potential for release dependent on the physical conditions of the final placement of the HLP material?

All DQOs established for the HLP investigation were achieved. Total metals concentrations of the sampled material are known except for total selenium and total mercury. These data are presented in the database as HEAP LEACH PAD.

2.4.3.4 Soil and Vegetation Investigation

The objective of the soil and vegetation investigation was to characterize the physical and chemical properties of the 11 stockpiled soil sources to determine if these soil sources are capable of initiating and/or sustaining long-term vegetation at selected areas throughout the site. Specifics with respect to this investigation are detailed in the SAP (CDM 2001c).

The sampling was conducted from October 10 through 13, 2001, and 38 soil samples were collected from the stockpiles. Samples were analyzed for total metals, SPLP, electrical conductivity, cation exchange capacity, plant available nutrients, sodium adsorption ratio, ABA, organic matter, and texture. Field measurements included paste pH and field measurement of percent coarse fragments.

The deviations from the SAP include the following:

- It was stated that sample containers would consist of five 8-ounce (oz) jars and one 18-oz Whirl Pak bag, or equivalent. After reviewing the sample container requirements for the unique laboratory service analysis (ULSA) samples, sample containers were changed to consist of one 8-oz jar, one 4-oz jar, and two 18-oz Whirl Pak bags, or equivalent. This change was necessary to conserve space and to reduce costs associated with shipping and purchasing sample containers.

- It was stated that samples would be shipped to the Contract Laboratory Program (CLP) and ULSA laboratories from the site. Because actual sampling procedures took longer than expected, samples were brought back to the CDM field support facility for preparation and shipping to reduce costs associated with travel.

- It was stated that percent coarse fragments would be determined in the field during sampling. The soil samples contained too much moisture to be effectively sieved. Therefore, the soil samples were brought back to the CDM field support facility for drying and sieving.

The QC activities completed during this investigation included field duplicates and MS/MSDs. A total of 6 field duplicates and 3 MS/MSDs were submitted for a total of 47 soil samples. All QC activities for this investigation were in accordance with the SAP.

All data were evaluated and determined usable. All soil sample results met the QC guidelines as stated in the SAP. No analytical results were rejected and, therefore, all results are usable for their intended purpose.

The principal study questions as stated in the SAP are to determine:

(1) Can soil stockpiles meet the acceptable criteria and thus be used as suitable plant growth media for revegetation efforts at the Ruby Gulch waste rock dump?

(2) Can the soil cover materials meet the acceptable criteria and, therefore, can be used for sustaining long-term vegetation at the current location or initiating vegetation, if needed, at other locations at the site?

These two DQOs were met using the analytical results of samples collected during the sampling event in October 2001. The data are presented in the database as SITE WIDE VEGETATION.

2.4.3.5 Supplemental Feasibility Study Investigation

The specific objective of the supplemental FS investigation was to perform investigations (including collection and analysis of samples along with visual inspections) to provide physical and chemical data necessary to support evaluation of the potential use of source materials such as site fills and stockpiled soil for construction materials during the OU-1 remedial action. Specifics with respect to this investigation can be found in the SAP (CDM 2007b).

Areas of the site investigated include some of the same areas already characterized during the aforementioned investigations (fill material, subsurface soils, HLP, and soil and vegetation). The chemical data (paste pH and ABA) obtained are useful for further describing the nature and extent of contamination in site fills and soil stockpile materials; thus, these data are included in the RI.

Sampling was conducted From April 2 through April 10, 2007. Field measurements and observations performed by CDM on most of the samples collected include paste pH, Unified Soil Classification System (USCS) logging, and visual determination of the percentage of 6-inch material and larger to the remaining soil by volume. Analytical tests performed include both chemical and physical methods. The only chemical method analyzed was ABA while physical analyses include laboratory USCS logging, bulk density, grain size distribution, moisture content, saturated hydraulic conductivity, standard proctor, and soil water characteristic curve. A total of 37 samples were analyzed in the field for paste pH. A subset of 15 of these samples was analyzed for ABA and a subset of 18 samples was analyzed for geotechnical characteristics.

The deviations from the SAP include the following:

- The SAP stated that separate samples would be collected from the excavator bucket using disposable scoops or trowels and placed in the appropriate containers for either onsite lab analysis or offsite shipping to the analytical laboratories. The following sampling procedure describes the deviations from the SAP procedure:

    - *Sample material for each location/depth was dumped from the excavator bucket onto plastic sheeting for USCS analysis and visual gradation. After removing greater than 6 inch cobbles from the sample pile, composite samples were collected with a shovel and placed in a set of three 5-gallon buckets. The shovel was decontaminated between each sample loading. Onsite lab analysis (paste pH) was conducted by taking a small grab sample of finer material from one of the three buckets. If a particular sample (e.g. depth 01, 02, or 03) was selected for laboratory analysis (based on paste pH), the same bucket was later split using a sample splitter, which was decontaminated between splits. A portion of the split was placed in a whirl-pak bag for shipment for ABA analysis and the remainder was retained in the bucket and shipped for bulk density analysis. The remaining two buckets were retained until ABA results were received. Based on these results, the appropriate amount of lime was added to each bucket using a weight-to-weight basis. The two buckets for each sample were then submitted to the geotechnical laboratory for further analyses.*

- The SAP indicated to collect separate samples for paste pH in 8 oz glass jars. Paste pH was analyzed in the field for each location and depth by collecting a small sample of finer material from the larger sample using a disposable trowel. The sample was then placed in a disposable plastic cup for paste pH analysis.

- Paste pH measurements were not conducted using the modified Sobek method. Rather, CDM used a similar method as demonstrated by RGC and CDM during other investigations. This method consisted of adding a small amount of fine sample material to a disposable plastic cup, followed by addition of a near equivalent amount of store-bought distilled water. The mixture was stirred briefly and the paste was analyzed using a portable pH meter. Paste pH for a majority of the samples was measured twice. Field paste pH measurements were first conducted at the pit or trench site using approximate proportions (e.g. visual estimation) of sample to distilled water. Repeat paste pH measurements were conducted at the site laboratory using measured amounts of sample (25 grams) and distilled water (20 milliliters [ml] or 25 ml). The 20 ml volume was used for a majority of the samples due to the high moisture content present. All containers/stirrers were one-time use and were disposed after each measurement. The paste pH meter was decontaminated between each sample measurement.

- Additional paste pH measurements were sometimes conducted at additional depths than specified in the SAP for the purposes of better understanding the lithology of each pit or trench.

- Actual locations of some of the excavated test pits and trenches were modified from the specified locations in the SAP based on actual field conditions and accessibility.

- Shallow subsurface soil samples (0 ft to 2 ft below ground surface [bgs]) were not collected with the use of hand tool or auger as specified in the SAP. Rather, these samples were collected with the use of the excavator.

- The SAP specified that three samples were required to characterize a pit. The middle-depth sample of pit 16 was not collected due to unsafe conditions near the pit. The final-depth sample of pit 13 was not collected due to reaching the alluvial groundwater table of upper Strawberry Creek. Only two samples were used to characterize each of these pits.

The QC activities completed during this investigation included collection of field duplicates, calibration of field instruments, and decontamination of equipment used. Field duplicate samples were collected at a rate of 10 percent of samples analyzed for ABA and paste pH. No duplicate samples were submitted for physical analyses, per the SAP. The field pH meter used for paste pH measurements was calibrated on a daily basis. Decontamination of all non-dedicated equipment (shovel, pH meter, excavator bucket, etc.) was performed in accordance with the SAP. All ABA was evaluated and determined usable.

The principal study questions as stated in the SAP are:

(1) Are geotechnical characteristics of the HLP spent oxide ore appropriate for construction of the capillary break layer for an evapotranspiration (ET) cover?

(2) Are geotechnical characteristics of the HLP spent oxide ore of sufficient quality to evaluate the required thickness of the capillary break layer for an ET cover?

(3) Do topsoil and subsoil resources require lime-amendment for cover construction?

(4) Do required lime-amended topsoil and subsoil resources have the appropriate geotechnical and chemical characteristics for cover construction?

(5) Are geotechnical characteristics of the topsoil and subsoil resources of sufficient quality to evaluate the required thickness of topsoil and subsoil layers of the covers?

(6) Are topsoil and subsoil resources of sufficient volume and homogeneity to construct covers?

Geochemical data from this investigation are evaluated in this RI report and presented in the database as SUPPLEMENTAL FEASIBILITY STUDY.

2.4.3.6 Site-Wide Sludge Investigation

The overall objective of the site-wide sludge sampling was to characterize the sludge present at the site and utilize these results to determine appropriate disposal/ treatment options, if necessary. The specific objectives for each of the six major sludge sampling events are defined as follows:

Sunday Pit, Dakota Maid Pit, Pond C, and Hoodoo Gulch Ponds 1 and 2

- Collect data on sludge thickness in the Sunday Pit and Dakota Maid Pit to calculate volume quantities for remedial design of removal activities, as stated in the SAP (CDM 2001d).

- Collect and analyze sludge samples to evaluate the waste characteristics of the sludge in the Sunday Pit, Dakota Maid Pit, Pond C, and Hoodoo Gulch ponds 1 and 2, as stated in the SAP (CDM 2001d).

- Understand the reactive interaction between Sunday Pit and Dakota Maid Pit sludges and ARD present at the site and determine if the sludge is a source of secondary contaminants (e.g. metals, sulfate, TDS, etc.) when in contact with ARD (CDM 2007c).

Surge Pond (Process Plant Pond)

- Collect data on sludge thickness in the Surge Pond to calculate volume quantities for remedial design of removal activities, as stated in the SAP addendum (CDM 2004a).

- Collect and analyze a composite sludge sample from the Surge Pond in order to evaluate its waste characteristics (CDM 2004a).

Cyanide Neutralization Sludge

- Collect and analyze sludge samples in order to evaluate the waste characteristics of the sludge at the HLP and the Ruby earthen pond, as stated in the SAP (CDM 2001e).

Anchor Hill Pit

- Establish the sediment (sludge) composition of the Anchor Hill Pit prior to and after the implementation of the Sheperd-Miller Inc. (SM) Neutra-Mill technology and Green World Science Inc. (GWS) redox-mediated biotransformations (RMB) remediation process (MSE Technology Applications, Inc. [MSE] 2001).

- Collect and analyze sludge samples to evaluate the waste characteristics of the sludge in Anchor Hill Pit (CDM 2007c).

- Collect data on sludge thickness in the Anchor Hill Pit to calculate volume quantities for remedial design of removal alternatives (CDM 2007c).

- Understand the reactive interaction between Anchor Hill Pit sludge and ARD present at the site and determine if the sludge is a source of secondary

contaminants (e.g. metals, sulfate, TDS, etc.) when in contact with ARD (CDM 2007c).

Ruby Pond

- Collect and analyze a sludge sample from the Ruby Pond in order to evaluate its waste characteristics.

Stormwater Pond

- Collect and analyze sludge samples from the Stormwater Pond in order to evaluate its waste characteristics (CDM 2007c).

- Understand the reactive interaction between Stormwater Pond sludge and ARD present at the site and determine if the sludge is a source of secondary contaminants (e.g. metals, sulfate, TDS, etc.) when in contact with ARD (CDM 2007c).

All fieldwork was performed in accordance with the appropriate SAPs. Specific analysis performed for all of the sludge samples collected includes the following:

- Total TAL concentrations (i.e., arsenic, aluminum, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, selenium, silver, and zinc)

- Total cyanide (CN)

- TAL concentrations using SPLP

Additional analyses completed for specific ponds and pit lakes are: Sunday Pit, Dakota Maid Pit, Pond C, Hoodoo Gulch ponds 1 and 2, and Stormwater Pond - TAL concentrations using TCLP, the paint filter liquids test, and ABA; Surge Pond - total TAL using TCLP, paint filter liquids test, total gold, WAD CN, and ABA; Anchor Hill Pit - total TAL using TCLP and ABA; and Ruby Pond – ABA; Sunday Pit, Dakota Maid Pit, Anchor Hill Pit, and Stormwater Pond – strong acid leach test (SALT).

Each of the six sludge sampling events are further described below, each with discussions of when the investigation was performed, number of samples collected, deviations from the SAP, quality control summary, assessment of DQOs, and database nomenclature.

Sunday Pit, Dakota Maid Pit, Pond C, and Hoodoo Gulch Ponds 1 and 2 Sludge Sampling

Sunday Pit sludge depths were measured in August and September, 2001 while Dakota Maid sludge depths were measured in March 2007. In September and October of 2001, the following sludge samples were collected: six samples from Sunday Pit, three samples from Dakota Maid Pit, one sample from Pond C, and one sample each from Hoodoo Gulch ponds 1 and 2. Three additional sludge samples each were collected from the Sunday and Dakota Maid pits in March 2007, specifically for analyzing the sludge using the SALT procedure.

Deviations from the SAP include the following:

- Sixteen sludge depths were to be collected from Sunday Pit Lake. Due to the difficult conditions of sample collection, only 13 samples were collected.

- Three composite samples were to be collected for the sludge at Dakota Maid Pit Lake. Due to the unsuccessful collection attempts from the bed of the pond, sludge samples were collected from areas other than the deepest part of the pit. Samples were taken from areas of the pit that were once underwater but due to pumping of the pit are currently exposed. These locations were staggered across this surface and were assumed to be representative of the entire sludge body.

- The SALT procedure utilized was modified from the procedure set forth in the SAP Addendum 2. Rather than using two sequential extraction tests on the same sludge sample, two separate leach tests were conducted using 5:1 and 10:1 ARD to sludge ratios.

The QC activities completed during this investigation included collection of a field duplicate, collection of an MS/MSD, and decontamination of equipment used. Two field duplicates and 1 MS/MSD were submitted for the 12 sludge samples collected in 2001. No QC samples were collected for the 2007 sampling event. All QC activities for this investigation were conducted in accordance with the SAP (CDM 2001d) and SAP Addendum 2 (CDM 2007c).

All analyses were evaluated, validated, and reviewed by CDM staff for the sampling events. The SPLP and TCLP mercury results for 11 of the 14 samples were rejected due to poor QC sample results. Additionally, the hydrochloric acid (HCl) fraction of the total sulfur for 1 of the 13 samples was rejected. The remainder of the results was deemed usable for evaluating the data quality objectives.

The principal study questions as stated in the original SAP are:

(1) What is the thickness of sludge in the waste pit lake area at the Sunday and Dakota Maid pits?

(2) What are the waste characteristics of the sludge at the Sunday, Dakota Maid, Pond C, and Hoodoo Gulch ponds?

Both DQOs were achieved based on the data received from both the 2001 and 2007 investigations. The additional DQO from the SAP Addendum 2 was achieved in that the reactive interaction between pit lake sludges and ARD was identified. These data are presented in the database as SITE WIDE SLUDGE and SITE WIDE SLUDGE STUDY.

Surge Pond
Sludge depths for the Surge Pond were measured in January 2005 while one composite sample was collected on February 10, 2005.

Deviations from the SAP addendum include the following:

- Three composite samples were to be collected from the central, northwest, and southeast regions of the Surge Pond. However, following the January 2005 sludge thickness assessment, it was identified that the depth and extent of sludge was most likely less than the originally anticipated depth of 4 ft. As a result, only one composite sample was required in order to adequately characterize the sludge.

- TCLP analysis was not required under the SAP addendum; however, following discussions, and as requested by EPA and DENR, it was included in the analytical package. All analytical analyses were performed by Energy Laboratories, Inc., a CDM subcontracted laboratory. As such, TAL metals were not analyzed under the CLP as outlined in the SAP addendum.

Quality control activities completed during this investigation included decontamination of sampling equipment (e.g., 5-gal bucket). All QC activities for this investigation were conducted in accordance with the SAP. Data collected to identify waste characteristics of sludge contained within the Surge Pond were of sufficient quantity and quality.

The DQOs for Surge Pond sampling activities were limited to the collection of a composite representative sludge sample and associated comprehensive waste characterization data. Data are considered usable for evaluating this data quality objective, and the DQO was achieved. These data are presented in the database as SITE WIDE SLUDGE.

Cyanide Neutralization Sludge
Sludge samples for the cyanide neutralization sludge were collected on September 5, 2001. Three composite samples were collected from test pits, and two composite samples were collected from the former cyanide neutralization sludge waste drums formerly located on the HLP.

Deviations from the SAP include the following:

- Three test pits were to be dug in the Ruby Earthen Pond and one composite sample was to be collected from each of the three pits. Since the cyanide neutralization sludge was not encountered in the Ruby Earthen Pond, the test pits from which the sludge was sampled were within a trench southeast of the Ruby Earthen Pond. This deviation allowed the sampler to collect more representative samples of the sludge than had presently been stored in the Ruby Earthen Pond.

- The sludge samples were to be subjected to the TCLP. This was not done because it was not necessary to determine the sludge's characteristics under conditions similar to what is mimicked in the TCLP (i.e., mildly acidic, organic matrix). Rather, the SPLP was used to determine the sludge's characteristics under conditions similar to a rainwater leach. This deviation reduced the acidic leaching conditions under which the sludge was subjected during the testing. However, it

is believed that the SPLP leachate results are more representative of the leaching environment that the sludge may be placed in than the TCLP.

The QC activities completed during this investigation included collection of a field duplicate, collection of an MS/MSD, and decontamination of equipment used. One field duplicate and one MS/MSD were submitted for five sludge samples collected. The backhoe bucket was decontaminated in accordance with the SAP between test pits and after sampling was completed. Disposable plastic scoops were used to sample the drums formerly located on the HLP. All QC activities for this investigation were conducted in accordance with the SAP. All data were evaluated and determined usable.

The principal study question as stated in the SAP is "What are the waste characteristics of the sludge at the HLP and the Ruby Earthen Pond?" The data collected from the cyanide neutralization sludge located in the trench on top of the former Ruby Gulch Waste Rock Dump and the drums formerly located on the northwest section of the HLP were of sufficient quality to answer the primary question. These data are presented in the database as SITE WIDE SLUDGE.

Anchor Hill Pit Lake Sludge

The Anchor Hill Pit Lake sludge was sampled in accordance with the *QAPP for Bioremediation of Pit Lakes* (MSE 2001) and the CDM SAP Addendum 2 (CDM 2007c). Four native sediment samples were collected from Anchor Hill Pit on March 19, 2001, prior to initiation of the Anchor Hill Pit Lake Treatability Study. Two sludge samples from the Anchor Hill Pit were collected on May 24, 2001 after completion of the first phase of lime neutralization for the treatability study. Three additional sludge samples were collected from Anchor Hill Pit in March 2007 after the treatability study had been completed in 2006.

Deviations from the MSE QAPP and CDM SAP Addendum 2 include the following:

- Sediments/sludge were to be sampled prior to lime neutralization of the pit lake, after lime neutralization, after addition of organic carbon to the pit lake, and at the end of the study. Sediments/sludge were sampled prior to lime neutralization, after lime neutralization, and at the end of the study. Samples collected after lime neutralization would be expected to contain a mixture of sediments present at the base of the pit lake and sludges resulting from the lime neutralization. Samples collected at the end of the treatability test would be expected to contain a mixture of sediments, lime neutralization sludge, sodium hydroxide neutralization sludge, biomass, and metal sulfides.

- These samples were to be collected with a box corer device in order to evaluate potential layering within the sediments. Samples collected after neutralization were to be quick frozen using a freeze box sampler to capture fine-grained sediments/precipitates at the bottom of the pit. The samples were collected with an Ekman sampling device and a ponar dredge sampling device rather than a box

corer or freeze box. The Ekman and ponar sampling devices do not preserve layering within the sludge/sediment sample or freeze the sample.

- The sludge/sediments were planned to only be analyzed for TAL metals, TCLP, and SPLP (MSE 2001). ABA analyses were also conducted on the post-lime neutralization sludge.

- The SALT procedure utilized was modified from the procedure set forth in the SAP Addendum 2. Rather than using two sequential extraction tests on the same sludge sample, two separate leach tests were conducted using 5:1 and 10:1 ARD to sludge ratios.

Samples were collected, analyzed, and validated in accordance with the QAPP, with minor variations. The Eckman and ponar samplers were decontaminated by cleaning off excess sediment and drying with Kimwipes. This level of decontamination was adequate because the samplers were lowered through the pit lake water column prior to collecting the sample.

Data are considered usable to evaluate characteristics of sediments/sludge before lime addition, after lime addition, and at the end of the test. Data are not considered usable to evaluate the sediment/sludge characteristics after addition of organic carbon to the pit lake because no sample was collected at this time. The additional DQO from the SAP Addendum 2 was achieved in that the reactive interaction between the pit lake sludge and ARD was identified. Anchor Hill Pit Lake sludge data are presented in the database as SITE WIDE SLUDGE.

Ruby Pond Sludge
One sample was collected from the Ruby Pond sludge on September 20, 2005.

Deviations from the SAP include the following:

- One sludge sample was collected from Ruby Pond. It was analyzed for TAL metals, SPLP, and ABA in accordance with the SAP. However, TCLP and paint filter/filter press characteristics analyses were specified in the SAP but were not completed. ABA and total cyanide analyses were added to the analysis package specified in the SAP. TAL metals were not completed at an EPA CLP laboratory. All analyses were completed at Energy Laboratories, Inc., a CDM subcontracted laboratory.

Quality control activities included sample collection in accordance with CDM standard operating procedures, sample custody documentation, analytical QC, and data management in accordance with the SAP. Sample collection, preservation, storage, and shipping were completed in accordance with procedures set forth in the SAP. The sample was analyzed by a CDM contract laboratory in compliance with quality assurance (QA) requirements set forth in the laboratory contract. Data are considered usable for this investigation.

The opportunity sample collected from the Ruby Pond sludge and the associated analyses are adequate to meet the data quality objectives of collecting a representative sludge sample for known characteristics of the sludge. These data are presented in the database as SITE WIDE SLUDGE.

Stormwater Pond Sludge
Three samples were collected from the Stormwater Pond sludge in March 2007.

Deviations from the SAP Addendum 2 include the following:

- The SALT procedure utilized was modified from the procedure set forth in the SAP Addendum 2. Rather than using two sequential extraction tests on the same sludge sample, two separate leach tests were conducted using 5:1 and 10:1 ARD to sludge ratios.

Quality control activities completed during this investigation included decontamination of sampling equipment (e.g., 5-gal bucket). All QC activities for this investigation were in accordance with the SAP Addendum 2. Data collected to identify waste characteristics of sludge contained within the Surge Pond were of sufficient quantity and quality.

The DQOs for the Stormwater Pond are:

(1) What are the waste characteristics of the sludge in the Stormwater Pond?

(2) What is the reactive interaction between Stormwater Pond sludge and ARD present at the site, and secondly is the sludge a source of secondary contaminants when in contact with ARD?

The data collected from the Stormwater Pond sludge were of sufficient quantity and quality to achieve these DQOs. These data are presented in the database as SITE WIDE SLUDGE.

2.4.3.7 Groundwater Investigation

The overall objectives of the groundwater investigation were to collect data necessary to characterize the nature and extent of groundwater contamination and understand the hydraulic characteristics of the aquifers present at the site. The groundwater investigation includes all of the groundwater-related work completed under the following SAPs:

- *Final Sampling and Analysis Plan for Groundwater Sampling, Spring 2001* (CDM 2001f)

- *Final Sampling and Analysis Plan for Quarterly Surface Water, Groundwater, and Sediment Sampling* (CDM 2001g)

- *Final Sampling and Analysis Plan for Monitoring Well Rehabilitation and Installation* (CDM 2002b)

- *Revised Final – Sampling and Analysis Plan for Additional Groundwater Characterization and Fill Confirmation* (CDM 2004b)
- *Final Sampling and Analysis Plan for Groundwater Aquifer Pumping Test* (CDM 2006a)
- *Final Sampling and Analysis Plan for Groundwater Remedial Investigation* (CDM 2007d)

Objectives for all Groundwater Investigations
As expected with this many SAPs, there were numerous objectives for the groundwater investigations. Specific objectives for each of these SAPs are listed in Exhibit 2-1.

For fieldwork involving water quality sampling activities, specific analysis performed for the majority of the investigations includes the following: total and dissolved metals/metalloids, acidity, alkalinity, bicarbonate, bromide, carbonate, chloride, total and WAD cyanide, conductivity, dissolved oxygen, fluoride, hardness, nitrate/nitrite, nitrogen as ammonia, oxidation reduction potential (ORP), phosphates, pH, silica, sulfate, sulfide, temperature, total suspended solids (TSS), TDS, and turbidity. Deviations or modifications from this analyte list for specific investigations were the result of field conditions (i.e. weather) and/or direction from EPA. Additionally, the list of specific total and dissolved metal/metalloids analyzed were sometimes different for specific investigations.

The QC activities conducted during these investigations included collection of field duplicates and extra volume for MS/MSDs, calibration of field instruments, collection of rinsate blanks, and decontamination of equipment. The collection and submittal of field duplicates and MS/MSDs and rinsate blanks were at least at a frequency of 1 per 10 and 1 per 20 samples, respectively. All QC activities for these investigations were completed in accordance with the corresponding SAPs, if applicable (i.e. if water quality samples were collected), or unless otherwise noted.

Each of the groundwater well installation/sampling events are further described below, each with discussions of when the investigation was performed, what was performed, deviations from the SAP, data usability, and assessment of DQOs. All groundwater data are presented in the database as GROUNDWATER STUDY or COMPLIANCE MONITORING.

Deviations from the SAPs for All Groundwater Studies

<u>Groundwater Sampling, Spring 2001</u>
Groundwater sampling was conducted under this SAP (original SAP) from May 2001 through May 2007. Additional groundwater-specific SAPs were created during the remedial investigation period, as shown above, that may have overridden this SAP or referenced this SAP. QA/QC discussions for the additional SAPs are described in separate sections below. The number of wells sampled and parameters analyzed were modified throughout this period from what was specified originally in this SAP.

Exhibit 2-1. Groundwater DQOs by Specific SAP

SAP	DQO
Groundwater Sampling, Spring 2001	• Monitor water levels to determine direction of flow, define interactions between groundwater in surficial deposits and bedrock, and identify temporal changes • Collect and evaluate data on concentrations of PCOCs in groundwater and exceedances of applicable water quality criteria • Characterize existing water quality for the purposes of evaluating future remediation actions
Quarterly Surface Water, Groundwater, and Sediment Sampling	• Collect/evaluate data on concentrations of PCOCs and exceedances of applicable water quality criteria and levels that are toxic or a risk to aquatic biota • Monitor water levels to determine direction of flow, define interactions between groundwater in surficial deposits and fractured bedrock, and identify temporal changes • Characterize existing water quality for the purposes of evaluating future remediation actions
Monitoring Well Rehabilitation/ Installation	• Reconstruct four wells (GW-MW-01, 02, 03, and 04) to improve their utility for future monitoring • Install four wells to investigate the amount of groundwater present in surficial deposits and its permeability, quality, and interaction with the fractured bedrock system • Install two wells to investigate the interaction of the fractured bedrock system with the surficial alluvial system in the Strawberry Creek drainage
Additional Groundwater Characterization and Fill Confirmation	• Install, log, test, and sample bedrock wells and test and sample reconstructed wells to validate existence of fracture zones, determine hydraulic properties, assess sources of recharge, determine if they are (or could be) transport pathways for contaminated groundwater, and assess the magnitude of impact that deep groundwater discharge may have on surface water, shallow alluvium, and offsite groundwater
Groundwater Aquifer Pumping Test	• Determine hydraulic parameters of the aquifer upgradient of Dakota Maid Pit to determine feasibility of a groundwater interception system to reduce groundwater (gw) inflow to the pit. • Characterize aquifer's directional properties and the degree of control by fractures to design gw interception system • Determine interaction of bedrock aquifer with shallow alluvial gw and nearby surface water features
Groundwater Remedial Investigation	• Further define extent of gw contamination in Strawberry Creek, southeast of Hoodoo Gulch, in Terrible Gulch, and north of the HLP and Ruby Repository • Define rate of gw and contaminant transport through Precambrian hydrogeologic unit to the southeast of Hoodoo Gulch and Terrible Gulch • Define potentiometric surface surrounding Anchor Hill Pit to understand potential effects of remedial action • Define the background gw quality and site aquifer characteristics

These changes were made in response to EPA's requests and as a result of new monitoring well additions in 2002, 2004, and 2007.

Deviations from the original SAP include the following:

- Water level collection from monitoring wells GW-2A, BES-14, BED-14, or BED-17 were inadvertently missed during the May 2001 sampling event. This limits the ability to accurately predict water level near these wells. However, this did not substantially inhibit development of a potentiometric surface for this time period.

For CDM's May 2001 groundwater samples, the following parameters contained rejected results due to poor laboratory QC:

- Bromide – 9 samples
- Fluoride – 1 sample
- Total selenium – 15 samples
- Strontium – 1 sample
- Nitrate/nitrite – 5 samples

For CDM's July 2003 groundwater samples, the following parameters contained rejected results due to poor laboratory QC:

- Dissolved mercury – 6 samples

All other data collected during the investigation period are considered usable, unless described differently in the remaining sections. Although some data were rejected, the usable data within the database can be used to determine groundwater quality trends over time; therefore, rejected data have had a minimal impact to the investigation.

The principal study questions as stated in the SAP are:

(1) What are the magnitudes, locations, and spatial variability of concentrations of PCOCs in groundwater?

(2) What are the magnitudes, locations, and spatial variability of PCOC exceedances of water quality criteria for target species in groundwater?

(3) What are the magnitudes, locations, and spatial variability of the groundwater flow direction and gradient at the site?

(4) What are the magnitudes, locations, and spatial variability of temporal changes in groundwater level over time?

(5) What is the interaction of groundwater with surficial deposits and the fractured bedrock?

The quality of the results collected under this SAP was adequate and appropriate to meet these DQOs.

Quarterly Surface Water, Groundwater, and Sediment
Groundwater sampling was conducted under this SAP from September 2001 to October 2002.

Deviations from the quarterly SAP include the following:

- Water levels from monitoring wells GW-2A, GW-8A and GW-9A were inadvertently missed and not collected during the September 2001 sampling event. This limits the ability to accurately predict water level near these wells. However, this did not substantially inhibit development of a potentiometric surface for this time period.

- Water levels from 13 wells (BED-7, BED-8, BES-8, BED-15, BED-16, BES-16, BED-17, BED-19, GW-2A, GW-3, GW-8A, GW-9A, and GW-10A) were not obtained during the February 2002 sampling event due to inaccessibility. This limits the ability to accurately predict water level near these wells. However, this did not substantially inhibit development of a potentiometric surface for this time period.

- Water levels from monitoring wells GW-8A and GW-9A were not collected during the May 2002 sampling event due to earth work being performed on the Ruby Repository. This limits the ability to accurately predict water level near these wells. However, this did not substantially inhibit development of a potentiometric surface for this time period.

- Due to rehabilitation of monitoring wells GE-MW-01, GE-MW-02, GE-MW-03, and GE-MW-04, water levels were not collected during the May 2002 sampling event. This limits the ability to accurately predict water level near these wells. However, this did not substantially inhibit development of a potentiometric surface for this time period.

- Groundwater was not sampled from GW-10A as it could not be extracted from this well in the fall of 2001 and during all of 2002.

- Groundwater from GE-MW-04 was not sampled during the May 2002 sampling event. This well was being rehabilitated by CDM and could not be sampled.

- Groundwater was not sampled from GE-MW-01, GE-MW-02, GE-MW-03, and GE-MW-04 during the August 2002 sampling event. These wells were rehabilitated, renamed as GWCDM01, GWCDM02, GWCDM03, and GWCDM04, respectively, and sampled in August 2002.

These deviations had no effect on the data quality of samples collected. These deviations did create a metal and water quality data gap for the time period not sampled. However, metal and water quality trends can be made using prior and post data sets.

For CDM's fall 2001 groundwater samples, the following parameters contained rejected results due to poor laboratory QC:

- Total and dissolved silver – 1 sample each
- Bicarbonate and carbonate – 15 samples each

For CDM's spring 2002 groundwater samples, the following parameters contained rejected results due to poor laboratory QC:

- Dissolved silver – 11 samples
- Total silver – 13 samples
- Total and dissolved mercury – 1 sample each
- Total selenium – 1 sample
- Total thallium – 1 sample

For CDM's August 2002 groundwater samples, the following parameters contained rejected results due to poor laboratory QC:

- WAD cyanide – 4 samples
- Total and dissolved selenium – 12 samples
- Dissolved thallium – 11 samples
- Total thallium – 13 samples
- Sulfate – 5 samples
- Turbidity – 11 samples

For CDM's October 2002 groundwater samples, the following parameters contained rejected results due to poor laboratory QC:

- Fluoride – 3 samples
- Turbidity – 4 samples

All other data collected for the investigation period are considered usable. Although some data were rejected, the usable data within the database can be used to determine PCOCs trends over time; therefore, rejected data have had a minimal impact on the investigation.

The principal study questions as stated in the SAP related to groundwater are:

(1) Do the PCOC concentrations exceed action levels?

(2) Is groundwater contributing to PCOC concentrations in surface water?

The quality of the results collected during the sampling events included in this report are adequate and appropriate to aid in meeting the primary and secondary objectives listed above.

Monitoring Well Rehabilitation and Installation
Four existing wells (GWCDM01, GWCDM02, GWCDM03, and GWCDM04) were reconstructed, and six new wells (GWCDM09, GWCDM10, GWCDM11, GWCDM12, GWCDM13, and GWCDM14) were installed as part of the SAP. The well strings (i.e., well casing and screen) were removed from the open boreholes of the wells to be reconstructed on April 28 and a geophysical survey was completed on May 14, 2002. The six new monitoring wells were installed from June through July 2002. Well development was conducted in July 2002. No groundwater sampling was conducted as part of this SAP; rather, groundwater sampling at the rehabilitated and new wells were conducted at a later date as specified in the original SAP.

Deviations from the SAP for Monitoring Well Rehabilitation and Installation include the following:

- A geophysical survey was not performed in the GE-MW-04D borehole due to rock caving in the borehole. The sloughed material was removed from the borehole using the air rotary drill. Approximately 7 ft of this material was present in the borehole.

- Based on the log for well GE-MW-03D, it was assumed that bedrock would be contacted at 30 ft bgs for well GWCDM13. After repeated attempts, refusal occurred at 21 ft bgs, and the well was constructed from this depth. Since the objective was to capture water in the surficial deposits, this is expected to have no effect on the data usability.

- Well GWCDM09 was originally planned to be located near the site of the hard bucket system in Hoodoo Gulch. Due to the steep slope of the road at that location, the well was located to an area near the sedimentation pond more conducive to drilling. As the objective of this well is to capture the properties of the water in the Hoodoo Gulch drainage, there is expected to be no effect on the data usability.

- Delays in the drilling of the deep wells resulted from a forest fire through the area of the mine. During this period, work was conducted sporadically, and due to budget constraints, CDM was not able to provide oversight of the well installation. For sand placement and documentation, reliance was placed on the experienced, licensed driller. This is thought to have no effect on the data usability of the investigation.

- Well development was conducted by Taylor Drilling using a Smeal water development rig. Compressed air released into the well near the well's end cap was used to clean out any debris and increase connectiveness with the aquifer. A bailer and surge block was also used during development. Each well received approximately 3 hours of development. Because of the sporadic nature of the work following the forest fire, CDM did not oversee development, and no field measurements were collected. However, lack of monitoring data is not expected to affect data usability.

The principal study question stated in the SAP is:

(1) Are the monitoring wells rehabilitated and installed in this field effort available for future data collection?

Based on the useable water quality data collected from these wells, this DQO was achieved.

<u>Additional Groundwater Characterization and Fill Confirmation</u>
Under this SAP, five angle-drilled bedrock wells (GE-MW-15, GE-MW-16, GE-MW-17, GE-MW-18, and GE-MW-19) were installed in April 2004. These five new wells, four reconstructed wells, and six existing wells were hydraulic tested, water levels were measured, and groundwater samples were collected. Additional development of the new bedrock wells and hydraulic testing of all 15 wells was completed between June 1 and June 15 2004. Sampling of the 15 wells was performed on June 14 and June 16, 2004.

Deviations from the SAP for Additional Groundwater Characterization and Fill Confirmation (described for groundwater only below) include the following:

- Locations, angles, and lengths of the new angle-drilled bedrock wells were slightly modified from the specifications of the SAP due to complexities with intersecting the bedrock fracture zones. The specifics of each well are:

  - GE-MW-15 was moved approximately 200 ft southwest (toward GE-MW-07) from the position shown in the SAP. The well location was moved to the footwall side of the fracture zone and angle drilled on an azimuth of 315 degrees, with an angle of -65 degrees.

  - GE-MW-16 was positioned within the fracture zone structure and drilled on an azimuth of 315 degrees, with an angle of -75 degrees.

  - GE-MW-17 was positioned on the footwall side of the fracture zone and drilled on an azimuth of 315 degrees, with an angle of -75 degrees.

  - GE-MW-18 was positioned within the fracture zone and drilled on an azimuth of 315 degrees, with an angle of -65 degrees.

  - GE-MW-19 was positioned with fracture zone and drilled on an azimuth of 115 degrees, with an angle of -75 degrees.

- Straddle packer tests were not conducted on all five new wells as specified in the SAP. Straddle packer tests were only conducted on borings GE-MW-15 and GE-MW-17 using the single packer test method. Packer testing of these well was not necessary since well screen placement determination was based on encountering significant water.

- Six-inch inside diameter low carbon steel surface casing was utilized for well installation instead of 8-inch outside diameter low carbon steel surface casing.

- A CDM subcontractor, instead of CDM's field geologist, completed lithologic logging.

- Clean 10/20 silica sand was placed by a tremmie except at locations GE-MW-15 and GE-MW-17, as borehole conditions were suitable for gravity placement from the surface. These two wells were backfilled with the sand from the targeted depths so that the screen intervals could be positioned in accordance with the zones selected by the CDM field geologist based upon results of the packer test and/or borehole observation of the lithology and water availability. GE-MW-17 was backfilled from 181 ft to 150 ft bgs. GE-MW-15 was backfilled from 350 ft to 340 ft bgs.

- The silica sand seal was changed from 200 mesh to 100 mesh to facilitate better placement in the borehole. The 100 mesh silica sand interval of 3 ft was then either increased or decreased depending upon the anticipated weight of the bentonite grout placed above the 100 mesh silica sand seal. GE-MW-15 had 9 ft of 100 mesh silica sand, with 293 ft of grout installed. GE-MW-17 had 7.5 ft of 100 mesh silica sand, with 111 ft of bentonite grout to be installed. GE-MW-19 had 2.2 ft of 100 mesh silica sand recorded.

- A high solids bentonite grout was used from the interval above the 100 mesh silica sand instead of a cement-based mixture. The high solids bentonite grout was proposed as an alternate seal.

- Bentonite chips were to be installed from the ground surface to the interval at which the high solids bentonite seal settled to after placement. The bentonite chips were utilized after at least two lifts of the high solids bentonite grout were placed to ground surface and settled to an interval ground surface.

- The well surface completion was changed so that the 6-inch ID steel casing installed through the unconsolidated sediments/waste rock would extend above the ground surface and serve as the locking protective casing. A lockable cap was placed on top of the steel casing.

- Drill rods and bit were not decontaminated per the SAP between monitoring well location GE-MW-15 and-17. Several hundred gallons of site process water were used to flush the rod between the borings.

- Monitoring well GE-MW-15 could not be developed with the gas displacement pump provided by the drilling crew. The depth of the water was too great for the lift capabilities of the development pump. A 2-inch stainless-steel submersible pump supplied by CDM was used to develop this well.

- Water quality parameters of conductivity, pH, temperature, turbidity, dissolved oxygen, and ORP were not measured during bedrock monitoring well development. Since all wells had relatively slow recoveries, field measurement of these parameters was not deemed necessary. Each well received approximately 3 hours of development. Lack of monitoring data is not expected to affect data usability.

The principal study questions stated in the SAP are:

(1) Is the fractured bedrock transporting contaminated water off site and/or are bedrock fractures currently transporting, or could they in the future transport, contaminated waters to Strawberry Creek?

(2) If contaminated waters are being transported, to what extent is metals loading occurring, high, moderate to low, or low to insignificant?

All data from the June 2004 sampling event are considered useable. Therefore, the DQOs for this SAP were achieved.

<u>Groundwater Aquifer Pumping Test</u>
A multi-well aquifer pumping test was completed in August 2006. This test consisted of pumping down well GW-4 over a 5-day period and monitoring the water levels in a series of other nearby wells (GW-3, GW-5, GE-MW-01, GE-MW-04, GE-MW-08, BED-7, and BED-8), Dakota Maid Pit, and Anchor Hill Pit, in an effort to determine the degree of connectiveness of the surface water and groundwater locations. Discharge water from GW-4 was sampled at the beginning, middle, and end of the test for major anions and cations and dissolved metals. Field parameters of temperature, pH, conductivity, dissolved oxygen, and ORP were measured four times per day at well GW-4.

Deviations from the Groundwater Aquifer Pumping Test SAP include the following:

- The pumping test was only conducted for 5 days rather than 14 days as originally specified in the SAP.

- Water level at GE-MW-04 was measured using an electronic water level indicator rather than a transducer as specified in the SAP. Water level in all other wells was measured using pressure transducers as specified by the SAP.

The principal study questions stated in the SAP are:

(1) What are the hydraulic properties of the bedrock aquifer upgradient to the Dakota Maid Pit?

(2) Are the hydraulic properties directionally dependent or do they vary depending on the direction of measurement and the regional fracture system?

(3) What is the interaction of groundwater in the fractured bedrock with alluvial groundwater and surface water features, such as the open pits?

The aquifer testing data collected from this investigation were of sufficient quality and quantity to achieve all of these DQOs.

Groundwater Remedial Investigation

This SAP represented the final portion of the remedial investigation at the site. The field activities conducted include installation of 8 new bedrock wells, comprehensive groundwater sampling of almost every well on site (49 well samples, including the 8 new wells), single well pump testing of 11 wells (including the 8 new wells), and redevelopment of 2 bedrock wells (BED-7 and BED-19). Well installation was completed in April 2007 and well sampling was conducted in April and May 2007. Single well hydraulic testing was conducted from April 11, 2007 through July 2007. Groundwater sampling during this period took the place of normal quarterly sampling defined under the quarterly SAP.

Deviations from the Groundwater Remedial Investigation SAP include the following:

- A single well pump test was not conducted on a new well, GWCDM25, due to the excessive depth of this well. The depth of the well was beyond the available head capacity of the pump used during testing; therefore, testing of the well was not conducted.

- The locations of the new bedrock wells GWCDM24 and GWCDM27 were slightly modified from that specified in the SAP due to limited field accessibility of drilling equipment.

- A first round of sampling of the 49 groundwater wells was conducted in April 2007. Decontamination of sampling equipment (bailer, grundfos pump, tubing, etc.) was not conducted in accordance with the SAP between some of the samples collected on April 18 and April 19. Improper decontamination procedures affected the data quality of a total of 17 samples collected during this time period, and as a result, these wells were re-sampled between May 21 and May 27, 2007.

- Single well pump tests have not yet been conducted on wells BED-11, BED-14, and BED-15 as of the time of submittal of this RI report. Well testing is ongoing and expected to be completed in mid-August.

For data collected under this SAP, 17 cadmium analyses were rejected from the analytical data set for samples collected during the April 2007 sampling event. All other data are considered usable.

The principal study questions as stated in the supplemental SAP were:

(1) What is the extent of groundwater contamination at the site?

(2) What is the rate of groundwater and contaminate transport through the Precambrian hydrogeologic unit?

(3) What is the relation between Anchor Hill Pit water elevations and local groundwater potentiometric surface gradient?

(4) What are the background groundwater quality and aquifer characteristics of the site?

The DQOs established for the groundwater investigation were achieved.

2.4.3.8 Low/High Flow Synoptic Surface Water and Sediment Sampling

The objective for the low/high flow synoptic surface water and sediment investigation was to collect the data necessary to characterize surface water and sediment, determine if exceedance of applicable water quality criteria occurred, and determine if exceedances are at levels that pose a risk to aquatic biota. Specifics with respect to this investigation are detailed in the *SAP for Low Flow Synoptic Surface Water and Sediment Sampling, Autumn 2000* (CDM 2000c).

The field investigation was conducted from October 2000 through September 2001, with low flow synoptic sampling events conducted in October 2000 and September 2001, and a high flow synoptic sampling event conducted in May 2001. Analytical tests performed on the samples collected during the field investigation were total metals analyses, dissolved metals, pH, conductivity, TSS, TDS, alkalinity, sulfate, bromide, silica, chloride, fluoride, sulfide, nitrogen as ammonia, nitrate/nitrite, hardness, turbidity, acidity, WAD cyanide, and ABA.

The deviations from the SAP include the following:

- May 2001 – High Flow Synoptic – No bank material was sampled along Strawberry Creek. This deviation does not affect the quality of the sampling event because bank material samples were collected during the previous sampling event, and the bank material quality was not expected to change significantly between these two sampling events.

- September 2001 – Low Flow Synoptic – There was no dye travel time measurement and no sample was collected from SWCDM11. The dye travel time measurements were not completed because of the extremely low flow conditions in Strawberry Creek, which would have resulted in an exorbitant amount of time to complete the synoptic sampling. This deviation caused the sampling within

Strawberry Creek not to be completed within the same "slug" of water. There was not a sample collected from sampling location SWCDM11 within Strawberry Creek due to a large increase in flow prior to reaching this location. Rather, the field personnel quickly moved to the next downstream sampling location to ensure that the remaining locations within Strawberry Creek were sampled prior to changes due to this large increase in flow. Although this deviation limited the ability to obtain details in water quality changes within this region of Strawberry Creek, it assured that the remaining samples collected were not skewed by the large flux of water surging through Strawberry Creek.

The QC activities completed during this investigation included: field duplicates, MS/MSD, calibration of field instruments, and decontamination of equipment used. The collection and submittal of field duplicates and MS/MSDs were at least at a frequency of 1 per 10 and 1 per 20 samples, respectively. All QC activities for these investigations were completed in accordance with the corresponding SAP.

All of the analyses were evaluated, validated, and reviewed with the following results:

- October 2000 - Low Flow Synoptic - All of the results for the following parameters were rejected due to exceedance of holding times: bicarbonate alkalinity, carbonate alkalinity, conductivity (laboratory), sulfide, turbidity (laboratory), and nitrate/nitrite. These analyses were not completed within the method specified holding times due to the length of time it took to procure the laboratory. Although both bicarbonate and carbonate alkalinity results were rejected, total alkalinity results were not rejected and, therefore, deemed usable. Additionally, laboratory conductivity and turbidity results were rejected; however, the field conductivity and turbidity were deemed usable. There are, however, no substitutable parameters or results for the sulfide and nitrate/nitrite.

- May 2001 - High Flow Synoptic - All of the results for the following parameters at non-detectable concentrations were rejected due to exceedance of holding times: ortho-phosphate, strontium, and total sulfate. Although the samples were received by the laboratory within 48-hours of sampling, the analyses were not completed within the method specified holding times.

- September 2001 - Low Flow Synoptic - All of the results for the following parameters at non-detectable concentrations were rejected due to poor matrix spike recoveries: silver, total and dissolved, and selenium, total and dissolved.

The principal study questions as stated in the SAP (CDM 2000c) for the synoptic surface water and sediment sampling investigation events are:

(1) What are the concentrations of PCOCs in surface water, streambed material (i.e., sediment), and bank material and do these concentrations exceed applicable water quality criteria or are at levels that may be toxic or a risk to aquatic biota?

(2) What is the loading of PCOCs to surface water, the locations and magnitudes of source areas, and the interactions with and losses to groundwater and potential contaminant transport mechanisms?

The quality and number of results collected during the sampling events included in this report are adequate and appropriate to aid in meeting the primary and secondary objectives listed above. These data are presented in the database as SURFACE WATER STUDY or SEDIMENT STUDY.

2.4.3.9 Quarterly Surface Water, Groundwater, and Sediment Sampling

The QA/QC section for this SAP describing groundwater sampling was discussed in the groundwater investigation section above. This section will focus on surface water and sediment only.

The objectives for the site quarterly surface water, groundwater, and sediment sampling were to:

- Collect and evaluate data on concentrations of PCOCs in surface water and streambed material (sediment), exceedances of applicable water quality criteria, and exceedances of levels that are toxic or a risk to aquatic biota
- Collect and evaluate data on loadings of PCOCs in surface water to identify locations and magnitudes of source areas and gain information on interactions with and losses to groundwater and potential contaminant transport mechanisms
- Characterize existing water quality for the purposes of evaluating future remediation actions

Specifics with respect to this investigation are detailed in the *SAP for Quarterly Surface Water, Groundwater, and Sediment Sampling* (CDM 2001g).

The field investigation was conducted from February 2002 through August 2003 for surface water and sediment. Analytical tests performed on the samples collected during the field investigation were total metals analyses, dissolved metals, pH, conductivity, TSS, TDS, alkalinity, sulfate, bromide, silica, chloride, fluoride, sulfide, nitrogen as ammonia, nitrate/nitrite, hardness, turbidity, acidity, and WAD cyanide.

The deviations from the SAP include the following:

- February 2002 1st Quarter - Deviations were associated with the thick ice (1 feet to 2 feet thick) on top of the creeks and included no dye travel time measurements, only one surface water flow measurement, only five surface water quality sampling locations, and no sediment sampling. Although these deviations limited the usability of the results from this sampling event, they were necessary due to the weather conditions at the site during February. The March 2002 sampling event was completed to supplement this quarterly sampling event and minimize the effect of this deviation.

- March 2002 – Sampling prior to Water Treatment Plant Discharge to Strawberry Creek - There was no dye travel time measurement and no sediment sampling, and only a selected number of sampling locations were sampled within Strawberry Creek. This sampling event was not a pre-planned sampling event and was completed to determine baseline conditions within Strawberry Creek prior to the restart of the Water Treatment Plant (WTP). The usefulness of this added sampling event was beneficial to the overall evaluation of Strawberry Creek water quality.

- May 2002 2nd Quarter - The deviations included no dye travel time measurement and sediment sampling from only selected locations. The dye travel time measurement was not completed due to the unseasonably low flow conditions within Strawberry Creek. The effects of only collecting sediment from selected locations where there was known to be a substantial amount of fines limited the resolution at which the sediments within Strawberry Creek could be evaluated as compared to previous sampling events.

- August 2002 3rd Quarter - The deviations included no dye travel time measurement, no sediment sampling, and a limited number of flow measurements within Strawberry Creek. The dye travel time measurement was not completed due to the very low flow conditions present within Strawberry Creek during this sampling event. Dye flow measurements would have resulted in an exorbitant length of time for synoptic sampling. Therefore, samples within Strawberry Creek were collected from upstream to downstream but not synoptically. Sediments were not collected because it was assumed that the sediment quality did not alter substantially from the last sediment sampling event. Although flow measurements were only made at a few select locations within Strawberry Creek, the locations were chosen based on previous results to best represent the major segments of the creek and at locations where the flow could be measured with the best precision. The limited number of flow measurement locations limits the ability to observe the flow variability on a scale similar to previous sampling events.

- October 2002 4th Quarter - Deviations included no dye travel time measurement, no sediment sampling, and a limited number of flow measurements within Strawberry Creek. These deviations occurred because of a 1- to 3-inch layer of ice present within the Strawberry Creek drainage.

The QC activities completed during this investigation included field duplicates, MS/MSD, calibration of field instruments, and decontamination of equipment used. The collection and submittal of field duplicates and MS/MSDs were at least at a frequency of 1 per 10 and 1 per 20 samples, respectively. All QC activities for these investigations were completed in accordance with the SAP.

All of the analyses were evaluated, validated, and reviewed with the following results:

- February 2002 1st Quarter - None of the results from this sampling event were rejected.

- May 2002 2nd Quarter - Some of the results for the following parameters at non-detectable concentrations were rejected due to low matrix spike recoveries: silver, total (7/25 samples) and dissolved (6/25 samples) and selenium, total (4/25 samples).

- August 2002 3rd Quarter - Some of the results for the following parameters at non-detectable concentrations were rejected due to low matrix spike recoveries: bromide (8/24 samples); cyanide, total (9/23 samples) and WAD (16/24 samples); and thallium, total (7/23 samples) and dissolved (11/24 samples). Additionally, 3 of 25 sulfate results were rejected due to gross exceedance of the holding time criteria even though the samples were delivered to the lab within 48-hours after they were collected.

- October 2002 4th Quarter - Some of the results for the following parameters at non-detectable concentrations were rejected due to poor matrix spike recoveries: silver, total (6/26 samples) and dissolved (6/26 samples) and selenium, total (6/26 samples).

The principal study questions as stated in the SAP (CDM 2001g) for surface water sampling events are:

(1) Do the PCOC concentrations exceed action levels?

(2) Is groundwater contributing to PCOC concentrations in surface water?

The quality and number of results collected during the sampling events included in this report are adequate and appropriate to aid in meeting the primary and secondary objectives listed above. These data are presented in the database as SURFACE WATER STUDY or SEDIMENT STUDY.

2.4.3.10 Surface Water Investigation (O&M)

As part of the surface water investigation and/or monitoring program, several CDM investigations have collected and characterized surface water within the primary mine disturbance area. Surface water within the disturbed area of the site include the pit lakes, lined and un-lined ponds, Ruby Repository discharges, Hoodoo and Pond C flows, seeps, adits and weirs, and HLP waters. Because many of the CDM surface water investigations cut across multiple mine waste units or study areas (Strawberry Creek, Bear Butte Creek, etc.), this section only addresses water quality data obtained during routine operation and maintenance (O&M) activities.

Virtually all surface water within the primary mine disturbance area is collected and conveyed into the site water treatment circuit. Investigation of surface water quality within the mine disturbance area is focused on evaluation of parameters that affect water treatment requirements, such as pH, total dissolved solids, sulfate

concentrations, mineral acidity, and representative total recoverable toxic metal and metalloid concentrations.

The objectives of the O&M monitoring program were to:

- Collect surface water at the compliance points to determine if metal concentrations, pH levels, and other measurements are within established levels
- Collect performance samples and monitoring of surface water (including daily inspections) to determine if changes in treatment and/or flow rates are necessary to optimize operations at the site

Specifics with respect to this investigation are detailed in the SAP for Site Management Operations (CDM 2003a).

The O&M data used in the RI were collected from 2000 through the present. Approximately 300 records exist in this data set and were analyzed for total and dissolved metals/metalloids, hardness, pH, TSS, TDS, conductivity, nitrogen as ammonia, nitrate/nitrite, sulfate, and alkalinity.

The deviations from the SAP include the following:

- Surface water sampling locations SWCDM11 on Strawberry Creek and OPCDM06 on Hoodoo Gulch were possibly reversed during O&M monitoring from 2004 through 2006. This error was a result of a change in the site field team leader and sampling personnel during sampling events after 2003. Therefore, water quality data from these locations shown in the site database (Appendix B) may not be representative of their station location name. As a result, data collected from these two sampling locations during 2004 to 2006 are not considered usable.

The QC activities conducted during this investigation included collection of field duplicates. The collection and submittal of field duplicates were at least at a frequency of 1 per 20 samples. All QC activities for these investigations were completed in accordance with the corresponding SAP.

All of the analyses were evaluated/reviewed by CDM staff for all of the samples. All water sample results met the QC guidelines as stated in the SAP. Based on the data validation record, no analytical results were rejected. As described above, 2004 through 2006 data from sampling locations SWCDM11 and OPCDM06 are not usable for their intended purpose. All other data collected are considered usable.

As stated in the SAP, the principal study questions were:

(1) Are the values of the parameters listed in the historic NPDES above the acceptable limits?

(2) Are the measurements and analytical data collected at performance points showing optimal use of treatments and/or flow rates at the site?

The DQOs established for this O&M monitoring were achieved. These data are presented in the database as O&M and COMPLIANCE MONITORING.

2.4.3.11 Tailings Present in Strawberry Creek

The objective of this investigation was to collect and analyze tailing samples to evaluate the characteristics of the tailings along Strawberry Creek between Last Chance Pond and Hoodoo Gulch. Specifics with respect to this investigation are detailed in the *SAP for Tailings Present in Strawberry Creek* (CDM 2003b).

Tailings located on the banks of Strawberry Creek were sampled on October 22 and 23, 2003. The field geochemist created transects of the flood plain indicating where samples were collected and an initial evaluation of the presence of tailings. Thirty-three transects were measured, resulting in 132 samples being collected.

The deviations from the SAP are:

- Only 33 of the proposed 35 transects were measured, resulting in only 132 of the proposed 140 samples were collected. This deviation does not affect the usability of data although transect measurements did not extend completely to Hoodoo Gulch. This deviation does affect the ability to completely quantify the aerial extent and volume of tailings between Last Chance Pond and Hoodoo Gulch.

- The SAP also specified that photographs be collected at every sample location; however, photographs were collected only at select locations for the sampling event. This deviation does not affect the usability of data.

The QC activities completed during this investigation included collection of a field duplicate and decontamination of equipment used. One field duplicate was submitted for the seven samples sent to the laboratory. Sampling shovels were decontaminated in accordance with the SAP between uses and after sampling was completed. Disposable plastic scoops were used to collect each of the 133 samples. All QC activities for this investigation were in accordance with the SAP. All of the laboratory analyses were evaluated, validated, and reviewed. All of the results are deemed usable for evaluating the data quality objectives.

The principal study question as stated in SAP (CDM 2003b) is

(1) What are the physical and chemical characteristics of the tailings located in Strawberry Creek?

The data collected was of sufficient quality to answer the DQO for the Strawberry Creek tailings, and physical and chemical characteristics of the tailings are known. These data are presented in the database as STRAWBERRY CREEK TAILINGS.

2.4.3.12 Merrill-Crowe and Process Plant Equipment

The objective of the Merrill-Crowe Gold Recovery Circuit (MCGRC) investigation was to collect and analyze liquid, sludge, and scalant samples to evaluate waste

characteristics in preparation of circuit demolition/decontamination (i.e., worker health and safety issues pertaining to circuit demolition/decontamination) and to collect and analyze liquid, sludge, and scalant samples to evaluate waste characteristics in preparation of circuit disposal (i.e., secondary release of contaminants into the environment following disposal). Specifics with respect to this investigation are detailed in the *SAP for Merrill-Crowe Gold Recovery Circuit* (CDM 2002c).

The sampling effort was conducted on August 1, 2002. A total of 11 liquid, sludge, and/or scalant samples were collected from the process unit equipment. Samples were analyzed for total and WAD cyanide, Resource Conservation and Recovery Act (RCRA) metals, pH, and TCLP RCRA metals.

The deviations from the SAP are:

- Five of the proposed sampling locations were not sampled due to either (1) inaccessibility of the sampling location, (2) current use as part of the HLP re-wetting system, or (3) the equipment had already been sold and is not of concern in this investigation. Sample location 01, the pregnant sump, and sample location 08, the barren sump, were full of water and part of the HLP re-wetting system. The diatomaceous earth tank, sample location 04, was being used to add lime to the HLP solution circuit and was not sampled. The clarifier out-pipe, sample 09, was no longer present or available for sampling. Finally, the filter press out-pipe, sample 10, was sold and was no longer on site. As a result, disposal was not necessary and, therefore, sampling was not conducted. These deviations limited the amount of information gathered for the affected equipment but did not affect the overall achievement of the objectives.

- Analyses of liquid for WAD cyanide, RCRA metals, and pH were not performed due to a lack of liquids contained in the samples. Although some sample locations contained water, it was determined that sampling should be performed after the equipment was removed from the HLP re-wetting system. This deviation had no effect on the equipment that can be removed from service.

- Analysis for cyanide and pH were not performed due to limited scalant sample volumes. This deviation limited the amount of information gathered for the affected equipment but did not affect the overall achievement of the objectives.

- Due to limited scalant sample volume, additional volume for a MS/MSD could not be obtained. This deviation limited the data available for QC review but did not affect the overall achievement of the objectives.

The QC activities completed during this investigation included the collection of field duplicates and calibration of the field instrument. One field duplicate sample was submitted for analysis. No field blanks were collected due to the use of dedicated equipment. The field instrument was calibrated at the beginning and at the end of the field sampling day. All QC activities for this investigation were in accordance with

the SAP. All of the analyses were evaluated, validated, and reviewed. No TCLP RCRA metal data were rejected; therefore, all data are considered usable.

The principal study question as stated in SAP (CDM 2002c) for the MCGRC investigation is:

(1) What are the waste characteristics of the liquid, sludge, and scalant in the MCGRC?

In addition, the data collected must be able to characterize the material so as to determine health and safety issues for preparation of circuit disposal. Analytical results provide a quantitative assessment of the waste characteristics, providing information to make informed disposal recommendations. Field observations and monitoring provide information to make informed health and safety recommendations for disposal. Therefore, the DQOs listed in the SAP were achieved. These data are presented in the database as MERRILL-CROWE.

2.4.4 EPA RAC Data - Treatability Studies

Several treatability studies were conducted at the site. Although not used to define nature and/or extent of contamination, these studies are summarized here and were used to screen the remedial alternatives discussed in the FS report.

2.4.4.1 Anchor Hill Pit Treatability Study

EPA sponsored a treatability study at the site to investigate the efficacy of treating ARD contained within a pit lake by neutralization followed by an enhancement of microbiological processes within the pit lake water column and sediments. The purpose of the project was to determine cost, performance, and long-term stability of both a neutralization of the pit lake using SM's Neutra-Mill technology, and GWS's RMB, in other words, in-situ remediation of the pit water by dosing the water with a proprietary liquid organic material.

The primary objective was to achieve reduction in pollutants in the pit lake water such that the samples collected from the pit lake at the end of the project achieve the Criteria for Coldwater Marginal Fish Life Propagation Waters and the Surface Water Quality Standards for Toxic Pollutants (acute, aquatic life only). A summary of the study, including an evaluation of the success of the technology, is presented in the final treatability study report (MSE 2007).

2.4.4.2 Bauxsol Treatability Study

EPA sponsored a treatability study to investigate the efficacy of mitigating ARD emanating from sulfidic waste rock, the efficacy of treating a pit lake, and the efficacy of a passive treatment system using Virotec International Ltd.'s (Virotec's) Bauxsol treatment technology. The purpose was to determine performance and long-term stability of Virotec's Bauxsol technology. The primary objective was to achieve a reduction in pollutants, in comparison to the non-treated source, such that the samples collected are equal to or less than the South Dakota Surface Water Quality Standards.

The investigation involved four independent studies:

- Trench system
- Passive treatment system
- Pit lake water treatment system
- Drums with varying Bauxsol concentrations and waste rock types

The investigation was conducted in 2001 for the four studies described above. A summary of these studies, including an evaluation of the success of the technology, is presented in the *Bauxsol Treatability Study Report (2001)* (CDM 2002d). A separate report, *Bauxsol Trench System Treatability Study Report* (CDM 2006a), was prepared later to evaluate additional yearly data (through 2005) and determine the long-term effectiveness of the trench system treatment.

Based on the initial data gathered in 2001, an additional study was conducted using the Bauxsol material in 2004. This study involved a permeable reactive barrier system containing the Bauxsol material used to treat ARD-affected water. A third report describing this study and an evaluation of the success of the technology is presented in the *ViroMine™ Permeable Reactive Barrier Treatability Study Report* (CDM 2006c).

2.4.4.3 Multi-Cell Treatability Study

EPA Region 8, CDM, EPA Office of Research and Development's (ORD) Mine Waste Technology Program (MWTP), and MSE, under contract with the Department of Energy and ORD, collaborated on this treatability study. The purpose was to assess the effectiveness of emerging technologies for the treatment of ARD-producing waste rock in comparison to the conventional presumptive remedy (lime amendment). This study consisted of 12 cells, each containing about 150 cubic yards (cy) of ARD-producing waste rock. Each of the three technologies was allotted two cells, while three cells were dedicated to the PR, and three to the waste rock control cells.

After 2002, the data generated were compiled by CDM and given to EPA Region 8, EPA ORD-MSE, and the technology vendors. The vendors then completed a cost estimate to treat a 500,000 cy waste rock dump based on the data obtained from the first year of the treatability study. Once ORD-MSE received the cost estimates, the subcontract with the technology vendors was fulfilled. EPA Region 8, EPA ORD-MSE, and CDM then used the treatability and cost data to evaluate the technologies. A final report was written by ORD-MSE and completed by September 2003 (MSE 2003). The treatability study has continued past the original completion date in order to provide a longer analysis of the effectiveness of the treatment types. Samples were collected through 2005. A final summary of the multi-cell treatability study is presented in the *Multi-Cell Wasterock Treatability Study Report* (CDM 2006d).

2.4.5 EPA RAC Data - Pilot Studies

CDM conducted two water treatment plant pilot studies at the site as part of the Interim Water Treatment Operations OU2 FS.

2.4.5.1 Lime-Based High-Density Sludge (HDS) Pilot Study

A pilot study was completed to confirm effluent water quality and costing presented in the *Final Focused Feasibility Study for Gilt Edge Mine Site; Interim Water Treatment Operations Operable Unit 2* (CDM 2001h). The pilot was designed to verify whether the technology can meet cleanup criteria for the site and at what cost. A summary of the results from the lime-based HDS pilot study completed at the site is presented in the *Final Technical Memorandum for the Lime HDS Pilot Plant Testing Report* (CDM 2002e). The lime-based HDS treatment technology was selected in the OU2 interim ROD.

2.4.5.2 Metals Coordination Pilot Study

A pilot study was completed to confirm Water Solutions Inc.'s (the proprietor of the metals coordination technology) claims of effluent water quality and costing presented in the *Final Focused Feasibility Study for Gilt Edge Mine Site; Interim Water Treatment Operations, Operable Unit 2* (CDM 2001h). A summary of the results from the pilot study can be found in the *Draft Technical Memorandum for the Metals Coordination Pilot Plant Testing Report* (CDM 2002f).

2.4.6 Investigations Performed by Others

2.4.6.1 Geologic Reconnaissance Mapping Investigations

The U.S. Department of Interior, BOR, under contract to EPA, conducted a geologic reconnaissance mapping investigation of the underground mine workings and Dakota Maid and Sunday Pit highwalls. As stated in the report, surface geologic mapping was performed to collect geologic data for groundwater analysis of the King Adit level and the highwalls of the Dakota Maid and Sunday pits. The intent of the mapping is to determine the geometry of the discontinuities as well as the lithology, weathering, and other characteristics relating them to the geochemistry and groundwater recharge and discharge. These studies also support the engineering and design aspects for reclaiming the open pits and other areas disturbed by mining. The results of these investigations are presented in *Geologic Reconnaissance Mapping Investigations and Analysis* (BOR 2003).

2.4.6.2 Quantification of Mass Loading to Strawberry Creek near the Gilt Edge Mine

The U.S. Geological Survey (USGS) conducted a mass loading investigation at the site to understand if there is a connection, through shear zones associated with the ore bodies, between metal-rich water in the pits and in Strawberry Creek. USGS developed the approach and methodology for the study, and fieldwork was conducted in June 2003. The mass-loading study was designed to identify the locations of metal loading to Strawberry Creek and to quantify the extent of that loading. The results of the study are presented in *Quantification of Mass Loading to*

Strawberry Creek near the Gilt Edge Mine, Lawrence County, South Dakota, June 2003 (USGS 2006).

2.4.6.3 Climatic Evaluation for the Gilt Edge NPL Site

The Plant Science Department of South Dakota State University prepared and submitted the Final Report for Climatic Evaluation for the site. The objectives of the evaluation were to detail and summarize the climatic information for the mine area, analyze the data for application for soil and vegetation purposes, and archive the raw weather data from Deadwood and Lead, South Dakota. Climatic analyses, raw weather data, and conclusions are presented in *Gilt Edge Mine NPL Site Lawrence County, South Dakota Final Report for the Climatic Evaluation* (Malo et. al 2001).

2.5 Laboratory Method and Analysis

Evaluation of ARD involves the use of specialized analytical methods. Correct interpretation and understanding of results requires understanding the specific methods as well as the mineralogy of the rock. The following subsection provides a description of the analytical methods used to evaluate source materials in order to provide necessary background to understand nature and extent discussions for the source materials. 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 analyses, extraction tests, paste pH, and ABA.

2.5.1 Total Analysis

Total analyses were completed for most source materials. These analyses were completed by EPA CLP laboratories according to methods set forth in the EPA contract. Total metal, metalloid, and cyanide concentrations were determined using inductively coupled plasma atomic emission spectroscopy (ICP-AES) with a nitric acid/hydrogen peroxide digestion. The digestion method is set forth in EPA Method 3050B. This digestion is not a total digestion for elements bound in aluminum silicate structures, such as potassium feldspar, the dominant mineral in source rocks. The digestion is intended to dissolve elements that are most likely to impact the environment.

Data from total analyses are used in estimation of potential risks to human health by inhalation and incidental ingestion of dust. The BRA (EPA 2006a) utilized total data for mine waste and soils exposed at the surface. These samples were collected by CDM according to procedures described in *Total Metals Concentrations in Surface and Subsurface Soils* (CDM 2003c). The samples were composites of discrete point samples collected from the upper 2 inches of exposed soil, waste rock, or spent ore and were screened to 100 percent passing -60 mesh (250 microns) in order to provide a sample of the size fraction most likely to be inhaled or ingested. In general, total metals analyses of these samples are slightly higher as compared to samples of the same media collected at depth and not screened to -60 mesh. This may be a result of the significantly higher surface area available for reaction during the nitric acid/hydrogen peroxide digestions of the -60 mesh samples as compared to the coarser grained samples.

RGC also conducted total analyses on a subset of samples collected during their 2000 reconnaissance program. The digestion method utilized by RGC is not specified in their report of investigations. A comparison of RGC total analyses data to CDM total analyses data was completed for samples collected from the HLP. This evaluation indicated that RGC total analyses concentrations are generally higher than CDM total analyses concentrations. It is thought that RGC may have used one of the more common rock digestion procedures, such as aqua regia (a mixture of hydrochloric and nitric acid) or a multi-acid digestion (a mixture of hydrofluoric, nitric, and perchloric acids). These digestions are commonly used in lithogeochemical investigations of ore deposits because they dissolve many rock-forming minerals. Because the primary purpose of the total analyses was evaluation of potential toxicity based on EPA methods, evaluation of the CDM total metals dataset is prioritized in areas where both CDM and RGC analyses are available. The RGC data are evaluated in areas where only RGC total analyses data are available. Additional information regarding RGC total metals analyses can be found in RGC (2000).

2.5.2 Paste pH

The purpose of the paste PH analysis is to rapidly evaluate acid generating characteristics of mine waste in the field. The field analysis method is modified from Sobek (1978). In this method, a small sample of fine-grained rock or soil is mixed with deionized water to form a paste. The pH and total dissolved solids concentration of the paste are measured in the field. This type of analysis is very useful in areas of acid generating rock that were exposed to surface weathering for a period of years to decades. The tests qualitatively measure the water-soluble products of previous acid rock generation.

2.5.3 Extraction Test

Acid generation liberates contaminants from the mineral matrix into forms that dissolve readily. This significantly increases the mobility of the contaminants into surface or groundwater. Extraction tests evaluate the mobility of contaminants in solid phase mine waste in an extraction fluid.

Generally speaking, the tests are intended to simulate percolation of surface water through the mine waste and include:

- Addition of a known quantity of mine waste into an extraction vessel
- Addition of the extraction fluid
- Agitation of the mixture
- Measurement of dissolved contaminants in the extraction fluid

Three extraction test procedures were utilized in examining site samples, EPA Method 1311 TCLP, EPA Method 1312 SPLP, and a modified SPLP method developed by RGC. TCLP results can be used to assess whether a solid media (sludge) is

hazardous as defined under RCRA and was developed to simulate potential leachate formation within a landfill.

Details of the SPLP method are set forth as EPA Method 1312. The solution to solids ratio of the SPLP method is 20:1, with an extraction fluid intended to simulate natural precipitation. In the United States west of the Mississippi River, the extraction fluid is deionized water acidified to a pH of 5.00 ±0.05 standard units (su) with 60:40 mixture of sulfuric and nitric acid. This extraction fluid was used in site SPLP analyses. 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. SPLP tests conducted on site samples evaluated metals and metalloids potentially present in source materials.

The modified SPLP test is similar to EPA Method 1312. The primary difference is a reduced solution to solids ratio. The solution to solids ratio is reduced 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 extraction fluid in the modified procedure is deionized water acidified to a pH of between 5.0 and 5.5 using hydrochloric acid. The extraction vessel is an Erlenmeyer flask. The flask is capped and agitated in an automated agitation devise for 23 hours. Suspended solids are allowed to settle for a period of 1 hour, and the extraction fluid is filtered using a standard 0.45 µm millipore filter. The filtered extraction fluid is then preserved as necessary and analyzed for metals and metalloids. 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 modified procedure is valuable for mine waste samples for several reasons. Mine waste, 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 waste 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 waste ranges from about 20 percent to 50 percent (Freeze and Cherry 1978). This corresponds to a solution to solid ratio of about 1:2. So under natural conditions, the solution to solid ratio of mine waste under natural conditions is far lower than the solution to solid ratio of the EPA Method 1312 SPLP test. The modified procedure decreases the error associated with the solution to solid ratio somewhat.

Large unsaturated mine waste 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 report as non-detect results in the SPLP test. The modified procedure also decreases somewhat the errors attributed to dilution of very low concentrations of mobile contaminants. However, it is very important to recognize that a non-detect SPLP value for contaminants in the SPLP test or the modified SPLP test does not prove that discharge from mine waste piles will meet regulatory criteria because of the lack of sensitivity that is caused by the high ratio of extraction fluid to solids.

The substitution of hydrochloric acid for sulfuric/nitric acid in the modified test allows evaluation of sulfate and nitrate in the extraction fluid. Nitrate is the primary degradation product of cyanide under oxidizing conditions (Smith and Mudder 1999). Sulfate is an important product of acid generation. Acidification of the extraction fluid using sulfuric/nitric acid in the standard SPLP test interferes with the ability to evaluate these important contaminants.

Although the extraction fluid in both the SPLP and modified SPLP procedures is acidified, the buffering capacity of the extraction fluid is very low. In the case of strongly acid generating mine waste sample, the pH of the extraction is controlled by soluble acidity in the mine waste 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.

2.5.4 Acid Base Accounting

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 dependant on both the acid generating and acid neutralizing potential of a rock. Acid generation results from oxidation of sulfide minerals, such as pyrite (FeS_2). Acid neutralization results from minerals that will neutralize acid, such as calcite ($CaCO_3$) 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. Residual hydrated lime that was added to the ore as a process reagent is also a potential source of neutralization in spent ore. 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).

ABA investigations at the site were conducted in two phases. The first phase was completed by RGC and focused on surface and near-surface samples. This phase utilized an ABA method generally based on Lawrence (1990), which is a modification of the Sobek method (Sobek et al. 1978). The second phase of ABA investigation was conducted by CDM. This phase of the investigation utilized a similar method for estimation of acid potential, but it used a method of estimating neutralization potential based generally on the original Sobek method. These methods are discussed in the following paragraphs. It is necessary to incorporate data from both investigations into this remedial investigation analysis in order to retain an adequate sample density to understand variations in geochemical characteristics of source materials. Use of different ABA methods affects interpretation of the neutralization potential of the samples. This must be considered in order to correctly interpret available data.

In both ABA methods, 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 hydrochloric acid digestion is assumed to be gypsum ($CaSO_4 \cdot 2H_2O$) 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 ($Fe_3(SO_4)_4 \cdot 14H_2O$). Gypsum, coquimbite, rhomboclase, and roemerite were identified in X-ray diffraction analyses of secondary precipitates collected from acid generating rock in the Dakota Maid Pit (Gobla, M. written communication 2002). 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" (i.e. sulfur present in the mineral pyrite) is estimated based on sulfur in the nitric acid plus residual digestions or the difference between total sulfur and hydrochloric acid digestions. This assumption is valid at the Gilt Edge site because the dominant sulfide mineral present is pyrite. Sulfur interpreted to be sulfide sulfur based on this approach may also include barite ($BaSO_4$), a sulfate mineral with very low solubility, or other minerals containing sulfur, such as jarosite ($KFe_3(SO_4)_2(OH)_6$), that were incompletely digested in the ABA analysis. In the absence of detailed mineralogical analyses, a conservative interpretation is that this sulfur is pyrite. Nitric acid is not efficient at digesting silicate minerals, such as orthoclase or quartz, important mineral components of Gilt Edge rock. Solubility of pyrite or other sulfur-containing minerals in the various digestions is dependant on the efficiency of particle size reduction completed during sample preparation to liberate pyrite contained within mineral grains. Pyrite or other sulfur-containing minerals that are not liberated by particle size reduction may be encapsulated in silicate mineral phases. Sulfur within these encapsulated sulfur-containing minerals may not be detected in the nitric acid digestion but are detected in the total sulfur analysis.

The ABA method assumes that pyrite is the only sulfide mineral present and that the pyrite is oxidized by oxygen producing four moles of H^+ per mole of pyrite as shown below.

$$FeS_2 + 3.75O_2 + 3.5H_2O \rightarrow Fe(OH)_{3(s)} + 2SO_4^{2-} + 4H^+$$

Pyrite oxidation by dissolved ferric iron (Fe^{+3}) is also common, and the quantity of acid generated per mole of pyrite varies based on the reaction path. In addition, other sulfide or sulfosalt minerals are commonly present, which may or may not generate acid.

Estimating the neutralization potential of site samples was completed using two methods, which are termed the RGC method and CDM method. The RGC method is based generally on Lawrence (1990). This method uses a 2 gram sample, which is

crushed to -60 mesh (250 µm). Neutralization potential is estimated by adding a known quantity of hydrochloric acid to the sample followed by titration of the solution back to a pH of 8.3. 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. The quantity of acid consumed by the sample is the neutralization potential, which is estimated by difference and expressed in units of tons per kiloton calcium carbonate equivalent (t/kt CaCO3 eq).

The volume and normality of the hydrochloric acid is determined by a "fizz test" where a small amount of 25 percent hydrochloric acid is added to a 1 to 2 gram pulverized sample. Hydrochloric acid is added to the 2-gram sample in volumes that range from 20 ml to 80 ml in concentrations ranging from 0.1 to 0.5 normal. A qualitative "fizz rating" is estimated based on the amount of effervescence that occurs when the acid is added to the sample. Samples that contain significant quantities of carbonate minerals effervesce rapidly, whereas samples with low or nil concentrations of carbonate minerals effervesce slightly or not at all. The purpose of the fizz test is to determine the correct addition of hydrochloric acid to reduce the pH of the sample slurry to 2.0 to 2.5. The slurry of hydrochloric acid and sample is agitated for a period of 24 hours. The pH of the slurry is monitored, and the test is repeated if the correct pH range is not attained. The pH of the neutralization potential test affects the degree of mineral dissolution that occurs, with lower pHs causing additional dilution and therefore higher neutralization potential values (Jambor et al. 2003).

The neutralization potential analysis used in the CDM method is generally based on the method of Sobek et al. (1978). In the CDM method, the samples were crushed to 100 percent passing 100 mesh (screen aperture 149 micron). The finer grain size increases the surface area available for reaction, which generally increases neutralization potential measured in the test (Jambor et al. 2003). The fizz test is also used in this method. The initial quantity and normality of acid added to the sample is determined in the same manner. However in the CDM method, the slurry is heated nearly to boiling until the neutralization reaction is complete as indicated by the lack of gas evolution and particles settling evenly over the base of the flask. One hundred twenty-five ml of distilled water is then added, and the slurry is boiled for 1 minute. The resulting slurry is titrated in the same manner as described in the previous method. Heating and boiling of the sample slurry causes a more rigorous digestion of the sample. The resulting pH of the digestion in this method is less than 2.0. Both the finer grain size and the more rigorous digestion in the method used by CDM are likely to cause higher neutralization potentials as compared to the RGC method.

As a result of the uncertainties described in proceeding paragraphs, interpretation of ABA data is based on empirically derived thresholds. Application of these thresholds is site-specific and based on an understanding of the mineralogy of the mine waste and other factors. Acid potential (AP) and neutralization potential (NP) are expressed in equal units of t/kt $CaCO_3$ eq. The difference between neutralization potential and acid potential 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.

2.5.5 Inorganic Carbon Analysis

Inorganic carbon analyses were completed by RGC (2000) in order to limit the uncertainty in analyzing site neutralization potential (NP) data. The uncertainties include:

- Which minerals dissolve in the NP test?
- What is the effective pH of these mineral dissolution reactions?
- How do the kinetics of these dissolution reactions relate to the kinetics of sulfide oxidation in the field?

Carbonate minerals, such as calcite ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$), readily dissolve at slightly acidic pH values and provide kinetically rapid buffering capacity to resist decreases in pH caused by sulfide oxidation. It is now widely accepted that minerals other than carbonates dissolve at the low pH of the NP test and contribute to measured NP values (e.g. White et al. 1999, Jambor 2003). However, the effective pH and rate of dissolution of these minerals is not adequate to provide effective NP in the field. The purpose of inorganic carbon analysis is to estimate the quantity of NP that is attributable to carbonate minerals, which represents the "effective" NP of the sample.

Potential sources of inorganic carbon in a rock sample include carbonate minerals and graphite. In this evaluation, the quantity of inorganic carbon in a sample is assumed to be the carbonate mineral calcite ($CaCO_3$). The content of calcite is estimated based on the inorganic carbon concentration and is compared with NP values for the same samples. The evaluation indicates whether NP measured in the ABA test is attributable to carbonate minerals or to other minerals, which may not provide effective NP to the sample.

Section 3
Physical Characteristics

Section 3 focuses on physical characteristics of the site. As set forth by CERCLA guidance (EPA 1988), the purpose of this section is to describe the environmental setting at the site, including features such as soils, geology, hydrology, and climate. This evaluation focuses on physical characteristics important in understanding the generation, control, and remediation of ARD; migration routes; and exposure pathways. Developing an adequate understanding of site physical characteristics is vital to understanding the nature and extent of contamination, fate and transport, and risk assessments, which are discussed in detail in Sections 4, 5 and 6.

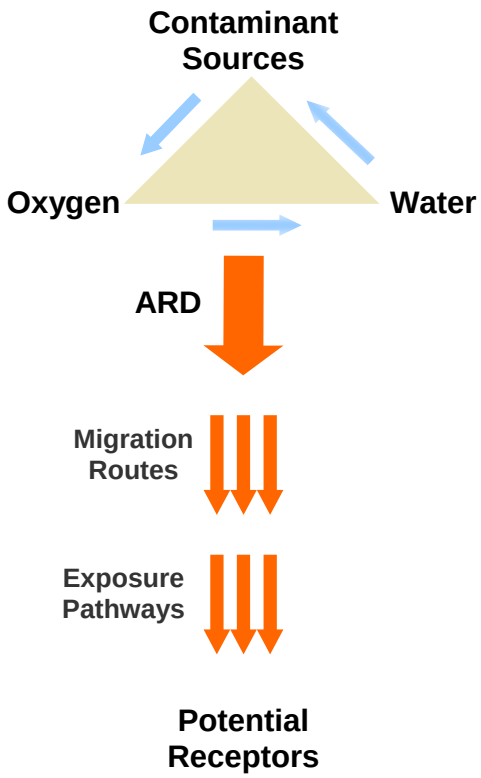


Exhibit 3-1. ARD Generation and Transport Model

Figure 3-1 shows the site boundary and the primary mine disturbance area.

The physical characteristics subsections are:

- Remediation subareas
- ARD collection and conveyance facilities
- Climate
- Geology
- Surface water
- Groundwater
- Groundwater-surface water interactions
- Water balance
- Land use and demographics

A brief discussion of the key points of each subsection is presented below:

Remediation subareas

- Subareas are an organizational strategy to describe major site features, such as mine pits, waste rock dumps, stockpiles, underground workings, and water treatment facilities.
- The subareas correspond to the FS, which addresses potential remedial technologies applicable to large areas having interrelated features that require integrated remedial strategies.

- The mining process removed rock from deep within the earth where oxygen is limited, increased its surface area through crushing and other processes, and placed it (in dumps, fills, etc.) in a near-surface oxygen rich environment.

- Exposure to air is an important component of the ARD generation and transport model (Exhibit 3-1) and is represented by the term "oxygen."

ARD Collection and Conveyance Facilities

- ARD is generated at numerous locations in the primary mine disturbance area.

- A complex network of pumping stations, pipelines, and storage facilities was developed in order to collect ARD and prevent catastrophic discharge into streams and drinking water sources.

- Site collection facilities capture most surface water at the site and convey it to Sunday Pit where the water is stored prior to treatment in the WTP.

- Although major releases are prevented, the system does allow smaller releases to surface water and underlying groundwater.

- These systems address the "ARD" portion of the ARD generation and transport model.

Climate

- The amount, timing, and potential for above average precipitation are critical factors necessary to evaluate ARD management and storage requirements.

- The site gets a significant amount of annual precipitation (rain, 29 inches, and snow, 139 inches), and the total annual precipitation for 95 percent of the water years was less than 40 inches.

- April, May, and June are the wettest months, with median monthly precipitation of 3.27, 3.61, and 3.33 inches, respectively.

- Departures from average precipitation are important to understanding the site (e.g., a precipitation record of 14.84 inches was set in May 1965).

- The evaluation of climate addresses the "water" component of the ARD generation and transport model.

Geology

- The site is a highly mineralized area with widespread pyrite mineralization and natural enrichments of metals, important factors contributing to generation of ARD.

- The geologic structure is complex and includes major areas of folding and fractures that influence infiltration of precipitation and fate and transport of contaminants in groundwater.

- The geology evaluation addresses the "Source Material" and "Migration Routes" components of the ARD model (Exhibit 3-1).

Surface Water

- Surface water is important to the potential migration of ARD-related contaminants and exposure of ecological receptors to contamination.
- Surface water bodies within and downstream of the site include perennial (Strawberry Creek and Bear Butte Creek), intermittent (Hoodoo and Ruby Gulches), and ephemeral streams.
- The site is a headwater area that contributes flow to coldwater fisheries in the two perennial streams.
- Surface water is a potential migration route into sensitive karst-hosted aquifers downstream of the site, which are a drinking water source for residential and municipal wells.
- ARD collection systems are present in Ruby and Hoodoo Gulches.
- The evaluation of surface water is particularly relevant to the "Migration Routes" portion of the ARD model.

Groundwater

- Groundwater is contaminated in the primary mine disturbance area, and understanding groundwater physical characteristics is critical to understanding the potential for this contamination to migrate in groundwater and affect potential human or ecological receptors.
- Aquifers present at the site include bedrock aquifers and alluvial aquifers, and groundwater velocity ranges from about 50 to 100 feet annually in the Strawberry Creek area.
- An uncontrolled discharge of ARD from the site could impact groundwater in a broad area extending eastward toward Sturgis and encompassing several regional aquifers (Madison and Minnelusa) that are used as private and municipal water sources.
- The evaluation of groundwater is pertinent to the "Migration Routes" portion of the ARD model.

Groundwater-Surface Water Interactions

- Groundwater-surface water interactions are extensive, control migration of ARD on and off site, and are important in understanding potential risks to receptors.
- Significant interactions include discharges of ARD from flooded underground mine workings and from springs to surface water.

- Dakota Maid Pit water is directly connected to groundwater, and the Sunday and Anchor Hill pits also appear to be connected, although not as directly.

- Bear Butte Creek averages a 100 percent loss of stream flow as it enters one of three loss zones, and these losses recharge the Madison aquifer throughout the year and also the Minnelusa aquifer (during periods of high stream flow).

- This discussion is germane to "Migration Routes" on the ARD model.

Site Water Balance

- The water balance defines an annual expected ARD yield (103 million gallons for average precipitation) and the normalized ARD yield (3.6 million gallons/inch of precipitation).

- Estimated inflows have ranged from 122 million gallons (2007 water year) to 42 million gallons (2004 water year).

- During particularly wet years (greater than 95 percentile precipitation), ARD inflows could exceed 148 million gallons. The record monthly precipitation of 14.84 inches of precipitation could generate ARD inflows of 53 million gallons in one month.

- The estimated rate of ARD collected from *groundwater* in the areas of primary mine disturbance is 69 gpm (36 million gallons annually).

- Approximately 112 gpm of ARD is collected from *surface water* runoff and direct precipitation on pit lakes and ponds.

- Water balance data allow impacts of wet years to be estimated, including requirements for ARD collection, storage, and treatment to prevent a catastrophic release.

- The site water balance addresses the "ARD" portion on the ARD model.

Land Use and Demographics

- Land data are useful for issues related to final land use and institutional controls and are part of the evaluation of "Potential Receptors."

- Site land is mostly private, with some federal land and isolated parcels of state-owned land acquired to provide for construction of the Ruby Repository.

- Nearby private land is mostly residential but includes a few small ranches and businesses.

- Nearby public land is used for recreation (hiking, hunting, and all-terrain vehicle operation) and industry (logging and forest management activities).

3.1 Remediation Subareas

As described in Section 1, a systematic method of categorizing contaminated media of concern and site features by geographic location was initially developed during the preliminary feasibility study (CDM 2004c). This approach divided the site into multiple geographical regions (remediation subareas) that encompass large expanses of the site with interrelated features requiring integrated remedial strategies. This organizational strategy was adopted for this remedial investigation report in order to provide continuity between the remedial investigation and feasibility study reports. The remediation subareas are shown on Figure 3.1-1.

3.1.1 Anchor Hill Pit Remediation Subarea

The Anchor Hill Pit Remediation Subarea is located on the northwest edge of the mine disturbance area and includes the Anchor Hill Pit, two areas of shot muck, a small topsoil stockpile, remnants of several EPA treatability tests, and alkaline waste products that were stockpiled by BMC to use in mine reclamation. The pit is currently used as a storage facility for water that is not dischargeable quality. This water includes ARD pumped into the pit in 2006 and water that was partially treated in an EPA pit lake treatability study.

Exhibit 3-2. Anchor Hill Pit Remediation Subarea, Facing North

3.1.1.1 Anchor Hill Pit

The Anchor Hill Pit encompasses an area of approximately 28.6 acres. The pit is elongated in a northeast-southwest orientation with approximate dimensions of 1900 feet by 750 feet. The northwest highwall of Anchor Hill Pit has the highest vertical extent at 340 feet. The pit access road enters the pit on the south corner and wraps around the pit in a counterclockwise direction, declining to the pit floor.

The slope of the northwest highwall at Anchor Hill is approximately 60 degrees between benches. Safety benches are located at intervals of 60 vertical feet and range in width from 20 to 30 feet. The overall slope of the northwest highwall is approximately 50 degrees. A particularly steep highwall is located in the southwestern corner of the pit. The vertical height of this portion of the highwall is 115 feet, with a slope of approximately 71 degrees. It is common for highwalls to spall over time. This is reflected by common accumulations of broken rock on the pit safety benches. The steep highwalls at Anchor Hill Pit, as well as the highwall expanse with no safety bench for 115 vertical

Exhibit 3-3. Anchor Hill Pit, Facing Northeast

feet, are potential safety hazards that should be considered during remedial design at the site.

3.1.1.2 Stored Water and ARD Neutralization Sludge

The Anchor Hill Pit has been used for several purposes since the site was abandoned. In 2001, EPA initiated a large-scale treatability test in Anchor Hill Pit. This test involved pumping approximately 70 million gallons of ARD and HLP process solutions into the Anchor Hill Pit for treatment using an experimental biological sulfate reduction process. Reagents, including molasses, lime, sodium hydroxide, and phosphorous, were added to the pit lake to promote biological sulfate reduction. A portion of this water was successfully treated in the test and discharged to Strawberry Creek. However, approximately 52 million gallons of biologically treated water remain in the pit that is not discharge quality. The Anchor Hill Pit Lake also contains an estimated 4.6 million gallons of sludge that was generated by the treatability test. This sludge consists of a mix of native sediments, ARD neutralization sludge, biomass, and potentially metal sulfides.

The Anchor Hill Pit is currently used as a backup ARD storage facility. A heavy snowfall season in 2006 resulted in water balance problems, prompting the need to use Anchor Hill Pit as an ARD storage vessel. Currently, 112 million gallons of contaminated water are present in Anchor Hill Pit, including ARD and ARD that was partially treated in the Anchor Hill Pit Lake treatability test. Although some mixing of these waters has occurred over time, a sharp chemocline between circumneutral pH water and ARD is still present within the pit lake. ARD is pumped to the Anchor Hill Pit when the storage capacity in Sunday Pit exceeds the 60.4 million gallon operational limit (see Section 3.1.11 for a description of the Sunday Pit Remediation Subarea).

3.1.1.3 Unconsolidated Rock Piles

Unconsolidated rock, including shot muck and waste rock, is present in the Anchor Hill Pit Remediation Subarea. Shot muck is a mining term for rock that has been blasted but not excavated. The upper mining benches on the southwest and north sides of Anchor Hill Pit contain shot muck. This rock is basically in place, with the exception of displacement that occurred when the rock was blasted. This rock was fragmented by blasting, and although it is not technically fill material, it is discussed with the other various fill areas in Section 4, Nature and Extent of Contamination. The estimated volume of unconsolidated rock is 77,000 cy.

3.1.1.4 Soil Stockpile

A small soil stockpile is present on the south side of Anchor Hill Pit. The location of this stockpile is shown on Figure 3.1-2. The estimated volume of this pile is 1,100 cy. The stockpiled soil is a mixture of topsoil and subsoil that was removed from natural slopes during site development. Samples were collected from site soil stockpiles in order to evaluate physical and chemical characteristics of the stockpiles (CDM 2003d). Selected data collected during this investigation are presented in Table 3.1-1.

Soil textures were evaluated through particle size analyses and are described based on standard soil texture classifications (U.S. Department of Agriculture [USDA] 1993). The stockpile contains large quantities of rock fragments. For purposes of the USDA soil texture classification, rocks are defined as particles that are 2 millimeters in diameter or larger. The average content of rocks in soil samples collected from the stockpile is 82 percent. The components of the stockpiled soil that are smaller than 2 millimeters in diameter consist of sand, silt, and clay-sized grains. The textural classification of the stockpiled soils is an extremely rocky loam in the USDA soil texture classification. This generally corresponds to a silty gravel in the Unified Soil Classification System, which is denoted by the group symbol GM. The high rock content is advantageous in relation to mitigating erosion on reclaimed slopes. However, the rocks displace finer grained soil particles and limit water holding capacity and organic matter content. This decreases the capacity of the soil to support vegetation. The organic matter content in samples from the soil stockpile is 1.8 percent, which is in the very low range for soil organic matter concentrations (Munshower 1993).

3.1.1.5 EPA Treatability Tests

EPA conducted several treatability tests in the Anchor Hill Remediation Subarea, which consist of the pit lake treatability test, a multi-cell treatability test, and several treatability tests using a proprietary substance called Bauxsol. Remnants of the pit lake test were discussed previously. The multi-cell test involved large, lined bins that held highly acid generating rock. The Bauxsol tests included several barrels as well as a lined trench filled with mixtures of acid generating rocks and the Bauxsol reagent. An estimated 2,000 cy of fill is present within a multi-cell treatability apparatus constructed by EPA. This apparatus consists of a wood structure containing eight cells filled with strongly acidic waste rock. A small quantity of fill is also present that was hauled to the site but not placed into the treatability cells. These cells were treated with various reagents as described in CDM 2006d.

Exhibit 3-4. Multi-Cell Treatability Study Apparatus

3.1.1.6 Stockpiled Alkaline Waste Products

Two stockpiles of alkaline waste products are present in the Anchor Hill Pit Remediation Subarea (Figure 3.1-2). The alkaline waste products were collected by BMC to use in site remediation activities and were moved to their current location by EPA.

The first pile reportedly contains fly ash generated by Ben French Power Plant in Rapid City, South Dakota, which is operated by Black Hills Corporation. Fly ash is a waste product produced during combustion of coal for electricity generation. The fly ash may contain residual products of coal combustion, components that were

scrubbed from stack emissions, and unreacted lime resulting from the scrubbing process. The estimated volume of fly ash in the stockpile is 1,000 cy.

The second stockpile reportedly contains hydrated lime that was produced as a byproduct of acetylene gas manufacture in Gillette, Wyoming. This pile produces a white colored runoff with pH of about 11 su, which is characteristic of lime. The pile was exposed to the atmosphere for at least 7 years, so it is likely that is contains a mixture of hydrated lime ($Ca(OH_2)$) and calcium carbonate ($CaCO_3$), which is produced through interaction of hydrated lime with carbon dioxide. It is also likely that this pile contains sediments that resulted from re-handling of the lime. The volume of this pile is estimated at 2,000 cy.

3.1.2 Dakota Maid Pit Remediation Subarea

The Dakota Maid Pit Remediation Subarea is located in the central portion of the mine disturbance area and includes the Dakota Maid Pit, a tailings repository, a topsoil stockpile, a pit backfill, the King underground workings, and the Cyprus decline. The pit contains stored ARD as well as water treatment plant sludge.

Exhibit 3-5. Dakota Maid Pit, Facing Southwest

3.1.2.1 Dakota Maid Pit

The Dakota Maid Pit is a side-hill pit located on the east side of the Strawberry Creek drainage. The Dakota Maid Pit is constructed on the west side of a steep hill called Union Hill. The eastern highwall of the pit is the highest, with vertical relief of approximately 320 feet. The western side of the pit is adjacent to the Strawberry Creek drainage and is only 50 feet high as a result of the natural topography. The north highwall of the pit is approximately 220 feet high at the highest point. A highwall is not present on the south side of the pit, and a moderate slope leads from the access road into the pit. This is the current access to the pit floor. The dimensions of the Dakota Maid Pit are approximately 1,000 feet in the northeast-southwest direction by approximately 750 feet in the northwest-southeast orientation. The pit contains two lobes, one extending toward the north and one extending toward the northeast. The north-trending lobe was historically called the "bunny ear" by site personnel. The Bunny Ear portion of Dakota Maid Pit was backfilled and reclaimed. The disturbed area of the pit is approximately 14 acres, including the backfilled Bunny Ear Area.

The slope of the east highwall at Dakota Maid ranges from approximately 50 degrees to 56 degrees between safety benches, with an overall slope of approximately 44 degrees. The safety benches are spaced at a vertical interval of 60 feet and are approximately 20 feet wide. The safety benches have spalled in local areas to a width

of approximately 10 feet. The safety benches are covered with loose rock that has spalled from the highwall since the pit was constructed during the late 1980s and early 1990s.

A ridge of rock remains in an area between the Dakota Maid Pit and the Sunday Pit. This ridge is bounded by the southeast highwall of Dakota Maid Pit and the north highwall of Sunday Pit. The convex shape of the ridge causes this area to be at a higher risk of slope failure than the other highwalls at Dakota Maid and Sunday pits. The safety benches on the protruding edge of this ridge are wider, ranging up to 60 feet in some areas where they are associated with a bulldozer trail leading partially up the highwall. This mitigates the risk of large-scale slope failure in this area somewhat because it decreases the overall slope of the highwall.

3.1.2.2 Stored ARD and Water Treatment Plant Sludge

The Dakota Maid Pit contains stored ARD and water treatment plant sludge. The ARD results from runoff of precipitation from pit highwalls, direct precipitation on the ARD pit lake, and leakage from the Sunday Pit Remediation Subarea. The total volume of ARD stored within the Dakota Maid Pit was 6.89 million gallons at the end of the 2006 water year (i.e. September 30, 2006).

The Dakota Maid Pit also contains sodium hydroxide water treatment plant sludge. This sludge was generated in a water treatment plant operated by BMC in the mid-1990s. The plant used liquid sodium hydroxide to increase pH of ARD and precipitate metal hydroxide sludge. The sludge contains toxic heavy metals and other contaminants removed from ARD during treatment. Additional sludge was deposited within the pit from the Pond C hard bucket sodium hydroxide treatment system when it was in operation. In fall 2004, the hard bucket treatment system was removed, and a mixture of neutralization sludge and sediments from Pond C were excavated and placed in a pile to the west of the access road to the Dakota Maid Pit Lake. The volume of sludge present in the Dakota Maid Pit Remediation Subarea is estimated at 1.9 million gallons.

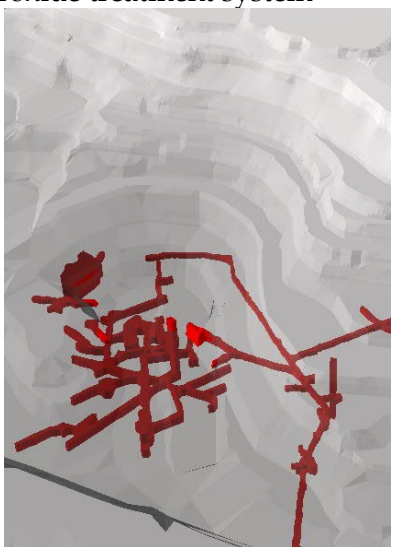


Exhibit 3-6. Schematic of Underground Workings Beneath Dakota Maid Pit

3.1.2.3 Underground Workings

The Dakota Maid Pit was constructed in a region of prior underground mining. Underground workings within the Dakota Maid Remediation Subarea include the upper and lower level King workings, the King Shaft, the King Adit, and the Cyprus decline. The King workings were partially mined through during construction of the pit. Two openings are currently present in the eastern highwall of the pit, which lead into the remaining portion of the upper-level King workings. These openings were created during construction of the pit. The lower-level King workings lie beneath the pit floor at a depth of approximately 80 to 100

feet. A vertical shaft is present in the northern portion of Dakota Maid Pit, which leads into the lower level King workings. The King Adit and the partially collapsed Cyprus decline are located along the southwestern margin of the remediation area. A map of the underground workings is shown as Figure 3.1-3.

The lower level King workings contain sub-horizontal tunnels that lead away from the shaft as well as mined out areas. Mined out areas are generally called "stopes" in mining terminology. The stopes were excavated upward from the lower level workings toward the current pit floor. In the winter of 2000-2001, a portion of the pit floor subsided into an old stope, leaving a vertical surface opening approximately 20 feet in diameter in the pit floor. This subsidence area is located approximately 50 feet south of the King Shaft. It is unknown if other areas of the pit floor contain stopes in close proximity to the current floor of the pit. The existing openings into the lower level King workings, as well as the potential for unknown stopes near the current base of the pit, are safety hazards that should be considered during feasibility study and remedial design.

Exhibit 3-7. Dakota Maid Pit East Highwall, Facing East

The King Adit and Cyprus decline are located on the southwestern edge of the Dakota Maid Remediation Subarea and intersect the upper level King workings based on available underground maps. An adit is an approximately horizontal tunnel into an underground mine. A decline is an opening into an underground mine that slopes downward as it enters the mine. The King Adit drains ARD from the upper level King underground workings into Pond D, which is located within the Strawberry Gulch Remediation Subarea (Figure 3.1-1). The King Adit is reported to have been plugged with bentonite although the drainage observed from the adit into Pond D is evidence that the plug is not preventing discharge of ARD from the Dakota Maid Pit Remediation Subarea into the Strawberry Gulch Remediation Subarea. Drainage from the King Adit controls the maximum level of ARD that can be stored in Dakota Maid Pit. The portal of the King Adit is collapsed, and the ARD discharge emanates from a zone of unconsolidated rock at the location of the adit portal. The Cyprus decline is located south and east of the King Adit and extends northeast from the slopes between Pond E (also known as Strawberry Pond) and Pond D toward the upper level King workings. This decline is partially collapsed and is marked on the surface by an area of subsidence. The exact location of the portal of the Cyprus decline is not evident based on current site topography.

3.1.2.4 Bunny Ear Pit Backfill

The Bunny Ear was backfilled in the second and third quarters of 1996 with reclamation fill mined from the Anchor Hill Pit. This area was covered with topsoil and revegetated. The volume of Bunny Ear fill is estimated to be 146,000 cy.

3.1.2.5 Tailings Repository

In the fall of 1993, BMC removed approximately 150,000 tons of acid generating tailings from Strawberry Creek. These tailings were blended with alkaline fly ash from a local coal-fired power plant and were placed into two tailings repositories. One of these repositories is located within the Dakota Maid Remediation Subarea. The tailings were placed in 12-inch thick compacted lifts. The tailings were amended with a volume of fly ash intended to achieve a neutralization potential to acid potential ratio of 3:1 (Durkin 1994).

The tailings repository within the Dakota Maid Remediation Subarea is located in the north end of the remediation subarea. This location was chosen because it is an area with limited potential for groundwater inflows and run-on of stormwater. A low permeability clay cover was constructed over the amended tailings repositories in 1994. Permit requirements for the clay cover included compaction to 90 percent modified Proctor density and 95 percent standard Proctor density, with a maximum permeability of 1×10^{-7} centimeters per second (cm/sec). The repositories were covered with topsoil and planted with a seed mixture approved by DENR (Durkin 1994). The volume of the tailings repository within the Dakota Maid Remediation Subarea is estimated at 50,000 cy.

3.1.2.6 Soil Stockpile

A soil stockpile is located on top of the tailings repository (Figure 3.1-2). The stockpiled soil is a mixture of topsoil and subsoil that was removed from previously undisturbed areas during site development. Samples were collected from the stockpiles in order to evaluate physical and chemical characteristics (CDM 2003d). Selected data collected during this investigation are presented in Table 3.1-1. The volume of the soil stockpile is estimated at 82,000 cy.

The stockpile contains large quantities of rock fragments. The textural classification of the stockpiled soils is an extremely rocky loam in the USDA (1993) soil texture classification, with an average rock content of 82 percent based on the CDM samples. The organic matter content in samples from the soil stockpile is 1.6 percent, which is in the very low range for soil organic matter concentrations (Munshower 1993).

3.1.3 Hoodoo Fill Remediation Subarea

The Hoodoo Fill Remediation Subarea is located on the southeast side of the mine disturbance area. The primary feature of the Hoodoo Fill Remediation Subarea is the Hoodoo Fill, which is essentially a small valley fill waste dump that was placed into the upper portion of the Hoodoo Gulch drainage. The historic Hoodoo mine is present underneath the fill based on available information. ARD generated within the Hoodoo drainage is collected at a facility located approximately 500 feet downstream

of the fill. This area is not included in the Hoodoo Fill Remediation Subarea; however, the pipeline extending from the collection facility to Sunday Pit extends up the angle of repose face of the fill and is buried within the road. Two stockpiles are also present in the subarea, which contain soil and riprap.

3.1.3.1 Hoodoo Fill

The Hoodoo Fill was constructed in the early stages of mine development in order to provide a haul road extending from Sunday Pit to the crusher area. The source of rock placed into the fill is unknown, but it may contain a mixture of rock mined from Dakota Maid and Sunday pits as well as rock excavated from construction cuts in other areas of the mine disturbance area. The estimated volume of the Hoodoo Fill is 335,000 cy.

Exhibit 3-8. Hoodoo Fill, Facing Northwest

3.1.3.2 Hoodoo Mine

Extensive underground mine workings are reported in the Hoodoo Gulch area, which include a vertical shaft, an adit, an extensive tunnel, and several crosscuts. The workings were not investigated in detail, and no attempts were made to locate or enter the workings. Several areas of surface excavations and associated waste rock dumps are evident in the area down-slope from the Hoodoo Fill. Waterland (1991) reports that the Hoodoo shaft extended to a depth of 350 feet and was connected to other underground workings in the Union Hill area. The Hoodoo mine is reported to have been extensively developed by tunnels and cross-cuts. Reported underground mine workings in the Hoodoo Gulch area are included on Figure 3.1-3.

3.1.3.3 Hoodoo Road Slope Soil Stockpile

The Hoodoo road slope soil stockpile is located on the east side of the Hoodoo Fill Remediation Subarea near the water treatment plant (Figure 3.1-2). A large portion of this stockpile was used during construction of the Ruby Repository. The volume of remaining soil in the stockpile is estimated to be 700 cy. This stockpile was sampled by CDM during the soils and vegetation investigation (CDM 2003d). The soil samples exhibited a similar texture to the piles previously discussed and are classified as an extremely rocky loam based on the USDA soil texture classification (USDA 1993). The stockpile contained 82 percent rock fragments based on the USDA threshold defining rocks as greater than 2 millimeters in diameter. The organic matter content was 1.7 percent, which is in the very low range for natural soils (Munshower 1993). Additional details regarding soil physical parameters are summarized in Table 3.1-1.

3.1.3.4 Hoodoo Riprap Stockpile

The Hoodoo riprap stockpile is riprap that was produced during construction of the clean water diversion system at the Ruby repository. The riprap was developed from rhyolite porphyry mined from the rock quarry area, which is located within the Ruby Repository Remediation Subarea (Figure 3.1-2). The estimated volume of the riprap resource is estimated to be approximately 1,000 cy.

3.1.4 Heap Leach Pad Remediation Subarea

The Heap Leach Pad Remediation Subarea encompasses the HLP liner system, construction fills placed during HLP construction, spent ore located on the HLP, construction rock stockpiles, and water treatment plant sludge from the existing high-density sludge water treatment plant.

3.1.4.1 Heap Leach Pad Liner System

The mineral processing circuit at the mine formerly included the HLP, several lined process water ponds, and the Merrill-Crowe mineral processing plant. Ore was placed on the HLP and treated with a dilute cyanide solution, which dissolved microscopic gold from the rock. The pregnant solution, a cyanide solution carrying dissolved gold, was collected on the HLP liner and pumped to the Surge Pond, which is located on the east side of the mineral processing plant. This solution was pumped into the plant and treated using a Merrill-Crowe process to remove dissolved gold.

Exhibit 3-9. Heap Leach Pad, Facing Southeast

The HLP covers an area of approximately 37 acres and was designed as an on- and off-load facility, with a maximum capacity of approximately 4 million tons. The HLP currently contains 13 cells as a result of expansions completed during 1996 and 1997. The original HLP consisted of seven cells. The facility was constructed by excavating along a ridge line and placing fill rock on the west side of the ridge line to form a flat area for HLP construction. The HLP was expanded in two phases. The first phase expansion is located east of the original HLP and consists of Cells 8, 9, and 10. The second phase expansion is located east of the first expansion and consists of Cells 11, 12, and 13. Both of the expansions were constructed on areas that were filled in with waste rock and spent ore during the mine development. A diagram of the HLP system is presented in Figure 3.1-4.

The HLP contains multiple liner systems. The upper liner is underlain by a permeable layer of gravel or geosynthetic net and a lower liner. Leak detection pipes extend between the two liners to allow detection and pumping of fluids that leak through the upper liner. These leak detection systems also serve to reduce the hydraulic head on the lower liner, which reduces the amount of leakage through the liner system. Each phase of HLP development utilized different construction processes and materials as described below.

The liner for the original seven cells was constructed in 1988 using the following materials described from the top down:

- A primary liner consisting of a 3-inch thick asphaltic concrete top layer, underlain by a petromat geotextile, and a 3-inch thick asphaltic concrete lower layer
- A 2-foot thick drain rock layer serving as leak detection, collection, recovery system (LDCRS) beneath the lower asphaltic concrete layer
- A 0.06-inch thick (60 mil) high density polyethylene (HDPE) secondary liner
- A 12-inch thick low-permeability soil liner consisting of relic tailings amended with bentonite to a hydraulic conductivity of less than 10^{-7} cm/sec

When leaching operations began in 1988, process solution was detected in the leak detection system in concentrations that exceeded limits established by permit conditions. Leaching operations were temporarily suspended. Subsequent design and construction investigations identified excessive cracking within the asphaltic concrete layers. The embedded petromat geotextile contributed to leakage because it provided a conduit for leakage between the upper and lower asphaltic concrete layers. Although the petromat was originally designed as a low permeability liner, it was identified that laying hot asphaltic concrete over the geotextile adsorbed the petroleum product out of the petromat geotextile and in effect robbed it of its low permeability attributes.

Initial liner repair efforts were limited to a surface treatment of the asphaltic top liner with medium curing asphalt (MC-70 and MC-250) and paving grade asphalts. Leakage rates were reduced; however, improvements were insufficient to meet conditions outlined within South Dakota Large Scale Permit No 439. Therefore, in 1989, BMC repaired the entire HLP liner system as follows, from top to bottom:

- A new 80-mil very low-density polyethylene (VLDPE) primary liner
- A protective geotextile
- A 4-inch thick sand secondary LDCRS layer
- A MC-70 tack coat
- The original pad lining system as previously described

The first HLP expansion encompassed 8 acres and added Cells 8, 9, and 10. The liner system constructed for this expansion (top to bottom) is as follows:

- An 80-mil textured HDPE primary liner
- A geonet LDCRS layer
- A 60-mil textured HDPE secondary liner
- A geosynthetic clay liner (GCL).

The liner system constructed for the second HLP expansion (top to bottom) is as follows:

- An 80-mil low-density polyethylene (LDPE) smooth sheet primary liner
- A 1-foot thickness ¾-inch minus drain rock as the LDCRS
- A 60-mil LDPE smooth sheet secondary liner
- A GCL

This most recent expansion was not approved for operational leaching. During hydrostatic testing in 1997, the primary liner of expansion Cells 11 through 13 was found to be leaking at rates up to 500 gallons per acre per day. During the time that BMC was investigating the cause for the leaks and considering necessary repairs, mining operations at the site ceased. Cells 11 through 13 were never used for cyanide leaching.

Currently, water that collects on the HLP flows toward the southwest corner where it collects in a sump. This water is periodically pumped to the Stormwater Pond and/or Sunday Pit for storage prior to treatment. Site personnel continue to maintain the leak detection system by pumping out operational cells on a routine basis. This decreases the potential for water to leak from the HLP system into groundwater. In the 2006 water year (October 1, 2005 to September 30, 2006), the HLP produced 7.5 million gallons of ARD.

3.1.4.2 Fills Placed During Heap Leach Pad Construction

Fills were placed during HLP construction in order to create suitable topography. Fills under the east side of the HLP are a part of Ruby Gulch waste rock dump and drain toward Ruby Gulch. Fills under the west side of the HLP are exposed in a constructed fill extending along the west side of the HLP. Drainage generated by these fills reports to the Strawberry Creek drainage. A volume of 344,000 cy was estimated for the western HLP construction fill based on available topographic and HLP construction data. The volume of fill on the east side of the HLP has not been evaluated because it is contiguous with the Ruby Gulch waste rock dump.

3.1.4.3 Spent Ore Located on the Heap Leach Pad

The HLP is loaded with crushed rock that has passed a 2-inch screen and run-of-mine rock, which is rock that was blasted in the mine pit but was not crushed. The grain size of the run-of-mine rock is on the order of 2 to 3 feet in diameter. Spent ore on the HLP is described as an angular sandy gravel of variable lithology (RGC 2000). The maximum elevation of the HLP is approximately 5,700 feet above mean sea level, with an average relief of 150 feet. Side slopes generally consist of loose gravel and have an average slope of two horizontal to one vertical or slightly steeper. A number of small scale slope failures are present along with gullies formed by erosion.

Available data regarding the source and location of rock placed on the HLP was compiled by DENR based on quarterly reports prepared by BMC and other unpublished DENR files. Spent ore on the HLP includes a mixture of rock classified by BMC as sulfide and oxide from the Dakota Maid, Sunday, Langley, and Anchor Hill pits.

The sulfide versus oxide designation was initially a metallurgical classification because gold associated with sulfide minerals is difficult to recover using the heap leach process. As part of state permit requirements for the Anchor Hill and Langley pit developments, BMC was required to complete analyses of acid potential prior to placing ore on the HLP from the Langley or Anchor Hill pits. Permit requirements also specified submittal of detailed reports to DENR, which included data regarding the ore placed on the HLP from Anchor Hill and Langley pits.

Exhibit 3-10. Lower West Side of Heap Leach Pad, Facing South

The HLP was loaded by end dumping mine haul trucks in lifts approximately 20- to 30- feet thick. Rock placed on the HLP was amended with lime in order to maintain the pH of the process solution above approximately 10. This is necessary in order to prevent formation of hydrogen cyanide gas. The lime addition rate is reported to have ranged from approximately 3 to 20 pounds per ton, with an average of about 5 pounds per ton (Hight 2001).

The sequence of loading and the general location of various ore types are known based on DENR compilation. The lower two lifts of Cells 1 through 7 were loaded with sulfide ore. This includes 44,000 tons of sulfide rock from a bio-oxidation test and 625,000 tons from a sulfide stockpile. The bio-oxidation rock is located on the first lift of Cell 5, and the sulfide stockpile rock is located on the first lifts of Cells 1, 2, 3, 4, 6, and 7 and the second lifts of Cells 1 through 7. This rock was mined from the Dakota Maid and Sunday pits prior to development of Anchor Hill or Langley pits. It

is likely that this rock was designated as sulfide based on metallurgical characteristics. The rock contained concentrations of sulfide minerals that rendered mineral processing and gold recovery less economic than processing of relatively more oxidized ore from Dakota Maid and Sunday pits. The sulfide ore was processed during a hiatus in active mining that occurred prior to state approval of Large Scale Mine Permit 468 in 1996. The sulfide ore was reportedly amended with extra lime and/or limestone in order to prevent ARD generation.

Ore mined from Anchor Hill and Langley pits was placed over the two lifts of Dakota Maid/Sunday sulfide ore on Cells 1 through 7 and on all lifts of Cells 8 through 10. The volume of ore placed on the HLP from Anchor Hill and Langley pits is estimated at 2.5 to 2.6 million tons. The total sulfur content of this ore was evaluated by BMC and DENR during mining in order to prevent placing acid generating ore on the HLP. Although the relative success of this program is unknown, total sulfur values measured by BMC and reported to DENR suggest that the ore contained significantly lower concentrations of potentially acid generating minerals than the underlying sulfide ore.

An additional 200,000 to 300,000 tons of ore reportedly was placed on the HLP from a low-grade stockpile mined from Dakota Maid and Sunday pits. This rock is commingled with rock from Anchor Hill and Langley pits. The degree of oxidation of this low-grade stockpile is unknown.

During construction of Ruby Repository between 2001 and 2003, approximately 430,000 tons of HLP spent ore was removed from the north end of the HLP (Gobla 2006). This material was used in construction of Ruby Repository as bedding beneath the low density polyethylene cover. This material was excavated from lifts containing both Anchor Hill/Langley rock and Sunday/Dakota Maid rock. The following data compilation assumes that 70 percent of the construction material came from upper lifts containing Anchor Hill/Langley rock, and 30 percent came from the lower lifts containing Sunday/Dakota Maid rock. This assumption is based on a visual estimate of the areas excavated during Ruby Repository Construction.

It is estimated that the HLP contains approximately 2.2 million cy of spent ore. Approximately 1.5 million cy of the total were mined from Anchor Hill and Langley pits under permit conditions set forth in Large Scale Mine Permit 468. Approximately 400,000 cy were mined at Dakota Maid and Sunday pits, contain high concentrations of sulfide minerals, and are located on the lower two lifts of Cells 1 through 7. Approximately 200,000 cy of the spent ore are from a low grade stockpile of ore mined from the Sunday and Dakota Maid pits. This rock is commingled with the rock from Anchor Hill and Langley pits. These values were rounded to the nearest 100,000 cy to reflect the degree of uncertainty in the estimate. Based on existing topographical features of the HLP, it appears that five lifts of ore were successively stockpiled and leached on the HLP, with each lift having an average thickness of approximately 20 to 30 feet.

3.1.4.4 Construction Rock Stockpiles

During construction of the Ruby Repository in 2002, a large quantity of construction rock was hauled to the site. This rock was hauled from the U.S. Highway 385 reconstruction project that was occurring near the mine site. A large stockpile of this rock remains on site, located on the east side of the heap leach pad (Figure 3.1-2). The majority of the rock is Precambrian mica schist and quartz mica schist. Smaller quantities of various Tertiary porphyry rocks, including latite porphyry and rhyolite porphyry, are also present. The volume of the Highway 385 stockpile is estimated to be 140,000 cy.

3.1.4.5 Water Treatment Plant Sludge

The northeast corner of the HLP is currently being used for storage of sludge generated in the WTP. This sludge consists of iron and aluminum hydroxides and hydroxysulfates that precipitate when hydrated lime is added to ARD solutions within the high-density sludge water treatment plant. The sludge has a gelatinous consistency and has a water content of 70 to 80 percent. The sludge contains high concentrations of toxic metals and metalloids that were removed from ARD. The volume of sludge placed on the HLP was approximately 2.5 million gallons through the end of the 2006 water year.

Exhibit 3-11. WTP Sludge Impoundment, Facing South

3.1.5 Langley Benches Remediation Subarea

The Langley Benches Remediation Subarea includes the Langley pits, several access roads leading to the pits, and areas of waste rock fills. The subarea is located on the south end of the mine disturbance area. The peak of Langley Hill separates the Langley Benches Remediation Subarea from the Sunday Pit Remediation Subarea.

Exhibit 3-12. Langley Benches Remediation Subarea, Facing Southeast

3.1.5.1 Mine Pits

The Langley Benches Remediation Subarea contains two side-hill pits. These pits are significantly smaller than the Dakota Maid, Sunday, or Anchor Hill pits. The pits are called the North Langley and Southeast Langley pits. The North

Langley Pit was partially backfilled with waste rock and is reclaimed. The southeast Langley pit also contains some backfill in the base of the pit. The estimated volume of backfill in the North Langley Pit is 121,000, cy and the estimated volume in the Southeast Langley Pit is 83,000 cy.

Highwalls at the Langley pits range from approximately 30 to 175 feet in height. The Southeast Langley pit has the largest highwall, which is located on the north side of the pit adjacent to Langley Hill. The vertical height of this highwall is 175 feet, with a slope of approximately 58 degrees. There is one safety bench that extends about halfway across the highwall. Highwalls on the south and south east sides are considerably smaller, ranging from approximately 30 feet to 60 feet in height.

3.1.5.2 Access Roads and Waste Rock Fills

The disturbance area associated with the Langley pits includes areas with thin veneers of waste rock formed by excavation of three access roads along the contour of the natural slope. Waste rock fills have also been placed in this area to facilitate access road construction. The volume of these waste rock fills is estimated at 119,000 cy.

3.1.6 Process Plant Remediation Subarea

The Process Plant Remediation Subarea is located in the central portion of the primary mine disturbance area and includes components of the gold processing plant, waste rock fills, remnants of EPA treatability investigations, the laboratory building, and storage areas (Figure 3.1-1). The primary gold processing plant was largely dismantled, and the building is now an important component of site operations and maintenance infrastructure, including break room, toilet facilities, offices, maintenance shop, and equipment storage facilities. The assay building is also a component of site operations and maintenance infrastructure and is used for sample filtration and preservation, field analyses, such as sulfate and turbidity, and storage.

3.1.6.1 Merrill-Crowe Gold Processing Plant

Exhibit 3-13. Process Plant Remediation Subarea, Facing South

The Merrill-Crowe process used at Gilt Edge included (1) filtration of the pregnant solution using clarifiers coated with diatomaceous earth to remove suspended solids; (2) removal of oxygen from the pregnant solution using a vacuum deaeration process; (3) addition of fine grained metallic zinc, which causes precipitation of gold; (4) collection of precipitated gold in filter presses; (5) treatment of precipitate in a mercury retort; and (6) melting of the precipitate with fluxes in an induction furnace to produce gold doré. The gold doré contained a mixture of gold and silver as well as other metals and was shipped off site for refining. The treated process solution is

referred to as "barren solution." The barren solution was adjusted to the proper pH and cyanide concentration and was recirculated to the HLP.

Major components of the Merrill-Crowe processing plant included the following:

- **Pregnant sump at Surge Pond.** As a cyanide solution percolated through the heap leach pile, gold was leached from the ore, and the pregnant solution flowed to the sump in the Surge Pond.
- **Clarifiers.** Pregnant solution was clarified using two clarifiers.
- **Diatomaceous earth tank.** A precoat of diatomaceous earth was used in the clarifiers to reduce turbidity of the leach solution.
- **Deaeration tower.** The deaeration tower removed oxygen from the solution in a vacuum environment. The tower was packed with deaeration balls.
- **Zinc chemical mix tank/feeder.** Zinc powder was added to the pregnant solution in this tank. Lead nitrate was combined with the zinc powder to activate the zinc.
- **Filter Press**. A filter press was used to filter out the precipitated gold.
- **Barren tank.** Barren solution from the filter press was returned to the barren tank.
- **Barren sump at Surge Pond.** After the barren solution entered the barren tank, it was then returned to the Surge Pond for cyanide makeup and redistribution to the HLP.
- **Mercury retort.** This is a closed furnace in which the precipitates were heated, causing volatization of any mercury present in the precipitate. Fumes from the mercury retort were passed through distillation tubes to recover mercury.
- **Induction furnace.** The precipitate removed from the mercury retort was combined with fluxes and melted in the induction furnace. This caused separation of slag and gold doré. The slag was poured off the top of the crucible, leaving a doré button containing gold and silver.

Exhibit 3-14. Process Plant Pond, Facing Southeast

The Gilt Edge HLP was an on-off load facility, meaning that spent ore was removed from the HLP after leaching was complete and the pad was loaded with fresh ore. Prior to off-loading the spent ore, it was necessary to neutralize residual cyanide within the spent ore pile. This was accomplished by redirecting effluent from one or more cells on the pad to the neutralization pond. Hydrogen peroxide solution was added to the effluent, which oxidized the cyanide (CN), producing carbon

dioxide (CO_2) and nitrate (NO_3).

Portions of the mineral processing circuit were altered and/or dismantled since the site was abandoned. A site auction was conducted in 2001 by Gerald Metals, one creditor of BMC and their parent corporation, Dakota Mining Corporation. At the site auction, several components of the mineral processing circuit were sold and removed from the site, including the induction furnace and filter presses.

EPA and DENR completed work subsequent to the Gerald Metals auction to evaluate contamination at the process plant, modify mineral processing facilities to benefit ongoing site operations and maintenance, and utilize components of the mineral processing circuit for various investigations. Major remaining components of the mineral processing plant were evaluated for potential contamination in 2002-2003 (CDM 2003e). Major components of the plant were removed from the plant building by CDM personnel and placed at temporary storage locations on the site. All surface pipelines and ancillary equipment were removed from the neutralization pond, with the exception of a subsurface pipeline that is reported to extend from the neutralization pond to the Surge Pond area (Hight 2006).

3.1.6.2 Assay Laboratory

The assay laboratory building is located west of the Process Plant. This building contains a wet chemical laboratory, assay furnaces, and sample preparation equipment, as well as office and storage space. EPA removed all chemicals remaining after abandonment of the mine during initial emergency response actions. Chemicals remaining in the facility are currently used in site activities and include sample preservatives as well as other ancillary supplies. Sample preparation equipment, including assay furnaces, large sample drying ovens, and rock crushers, remain at the facility.

3.1.6.3 Waste Rock Fills

The mineral processing plant and ancillary ponds and facilities are located within a tributary drainage to Strawberry Creek that was filled in with construction fill from an unknown source at the mine. The estimated volume of construction fill within the process plant area is 354,000 cy.

3.1.6.4 EPA Treatability Investigations

An EPA treatability investigation was initiated at the former neutralization pond. This investigation included placement of strongly acid generating waste rock into the neutralization pond, an HDPE lined processing pond formerly used for neutralization of cyanide solutions. This rock remains in place within the lined pond although the liner beneath the rock was breached. The volume of rock within the pond is estimated at approximately 10,000 cy.

3.1.6.5 Storage Areas

Various equipment is stored in areas within the Process Plant Remediation Subarea. This equipment includes miscellaneous tanks, piping, filters, and ancillary equipment

that were removed from the process plant and the former sodium hydroxide water treatment plant. Potential contamination associated with process plant equipment was investigated by CDM before the equipment was removed from the plant. This information can be found in *Draft Interim Status Measurement Report for the Merrill-Crowe Gold Recovery Circuit* (CDM 2003e).

3.1.7 Ruby Repository Remediation Subarea

The Ruby Repository Remediation Subarea is located east of the HLP area (Figure 3.1-1). The Ruby Repository was constructed as part of Operable Unit 3 (OU3) to cover acid generating spent ore within Ruby Gulch. The Ruby Gulch waste rock dump is valley fill waste dump containing 12 million cy of waste rock and spent ore. It was covered with a geosynthetic multi-layer cap system placed over the spent ore. Clean water diversion structures were constructed to convey clean storm-water runoff away from the repository and reduce the volume of water captured for treatment. The Ruby Repository Remediation Subarea also includes the rock borrow area, which was developed during construction of the repository.

3.1.7.1 Ruby Repository

The Ruby Repository encapsulates a major portion of the Ruby Gulch waste rock dump, which is a valley fill waste dump constructed by end dumping waste rock and spent ore into Ruby Gulch. Waste rock is rock that had to be mined to expose the gold ore but that did not contain sufficient gold concentrations to render processing and gold recovery profitable. The waste rock is mineralized to some extent and commonly contains pyrite as well as enrichments of trace metals. Spent ore is rock that has been processed on an HLP to recover gold. Most spent ore has been crushed to less than approximately 2-inch diameter. The estimated volume of waste rock and spent ore contained in the Ruby Gulch waste rock dump is 12 million cy. The area of the dump that was encapsulated by the repository is approximately 74 acres.

Exhibit 3-15. Ruby Repository, Facing West

A large portion of the dump was reclaimed in 2001 through 2004 with completion of the Ruby Repository. Eight acres of the waste dump were not capped during construction of the Ruby Repository. This area is located northwest of the WTP and is included in the Upper South Ruby Remediation Subarea. This uncapped area of the waste dump is an important source of ARD, which reports to the toe of the waste dump within the Ruby Repository Remediation Subarea. A collection system is in place at the toe of the Ruby Repository to collect ARD and convey it to Sunday Pit for storage prior to treatment. The lower portion of the repository includes an internal cutoff wall and outfall pipe that collects ARD seepage and conveys it to a 50,000 gallon underground vault for temporary storage. The vault is periodically evacuated by a pumping plant that

transfers ARD to Sunday Pit. A lined surface pond is present downgradient from the vault to supply additional storage capacity in the event that the subsurface storage capacity is not adequate. The pumping system is described in a later section along with other ARD collection, conveyance, and treatment infrastructure at the site. A groundwater collection facility referred to as the "Wet Well" is present downgradient from the primary collection facility. The Wet Well collects alluvial groundwater that contains trace concentrations of ARD-related contaminants that were not collected by the primary facility.

Performance of Ruby Repository is monitored by a multi-component system. The primary monitoring point is a continuous flow monitoring device located at the toe of the repository that measures the rate of ARD discharge. Performance of diversion ditches at the repository was evaluated during the time period of 2003 to 2006. Data indicate that leakage through the diversion ditches is an important component of ARD discharge measured at the toe of the repository. Other components contributing to ARD discharge from the repository include base flow caused by drain down from the waste rock pile and potential groundwater inflows, rapid interflow through the near-surface fractured bedrock zone, and direct infiltration through the 9 acre uncapped area of the dump. The current ARD discharge from the repository remains an important component of the site ARD yield. The ARD yield from Ruby Repository is discussed in a later section focused on the site water balance. Additional information regarding Ruby Repository can be found in *Draft- Estimation of Ruby Waste Rock Water Budget before and after Installation of Low-Permeability Cover* (CDM 2007a) and *Ruby Repository Diversion Test Summary* (CDM 2006e).

3.1.7.2 Rock Borrow Area

The rock borrow area is located south of Ruby Repository and encompasses approximately 5 acres of disturbance. The borrow area was constructed to provide a source of riprap and cover material for the repository. Additional resources are present within the borrow area that could be used in future remedial actions.

3.1.8 Lower Strawberry Creek Remediation Subarea

The Lower Strawberry Creek Remediation Subarea includes the Strawberry Creek area extending from the location of the WTP discharge to Boomer Creek, a stream distance of approximately 1.5 miles (Figure 3.1-1). This area contains tailings and tailings-impacted soils that were deposited into the drainage during 1938 to 1941 and stream sediment impacts resulting from the former sodium hydroxide water treatment plant operated on the site.

Exhibit 3-16. Lower Strawberry Creek

3.1.8.1 Relic Mine Tailings

A major portion of the tailings were removed in 1993 and were placed in tailings repositories located within the Dakota Maid Remediation Subarea and the Sunday Pit Remediation Subarea. The remaining tailings are present in overbank deposits located adjacent to Strawberry Creek. The overbank deposits are a mixture of talings and alluvial sediments. The tailings are fine sand-sized particles of rock that were treated to remove gold in the late 1930s and early 1940s. The estimated volume of the tailings in Strawberry Creek is 44,000 cy. This volume includes tailings and tailings-impacted alluvial sediments located along the banks of Strawberry Creek between Cabin Creek and Hoodoo Gulch.

3.1.8.2 Stream Sediments

Stream sediments within Strawberry Creek are impacted by periodic erosion of the tailings, precipitation of iron hydroxide precipitates and associated contaminants resulting from groundwater inflows, and discharges from the former sodium hydroxide water treatment plant that operated on the site. These impacts vary spatially and temporally within the remediation subarea and is discussed in more detail in Section 4, which is focused on Nature and Extent of Contamination.

3.1.9 Strawberry Gulch Remediation Subarea

The Strawberry Gulch Remediation Subarea includes the portion of the Strawberry Creek drainage that extends from the location of the water treatment plant discharge to the approximate area of the Stormwater Pond. This portion of the Strawberry Creek drainage is ephemeral, with surface water flow occurring very rarely and only in response to major storm events. The Strawberry Gulch Remediation Subarea is heavily impacted by mine disturbance. It contains areas of fill; critical components of the site ARD collection, conveyance, and treatment infrastructure; as well as site infrastructure, such as the office building, septic system, roads, and a powerline.

3.1.9.1 Fill Rock in Strawberry Gulch Remediation Subarea

Exhibit 3-17. Strawberry Gulch Remediation Subarea, Facing Northwest

The Strawberry Gulch Remediation Subarea contains a large volume of waste rock fills that were placed during mine development. The fills bury the natural drainage of upper Strawberry Creek and provide the base for the primary access road leading from the mine office area to the process plant. A culvert system is present within the fills to convey alluvial groundwater toward Pond C where it is collected and conveyed into the ARD treatment system. A system of fresh water diversion pipes is also present, which conveys clean water collected upgradient of the remediation

subarea to Strawberry Creek. The estimated volume of fills within the Strawberry Gulch Remediation Subarea is 304,000 cy.

3.1.9.2 Components of Site ARD Collection, Conveyance, and Treatment Infrastructure

Critical components of the site ARD collection, conveyance, and treatment infrastructure are present in the Strawberry Gulch Remediation Subarea. These components are described in Section 3.2.

3.1.9.3 Site Infrastructure

The Strawberry Gulch Remediation Subarea includes components of site infrastructure, including the mine office, the mine office septic system, electrical lines, and communications lines. A regional telephone cable is also present following the road that leads from Strawberry Creek to Gilt Edge Road.

3.1.10 Stormwater Pond Remediation Subarea

The Stormwater Pond Remediation Subarea includes a large area located on the north end of the site. This area includes the Stormwater Pond and adjacent fill rock, stored water treatment plant sludge and ARD, several areas of fill rock placed to develop access roads, components of site infrastructure, a soil stockpile, and areas of natural ground that were impacted only by topsoil removal.

3.1.10.1 Stormwater Pond

The Stormwater Pond is an HDPE lined pond designed to hold approximately 17 million gallons of water. The pond was constructed as a contingency pond to hold excess processing solutions that could result from heavy precipitation events on the expanded HLP. The pond liner leaks, and an operational capacity of 10.7 million gallons was established to maintain the water level of the pond below the zone of leakage. The total depth of the pond is 42 feet, which provides a general idea of the depth of the fill in the vicinity of the Stormwater Pond. The pond and associated fill rock was installed in 1996-1997 under permit conditions set forth by South Dakota Large Scale Mine Permit 468.

Exhibit 3-18. Stormwater Pond, Facing West

3.1.10.2 Stored Water Treatment Plant Sludge and ARD

The Stormwater Pond has been used for various purposes since EPA and DENR took over site management. During 2000 through 2002, water treatment plant sludge was pumped into the pond from the former sodium hydroxide water treatment plant. This sludge is still stored within the pond. The estimated volume of the sludge is 4.2 million gallons. The pond is currently used for interim storage of ARD generated on the HLP. The current volume of ARD within the pond is 6.5 million gallons. This

water is pumped to Sunday Pit on an intermittent basis for storage prior to treatment in the site water treatment plant.

3.1.10.3 Rock Fills

An estimated 430,000 cy of fill rock are present within the Stormwater Pond Remediation Subarea. This rock includes fills placed in the direct vicinity of the Stormwater Pond to form the pond basin, fills placed along an access road leading from Anchor Hill Pit to the Stormwater Pond, fills placed along an access road leading from the Stormwater Pond toward the northwest, and several miscellaneous piles.

3.1.10.4 Soil Stockpiles

Four soil stockpiles are present on the north end of the Stormwater Pond Remediation Subarea. The estimated volume of the stockpiles is 12,200 cy. One stockpile was sampled by CDM during the soils and vegetation investigation (CDM 2003d). The soil samples exhibited a similar texture to the piles previously discussed and are classified as a very rocky loam based on the USDA soil texture classification (USDA 1993). The stockpile contained 69 percent rock fragments based on the USDA threshold defining rocks as greater than 2 millimeters in diameter. The organic matter content was 1.0 percent, which is in the very low range for natural soils (Munshower 1993). Additional details regarding soil physical parameters are summarized in Table 3.1-1.

3.1.11 Sunday Pit Remediation Subarea

The Sunday Pit Remediation Subarea includes the Sunday Pit, which is currently used as the primary ARD storage vessel. The remediation area also includes the Rattlesnake underground mine workings, stored water treatment plant sludge, reclamation fill, and a tailings repository (Figure 3.1-1).

3.1.11.1 Sunday Pit and Rattlesnake Workings

The Sunday Pit is located approximately 1,000 feet southeast of the Dakota Maid Pit. The pit is elongated in the east-west orientation, with dimensions of approximately 1,650 feet by 950 feet. The disturbed area of the pit encompasses approximately 31 acres. The north highwall of the Sunday Pit is 340 feet high. The east and south highwalls are similar in height. A ramp leads into the pit from the west end, which was the final access into the pit for removal of ore and waste rock. The current access road leads into the pit from the west side and climbs up the south highwall to the upper Hoodoo Gulch area.

Exhibit 3-19. Sunday Pit, Facing West

The ramp into the pit is currently blocked by a rock dam that was constructed in order to increase the water storage capacity of the pit. The construction methods and design specifications of the dam are unknown. The dam was observed to leak excessively when the elevation of stored water in the pit exceeds approximately 5,350 feet. The geotechnical stability of this dam has not been investigated. Current water management practices at the site include maintaining the Sunday Pit water level below the 5,350-foot elevation. The estimated volume of fill used to construct the dam is 3,000 cy.

Exhibit 3-20. Sunday Pit, North Highwall, Facing North

Sunday Pit slopes range from approximately 47 to 56 degrees between benches. The width of the safety benches ranges widely from 50 feet to less than 10 feet. Portions of safety benches on the west side of the north highwall appear to have spalled and are now less than 10 feet wide. Benches are covered with loose rock that has spalled from the highwalls since the pit was constructed.The Sunday Pit is located in an area with preexisting underground workings. Excavation of Sunday Pit mined through portions of the Rattlesnake workings. The lower level Rattlesnake workings are still present beneath the pit floor. The upper level workings were mined through, and several portals accessing remaining upper level drifts are present in pit highwalls. The Sunday Pit has not been dewatered since DENR and EPA initiated site management, so the characteristics of connections between the pit floor and the upper and lower level Rattlesnake workings are unknown. These workings represent a potential safety hazard that should be considered during remedial design. Underground workings within the Sunday Pit Remediation Subarea are shown on Figure 3.1-3.

3.1.11.2 Stored ARD and Water Treatment Plant Sludge

Sunday Pit contains stored acid rock drainage and water treatment plant sludge. The volume of stored water at the end of the 2006 water year was 68.19 million gallons. Sunday Pit receives ARD pumped from Ruby Repository, Hoodoo Gulch, and the Pond C area in addition to ARD that is generated through interaction of precipitation with pit highwalls and direct precipitation on the pit lake. The ARD storage volume within Sunday Pit varies in response to the volume of site ARD inflows throughout the year.

Sunday Pit contains sodium hydroxide water treatment plant sludge that was placed into the pit during 1999 and 2000. The volume of stored water treatment plant sludge is estimated to be 4.14 million gallons (CDM 2006f). Residual mineral processing

sediments present in the Surge Pond were also transferred to the Sunday Pit in 2005, adding an additional 1.0 million gallons of material to the pit bottom (CDM 2006f).

A sludge drying impoundment is located on the south side of the pit on the upper bench. Sludge and sediment from the Hoodoo Gulch ponds was excavated and placed in the impoundment in the fall of 2004. Sludge from the former Ruby pond was excavated and placed in the same impoundment in the fall of 2005. Ruby pond sludge now resides on top of the Hoodoo Gulch sludge in the impoundment. The total volume of sludge in the impoundment is estimated to be 0.24 million gallons.

3.1.11.3 South Sunday Reclamation Backfill

The south Sunday fill is located on the southwest side of the Sunday Pit. This area was backfilled with rock mined from the Anchor Hill Pit and rock that was excavated in the process of HLP expansion. The south Sunday fill was placed in the second quarter of 1996. This fill was covered with topsoil and revegetated. The estimated volume of the south Sunday fill is 412,000 cy.

3.1.11.4 Sunday Tailings Repository

In the fall of 1993, BMC removed approximately 150,000 tons of acid generating tailings from upper Strawberry Creek. These tailings were blended with alkaline fly ash from a local coal-fired power plant and were placed into two tailings repositories. The first location is within the Dakota Maid Remediation Subarea, which was discussed previously. The second location is on the upper benches of the east side of Sunday Pit. The tailings were amended with alkaline fly ash to achieve a neutralization potential to acid potential ratio of 3:1 and were placed in 12-inch thick compacted lifts. (Durkin 1994).

The tailings repositories were constructed in areas that would not be influenced by groundwater inflows and that had relatively limited potential for run-on of stormwater. A low permeability clay cover was constructed on the tailings repositories in 1994. Permit requirements for the clay cover included compaction to 90 percent modified Proctor density and 95 percent standard Proctor density, with a maximum permeability of 1×10^{-7} cm/sec. The repositories were covered with topsoil and planted with a seed mixture approved by DENR (Durkin 1994). The volume of the Sunday tailings repository is estimated at 43,000 cy.

3.1.12 Union Hill Upland Remediation Subarea

The Union Hill Upland Remediation Subarea includes a rubble storage area, the former contractor's storage area, the former crusher area, a topsoil stockpile, and miscellaneous infrastructure components, such as power lines and pipelines (Figure 3.1-1).

3.1.12.1 Rubble Storage Area

The rubble storage area currently contains solid wastes that were generated in various site operations, such as scrap pipe, steel, fence, and bentonite. These materials were generated by various site activities, such as demolition of the former sodium

hydroxide water treatment plant. A significant portion of these materials were removed during a cleanup program conducted on site in 2006. Some of the material may be suitable for onsite disposal.

3.1.12.2 Former Contractor's Staging Area

The contractor's staging area was used for storage and maintenance of heavy equipment during active mining operations at the site. This broad flat area was constructed by a combination of cut and fill. The area is estimated to contain 47,000 cy of fill materials, which may have been generated from local cut and fills constructed during mine development and/or waste rock excavated from Dakota Maid and Sunday pits. The area also contains site infrastructure components, including a power line and pipeline.

3.1.12.3 Former Crusher Area

The former crusher area is a flat area that formerly contained the crushing plant and crushed ore stockpiles. All components of the former crushing plant were removed, with the exception of the crusher wall foundation. The area is currently used for storage of crusher fines remaining from construction of the Ruby Repository, which are used for sanding roads in winter months. An estimated 26,000 cy of waste rock is present in the former crusher area. The estimated volume of crusher fines is 11,000 cy. Crusher fines are a potential resource that may be used in site remediation.

Exhibit 3-21. Union Hill Upland Remediation Subarea, Facing South

3.1.12.4 Crusher Area Soil Stockpile

A soil stockpile is present just north of the crusher area. This pile is relatively small, with an estimated volume of 1,800 cy. The stockpile was sampled by CDM during the soils and vegetation investigation (CDM 2003d). The soil samples exhibited a similar texture to the piles previously discussed and are classified as a very rocky loam based on the USDA soil texture classification (USDA 1993). The stockpile contained 60 percent rock fragments based on the USDA threshold defining rocks as greater than 2 millimeters in diameter. The organic matter content was 1.7 percent, which is in the very low range for natural soils (Munshower 1993). Additional details regarding soil physical parameters are summarized in Table 3.1-1.

3.1.13 Upper South Ruby Remediation Subarea

The Upper South Ruby Remediation Subarea includes 8 acres of exposed waste rock within the Ruby Gulch drainage (Figure 3.1-1). This area is a part of Ruby Gulch waste rock dump that was not capped during construction of the Ruby Repository. The surface of this area was sloped to cause surface drainage to flow toward the west. However, water that infiltrates into the waste rock flows into Ruby Gulch and reports at the toe of Ruby Repository.

Exhibit 3-22. Upper South Ruby Remediation Subarea, Facing Southeast

3.1.14 Water Treatment Plant Remediation Subarea

The Water Treatment Plant Remediation Subarea includes the new water treatment plant, which was constructed in 2002 to 2003. The HDS water treatment plant was installed at the site in 2002-2003. This plant uses lime to increase the pH of ARD and precipitate metals in a sludge composed primarily of iron and aluminum hydroxides, hydroysulfates, and gypsum. The plant is located on the hill between Sunday Pit and Ruby Gulch waste rock dump.

The influent capacity of the water treatment plant is approximately 240 gpm. Over the 2006 water year (October 1, 2005, to September 30, 2006), the average discharge rate of the plant was approximately 200 gpm. Work is currently in progress to make minor adjustments to the plant to achieve an increased discharge rate.

Exhibit 3-23. Water Treatment Plant, Facing Southeast

The water treatment plant is capable of treating ARD solutions containing sulfate concentrations of up to 1800 mg/L. Influent sulfate concentrations greater than 1800 mg/L cause adverse scaling of sand filters within the plant. EPA is currently considering options to modify the plant to allow treatment of ARD containing over 1800 mg/L sulfate.

The water treatment plant produces approximately 6 million gallons (31,000 cy) of sludge slurry per year. This sludge is currently pumped to a lined area on the northeast corner of the HLP for storage. This sludge contains high concentrations of toxic metals precipitated from ARD and represents a potential contaminant source if improperly stored.

3.1.15 Groundwater Remediation Subarea

A remediation subarea has been reserved that addresses site-wide groundwater contamination. The extent of this remediation subarea is defined based on the Nature and Extent of Contamination, and is shown as Figure 3.1-5. Physical characteristics of the groundwater system are discussed in Section 3.6, and the extent of groundwater contamination is discussed in Section 4.3.

3.2 ARD Collection and Conveyance Facilities

The following section provides a summary of the ARD collection and conveyance infrastructure at the site. These components are present in numerous remediation subareas, and ARD is routinely pumped from one remediation subarea to another. For this reason, the ARD collection and conveyance facilities are summarized in this section to provide a description of the overall system. Some individual components of this system were briefly described in the preceding section. A complex array of ARD collection and conveyance facilities was constructed at the site in order to prevent discharge of ARD into area streams. These facilities capture most surface water at the site and convey it to Sunday Pit where the water is stored prior to treatment. The primary collection facilities are located in upper Strawberry Gulch, Ruby Repository, the HLP, and Hoodoo Gulch. Contaminated water is also currently stored at Anchor Hill Pit and in the Stormwater Pond. Figure 3.2-1 presents a diagrammatic representation of the ARD collection and conveyance facilities at the site.

3.2.1 Sunday Pit

Sunday Pit is the primary storage location for ARD at the site. ARD is pumped from Ruby Repository, Hoodoo Gulch, Strawberry Gulch, and the HLP for storage in Sunday Pit prior to treatment. Water is then pumped from Sunday Pit to Pond E/Strawberry Pond and from Pond E/Strawberry Pond to the water treatment plant. A dedicated 10 horsepower (hp) stainless steel electric submersible pump and pump-barge are present at Sunday Pit. This pump is connected to backup electrical power infrastructure located at Pond E/Strawberry Pond.

A series of pipelines convey ARD from the various source areas to Sunday Pit. ARD that discharges from the Ruby Repository is conveyed through a 10-inch diameter subsurface HDPE pipeline. This pipeline extends up the slope on the south side of the Ruby Repository into Hoodoo Gulch and through the Hoodoo fill area. A second subsurface 10-inch diameter HDPE pipeline extends from Pond E/Strawberry Pond to the Sunday Pit Dam area where it transitions to a 6-inch subsurface HDPE pipeline, extending to the water treatment plant. Electrical control infrastructure is located in the Sunday Pit Dam area.

Very limited data are available regarding the construction methods, construction materials, or integrity of the Sunday Pit Dam. Based on the exposed portions of the dam, it appears that it was constructed with spent ore rock. A sheet of HDPE liner is present on the east face of the dam. The dam leaks significantly if the water level in Sunday Pit exceeds an elevation of approximately 5,350 feet. The operational capacity

of the Sunday Pit for storage of ARD is limited to 60.4 million gallons in order to maintain the water level below this elevation.

3.2.2 Strawberry Gulch Facilities

Strawberry Gulch is located due east of the mine office building and west of Dakota Maid and Sunday pits. ARD collection facilities within Strawberry Gulch collect drainage from a relatively large basin of both disturbed and undisturbed land. Disturbed areas reporting to Strawberry Gulch include the Sunday Pit area, the Dakota Maid Pit area, Langley Adit, King Adit, the mineral processing area, Anchor Hill Pit, and several acid generating fill rock zones. Undisturbed areas include the upper Strawberry Gulch area north of the Stormwater Pond, a tributary drainage extending west from Pond C, and a tributary drainage located on the south side of Anchor Hill Pit. The mine pits are internally draining as long as active site management controls the water level of the pits.

Freshwater diversion structures were installed to collect clean surface water before it interacts with acid generating rocks and to convey this water through the contaminated portion of the site to Strawberry Creek. These structures are located north of the Stormwater Pond, south of the mineral processing plant, and in the tributary drainage reporting to Pond C. The efficiency of these structures in capturing clean water is unknown.

A series of three ponds is located in the Strawberry Gulch drainage, which are referred to as Pond C, Pond D, and Pond E. Pond C collects acid drainage from fill rock in the area. This water is conveyed in a subsurface pipeline to Pond D. Pond D collects ARD conveyed from Pond C as well as ARD discharging from the King Adit, which originates in the Dakota Maid Pit area. Pond D flows by gravity into Pond E/Strawberry Pond, which also collects water from the Langley Adit, the Wood Weir, and surface runoff from the Sunday Pit area.

Pumps at Pond E/Strawberry Pond have the capability of pumping water to the water treatment plant or to the Sunday Pit for storage through subsurface HDPE pipelines. Two large electrical stainless steel pumps are located at Pond E/Strawberry Pond, a primary pump and a backup pump. They are rated at 725 gpm and 680 feet of discharge head. The diesel fuel tank on the generator has a capacity of 150 gallons, which provides a run time of approximately 14 hours. A 365 kilo volt amp (KVA) generator is located at the Pond E/Strawberry Pond to provide backup power in the event of power outages. This is necessary to prevent uncontrolled discharge of acid rock drainage into Strawberry Creek in the event of a power outage. There is a small pond located below Pond E/Strawberry Pond, which is called Last Chance Pond. The purpose of this pond is to collect leakage from Pond E/Strawberry Pond. A small electric stainless steel submersible pump is located in Last Chance Pond to pump leakage back into Pond E/Strawberry Pond.

3.2.3 Hoodoo Gulch Facilities

A subsurface ARD collection facility is present in Hoodoo Gulch. This facility collects ARD and conveys it to Sunday Pit via an HDPE pipeline. The Hoodoo Gulch pipeline is located on the surface until it crosses the road in the area of the Hoodoo Fill. At this point, the Hoodoo pipeline is buried. A dedicated stainless steel electrical pump and backup generator are located at the Hoodoo collection facility. The pump capacity is 300 gpm, with a 300 foot discharge head. The generator is rated at 125 kilo volt amp (KVA) and has an 80 gallon fuel capacity. This provides a run time of approximately 18 hours.

3.2.4 Ruby Gulch Facilities

A major ARD collection facility is present at the base of the Ruby Repository. This facility includes a subsurface collection gallery that collects water discharging at the toe of the repository, a lined contingency pond, and a groundwater collection facility called the Wet Well. ARD collected at the facility is intermittently pumped uphill to the Sunday Pit for storage prior to treatment.

The primary collection facility is the subsurface collection gallery at the toe of Ruby repository. This gallery is composed of a series of large culverts with a maximum capacity of 50,000 gallons. This provides capacity to hold ARD draining from the repository for a period ranging from approximately 1.7 days to 4 hours, depending on the season. A secondary lined pond is also present to hold ARD in the event the capacity of the subsurface vault is exceeded.

An H-flume with automated flow monitoring instrumentation is located at the toe of the repository and is accessed through a manhole. This is an Occupational Safety and Health Administration (OSHA) permit-required confined space. ARD draining from the toe of the waste rock dump contains concentrations of dissolved iron in the reduced Fe^{2+} form, which is an oxygen sink. A fatal accident occurred at a similar facility at the Sullivan Mine in British Columbia in 2006. It is very important that this area is managed as a permit-required confined space in perpetuity and that positive pressure ventilation and/or continuous oxygen monitoring be conducted while accessing or maintaining this flow-monitoring facility.

A second subsurface collection structure called the Wet Well is located approximately 400 feet downgradient from the repository toe. The Wet Well collects water that is primarily clean stormwater that was impacted by leakage from the Ruby Gulch waste rock dump facilities. Although this water is less impacted by ARD, it must also be pumped back to Sunday Pit for treatment prior to discharge.

Two large stainless steel electrical pumps are present at the toe of the Ruby Repository, the primary pump and a secondary pump. These pumps are rated at a capacity of 725 gpm, with a discharge head of 680 feet. A two horsepower stainless steel submersible pump is also present in the Wet Well, which pumps contaminated groundwater to the primary Ruby Repository collection gallery for conveyance to Sunday Pit.

A backup generator at the waste dump toe is rated at 365 KVA. The generator has a fuel capacity of 150 gallons, which provides a run time of approximately 14 hours. This generator provides backup power to all facilities at the toe of the waste rock dump, including the primary pumps, the Wet Well, and the automated flow monitoring instrumentation.

3.2.5 Heap Leach Pad Facilities

Spent ore present on the HLP also generates acid. The HLP liner is generally intact, and ARD generated at the HLP is collected on the HLP liner and pumped to the Stormwater Pond for interim storage. On an intermittent basis, this water is pumped to either Sunday Pit or Anchor Hill Pit for storage prior to treatment in the site water treatment plant.

Neither electrical power infrastructure nor dedicated pumps are present at the HLP. Water from the HLP is pumped using one of three portable stainless steel Godwin HL5 diesel pumps that are present on the site. A dedicated 6-inch diameter HDPE pipeline is present at the HLP, which has the capacity to convey water to either Anchor Hill or Sunday Pit. This pipeline is not buried, so winter freeze-up is an operation and maintenance concern. However, the surface pipelines can be moved relatively easily, which provides flexibility in ARD management options at the site.

3.2.6 Dakota Maid Pit

The Dakota Maid Pit contains stored ARD and sludge. Sodium hydroxide water treatment plant sludge was placed into the pit by BMC in the mid 1990s. This sludge was generated in a water treatment plant called the Unirube, which operated at the site for a short period of time. ARD drainage in the Dakota Maid Pit is a result of leakage from Sunday Pit as well as drainage generated by the Dakota Maid Pit highwalls and other local zones of acid generating rock. The volume of ARD in the Dakota Maid Pit is controlled by intermittent pumping using a portable Godwin HL5 pump. A 6-inch HDPE pipeline is present at Dakota Maid Pit, which extends to the Anchor Hill Pit. Water can also be pumped from Dakota Maid Pit into Sunday Pit for storage through the Strawberry Gulch conveyance system.

3.2.7 Anchor Hill Pit

Anchor Hill Pit is currently used for storage of water partially treated in the Anchor Hill Pit Lake Treatability study and for contingency storage of ARD during periods when storage capacity at Sunday Pit is exceeded. Permanent pumping stations and associated electrical power infrastructure are not present at Anchor Hill Pit. A surface pipeline is present that can pump ARD to or from Anchor Hill Pit. One of the portable stainless steel Godwin HL5 pumps are used at Anchor Hill Pit when necessary.

3.2.8 Stormwater Pond

The Stormwater Pond is used for interim storage of ARD. Pipelines are in place to convey water from the HLP to the Stormwater Pond and from the Stormwater Pond to Sunday Pit. One of the portable stainless steel Godwin HL5 pumps is used at this location when necessary to convey water from the Stormwater Pond to Sunday Pit.

3.3 Climate

General climatic conditions at the site include cold winter temperatures with moderate summer temperatures. The average daily temperature is 44.2° Fahrenheit. Average precipitation for water years 1949 to 2006 is about 29 inches (in.). Precipitation from mid October through mid April is generally snow. Average snowfall is about 130 in. per year. Precipitation during the summer months is generally thunderstorms, which cause large local variations in precipitation amounts. The growing season at the site extends from late May through early September for an average of 130 days. Detailed analyses of climatic data for the site are available in Malo et al. (2001).

Evaluation of precipitation at the site is based on data collected at the Lead, South Dakota weather station. This station is located approximately 4.5 miles northwest of the site at a similar elevation. Although some site precipitation data are available, the significantly longer period of record at the Lead site makes the Lead data most useful for purposes of characterizing site climatic conditions. The accuracy of site precipitation data is also in question as a result of the data collection methods. Comparison of site precipitation data with Lead precipitation data for the 2001 though 2006 water years is shown in Table 3.3-1.

It is possible that some of the variation observed between site data and Lead data is related to orographic effects on the distribution of precipitation. Orographic effects of precipitation in the Black Hills were evaluated by Driscoll et al. (2000). Based on a geostatistical analyses of Black Hills precipitation data (Driscoll et al. 2000), estimated annual precipitation is 1 to 2 in. lower at the site as compared to the Lead weather station. An isohyetal map showing variation in annual precipitation in the Black Hills is shown in Figure 3.3-1. The 1- to 2-inch variation in precipitation is substantially less than the variation suggested by the site precipitation gauges. The following discussion of precipitation is based on data from the Lead station. This is considered the best data set to use for the site based on the longer period of record as well as the questions regarding accuracy of site precipitation gauges.

Precipitation evaluations consider both short-term data and long-term data. The short-term and long-term precipitation data are useful for different purposes. Monthly and annual data, including long-term averages and evaluation of departures from the long-term averages, are appropriate for evaluation of ARD storage capacity and required ARD treatment rates. The 24-hour storms are valuable for short-term hydrological evaluations. These include sizing of diversion ditches, pipelines, and pumping systems.

Figure 3.3-2 is a box plot showing monthly precipitation summary statistics for the site. April, May, and June are the wettest months of the year, with median monthly precipitation of 3.27, 3.61, and 3.33 in., respectively. December, January, and February are the driest months, with median monthly precipitation of 1.32, 1.10, and 1.35 in., respectively. The wettest month on record is May 1965 when 14.84 in. of precipitation were recorded at the Lead station.

The average annual precipitation for water years 1949 through 2006 is 28.85 inches. Annual precipitation for this time period is shown as Figure 3.3-3, and monthly precipitation data are presented in Table 3.3-2. Precipitation ranged from a minimum of 17.43 inches in 1961 to a maximum of 43.58 inches in 1995. Total annual precipitation for 95 percent of the water years was less than 39.58 inches. The upper and lower quartiles are 33.66 inches and 23.69 inches, respectively. Figure 3.3-4 shows the annual departure from average precipitation for the period of record. Most years are within about 10 inches of the average. 1962, 1965, and 1995 were particularly wet years, with departures ranging from 12 to 15 inches above the average. 1961 and 1985 were particularly dry years, with departures ranging from 10 to 12 inches below average precipitation.

Figure 3.3-5 shows the cumulative departure from the long-term average. This figure is useful to evaluate trends in annual precipitation. The period of 1949 to 1961 was particularly dry, with a cumulative departure for the 12-year period of -54.94 inches. Other particularly dry periods include 1979 to 1981 (-20.16 inches), 1986 to 1992 (-47.48 inches), and 2000 to 2005 (-16.85 inches). Particularly wet periods include 1962-1965 (+42.01 inches), 1970 to 1973 (+19.94 inches), and 1993 to 1999 (+56.27 inches). The mid to late 1990s were one of the wettest periods on record.

Estimation of 24 hour storm event frequency is presented in Figure 3.3-6. The magnitude of 24-hour storms of various recurrence intervals are shown on the figure. This evaluation includes data from large storm events that occurred in October 1994 and May 1995. Inclusion of these events increased the intensity of the storms for the various recurrence intervals as compared to previous estimates. Based on this evaluation, the 5-year, 10-year, 25-year, and 100-year 24 hour storm intensities are 3.4 inches, 4.5 inches, 5.8 inches, and 8.0 inches, respectively. The meaning of the term 100-year storm event is often misunderstood. In any year, the probability of receiving a 100-year storm is 0.01, which equates to a 1 in 100 chance that a 24-hour storm exceeding 8 inches would occur at the site in any given year.

3.4 Geology

The site is located in the northern Black Hills of South Dakota. The Black Hills are an elongated domal uplift extending approximately 150 miles in a north-south direction and approximately 50 miles in an east-west direction. Precambrian igneous and metamorphic rocks are exposed in the core of the Black Hills and are surrounded by outwardly dipping Phanerozoic sedimentary rocks. An east-west trending zone of Tertiary intrusive rocks is present in the northern portion of the Black Hills. This zone extends across the width of the Black Hills from Bear Butte near the Town of Sturgis to the Bear Lodge Mountains in northeastern Wyoming.

The oldest rocks in the Black Hills are Archean to early Proterozoic metamorphic and igneous rocks, including mica schist, greywacke, metabasalt, iron formations, and granite. These rocks were subject to regional deformation resulting in numerous episodes of ductile folding and development of one or more cleavage planes. The rocks are intensely folded and tilted into a near vertical orientation. These rocks were

eroded to an approximately flat surface prior to deposition of the overlying sedimentary rocks.

Sedimentary rocks overlay the Precambrian rocks, forming an angular unconformity. The sedimentary rocks include the Deadwood Formation, Winnepeg Formation, Whitewood Formation, Englewood Formation, Pahasapa Limestone, and Minnelusa Formation. These rocks range in age from Cambrian to Mississippian and consist of clastic and chemical sedimentary rocks.

An eastward-trending zone of igneous intrusive rocks is present in the Black Hills extending from the Bear Butte area on the eastern side of the Black Hills to the Mineral Hill area on the west side of the Black Hills. These rocks are porphyritic alkaline intrusives, including quartz trachyte porphyry, trachyte porphyry, latite porphyry, and others.

The Black Hills have produced approximately 44 million ounces of gold. The vast majority of this gold was produced in a small geographical area in the northern Black Hills centered around the Town of Lead. The Homestake mine produced approximately 40 million ounces of gold from Precambrian iron formation hosted gold deposits. About 4 million ounces were produced at other mines near Lead, including Annie Creek, Bald Mountain, Clinton, Richmond Hill, Golden Reward, Gilt Edge, as well as many small historical operations. These mines exploited mesothermal to epithermal gold deposits associated with the east-west tending zone of intrusive rocks.

The geology of the site is characterized by accumulations of gold within Tertiary porphyry rocks, associated intrusive breccias, and contact metamorphic rocks formed by thermal metamorphism of the Cambrian age Deadwood Formation. Rock exposed at the site is strongly mineralized, with widespread pyrite mineralization and natural enrichments of numerous metals and metalloids. Detailed descriptions of the geology of the Gilt Edge mine are available in Macleod (1986). A geologic map of the site is presented as Figure 3.4-1.

3.4.1 Lithology and Stratigraphy

The oldest rocks in the Gilt Edge area are Precambrian amphibolite, quartzite, and quartz-mica schist. The amphibolite is very dark greenish gray to black, fine-grained, and weakly foliated. The quartzite is fine grained with white and black banding. The quartz-mica schist is strongly foliated and strikes north 30° to 50° west and dips southwest at 20° to 60°.

Precambrian rocks are unconformably overlain by the Cambrian Deadwood Formation, which consists of interbedded greenish gray to brown sandstone, siltstone, shale, and carbonates that are reported to be up to 400-ft. thick. In the Gilt Edge area, portions of the Deadwood Formation were thermally metamorphosed by the intrusions to dark greenish gray hornfels and white to gray quartzite. The Deadwood Formation contains three hydrogeological units. The upper unit is dominantly sandstone with interbedded carbonates, local shale, and siltstone. The middle unit is

dominantly shale. The lower unit is similar to the upper and consists of sandstone with interbedded carbonates, local shale, and siltstone. The base of the formation is a pebble conglomerate. Groundwater is conveyed primarily through the upper and lower units. The middle unit is a confining layer that restricts vertical movement of groundwater.

Northeast of the Gilt Edge area, younger sedimentary rocks that overlie the Deadwood Formation are exposed (Redden et al. 2001). One of these units is the Pahasapa Limestone, which is a local equivalent of the Madison Limestone. Although the limestone is not present at the site, it is an important hydrogeologic unit at other locations in the Black Hills. This is because it hosts karst solution features that can profoundly affect groundwater movement and is a significant source of groundwater to area residential and municipal wells.

The tertiary intrusive rocks present at the Gilt Edge site consist of various types of trachyte porphyry intrusive rocks. Porphyry is a dense crystalline rock composed of coarse-grained phenocrysts of feldspar, quartz, and/or hornblende contained within a fine grained crystalline matrix. These units form various types of intrusive bodies, including sills and stocks. The various rock names reflect the chemical composition of the rock based on detailed mineralogical studies completed by MacLeod (1986). The hydrological characteristics of the porphyry are all similar. Primary permeability of the porphyry is very low as a result of the dense crystalline rock matrix. Water is conveyed through these rocks in secondary permeability related to interconnected fractures.

Sills are igneous intrusions that are concordant with the local bedding of the rocks they intrude. In the Gilt Edge area, these intrusive bodies are broad, relatively flat lying units that occur within Deadwood Formation sedimentary rocks. The extensive area shown on the west and north portions of Figure 3.4-1 as Hornblende Trachyte Porphyry is a sill, which overlies the lower Deadwood Formation.

Stocks are near-vertical discordant intrusive units that cut through the underlying rock units, including the Deadwood Formation and the Precambrian Rocks. The areas on Figure 3.4-1 shown as Union Hill Quartz Alkali Trachyte Porphyry, Undifferentiated Quartz Trachyte Porphyry, Union Hill Quartz Alkali Trachyte Porphyry, and Rattlesnake Alkali Trachyte Porphyry are stocks.

Hornblende trachyte porphyry is the oldest of the intrusive units at the site. It is medium to dark grayish green in color and consists of hornblende and plagioclase feldspar phenocrysts in an aphanitic groundmass. An aphanitic texture refers to mineral grains that are too small to see with the naked eye. It occurs as an extensive sill within the Deadwood Formation and crops out over the majority of the west and north portions of the site. The unit is moderately fractured and contains local carbonate veining that provides some buffering to ARD.

The trachyte porphyry is light to medium gray and is composed of 60 percent to 70 percent coarse-grained euhedral phenocrysts of potassium feldspar within an

aphanitic groundmass. The most significant exposure of this unit underlies the HLP area. The quartz trachyte porphyry is light to medium gray or tan in color and consists of 45 percent to 55 percent euhedral medium-to coarse-grained quartz and feldspar phenocrysts in a cryptocrystalline groundmass. Clay alteration is locally present within this unit.

Breccia zones are found at several locations on the site and are often present along the margins of the intrusions. The breccias consist of a variably lithified aggregation of angular clasts from the other rock materials. They are often highly altered and/or weathered. They range from 20-to 120-feet in width and extend to at least 100 feet in depth. Contacts are generally gradational with the adjacent intrusive rock.

Quaternary age sediments are unconsolidated materials derived from weathering and mass wasting of the bedrock units discussed above. They largely consist of colluvium and alluvium that is generally less than 25 feet in thickness. The colluvial material generally occurs in upland and side-slope areas and consists of an unsorted mixture of pebble-to boulder-size angular rock fragments embedded in a matrix of clay, silt, and sand. The alluvial sediments are slightly to moderately sorted deposits of gravelly sand and silty sand located along the bottoms of the major drainages.

3.4.2 Structural Geology

The structural geology of the site is a major control on groundwater movement. The site is located in an area of complex structure resulting from local and regional tectonic displacements occurring over the last approximately 2 billion years. The structural geology of the northern Black Hills was extensively described by previous investigators. Two site-specific structural geology investigations were completed. The first investigation was completed by BOR and DENR geologists and consisted of detailed fracture mapping within Sunday Pit, Dakota Maid Pit, and the King-level underground workings (BOR 2000b). The second investigation was completed by Rod MacLeod, a former chief geologist at the Gilt Edge mine. Mr. MacLeod compiled exploration drilling data from the Gilt Edge mine database, which included data from hundreds of exploration drill holes.

The structural geology of the site is controlled by regional and local structural features. The oldest stratigraphic unit at the site is the Precambrian metamorphic rocks. These rocks are moderately to strongly foliated, with the dominant cleavage striking toward the northwest and dipping moderately to the west. These rocks were intensely deformed during regional metamorphism, resulting in areas of refolded folds and numerous cross-cutting cleavages. Pre-existing zones of structural weakness within the Precambrian rocks contribute to localization of later structural displacement. Intrusion of the major stocks present at the Gilt Edge site was likely controlled by these preexisting zones of weakness. Intrusion of the major stocks also resulted in brittle deformation of adjacent metamorphic and sedimentary rocks. This deformation is demonstrated by zones of breccia emplacement adjacent to the major stocks and by strongly displaced units of metamorphic and sedimentary rocks along the periphery of the stocks. Structural displacement continued after intrusion of the

stocks as displayed by major fracture zones which cross-cut igneous, sedimentary, and metamorphic rock units. It is very likely that structural displacement along these zones occurred repeatedly over the geologic history of the site, resulting in the current orientation and characteristics of fractures observed at the site.

The various lithologic and stratigraphic units described in Section 2.4.1 exhibit differing rheologic characteristics. Rheologic characteristics describe the how a rock deforms under applied stress, such as the stress that caused formation of fracture zones at Gilt Edge. Fracture zones are important controls on movement of contaminants in groundwater. Information regarding rheologic characteristics provides information useful in understanding the likely extent, interconnectedness, and openness of fractures that penetrate various rock types. The intrusive porphyry rocks are relatively more brittle than the sedimentary and metamorphic rock units at the site. This results in more extensive fracturing of the intrusive units, greater linear extent of major fracture zones through these units, and increased openness and interconnectivity of fractures within major fracture zones. The Precambrian metamorphic rocks are relatively more ductile, which results in less extensive fracturing, more restricted linear extent of fracture zones, and decreased openness and interconnectivity of fractures. Rheologic characteristics of sedimentary rocks range from relatively ductile rock within the Deadwood Formation intermediate shale to more brittle rock within the lower Deadwood Formation sandstones. Fractures are major controls on effective porosity of all rocks at the site, but the magnitude of the effect of fractures on groundwater movement is greatest for the intrusive rocks.

The first investigation of fracture characteristics at the site was completed by BOR with assistance by DENR. This investigation involved detailed mapping of fractures at Sunday Pit, Dakota Maid Pit, and accessible portions of the upper level King underground workings. This investigation was limited to the intrusive rocks exposed by the mine workings, so the data do not reflect fracture characteristics of the sedimentary and Precambrian rocks. Five major trends of fracturing were identified that may influence groundwater movement. Their strikes and dips are north 60° to 70° west/80° north, north 35° to 40° east/75° east, north 75° east/84° north, north 80° west/35° south, and north 38° west/38° east. Two major fracture zones were also observed, the Dakota Maid fracture zone and the Rattlesnake fracture zone. These major fracture zones are approximately linear zones of numerous closely spaced and interconnected fractures. The Dakota Maid and Rattlesnake fracture zones are exposed in highwalls of the mine pits. The Dakota Maid fracture zone is also exposed in the King underground workings northeast of Dakota Maid Pit within a zone of collapse in the underground workings. These major fracture zones were identified as important conduits of groundwater flow.

A second investigation was conducted as a result of recognition of the importance of these major fracture zones on groundwater movement (Macleod 2005). Five major fractures zones were identified with potential to contribute to offsite migration of contaminants in groundwater. These zones are shown on Figure 3.4-1. Individual fractures measured during the initial Bureau of Reclamation fracture investigation that are located outside of these major fracture zones likely impact only local

hydrogeologic characteristics. These fractures are more widely spaced and less interconnected than fractures within the major fractures zones.

3.5 Surface Water

The site is located in mountainous terrain that drains toward Bear Butte Creek, a tributary to the Belle Fourche River. Bear Butte Creek flows generally eastward toward the edge of the Black Hills. The site is located in the headwaters of three tributaries draining into Bear Butte Creek. These are Strawberry Creek, Terrible Gulch, and Ruby Gulch. Strawberry Creek is a perennial stream, and Terrible Gulch and Ruby Gulch are intermittent streams. A number of tributary drainages contribute flow to Strawberry Creek. Hoodoo Gulch is an intermittent tributary to Strawberry Creek, which is impacted by mining disturbance at the site. Cabin Creek and Boomer Gulch are perennial tributaries that drain into Strawberry Creek. These tributaries are not impacted by site disturbance.

There are also a number of ephemeral drainages that are located upgradient from the site. These ephemeral drainages contribute water to the site ARD collection, conveyance, and treatment system. Diversions are in place to capture water from the ephemeral drainages and convey it past areas of contamination to Strawberry Creek. The performance of these systems is currently being monitored. Perennial, intermittent, and ephemeral streams, as well as contributing drainage basins, are shown on Figure 3.5-1.

The ecology and habitat of the perennial and intermittent streams will not be discussed in this report. This information is discussed in the screening level ecological risk assessment, baseline ecological risk assessment, and biological monitoring report (EPA 2001, EPA 2003, EPA 2007).

3.5.1 Perennial Streams

3.5.1.1 Bear Butte Creek

Bear Butte Creek is located near the eastern margin of the site outside of the site boundary. The designated uses of Bear Butte Creek are marginal cold water fishery, limited contact recreation waters, fish and wildlife propagation waters, and irrigation waters (Administrative Rules of South Dakota [ARSD] 74:51). Bear Butte Creek is listed as impaired on the South Dakota 303(d) list for temperature. The 303(d) list is a requirement of Section 303(d) of the Clean Water Act and includes surface water bodies that do not meet their designated use. Water quality of Bear Butte Creek is discussed in Section 4 of this RI report, which is focused on nature and extent of contamination.

Summary statistics for daily flow data at a USGS flow monitoring station near Galena is shown in Figure 3.5-2. The period of record for these data is the 1989 through 2006 water years. The precipitation trends for the periods included in the Bear Butte Creek flow data set were included in the discussion of long-term precipitation trends presented in the previous section. Based on the available data, Bear Butte Creek flow is highest during the months of April, May, and June, with average flows of 18.8 cubic

feet per second (CFS), 23.3 CFS, and 15.1 CFS, respectively. Lowest average flows occur during a period extending from September through February, with average flows ranging from 1.4 to 1.6 CFS.

There are three stream loss zones located on Bear Butte Creek downstream of the Town of Galena. Driscoll et al. (2002) have estimated loss thresholds of 4 CFS for each loss zone, for a total of 12 CFS. Bear Butte Creek looses all of its flow up to the loss threshold when passing the loss zone. Under average conditions, Bear Butte Creek loses all of its flow into the first loss zone during the months of July through March. During the months of April, May, and June, a portion of the stream flow passes the first loss zone and proceeds downstream into the second and third loss zones. Under average conditions, 100 percent of the flow in Bear Butte Creek enters one of the three loss zones. Additional discussion regarding the loss zones is presented in Section 3.7, which is focused on groundwater-surface water interactions.

3.5.1.2 Strawberry Creek

Strawberry Creek is located on the south side of the site. It is a perennial stream that flows approximately 2.5 miles from the major site disturbance area to the confluence of Bear Butte Creek. Strawberry Creek is designated as marginal cold water fishery, limited contact recreation waters, fish and wildlife propagation waters, and irrigation waters (ARSD 74:51). Strawberry Creek is classified as impaired on South Dakota's 303(d) list as a result of zinc, cadmium, copper, total dissolved solids, specific conductivity, and pH. Strawberry Creek was heavily impacted by historic and recent mining activities although generally water quality and habitat are on improving trends at Strawberry Creek. The nature and extent of contamination in Strawberry Creek will be discussed in Section 4.5.

The flow of Strawberry Creek is significantly lower than Bear Butte Creek. Perennial flow begins in the general vicinity of the site water treatment plant discharge pipe, which is located about 300 feet upstream of Cabin Creek. Cabin Creek is a small tributary with perennial flow resulting in part from discharge of groundwater from the Deadwood aquifer. Cabin Creek is not impacted by the site. The Strawberry Creek flow rate increases steadily in the downstream direction from Cabin Creek to Boomer Gulch as a result groundwater inflows. Kimball et al. (2006) quantified these inflows during an investigation conducted in June 2003. The Kimball et al. (2006) work is discussed in Section 3.7, which is focused on groundwater-surface water interactions. A small amount of discharge to Strawberry Creek occurs at Hoodoo Gulch; however, most water in Hoodoo Gulch is collected and treated in the site water treatment plant. Boomer Gulch is a major tributary that enters Strawberry Creek approximately ¼ mile upstream from the confluence with Bear Butte Creek. Boomer Gulch adds significant inflows to Strawberry Creek.

Flow data for Strawberry Creek are available based on a Parshall flume located about 100 feet downstream from the confluence of Boomer Gulch with Strawberry Creek. This site was historically called CP001. Flow data measured at this site includes natural flows at Strawberry Creek as well as water treatment plant discharge. The water treatment plant discharge generally operates at 200 to 240 gpm, which is a

major component of flows observed at the Parshall flume. Flow data from this site are available for a period extending from the present to the early 1990s. However, the water treatment plant at the site operated intermittently and at various flow rates for the period extending from the early 1990s to approximately 2000. Detailed water treatment plant discharge rates are not available for this period, which makes interpretation of the data very difficult. Therefore, evaluations of the flow rate at Strawberry Creek are based on a period extending from 2001 to 2006 when flow data for Strawberry Creek and discharge data from the site water treatment plant are available.

The variation in natural flows in Strawberry Creek is presented in Figure 3.5-3. As discussed in the previous section on climate data, the period from 2000 through 2005 was relatively dry, with a cumulative departure from the long-term average of -16.85 inches over the 5-year period. The 2006 water year was relatively wet, with 37 inches of precipitation received at Lead, South Dakota. This is approximately 8 inches above the long-term average. Flows presented in Figure 3.5-3 were adjusted to remove the effect of the water treatment plant discharge. This was done using site records of the water treatment plant discharge rate. The site water treatment plant was operated intermittently during the period of 2001 to 2005. Based on this evaluation, flows in Strawberry Creek show a similar pattern to Bear Butte Creek. The highest flows occur during April, May, and June, with average flows of 506 gpm, 801 gpm, and 273 gpm, respectively. Flows are lowest during the months of September through February of each year, with flow rates ranging from 66 gpm to 90 gpm.

3.5.2 Intermittent Streams

Hoodoo Gulch and Ruby Gulch are intermittent streams, which flow only at certain times of the year in response to discharge from springs or short-term surface flows. The upper portions of both the Hoodoo Gulch and Ruby Gulch watersheds are contained within the site ARD collection, conveyance, and treatment system, which significantly reduces the flow rates in the downgradient portions of the drainages. Flow in Hoodoo Gulch below the collection facility is measured at a location about 50 feet upstream from the confluence of Hoodoo Gulch with Strawberry Creek. Flow in Ruby Gulch is monitored at a location approximately 500 ft. below the toe of the Ruby Repository.

Major changes in the Hoodoo Gulch collection system were completed in November 2005. These changes included construction of a new subsurface collection facility and a pipeline that conveys ARD to Sunday Pit. The water collected at Hoodoo Gulch is stored within Sunday Pit prior to treatment in the site water treatment plant. Prior to November 2005, semi-passive water treatment was conducted at Hoodoo Gulch. This treatment consisted of conveying the ARD springs into a pipe, neutralizing the ARD with solid sodium hydroxide, and settling out the precipitates in two detention ponds. After the solids settled, the water overflowed the lowermost detention pond and was discharged into Hoodoo Gulch. Therefore, flow data collected prior to November 2005 are not relevant to understanding current conditions in Hoodoo Gulch.

Figure 3.5-4 presents flow data for lower Hoodoo Gulch for the time period after completion of the new collection facility. As shown on Figure 3.5-4, flows discharging from Hoodoo Gulch into Strawberry Creek are generally very low. Average flows for July through February ranged from 0.05 gpm to 0.14 gpm. Flows in March, April, and May were highest, with average monthly flows of 2.58 gpm, 84.44 gpm, and 74.03 gpm, respectively. Flows in late April and early May were strongly influenced by a late April snowfall that left approximately 4 ft. of snow on the site. The 2006 water year was relatively wet, with annual precipitation about 8 in. above average. Based on available data since completion of the new collection facility, Hoodoo Gulch does not provide much base flow to Strawberry Creek. Hoodoo Gulch does contribute to increased flows in Strawberry Creek during the spring freshet. Flow rates from the portion of Hoodoo Gulch that reports to the subsurface collection facility are described in a later section focused on site water balance.

Significant new construction has also been completed in Ruby Gulch. This work was completed in May 2005. The work completed in May 2005 consisted of installation of a new subsurface ARD collection gallery generally referred to as the "Wet Well." This facility collects ARD that is not contained by the primary collection system in Ruby Gulch as well as unimpacted water present in the alluvial aquifer. It is likely that this facility also changed the hydrologic characteristics of the alluvial aquifer in lower Ruby Gulch by intersecting recharge that may have reported as spring flow further downgradient in Ruby Gulch. Flow records collected after completion of the new Wet Well are the best data to use in evaluation of current conditions in Ruby Gulch.

Flow data for monitoring site CP003 in Ruby Gulch below the collection facilities are shown in Figure 3.5-5. Flow at this site is intermittent for most of the year. Flow is highest in April, May, and June in response to the spring freshet and the generally higher amounts of precipitation received during these months. Average monthly flows range from 0 gpm to 2.8 gpm for the months of July through March, with the exception of August, which appears to be anomalous. Average monthly flows for August are 13.8 gpm for the time period examined. It is possible that repository diversion tests conducted in August and September 2006 contributed to flows at the monitoring point.

3.5.3 Ephemeral Streams

There are three ephemeral drainages upgradient of the site. These consist of the Pond C Tributary, the Process Area Tributary, and the Anchor Hill Tributary. Water in these drainage flows only in response to large precipitation events or rapid snow melt. Springs are not present within these drainages, which indicate that the drainages are above the water table at all times. Surface water flow in these drainages is not monitored. Surface water diversions are present on the site to capture these flows and convey the clean water directly to Strawberry Creek.

3.6 Groundwater

3.6.1 Regional Hydrogeology

The site is located in the northern Black Hills near the contact of the Precambrian core with overlying sedimentary units. Groundwater-surface water interactions are extensive in this region, so the site potentially could impact groundwater in a broad area extending from the site toward the east to the general area of Sturgis, a small town located on the eastern margin of the Black Hills uplift. This area includes several regional aquifers, including the Deadwood aquifer, Madison aquifer, and Minnelusa aquifer, which are used as private and municipal water sources. Local aquifers are present within Precambrian rocks and Quaternary alluvial deposits. These local aquifers are widely used for private water supplies within the Precambrian core of the Black Hills (Driscoll et al. 2002).

In the following paragraphs, the regional aquifers are discussed first. The Minnelusa and Madison aquifers are not present on the site; however, contaminant migration could impact these units. A portion of the Deadwood aquifer is present on the site. Local aquifers within Precambrian and Quaternary rocks are discussed following the regional aquifers.

The Minnelusa formation is a heterogeneous formation containing interbedded shale, siltstone, sandstone, limestone, and evaporates. The aquifer occurs within sandstone, dolomite, and anhydrite in the lower portion of the formation and sandstone and anhydrite in the upper part of the formation. A shale unit at the base of the Minnelusa Formation serves as a confining layer between the Minnelusa aquifer and the underlying Madison aquifer. Permeability in the Minnelusa Formation includes both primary intergranular permeability as well as secondary permeability related to fracturing, dissolution of anhydrite, and local collapse breccias. The contact zone between the Minnelusa Formation and the underlying Pahasapa Limestone is an unconformity marked by a hiatus in deposition and development of karst features on the upper contact of the Pahasapa Limestone. In some locations in the northern Black Hills, sinkholes are present in the Pahasapa Limestone, which are filled in with Minnelusa sediments. As a result, it is likely that the shales in the lower unit of the Minnelusa Formation form a leaky confining layer in some locations. This aquifer is recharged by precipitation as well as stream flow losses (Driscoll et al. 2002). The unit is present along Bear Butte Creek approximately 6 miles downstream from the site.

The Madison aquifer is hosted by the Pahasapa Limestone and the underlying Englewood Formation. This unit is widely used for residential wells and municipal water supplies. Permeability in the Madison aquifer is dominantly secondary permeability related to fracturing and karst development. The dissolution features range from enlargement of fractures and formation of local solution vugs to extensive cave systems. An estimated 270 caves are present within this unit in the Black Hills, including Jewel Cave and Wind Cave, the second and fifth longest caves in the world (Ohm 2006). The extensive karst development in the Madison aquifer results in extremely variable groundwater flow rates and flow pathways. This is discussed in a following section focusing on groundwater-surface water interactions. The Madison

aquifer is underlain by the Whitewood and Winnipeg Formations, which serve as a semi-confining layer between the Madison aquifer and the underlying Deadwood aquifer (Driscoll et al. 2002).

The Deadwood aquifer occurs in sandstones and carbonates of the Deadwood Formation. This unit is also widely used for residential and municipal wells. The aquifer occurs within sandstones and carbonates in the upper part of the formation and sandstones, carbonates, and local conglomerate in the lower portion of the formation. Permeability within these units includes primary intergranular permeability as well as secondary permeability resulting from fracturing and local dissolution of carbonates. An intermediate shale unit is present within the center of the formation, which acts as a confining layer between the upper and lower portions of the aquifer. The Precambrian rocks underlying the Deadwood aquifer generally act as a confining unit at the base of the Deadwood aquifer although there may be some groundwater communication between the Deadwood aquifer and the underlying Precambrian aquifers (Driscoll et al. 2002).

Groundwater is present within Precambrian rocks. The primary permeability of the Precambrian rocks is very low. Hydrogeologic characteristics of Precambrian rocks are controlled by secondary permeability related to fracturing and weathering of rocks. Groundwater within Precambrian rocks is best understood as numerous local aquifers, which are dependant on the depth of weathering and the degree of fracturing. It is likely that these aquifers are interconnected to varying extents based on local conditions. Artesian conditions are sometimes present within Precambrian rocks as a result of the local orientation of fracture systems.

Rahn (1985) estimates that the depth of the Precambrian aquifer in the Black Hills is less than about 500 feet. However, groundwater is encountered very deep within the Precambrian rocks at some locations. Inflows of groundwater into the Homestake mine approximately 4 miles northwest of the site were identified at depths up to 8,000 feet, which shows that groundwater is conveyed at great depths within Precambrian rocks. However, it is likely that the effective porosity of the Precambrian rocks is highest where the rocks are exposed at the surface. This is a result of weathering and associated enlargement of pre-existing fractures and cleavage planes. The base of the aquifer is not a distinct surface. It is likely that permeability decreases gradually with increasing depth. Areas such as natural drainages are likely to be more extensively weathered, which would lead to increased permeability resulting from enlargement of preexisting fracture zones and cleavage planes. The maximum depth of the aquifer would also vary based on the degree of brittle fracturing of the rock units, the presence of major ductile shear zones, and the lithology of the metamorphic rock units.

Alluvial aquifers are present in numerous areas within the core of the Black Hills. Alluvial aquifers are local in extent and occur because the rate of infiltration into the unconsolidated alluvial sediments exceeds the rate of infiltration into the underlying Precambrian bedrock aquifers. These alluvial aquifers are widely used in the central Black Hills for sources of residential water. The alluvial aquifers occur in alluvial

deposits, which are accumulations of unconsolidated sediments that were deposited by water. The alluvial aquifers are generally found within the bottom of gulches and valleys and are often in communication with nearby streams.

3.6.2 Site Hydrogeology

3.6.2.1 Site Groundwater Monitoring Network

An extensive network of wells is present at the site in order to monitor groundwater quality and aquifer characteristics. Currently, 56 wells are included in the groundwater monitoring network. This network is designed to allow monitoring of upgradient groundwater quality, effects to groundwater within the site, and potential migration of groundwater contaminants off site. The network includes wells established by BMC in compliance with state mine permitting regulations and state groundwater discharge permitting requirements, wells established by the EPA removal program, and wells established during the course of the various groundwater remedial investigations. Figure 3.6-1 illustrates the locations of these wells. The following discussion of physical characteristics is based on data collected during the various groundwater remedial investigations as well as the characteristics of the regional aquifers that were discussed previously.

3.6.2.2 Site Aquifers

Aquifers present at the site include bedrock aquifers and alluvial aquifers. The bedrock aquifers are deep aquifers that occur within bedrock units. Alluvial aquifers are local in extent and occur in unconsolidated alluvial sediments that are present within the upper parts of site drainages. Near the mine, the alluvial aquifers are often perched above the deeper aquifers with a zone of unsaturated rock located between the shallow alluvial aquifer and the underlying bedrock aquifer. However, the relationship between the alluvial and bedrock aquifers typically changes in the downgradient direction where water levels in the bedrock aquifers are higher than water levels in the alluvial aquifers.

Bedrock Aquifers

Two general types of bedrock aquifers are present on the site. These include unconfined aquifers and confined aquifers. A confined aquifer is an aquifer that is confined by low-permeability rock units called confining layers. Water in confined aquifers is under hydrostatic pressure, which causes water in a well to rise above the level of the aquifer. Unconfined aquifers are not confined by low permeability units, and the water level encountered in a well represents the upper boundary of the aquifer. The confined versus unconfined characteristics of groundwater at the site vary as groundwater migrates through the complex geologic terrain at the site.

Aquifer characteristics are strongly controlled by the hydrogeological characteristics of rock units that host the aquifer. The site geology includes metamorphic, igneous, and sedimentary rock units ranging in age from early Proterozoic to Tertiary, a span of almost 2 billion years. These rocks were extensively deformed, altered, and mineralized. In order to provide a framework to understand hydrogeologic characteristics of this complex geology, a group of hydrogeologic units were defined.

The units are defined based on hydrogeologic characteristics, including lithological, stratigraphic, and structural characteristics of the rock.

Hydrogeologic units consist of (1) layered sedimentary and igneous rocks, including Deadwood Formation sedimentary rocks and intrusive sills emplaced within Deadwood Formation sediments; (2) rocks located within deformation zones adjacent to major igneous stocks at Sunday/Dakota Maid pits and Anchor Hill Pit; (3) igneous crystalline stocks; and (4) Precambrian rocks located south and east of the site. The aerial extent of these hydrogeologic units is shown on Figure 3.6-3. A 3-dimensional schematic of the hydrogeologic units is shown in Figure 3.6-4. Table 3.6-1 presents transmissivity data for bedrock wells located within the various hydrogeologic units. The following discussion will consider the various hydrogeologic units in the general order that they are encountered proceeding from the Anchor Hill Pit area to Galena area.

The layered sedimentary and igneous hydrogeologic unit is present in the area west of Sunday and Dakota Maid pits. The unit is truncated by intrusive stocks in the Union Hill/Dakota Maid Pit/Sunday Pit area, but it is present north of Union Hill extending into the footprint of the Ruby Repository. The layered unit consists of sandstones of the lower Deadwood Formation, a regional hornblende trachyte porphyry sill that intrudes near the top of the lower Deadwood Formation sandstones, shales of the intermediate Deadwood Formation, and other miscellaneous intrusive sills within the Deadwood Formation. In the direct vicinity of the site, the intermediate shale was altered to hornfels by contact metamorphism. The Deadwood Formation sandstones are less affected by contact metamorphism. The primary effect is local recrystalization of the quartz grains resulting in a quartzite texture. A thin layer of dolomitic carbonates occurs within the lower Deadwood Formation sandstones. Dissolution of carbonate minerals within this zone resulting from either groundwater movement or hydrothermal solutions has the potential to increase the effective porosity of the lower Deadwood Formation.

The aquifer within the layered unit is confined in the upgradient areas west of Sunday and Dakota Maid pits. In this area, the upper confining unit is the extensive hornblende trachyte porphyry sill, which overlies the lower Deadwood Formation sandstones. Undifferentiated Precambrian rocks make up the lower confining unit. The effectiveness of the hornblende trachyte porphyry sill in confining groundwater in the lower Deadwood Formation sandstones is affected by the degree of fracturing, which causes secondary permeability in the crystalline confining layer. In the area of the upper Strawberry Creek drainage west of Sunday/Dakota Maid pits, the confining layer was removed by erosion. This causes a transition from confined conditions in upgradient areas distal to the upper Strawberry Creek drainage to unconfined conditions in the direct vicinity of the drainage.

Transmissivity estimates for the layered unit range from 1 to 29 feet squared per day (ft^2/day), with a median value of 7 ft^2/day. Based on available data, the transmissivity of the layered hydrogeologic unit is about an order of magnitude higher than the crystalline rocks. The aquifer of the lower Deadwood Formation

sandstones has not been specifically targeted in any wells although flow through the sandstones is likely a major component of groundwater movement in the layered unit. Additional hydrologic characterization is in progress for this unit.

The deformation zone hydrogeologic unit includes rocks of various lithologies that are located within a zone of brittle deformation at the margins of major igneous stocks. The major igneous stocks at the site intruded vertically through the layered unit. Structural displacement, brittle deformation, and thermal metamorphism were associated with intrusion of these stocks. The deformation zone hydrogeologic unit includes rocks adjacent to the margins of the igneous stocks that were significantly disturbed by the intrusions. This unit includes breccias that are present at the margins of the stocks as well as an interpreted zone of increased brittle deformation, which has created a zone of increased secondary permeability attributed to stock emplacement. Rocks within the deformation zone hydrogeologic unit are not exposed at the surface. Therefore definition of the deformation zone hydrogeologic unit is based on an understanding of the overall structural regime present at the site as well as data developed from aquifer tests within the deformation zone hydrogeologic unit. The outer boundary of the deformation zone unit is subjective, and this boundary would be expected to be gradational as the brittle deformation associated with stock emplacement decreased in intensity with increasing distance. The fracture density, openness, and spacing within the deformation zones would also be dependant on the relative rheology of the units adjacent to the stocks. The sandstone and porphyry rocks in the layered unit would be expected to deform in a more brittle manner leading to greater density, openness, and interconnectivity than the relatively more ductile Precambrian rocks.

MacLeod (2005) interpreted the presence of a synclinal fold in the upper Strawberry Creek area based on historical exploration drilling data. This area is located within the deformation zone hydrogeologic unit. The fold is attributed to differential displacement of the layered unit caused by emplacement of the intrusive stocks. Formation of this fold would lead to increased fracturing along the axis zone of the fold resulting from compressional stresses. The brittle deformation associated with this fold may contribute to increased secondary permeability in the upper Strawberry Creek area.

Hydrogeologic characteristics of the deformation zone unit were extensively investigated by aquifer tests, particularly within the Strawberry Creek area (CDM 2007e). Groundwater within the deformation zone units is unconfined. Estimated transmissivities within this area range from 52 to 879 ft^2/day. Wells BED-8 and GE-MW-08 are located within a deformation zone surrounding the Anchor Hill stock and exhibit estimated transmissivities of 173 ft^2/day and 286 ft^2/day, respectively. The range of transmissivities measured in the deformation zone hydrogeologic unit are two to three orders of magnitude higher than rocks of similar lithology located outside of the deformation zones. It should be noted that the estimated transmissivity of the deformation zone unit is based on multiple well pumping tests, whereas the hydrogeological characteristics of the other units are based on single well tests. It is

likely that the multiple well tests also contribute to the higher interpreted transmissivity of the deformation zone unit.

The crystalline hydrogeologic unit includes the Union Hill stock, the Langley stock, the Anchor Hill stock, and a large igneous intrusion exposed at the base of Ruby Gulch. The lithology of these units is alkaline, with rock types ranging from quartz trachyte porphyry to rhyolite. The hydrogeologic characteristics of these units are similar and are characterized by very low transmissivity. These units are crystalline intrusive rocks with negligible primary permeability. Although outcrops of these units display abundant fractures, the extent, openness, and interconnectivity of the fractures are not sufficient to markedly increase the transmissivity.

Groundwater within the igneous crystalline hydrogeologic unit is unconfined. Based on existing data, the estimated transmissivity of this hydrogeologic unit is very low and ranges from 0.1 to 0.8 ft^2/day, with a median value of 0.5 ft^2/day. The water level within several wells located within this hydrogeologic unit takes weeks to recover after a single sampling event. The igneous stocks represent local barriers to groundwater flow, which may cause local permutations in groundwater flow directions.

The Precambrian hydrogeologic unit includes undifferentiated Precambrian metamorphic rocks located south and east of the site. Groundwater flowing off of the site toward Bear Butte Creek flows through the Precambrian unit. These rocks have very low primary permeability. Secondary permeability associated with open fractures and weathered cleavage planes are important controls on hydrological characteristics of this unit. The hydrogeological characteristics of the Precambrian unit are not well defined. Estimated transmissivity for wells in the Precambrian hydrogeologic unit range from 0.2 to 95 ft^2/day, with a median of 5 ft^2/day.

Major Fracture Zones

Major fracture zones cross-cut hydrogeologic units in the vicinity of Dakota Maid and Sunday Pit based on interpretive fracture trends provided by MacLeod (2005). These fracture zones provide potential conduits for groundwater flow. Angle holes were drilled across these fracture zones in 2004 in order to measure the water quality and transmissivity within the fracture zones. This program had limited success intersecting specific fractures displaying high transmissivity; however, the data provide information useful in understanding hydrogeological characteristics of the fracture zones.

It is likely that rheologic characteristics of the hydrogeological units and the depth affect the extent, spacing, and openness of the fractures. The major fracture zones are well developed in the relatively brittle intrusive units exposed in Sunday and Dakota Maid pits. It is likely that the transmissivity of the fracture zones decreases as the zones pass from igneous rock into more ductile Precambrian rock located south and east of the site. It is also likely that the transmissivity of the fracture zones decreases with depth as the fractures become less open. GE-MW-16 intersected the Rattlesnake Fracture zone northeast of Sunday Pit within the Precambrian hydrogeologic unit.

The well was screened at a depth of 320 to 340 feet. The estimated transmissivity at this location is 0.5 ft^2/day, which supports the hypothesis that the extent of the fractures is limited at depth and that the relatively more ductile rheology of the Precambrian rocks impacts the extent, openness, and interconnectivity of the fracture zones.

Angle wells GE-MW-17 and GE-MW-18 attempted to intersect the fracture zones within the crystalline hydrogeologic unit on the south side of Sunday Pit. Groundwater within these wells is impacted by ARD-related contaminants; however, neither well intersected zones of high transmissivity. It is likely that the projection of the fracture zone and/or the orientation and angle of the well were not accurate enough to penetrate the fracture zone. The very low transmissivity is within the general range of transmissivity measured within the igneous crystalline hydrogeologic unit. Water samples collected from these wells indicate that groundwater at these locations is contaminated and that ARD-related contaminants are migrating from the Sunday Pit area along the general trend of these fracture systems.

Two of the angle wells intersected fracture zones within the Precambrian hydrogeologic unit in the Strawberry Creek area, wells GE-MW-18 and GE-MW-19. These wells were relatively shallow wells at 50 feet and 45 feet, respectively. Moderate transmissivity values of 8 ft^2/day and 5 ft^2/day were estimated for these wells. This is compatible with the hypothesis that the extent, openness, and interconnectivity of the fractures are higher near the surface than at depth.

Alluvial Aquifers

Alluvial aquifers occur within unconsolidated Quaternary sediments located in the base of valleys, such as Strawberry Creek, Hoodoo Gulch, and Ruby Gulch. The alluvial aquifers are unconfined aquifers. The lower boundary of the alluvial aquifers extends into the near-surface fractured and weathered bedrock underlying the alluvial sediments. It is likely that the lower boundary of the alluvial aquifers varies in response to the weathering characteristics and the degree of fracturing of the underlying bedrock.

The locations of major alluvial aquifers on the site are shown on Figure 3.6-2 while a schematic is shown as Figure 3.6-5. The Strawberry and Hoodoo alluvial aquifers contribute to contaminant migration at the site. Other alluvial aquifers are sources of water flowing onto the site, which eventually interacts with either acid generating rock or acid rock drainage. Aquifer characteristics for alluvial wells are summarized in Table 3.6-2 and Figure 3.6-6 (hydraulic conductivity).

The Strawberry Creek alluvial aquifer extends generally from the confluence of Strawberry Creek and Bear Butte Creek to the upper reaches of the Strawberry Creek basin north of the Stormwater Pond. The alluvial aquifer is present in the upper portion of the Strawberry Creek basin north of the approximate location of Last Chance Pond, extending for a distance of at least 2300 feet. This aquifer is hosted by a mixture of natural alluvial sediments and mine waste backfill. The width of the

alluvium in this area ranges from about 250 feet to 600 feet (Macleod 2005). It is likely that the width of the aquifer is less than the overall width of the alluvial sediments as a result of the natural slope of the bedrock/alluvium interface and the depth of the water table. The alluvial aquifer north of the approximate location of Last Chance Pond is perched above the underlying bedrock aquifer. Five alluvial monitor wells are present within this potion of the Strawberry Creek alluvial aquifer: GW-7, GW-3, GW-2A, GWCDM11, and GWCDM12.

The amount of water flowing through the Strawberry Creek alluvial aquifer can be estimated based on the hydraulic conductivity, the saturated thickness, the hydraulic gradient, and the cross-sectional area of the aquifer based on Darcy's law. The saturated thickness of the alluvial aquifer at GW-3 and GW-7 are estimated to be 13.8 and 9.8 feet, respectively. The hydraulic conductivity estimated at GW-3 is 4 feet per day (ft/day), and the hydraulic conductivity estimated at GW-7 is 0.8 ft/day based on evaluation of single well pump tests. The cross sectional area of the aquifer is estimated at 244 square feet based on an average saturated thickness of 11.8 feet and a slope at the base of the aquifer of 1.75:1. The hydraulic gradient between GW-3 and GW-7 is 0.06. This provides a value for groundwater flow through the alluvial aquifer of about 0.2 gpm. This value may be slightly lower because GW-3 and GW-7 may not be located within the deepest portion of the aquifer so the true cross-sectional area may be higher than estimated. It is likely that the flow rate through the Strawberry Creek alluvial aquifer in the region west of Dakota Maid/Sunday pits is less than 1 gpm. This suggests that the alluvial aquifer does not provide significant base flow to Strawberry Creek.

The Strawberry Creek alluvial aquifer extends downstream from the area of Last Chance Pond; however, the alluvium downstream of Last Chance Pond is discontinuous as a result of tailings removal actions completed in Strawberry Creek during 1993. The tailings removal actions excavated a slot down to bedrock through a mixture of relict tailings and alluvial sediments. The relationship between the bedrock and alluvial aquifers changes within several hundred feet below Last Chance Pond. Between paired alluvial/bedrock well sets GW-6/GW-7 and BES-11/BED-11, the potentiometric surface of the bedrock aquifer changes from being below the potentiometric surface of the alluvial aquifer to above. Groundwater from the alluvial aquifer flows downward into the underlying bedrock aquifer in the general region upgradient of GW-6/GW-7. In the general region of BES-11/BED-11 and below, groundwater from the bedrock aquifer flows upward, recharging the alluvial aquifer and surface water within Strawberry Creek. In the lower reaches of Strawberry Creek, the alluvial aquifer is in communication with surface water, and it is likely that flow from the alluvial aquifer into Strawberry Creek as well as flow from Strawberry Creek into the alluvial aquifer varies spatially and temporally. This is discussed further in a later section focusing on groundwater surface-water interactions. Figures 3.6-7 and 3.6-8 display the water level data for these paired well sets.

The Hoodoo alluvial aquifer is present in the base of Hoodoo Gulch in an area extending from the confluence of Hoodoo Gulch and Strawberry Creek to the upper reaches of Hoodoo Gulch. A perennial spring is present at Hoodoo Gulch, which is a

result of flow from both the Hoodoo alluvial aquifer and the underlying bedrock aquifer. A set of paired alluvial and bedrock wells is present in the upper reaches of Hoodoo Gulch, wells GWCDM09 and GWCDM10. At this location, an upward vertical gradient is present, indicating that the bedrock aquifer is recharging the alluvial aquifer in Hoodoo Gulch. Figure 3.6-9 shows the water level data from this paired well set.

A subsurface collection system in Hoodoo Gulch collects groundwater and runoff in Hoodoo Gulch. The hydrograph for the Hoodoo Gulch collection system provides information regarding the relative components of surface water runoff and groundwater discharge that contribute to the observed flows at the Hoodoo Gulch collection system. As shown in Figure 3.6-10, the pumpback rate at the Hoodoo collection system varies markedly in response to seasonal runoff conditions and large precipitation events. The hydrograph is dominated by short-term or intermittent variation in pumpback rates, with a minor contribution attributed to base flow. This suggests that runoff is a major contributor to the observed pumpback rates in Hoodoo Gulch. Data from paired wells GHWCDM09 and GWCDM10 indicate that discharge from the deep bedrock aquifer also contributes to the observed flow rates.

Alluvial aquifers are also present upstream of the major disturbance areas on the site. These include the Pond C Tributary, Process Area, and Anchor Hill alluvial aquifers. A perched alluvial aquifer is present in the Anchor Hill alluvial aquifer as demonstrated by paired well set BED-8/BES-8. The Anchor Hill alluvial aquifer is located at the highest elevation and has the smallest contributing drainage basin of the upgradient alluvial aquifers. This suggests that alluvial groundwater is likely present in both the Process Area and Pond C Tributary drainages. Alluvial groundwater flowing through these aquifers would report to the Pond C collection system where it would be captured and pumped into the site ARD treatment system.

Waste Rock Dump Water Bearing Unit

The waste rock dump water bearing unit occurs in natural alluvial sediments as well as waste rock fill placed in Ruby Gulch. The waste rock dump water bearing unit is the source of perennial flow at the toe of the Ruby Repository. Water flow in waste rock dumps is a complex process that involves infiltration of precipitation through a heterogeneous pile under unsaturated conditions, and in the case of the Ruby Gulch waste rock dump, recharge of a saturated zone in the base of the waste rock dump. Currently, details of flow mechanics in waste rock dumps are incompletely understood (Nichol et al. 2000). A difficult aspect is adequately understanding the variation in hydraulic conductivity within the dump. Hydraulic conductivity in waste rock dumps varies widely as a result of factors including inherent characteristics of the mined rock, the degree of particle size reduction during mineral processing, segregation of various particle sizes caused by construction methods, localized zones of compaction associated with equipment travel routes, weathering of broken rock within dump, and the water content of the broken rock. Preferential flow pathways are commonly present within a waste rock dump and vary markedly between the unsaturated and saturated zones (Younger et al. 2002).

The rate of water infiltration through preferential flow pathways in the unsaturated zone varies in response to the magnitude of a precipitation or snow-melt event as well as the water content of the waste rock. This is caused by the dependence of unsaturated hydraulic conductivity on moisture content. Unsaturated hydraulic conductivity is also dependant on the grain size distribution of the waste rock, which is extremely variable within the waste rock dump. The details of infiltration rates through various preferential flow paths within the waste rock dump would be difficult to discern; however, an examination of flow data from the toe of the waste rock dump in relation to precipitation shows several important factors, as shown in Figure 3.6-11.

Two important observations are evident in Figure 3.6-11. The first observation is that flows from the toe of the waste rock dump occur continuously year round. Flows decrease to a rate of about 8 to 10 gpm, but the flow rate never decreases to zero. The second observation is that the flow rate varies markedly in response to precipitation and snowmelt. Rapid responses to major precipitation events are evident, with a tail of increased waste rock dump discharge rates lasting days to weeks after a given precipitation event. The response to precipitation events shows that water is infiltrating through the waste rock dump at varying rates, which is a result of the specific characteristics of preferential flow paths, such as the flow distance and unsaturated hydraulic conductivity. Although the detailed characteristics of these flow paths are unknown, the waste rock dump discharge can be understood in terms of intermittent flow responses that occur at the waste rock dump toe within a period of days to weeks after precipitation or snow-melt events and longer-term responses that contribute to the year-round discharge.

Year-round discharge of water from the toe of the Ruby Gulch waste rock dump is evidence of a saturated zone within the waste rock dump. ARD that discharges as a spring at the base of the waste rock dump is discharged from groundwater, which is strictly defined as water below the earth's surface in the zone of saturation. An aquifer is defined as the saturated portion of a formation, group of formations, or part of a formation with sufficient permeability to provide a significant source of water to wells or springs. The saturated zone within the waste rock dump functions in a manner similar to natural aquifers. The waste rock dump water bearing unit is a saturated zone of unconsolidated waste rock and natural alluvial sediments located in the lower portion of the waste rock dump. The waste rock dump water bearing unit receives recharge from a number of sources, which are described below.

The Ruby Gulch waste rock dump is a valley fill waste rock dump, which was constructed by filling in a valley with waste rock and spent ore. The hydrological characteristics of the valley remain an important aspect affecting infiltration into the waste rock dump and recharge of the waste rock dump water bearing unit. These characteristics include (1) a soil layer on natural slopes surrounding the dump, which attenuates runoff, stores water, and provides a long-term source of moisture to vegetation; (2) a layer composed of sub-soil and colluvial sediments with capacity to convey water both vertically and laterally; (3) a zone of unsaturated bedrock; and (4) the saturated zone, which is marked by the water table and referred to as the bedrock

aquifer. An accumulation of alluvium is present within the base of the valley orientated along the axis of the valley.

Figure 3.6-12 is a schematic diagram depicting the current configuration of the repository. A low permeability cover was installed on the waste rock dump significantly limiting the potential for direct infiltration of precipitation into the waste rock dump. The low-permeability cover is overlain by approximately 4 feet of unconsolidated cover material. An engineered system is designed to convey overland flow from the surface of the dump as well as interflow within the cover material outwards to perimeter ditches. The ditches are located at the interface of the cover system with the undisturbed slopes surrounding the dump. Approximately 9 acres of waste rock are not covered by the liner and remain exposed to direct infiltration of precipitation into waste rock.

The diversion ditches represent a significant pathway for infiltration of water into the Ruby Gulch waste rock dump from both the waste rock dump cover and the surrounding undisturbed slopes. The diversion ditches were shown to leak at rates varying from approximately 10 percent to 100 percent, with an average leakage rate of about 40 percent (CDM 2006e). The diversion ditches are designed to collect and convey water from both the undisturbed natural slopes surrounding the dump and from the low-permeability cover system. Water from surrounding undisturbed slopes includes the surface and subsurface components of runoff, overland flow, and interflow. Water that flows into the perimeter ditches from the engineered cover system includes overland flow and water conveyed through the system of benches, drain-rock layers, and piping. The engineered system is analogous to the natural system of overland flow and interflow; however, the efficiency of the engineered system is higher at conveying precipitation from the repository cover toward the diversion ditches. So the temporal characteristics of infiltration resulting from runoff from adjacent undisturbed slopes and from conveyance of water through the engineered cover system are rapid, with effects of precipitation occurring within a period of days to weeks following a precipitation event.

It is currently unknown whether the bedrock aquifer discharges water into the waste rock dump water bearing unit and therefore provides a source of base flow to the waste rock dump, however available data suggests that this is not occurring.

A paired set of alluvial/bedrock wells were formerly present near the toe of the waste dump, GW-8 and GW-9. Data from these wells provide information regarding the vertical hydraulic gradient in this area. Figure 3.6-13 shows available water level data for these wells. At that time, the waste rock dump water bearing unit was perched above the deeper bedrock aquifer, indicating a downward vertical hydraulic gradient. This indicates that the deep bedrock aquifer was not discharging to the shallow system and contributing to waste dump flows at that time. Additional details regarding the waste rock dump water bearing unit are presented in a later section discussing the waste dump water budget.

A natural alluvial aquifer is present in Ruby Gulch downstream of the toe of the Ruby Repository extending to the confluence of Ruby Gulch with Bear Butte Creek. A paired well set, GW-8A and GW-9A, is present approximately 400 feet downgradient from the Wet Well. Water level data for these wells are presented in Figure 3.6-14. The relationship between the alluvial aquifer and the bedrock aquifer within Ruby Gulch appears to be similar to Strawberry Creek and Hoodoo Gulch, with the alluvial aquifer perched above the bedrock aquifer in the upper portions of the drainage and the bedrock aquifer perched above the alluvial aquifer in the lower parts of the drainage. However, surface water flow in Ruby Gulch is intermittent rather than perennial. This is likely related to the presence of a large zone of rocks within the area of the crystalline hydrogeologic unit, which exhibits very low transmissivity. Collection of virtually all surface flow at the Ruby repository toe as well as collection of alluvial groundwater in the Wet Well also contributes to the lack of surface flow in Ruby Gulch.

3.6.2.3 Potentiometric Surface/Hydraulic Gradient

The potentiometric surface for the bedrock hydrogeologic units was interpreted based on water level measurements at the site for the period of 2000 to 2007. The interpreted potentiometric surfaces are shown in Figures 3.6-15 (August 2002) and 3.6-16. A potentiometric surface is an imaginary surface that describes the total head of groundwater, which is the height that water will rise in a well. In aquifers composed of isotropic granular media, the direction of groundwater flow is perpendicular to potentiometric contours in a downgradient direction. The rate of change of total head per unit of distance is the hydraulic gradient. The hydraulic gradient varies in response to the potentiometric surface and the hydrogeologic characteristics of the aquifer.

The potentiometric surface provides a general idea of the overall direction of groundwater flow at the site. The variation in hydrogeologic units, the degree of fracturing, the orientation of fractures, and the depth of weathering are also important controls on the direction of groundwater flow at the site. These factors cause variations in groundwater flow directions as compared to the overall flow direction indicated by the potentiometric surface. However, the overall flow direction is useful for a broad understanding of groundwater flow at the site. The potentiometric surface maps show that groundwater flows from the topographically higher portion of the site in the Anchor Hill area toward Bear Butte Creek.

It is likely that a groundwater divide is present northwest of Anchor Hill Pit generally coincident with the ridgeline. Flow east of the divide reports to the Bear Butte Creek basin, and flow west of the divide reports to the Two Bit Creek basin. The Gilt Edge mine is located near the top of the topographic divide between these drainage basins. If the groundwater divide is coincident with the topographic divide, it would indicate that recharge from precipitation within the general vicinity of the mine is the major component of groundwater recharge at the site. The drainage basin divide is shown on Figures 3.6-15 and 3.6-16 based on the interpretation of a groundwater divide that is coincident with the topographic divide.

The potentiometric surface maps show mounding of the water table in the area of Sunday Pit during periods when the pit lake elevation is high. This indicates that water flows from the pit lake to groundwater and therefore serves as a source to groundwater. This is discussed in more detail in a later section focused on groundwater-surface water interactions.

3.6.2.4 Groundwater Linear Velocity

The average linear velocity of groundwater was estimated using two methods, an analytical method and an empirical method. The average linear groundwater velocity represents the velocity that groundwater moves on a macro scale (Freeze and Cherry 1979). This analysis focuses on groundwater velocity on the Precambrian Hydrogeological Unit within the Strawberry Creek area because this area is particularly sensitive to potential groundwater contamination.

Application of the analytical method requires estimation of a number of parameters, including hydraulic gradient, transmissivity, saturated thickness, effective porosity. The hydraulic gradient is readily evaluated based on static water level measurements and potentiometric surface maps discussed in Section 3.6.2.3. The hydraulic gradient in the Strawberry Creek area is approximately 0.05. Transmissivity was estimated based on single well pump tests that were conducted within the Precambrian Hydrogeologic Unit in the Strawberry Creek area. The median transmissivity in this area is 5 ft^2/day.

The saturated thickness and effective porosity of the Precambrian Hydrogeologic Unit is not known. Rahn (1985) estimated an effective porosity of 0.001 and a saturated thickness of 400 feet for the Precambrian Aquifer in western South Dakota. As discussed previously in Section 3.6.2.2, primary porosity within Precambrian Rocks is very low and most groundwater movement occurs within secondary porosity related to cleavage planes, shear zones, and/or fractures. It is likely that the effective porosity of the unit is higher closer to the surface where weathering processes have enlarged the structural zones constituting secondary porosity.

The estimated transmissivity of Precambrian wells on the site vary as a function of the depth of the screened interval. Most pump test interpretation methods are based on an assumption of radial flow into a well that is fully screened over the saturated thickness of the aquifer. In practice, this ideal condition is often not attained. Screened intervals at Precambrian wells on the site range from 10 to 90 feet in length although most wells are screened over an interval of 20 feet. The depth of the screened intervals ranges from 25 to 340 feet. The data suggest that the estimated transmissivity is affected by the depth of the screened interval, which is compatible with the hypothesis that enlargement of cleavages, shear zones, and/or fractures as a result of weathering processes increases the transmissivity of Precambrian rocks. Estimated transmissivity of wells screened within 50 to 100 feet of the surface is approximately an order of magnitude higher then estimated transmissivity of wells screened at greater depth. This suggests that most groundwater movement in the Precambrian Hydrogeologic Unit occurs in the upper 100 feet of the unit. The unit is transmissive

at depths of at least 340 feet based on available data, but the rate of groundwater flow is likely lower with greater depth.

The average linear velocity of groundwater is estimated based on the hydraulic gradient in the Strawberry Creek area, the median transmissivity of Precambrian wells in the area, an estimated effective porosity of 0.01, and saturated thickness ranging from 100 feet to 400 feet. Based on these values, the average linear groundwater velocity in the Strawberry Creek area is estimated to be in the range of 23 to 91 feet per year.

An empirical approach was also used to evaluate the average linear groundwater velocity. This method considered the extent of groundwater contamination in the Hoodoo Gulch-Strawberry Creek area compared to available data regarding the time of construction of known contaminant sources, such as Sunday Pit, Langley Pit, and the Hoodoo Fill. The current distance between the leading edge of the contaminant plume to source areas at Sunday Pit, Langley Pit and the Hoodoo Fill is approximately 1,700 ft, 1,200 ft and 1,100 ft respectively (groundwater contaminant plumes will be discussed in detail in Section 4.3). Construction of the Sunday Pit and the Hoodoo Fill started in approximately 1987 and the Langley Pit was constructed in 1997. This provides a period of approximately 20 years since construction of Sunday Pit and the Hoodoo Fill and approximately 10 years since construction of Langley Pit. An empirical estimate of the linear velocity of groundwater can be developed by dividing the distance to the leading edge of the plume by the period since the source area was constructed. Based on this evaluation, the estimated average linear groundwater velocity ranges from approximately 60 to 110 feet per year.

The hydraulic gradient within the Hoodoo Gulch area is higher than the gradient in the Strawberry Creek area, and it is possible that the average linear groundwater velocity may be somewhat slower than suggested by the empirical approach. Based on consideration of the analytical and empirical approaches to estimate average linear groundwater velocity, an estimate of 50 to 100 feet per year appears to be reasonable.

3.7 Groundwater-Surface Water Interactions

3.7.1 Regional Groundwater-Surface Water Interactions

Groundwater-surface water interactions are common in the Black Hills. Stream-flow losses occur in many streams that cross rock outcrops of the Minnelusa Formation and the Pahasapa Limestone. These stream flow losses are important contributors of recharge to the Minelussa and Madison aquifer. Stream flow losses also occur as a result of losses to unconsolidated alluvial deposits located adjacent to streams (Hortness and Driscoll 1998).

Bear Butte Creek is one of many streams along the eastern slope of the Black Hills that loses significant proportions of stream flow into various loss zones. Three major loss zones are present downstream from the site on Bear Butte Creek. The first loss zone is located where the stream crosses over the Pahasapa Limestone outcrop 2.2 miles downstream from the site. Often up to 100 percent of stream flow in Bear Butte Creek

enters karst solution openings in the Pahasapa Limestone at this location. The second and third loss zones are located where the stream crosses outcrops of the Minnelusa Formation downstream from the site.

Work by Hortness and Driscoll (1998) observed that most streams lose all of their flow when crossing a loss zone up to some loss threshold. When the stream flow rate exceeds the loss threshold, surface water continues to flow downstream past the loss zone. Hortness and Driscoll (1998) estimated stream flow loss thresholds for Black Hills streams, including Bear Butte Creek. These estimates were developed based on stream flow data collected at USGS gauging stations located above and below the loss zone. The estimated loss thresholds for the upper, middle, and lower loss zones on Bear Butte Creek are 4 CFS for each zone, for a total loss threshold of 12 CFS.

Stream flow data for Bear Butte Creek at Galena were summarized previously. These data show that on average 100 percent of stream flow in Bear Butte Creek enters one of the three loss zones. The stream flow losses recharge the Madison aquifer 12 months of the year. Based on average stream flows, loss zones on Bear Butte Creek also recharge the Minnelusa aquifer during the months of April, May, and June. The flow pathways of water entering the loss zones from Bear Butte Creek into either the Madison or Minnelusa aquifers have not been evaluated.

Previous work has evaluated groundwater flow pathways in the Madison aquifer at a similar loss zone on Box Elder Creek, which is located approximately 15 miles southeast of the site. This work has shown that groundwater flow in the Madison aquifer may be extremely rapid and unpredictable. A dye tracer test experiment of the Pahasapa Limestone loss zone on Box Elder Creek was conducted by Rahn (1971). This experiment showed that groundwater flowed approximately 8 miles in 30 days and that the groundwater crossed a major surface watershed boundary to the Spring Creek watershed. Dye that was placed into the Pahasapa loss zone was detected at a municipal well for the City of Rapid City 30 days after initiation of the test.

3.7.2 Local Groundwater-Surface Water Interactions

Groundwater-surface water interactions are also extensive within the direct vicinity of the site. These interactions include both natural interactions, such as the groundwater discharges that support perennial flow in Strawberry Creek, and anthropogenic interactions that were created by the various mine development and reclamation activities that have occurred on the site. Groundwater-surface water interactions provide important pathways for contaminant transport.

3.7.2.1 Groundwater-Surface Water Interactions in Lower Strawberry Creek

Groundwater-surface water interactions in the Strawberry Creek area were evaluated in specific remedial investigations. These investigations include synoptic sampling studies conducted by CDM (2003f) and a chemical tracer test conducted by Kimball et al. (2006). The data indicate that groundwater inflows are a major component of surface water in Strawberry Creek. These investigations also evaluated how the contaminant load in Strawberry Creek varies. This aspect of the investigations is

discussed in Section 4, Nature and Extent of Contamination. The following paragraphs are focused on the physical characteristics of groundwater-surface water interactions in Strawberry Creek.

Synoptic sampling studies completed by CDM (2003f) included addition of rhodamine dye to surface water in Strawberry Creek to evaluate flow velocities and measurement of flow rates at numerous locations within Strawberry Creek. The data indicate that the surface water flow rate generally increases in the downstream direction, but measured surface water flow rates are highly variable. This variability is attributed to movement of surface water into and out of the hyporheic zone of Strawberry Creek. The hyporheic zone is a zone of saturated alluvial sediments under and adjacent to Strawberry Creek through which stream water readily exchanges. The hyporheic zone includes a portion of the alluvial aquifers adjacent to the creek, with the distinction between the hyporheic zone and the remainder of the alluvial aquifer based primarily on the time required for water to flow into and out of the unconsolidated sediments. This variability in flow rates within Strawberry Creek made delineating the groundwater discharge rate within specific segments of Strawberry Creek difficult.

Kimball et al. (2006) evaluated Strawberry Creek using a tracer dilution method, which is designed to facilitate accurate estimates of stream discharge in areas of gaining streams, such as Strawberry Creek. The tracer dilution method accounts for both surface water and water moving into and out of the hyporheic zone. The tracer dilution method allowed for specific estimates to be made regarding the location and inflow rates of groundwater entering Strawberry Creek. Kimball et al. (2006) sampled Strawberry Creek during June 2003. The results of this work represent a snapshot of groundwater-surface water interactions for June 2003. It is likely that these interactions vary temporally in response to changing precipitation rates, snowmelt, and long-term variations in climatic conditions. The investigation was completed during a period when the water treatment plant discharge was not operating, which simplifies interpretation of the data. However, semi-passive sodium hydroxide treatment systems were operating at Pond C and Hoodoo Gulch, and some treated water was being discharged. The Pond C treated water discharge was located just upstream from the uppermost sampling point. The Hoodoo Gulch treated water discharge was located in Hoodoo Gulch, which reports to Strawberry Creek at the confluence of Hoodoo Gulch and Strawberry Creek.

Kimball et al. (2006) observed an increase of approximately 400 gpm in the flow rate of Strawberry Creek between the uppermost sampling point just downstream from the Pond C treated water discharge pipe and the lowermost sampling point located on Strawberry Creek just above the confluence with Bear Butte Creek. The flow rate at the uppermost sampling point was 41 gpm. Contributions from specific tributaries to Strawberry Creek downstream of this point included 55 gpm at Cabin Creek, 14 gpm at Hoodoo Gulch, and 154 gpm at Boomer Gulch, for a total tributary inflow of 223 gpm. Other inflows to Strawberry Creek accounted for 178 gpm, which includes discharge of groundwater from the bedrock aquifer into Strawberry Creek. The other inflows include small springs and dispersed subsurface flow. Based on Kimball et al.

(2006) data, inflows from groundwater accounted for about 44 percent of stream flow in Strawberry Creek in June 2003. The results of the Kimball et al. (2006) investigation are discussed further in Section 4.5.4.1. Additional information can be found in *Quantification of Mass Loading to Strawberry Creek near the Gilt Edge Mine, Lawrence County, South Dakota, June, 2003* (Kimball et al., 2006).

3.7.2.2 Groundwater-Surface Water Interactions in Upper Strawberry Creek

The upper Strawberry Creek basin encompasses the general area upgradient of Last Chance Pond. This area was extensively altered by mining and environmental control activities and contains acid generating waste rock. An unknown volume of groundwater reports to the surface water ARD collection system in this area as a result of existing environmental control infrastructure. Abandoned underground workings in this area discharge ARD to surface water. This discharge is thought to be related to the elevation of stored water in Sunday/Dakota Maid pits.

Environmental control facilities in the area include Pond C and Pond D, which are ARD collection ponds excavated into the alluvium in the upper Strawberry Creek valley. These facilities collect alluvial groundwater from the Strawberry Creek alluvial aquifer and convey it to Pond E/Strawberry Pond where it is pumped into the Sunday Pit for storage prior to treatment in the site water treatment plant. Recharge to the Strawberry Creek alluvial aquifer in this area includes direct precipitation on waste rock backfill, inflows from upgradient alluvial aquifers, including the Pond C Tributary, Process Area, and Anchor Hill alluvial aquifers, and runoff from adjacent slopes.

Several underground workings also contribute to groundwater discharges reporting to the surface water ARD collection facilities in the upper Strawberry Creek area. These workings consist of the Langley Adit, the King Adit and the Wood Weir. The Langley Adit discharges ARD to Pond E/Strawberry Pond on an intermittent basis; however, discharge records for the Langley Adit are also not available.

The King Adit discharges water into Pond D. Discharges from the King Adit are also intermittent and may be related to the elevation of water in Dakota Maid Pit based on anecdotal evidence. However, flow records are not available for the King Adit. A review of water level data from Dakota Maid Pit during the 2007 water year provides a minimum water level in the pit of 5,324.9 feet, which was measured in September, 2007. During the water year, ARD management actions were not conducted at Dakota Maid Pit. The ARD level in the pit was allowed to equilibrate by free drainage to Pond D via the King Adit. During the water year, the water level of the pit was either equilibrated at a level of 5,324.9 to 5,325.0 ft, or the water level was higher. Based on review of the site topographic map, the elevation of the King Adit portal is approximately 5,325 ft. This suggests that ARD flows from the pit lake to the adit portal when the ARD level in the Dakota Maid Pit is approximately 5,325 ft or higher. The flow path of ARD from Dakota Maid Pit to the King Adit likely includes fracture flow as well as conduit flow through underground workings.

The Wood Weir also discharges groundwater to surface water. The Wood Weir discharge reports directly to Pond E/Strawberry Pond. A hydrograph comparing Wood Weir flow rates to the elevation of stored ARD in Sunday Pit is shown in Figure 3.7-1. The Wood Weir flow rate is thought to be related to the elevation of stored ARD in Sunday Pit. Based on a graphical analysis shown in Figure 3.7-1, the critical elevation of Sunday pit is between 5,322 and 5,342 ft. When the elevation of the Sunday pit lake is below 5,322 ft, the Wood Weir generally does not flow. When the elevation of Sunday Pit is above 5,342 ft, the Wood Weir flows at rates of up to 30 gpm. The flow rate of the wood weir is variable when the elevation of Sunday Pit is between 5,322 ft and 5,342 ft. Variation in the range of 5,322 feet to 5,342 feet may be related to seasonal and annual variations in the groundwater potentiometric surface. The elevation of the Wood Weir is approximately 5,320 ft.

3.7.2.3 Groundwater-Surface Water Interactions in Hoodoo Gulch

Groundwater-surface water interactions in Hoodoo Gulch largely consist of anthropogenic effects, which have increased the recharge rate to the local alluvial groundwater system. These anthropogenic effects include the Hoodoo Gulch fill, which is a small valley fill waste dump located in the upper portion of Hoodoo Gulch. Historic surface and underground workings are also present in Hoodoo Gulch. Potential effects of these workings on geochemical or hydrological conditions have not been investigated.

The Hoodoo Gulch fill was placed during the initial phases of mine development between about 1987 and 1992. This fill changes hydrologic conditions in the area through increased infiltration and decreased transpiration of precipitation that falls within the basin. The surface of the fill is porous, which contributes to rapid infiltration of precipitation. The area is not covered with topsoil or vegetated. This also increases the infiltration rate as a result of the lack of moisture storage capacity or transpiration of stored moisture back into the atmosphere. The water that infiltrates the fill reports to the alluvium of Hoodoo Gulch, which underlies the Hoodoo Fill. This water then flows in the Hoodoo alluvial aquifer to the subsurface ARD collection system in Hoodoo Gulch.

3.7.2.4 Groundwater-Surface Water Interactions in Upper Ruby Gulch

Groundwater-surface water interactions in upper Ruby Gulch were investigated in detail. This is discussed in Section 3.8.4.1, which is focused on the water budget of the Ruby Repository.

3.7.2.5 Hydraulic Communication between Pit Lakes and Groundwater

Available data suggest that the pit lakes at Dakota Maid, Sunday, and Anchor Hill are in communication with groundwater. This data include both physical data as well as chemical data. Physical data are discussed in this section. The chemical data are discussed in Section 4. The available data vary at the different pits. Groundwater-surface water interactions are well understood at Dakota Maid Pit and fairly well understood at the Sunday Pit. Data regarding potential groundwater-surface water interactions at Anchor Hill Pit are limited.

Dakota Maid Pit

The Dakota Maid Pit is clearly in connection with groundwater. The lower level King workings are located approximately 100 ft. below the pit floor. The workings are accessed by a vertical shaft, which extends to the floor of Dakota Maid Pit. It is likely that a collapsed stope, present approximately 50 ft. south of the shaft collar, also provides a direct hydraulic connection with the lower level King workings. The King workings were pumped in a long-term pump test conducted in 2000. The water levels in wells near the Dakota Mid Pit were monitored during the course of the pump test. Drawdown was observed at wells extending from GW-4 to GW-6 during this test. GW-4 is located approximately 700 ft. northwest of the King Shaft, and GW-6 is located approximately 1,400 ft. southwest of the King Shaft. Additional details regarding the King Shaft pump test can be found in CDM (2003g and 2007e).

Groundwater-surface water interactions at the Dakota Maid Pit are also influenced by the Dakota Maid fracture zone. This fracture zone crops out for a vertical distance of approximately 250 ft. in the Dakota Maid Pit highwall. It is likely that this fracture zone extends downward and laterally for a similar distance, intersecting both the King underground workings and the natural drainage of the upper Strawberry Creek basin. The Dakota Maid Pit is located at the transition zone between the crystalline hydrogeological unit and the deformation zone hydrogeological unit. The underground workings and the fracture zone likely provide conduits providing for efficient hydraulic communication between the pit and the adjacent deformation zone hydrogeologic unit in the upper Strawberry Creek area. The highest transmissivity values on the site were measured in wells within the deformation zone hydrogeologic unit in this area. This explains the extensive area of influence observed during the King Shaft pump test.

The propensity for ARD present in the Dakota Maid Pit Lake to migrate into groundwater is mitigated by the regional potentiometric surface as well as the configuration of the upper level King workings. Regional groundwater in this area flows generally from the topographical high in the Anchor Hill Pit area toward the southeast. So a hydraulic gradient is present in the upper Strawberry Creek basin causing groundwater to flow from the undisturbed area west of the Strawberry Creek drainage toward the Dakota Maid Pit. The upper level King underground workings control the water level in the Dakota Maid Pit through discharges from the King Adit into Pond D. This limits the maximum water level in the Dakota Maid Pit and reduces the potential for the pit lake water level to contribute to a significant hydraulic gradient causing water to migrate from the pit lake toward the west. The detailed flow paths in the direct vicinity of Dakota Maid Pit are very difficult to discern because the groundwater system is controlled by fracture flow and conduit flow through underground workings. It is likely that there is some migration of ARD from the Dakota Maid Pit toward the Strawberry Creek area.

The region located east of the Dakota Maid is a major igneous stock that holds up the topographical high at Union Hill. This stock is part of the crystalline hydrogeologic unit, which exhibits the lowest transmissivity values on the site. The very low transmissivity east of Dakota Maid Pit limits the potential for surface water in the pit

lake to migrate in groundwater toward the east in the general direction of the regional hydraulic gradient.

Sunday Pit

Available data also suggest that the Sunday Pit is in communication with groundwater although these data are not as direct as the Dakota Maid Pit data. Sunday Pit was used as the primary ARD storage facility at the site since the mid 1990s. The water level of the Sunday Pit Lake varies in response to site precipitation trends. Data indicating connection between the Sunday Pit Lake and groundwater include groundwater quality trends, which is discussed in Section 4.3. The primary physical data regarding potential connections are the water level elevations in the pit lake in comparison to the water level in adjacent wells. The Rattlesnake underground workings are present beneath the floor of Sunday Pit. However, the Rattlesnake underground workings are less likely to contribute to groundwater-surface water interactions than the King workings at the Dakota Maid Pit.

Figures 3.7-2 through 3.7-3 are hydrographs comparing the water level in wells (GE-MW-07 and GE-MW-06) adjacent to Sunday Pit with water levels at the Sunday Pit Lake. As displayed in the figures, there is a strong correlation in water levels between the wells and the pit lake. This indicates that there is hydraulic communication between surface water in the pit lake and groundwater. The Sunday Pit is located within the crystalline hydrogeologic unit, which exhibits the lowest transmissivity values on the site. Groundwater movement in the direct vicinity of Sunday Pit is likely controlled by the major fracture zones discussed previously.

The current floor of Sunday Pit intersects sub-vertical workings connected with a network of drifts and potentially stopes beneath the pit. However, available data indicate that these workings do not extend to other mine openings other than those present in the floor of the pit. Therefore, it is likely that the underground workings beneath Sunday Pit form a pool of stored ARD rather than a conduit that would increase the potential for migration of contaminants in groundwater. The Rattlesnake workings are also located within the crystalline hydrogeologic unit, which exhibits very low transmissivity values. Groundwater flow in the crystalline hydrogeologic unit is controlled by secondary permeability in the form of interconnected fractures and major fracture zones. It is likely that the openness, interconnectivity, and extent of these fractures decrease with depth.

Chemical data for wells in the vicinity if the Sunday Pit indicate that groundwater is flowing from the pit lake toward the west and southeast. Physical data that support this observation include the location of the Selway fracture zone as well as the natural topography in the Strawberry Creek area. The major fracture zones were discussed previously in Section 3.4.2. The Selway fracture zone is located on the east side of Sunday Pit and trends generally toward the South Langley Pit and Strawberry Creek. The Sunday Pit is a side-hill pit similar to Dakota Maid Pit. The highwalls are higher on the east side of the pit than the west side where the natural drainage of Strawberry Creek intersects the pit. Fractures located on the west side of the pit are therefore closer to the surface, which causes them to be more open as a result of weathering.

This increases the potential for stored ARD in the pit to migrate in groundwater. This is discussed further in Sections 4.3 and 4.5, which are focused on nature and extent of contamination in groundwater and groundwater interactions in the Strawberry Creek Area.

Anchor Hill Pit
Significantly less data are available to assess the degree of hydraulic connection between the Anchor Hill Pit and groundwater. Physical data consist of water level measurements from monitor wells BED-8 and GE-MW-08 compared with water levels in the Anchor Hill Pit. These data are shown in Figures 3.7-4 and 3.7-5. The data suggest that groundwater is in hydraulic connection with Anchor Hill Pit. Available chemical data for these wells pertinent to potential groundwater-surface water interactions in Anchor Hill Pit are discussed in Section 4.3.

3.8 Site Water Balance

The site water balance is evaluated in four sections. The first section considers the groundwater budget and is based on the hydrogeologic characteristics, climatic conditions, and other factors. The second section considers the overall budget of the site hydrologic system and relates annual precipitation to groundwater recharge, surface water runoff, and evapotranspiration. The final two sections are focused on the amount of ARD generated within the primary mine disturbance area. This information is critical to understanding current ARD treatment requirements, understanding the effect of previous remedial actions on the volume of ARD requiring treatment at the site, and evaluating effects of future site management actions.

3.8.1 Site Groundwater Budget

The groundwater budget was evaluated for the surface water basin encompassed by the site boundary. This area generally includes the drainage basin of Strawberry Creek upstream of Boomer Gulch, the Terrible Gulch drainage basin, and the Ruby Gulch drainage basin. The area considered in the groundwater budget analysis is strictly defined by the surface-water drainage basin boundaries, whereas the site boundary is based on the surface water drainage basin as well as land status boundaries. The boundaries are generally coincident although the specific boundaries and enclosed acreage are slightly different. The groundwater budget analysis includes an area of approximately 1,516 acres. This area includes approximately 1,200 acres that are relatively undisturbed and 316 acres that encompass the primary mine disturbance area. The primary mine disturbance area exhibits markedly different hydrological characteristics because of the lack of vegetation and the presence of highly permeable rock piles.

The groundwater budget was evaluated based on the theory of mass continuity, which can be expressed as follows:

$$\sum \text{inflow} - \sum \text{outflow} = \Delta\text{storage} \qquad (1)$$

This expression is stated as the sum of inflows minus the sum of outflows equals the change in storage. In this analysis, the change in groundwater storage is assumed to be negligible. Although this assumption is not strictly true, it is considered an acceptable approximation for this analysis. The approach used in evaluating the groundwater budget consists of tabulation of inflows and outflows to the groundwater system. Table 3.8-1 shows the results of the groundwater budget analysis.

Available data regarding inflows and outflows to the groundwater system were compiled. Inflows include precipitation recharge, inflows from the regional bedrock groundwater system, and inflows from diversion ditch leakage at Ruby Repository. Outflows include groundwater collection facilities associated with the primary mine disturbance area; consumptive use of groundwater from the site water supply at Oro Fino shaft; outflows through alluvial aquifers in the Strawberry Creek, Terrible Gulch and Ruby Gulch drainages; outflows through bedrock aquifers; and discharge of groundwater to surface water at Strawberry Creek.

Some components of the groundwater budget are measured as part of routine O&M activities. These data were compiled for ARD collection facilities at Ruby Repository, the Wet Well, Hoodoo Gulch, the Wood Weir, and Pond C. Average discharge rates were used for Ruby Repository, Hoodoo Gulch, and the Wood Weir. The rate of water collected at Pond C has only been monitored since March, 2007. The Pond C collection facility collects both surface water and groundwater discharged from the Strawberry Gulch alluvial aquifer. For purposes of the site groundwater budget estimate, the minimum observed rate of water collected from Hoodoo Gulch was utilized with the assumption that this represents base flow discharge from the alluvial aquifer. This assumption is necessary because the Hoodoo Gulch ARD collection system collects ARD from groundwater and surface water runoff. Additional data from the Pond C collection facility are required in order to better understand the groundwater component of this system. The groundwater discharge rate from the King Adit is not routinely measured. The King Adit discharge rate was assumed to be equal to discharge from the Wood Weir for the purpose of this analysis, which is generally compatible with general visual observations. The assumptions regarding groundwater discharge rates at Pond C and King Adit cause uncertainty in the estimate. The estimated rate of ARD collected from groundwater in the areas of primary mine disturbance is the sum of inflows collected from Ruby repository, the wet well, Hoodoo Gulch, the estimated groundwater component of Pond C inflows, the wood weir, and the King adit, which is estimated to be 69 gpm.

Discharge of groundwater to surface water also occurs at Strawberry Creek, which is a gaining stream for the entire stream reach included in this analysis. Kimball et al. (2006) evaluated groundwater discharges to Strawberry Creek as part of a quantitative tracer-dilution experiment conducted in June 2003. Dispersed groundwater discharge to Strawberry Creek was estimated to be 155.4 gpm for the reach of the stream extending from Boomer Gulch to the area of the site water treatment plant discharge. This is a portion of the entire study reach evaluated by Kimball et al. (2006), which was described previously in Section 3.7.2.1. This estimate

included only the dispersed groundwater discharge and excluded inflows to Strawberry Creek from Boomer Gulch, Hoodoo Gulch, and Cabin Creek. It is likely that a portion of the tributary inflows also results from groundwater discharges to surface water within the tributary reach. The Kimball et al. (2006) data represent groundwater discharge to Strawberry Creek at a single point in time, which causes uncertainty in the groundwater budget evaluation.

Subsurface groundwater outflows through the bedrock and alluvial systems were estimated using Darcy's law and data regarding transmissivity, hydraulic gradient, and aquifer width. The groundwater flow rate through the Strawberry Creek alluvial aquifer is estimated to be 2 gpm based on transmissivity of 30.6 ft^2/day, hydraulic gradient of 0.085, and aquifer width of 150 feet. The groundwater flow rate though the Terrible Gulch alluvial aquifer is estimated to be 1.5 gpm based on transmissivity of 30.6 ft^2/day, hydraulic gradient of 0.31, and an aquifer width of 30 feet. The groundwater flow rate through the Ruby alluvial aquifer is estimated to be 1.2 gpm based on transmissivity of 30.6 ft^2/day, hydraulic gradient of 0.076, and aquifer width of 100 feet. The groundwater flow rate through the bedrock system was evaluated on the southeastern edge of the analysis area where groundwater flows toward the Bear Butte Creek area. This area is within the Precambrian hydrogeologic unit. This estimate is based on an estimated transmissivity of 2.4 ft^2/day for the Precambrian hydrogeologic unit. The hydraulic gradient in this area is 0.07 and the width of the aquifer is 3,870 feet. Based on these values, the estimated groundwater flow rate is 3.4 gpm.

Groundwater inflows to the system include the regional bedrock system, precipitation recharge, and recharge that occurs as a result of leakage through the diversion ditch system at Ruby repository. The upgradient end of the analysis area is located along the surface water drainage divide between the Strawberry, Terrible, and Ruby drainages to the east and the Two Bit Creek drainage to the west. A groundwater drainage divide is interpreted to be coincident with the surface water devide in this area. Therefore, the hydraulic gradient in this area is very low and groundwater inflows from the regional system are considered to be negligible. Precipitation recharge varies in response to the level of denudation of the land associated with mine disturbance. Precipitation recharge within the primary mine disturbance area is estimated to be 38 percent of precipitation, which is based on recharge estimated for the 9 acre uncapped area of the Ruby Gulch waste rock dump in *Draft- Estimation of Ruby Waste Rock Water Budget before and after Installation of Low-Permeability Cover* (CDM 2007a). Precipitation recharge into the 1,200 acres of largely undisturbed land within the basin is estimated by difference to be 7 percent of precipitation. Estimated precipitation recharge for the disturbed and undisturbed areas is equivalent to 111 gpm and 124 gpm, respectively. Leakage through the Ruby Repository diversion ditches recharges the waste rock dump water bearing unit. This recharge was estimated to be 12 gpm based on analyses presented in CDM (2007a).

Evaluation of the groundwater budget displays several important observations. Recharge from precipitation is higher within the primary mine disturbance area as a result of denudation of natural vegetation and the presence of highly permeable mine

waste piles. ARD collected from groundwater in these areas accounts for approximately 69 gpm, which equates to 36 million gallons of ARD per year. This is an important component of annual water treatment requirements. Groundwater discharge to surface water in Strawberry Creek is about 155 gpm based on the work completed by Kimball et al. (2007). This groundwater discharge represents approximately 63 percent of the overall groundwater budget, which demonstrates the importance of Strawberry Creek in the overall hydrologic system at the site.

3.8.2 Site Hydrologic Budget

The overall hydrologic budget for the site can be expressed in terms of a basic input-output equation that describes the hydrologic cycle (Stone 1999).

$$P = RO + ET + R \qquad (2)$$

Where:

P = Precipitation

RO = Runoff

ET = Evapotranspiration

R = Recharge

Several components of the site hydrologic budget were described in previous sections. Precipitation averages 28.85 inches per year based on climatic data from the weather station at Lead, South Dakota. Recharge was estimated at 10.9 inches per year for the primary mine disturbance area and 2.0 inches per year over the relatively undisturbed areas of the site. The weighted average recharge based on the primary mine disturbance area of 316 acres and relatively undisturbed area of 1,200 acres is 3.7 inches per year. These areas were presented previously in Figure 3-1.

Runoff yield for the Strawberry Creek, Terrible Gulch, and Ruby Gulch basins has not been specifically estimated. Driscoll and Carter (2001) evaluated runoff from numerous basins in the Black Hills, including Bear Butte Creek. Their evaluation is based on a USGS stream gauge located on Bear Butte Creek approximately 1 mile downstream of the confluence of Strawberry Creek and Bear Butte Creek. Driscoll and Carter (2001) estimated annual surface water yield efficiency of 18.7 percent for the drainage basin upstream of this gauge for a period of record extending from 1950 to 1998. Annual surface water yield efficiency is the percentage of annual precipitation that is yielded as surface water flow. Based on application of the estimated Bear Butte Creek yield efficiency to the site, it is estimated that site runoff is about 5.4 inches per year.

Evapotranspiration at the site can be estimated by difference using data described in preceding paragraphs and the basic input-output equation for the hydrologic cycle (equation 2). Estimated evapotranspiration for the site is 19.8 inches per year based on this method. Evapotranspiration within the relatively undisturbed areas of the site is higher than the disturbed areas of the site as a result of the presence of vegetation, soil

cover, and the lack of highly permeable mine waste piles. The presence of soil cover and vegetation is a critical control on the evapotranspiration rate because it provides water holding capacity and a means for transpiration of moisture by vegetation.

3.8.3 ARD Water Balance

Understanding the ARD water balance within the primary mine disturbance area is a critical factor in developing and evaluating appropriate remedial actions. The overall water budget is evaluated based on a mass continuity approach. The approach is summarized as follows:

$$\sum \text{total inflow} - \sum \text{outflow} = \Delta\text{storage} \qquad (1)$$

Inflows include precipitation and groundwater inflows. Outflows include pit lake evaporation, evapotranspiration, water treatment plant discharges, and potentially, discharges to groundwater. Accurately estimating pit lake evaporation and evapotranspiration is difficult at the site. Therefore, a method has been developed to facilitate estimation of the net inflows of ARD to the site without relying on estimates of pit lake evaporation and evapotranspiration. This method is based on net inflow, which is described as follows:

$$\sum \text{net inflow} = \sum \text{total inflow} - \sum E_{pl} - \sum ET \qquad (3)$$

Where: E_{pl} = Water lost to pit lake evaporation
ET = Water lost to evapotranspiration

Equation 3 can be rearranged as follows:

$$\sum \text{total inflow} = \sum \text{net inflow} + \sum E_{pl} + \sum ET \qquad (4)$$

The sum of the outflows can also be expanded:

$$\sum \text{outflow} = \sum WTP_{out} + \sum E_{pl} + \sum ET \qquad (5)$$

Where: WTP_{out} = Water treated and discharged by water treatment plant

By substituting the expanded expressions for inflows and outflows into Equation 1, the terms related to pit lake evaporation and evapotranspiration cancel out.

$$\sum \text{net inflow} + \sum E_{pl} + \sum ET - \left(\sum WTP_{out} + \sum E_{pl} + \sum ET\right) = \Delta\text{storage} \quad (6)$$

Based on these relationships, the mass balance expression shown in Equation 1 can be expressed as:

$$\sum \text{net inflow} - \sum WTP_{out} = \Delta\text{storage} \qquad (7)$$

In order to provide a meaningful value of net inflow, the summation is completed over the water year, which is defined as October 1 to September 30. This period is

evaluated because it facilitates accounting for precipitation that falls as snow in the fall and subsequently melts in the spring during the same water year. It also provides for annual accounting of pit lake evaporation and evapotranspiration, which attenuates short-term variations in pit lake evaporation and evapotranspiration rates.

Equation 7 can be rearranged as follows:

$$\sum \text{net inflow} = \Delta\text{storage} + \sum \text{WTP}_{\text{out}} \qquad (8)$$

Based on Equation 8, the sum of net inflows to the site can be estimated by adding the change in water storage to the sum of the water treated and discharged by the water treatment plant. The volume of water stored on the site is tracked routinely, and includes water stored at Sunday Pit, Dakota Maid Pit, Anchor Hill Pit, the Stormwater Pond and the Surge Pond. Estimation of net inflows for the water year based on the relationship shown in Equation 8 is presented in Table 3.8-2.

As shown in Table 3.8-2, the total volume of ARD stored on the site at the end of the 2007 water year was approximately 168 Mgal, and net inflows during 2007 were approximately 122 Mgal. Estimated net inflows have ranged from a high of approximately 122 Mgal in the 2007 water year to a low of 42 Mgal in the 2004 water year. The estimated net inflow shown in Table 3.8-2 is defined as the "annual ARD yield".

The annual ARD yield is strongly influenced by the amount of precipitation received at the site. In order to evaluate relative changes from year to year, the "normalized ARD yield" for the site is defined as the ratio of annual ARD yield to total annual precipitation. Normalized ARD yield is expressed in units of million gallons per inch precipitation (Mgal/in). The normalized ARD yield for the Gilt Edge site is shown in Table 3.8-3 for water years 2000-2007.

The normalized ARD yield is rounded to the nearest 100,000 gallons per inch precipitation in order to reflect inherent uncertainties in the estimate. The primary uncertainties are the distance of the weather station from the site (about 6 miles) and variations in the timing of precipitation. Site precipitation during the summer months is dominantly in the form of large thunderstorms. Variations in precipitation are common over relatively short distances during summer thunderstorms in the Black Hills (Driscoll et al., 2000). Variations in the timing of precipitation also affect the measured ARD yield. The ARD runoff produced for a given precipitation event (say 1 inch) varies in relation to the soil moisture conditions. Precipitation that occurs during the spring when soil is moist causes more ARD per inch than precipitation that occurs in very dry months such as August and September. Snowfall also affects seasonal variations in ARD runoff because evaporation, infiltration and sublimation reduce the snowpack during winter months. The resulting spring runoff represents only a portion of the water that fell as snow in previous weeks or months.

The normalized ARD yield changes in response to changes in site conditions and ARD management practices. Site conditions have remained approximately stable

during the 2006 and 2007 water years. This is an advantage in terms of understanding the normalized ARD yield, because it allows averaging the normalized ARD yield for the 2006 and 2007 water years. The best estimate of the current normalized ARD yield is the average of the 2006 and 2007 normalized ARD yields of 3.1 Mgal/in and 4.0 Mgal/in. The higher normalized ARD yield observed during the 2007 water year is thought to be a result of uncertainties in the estimate caused by the distance of the precipitation gauge from the site and variations in the timing of precipitation events throughout the year. The range in values for the 2006 and 2007 water years of 3.1 Mgal/in to 4.0 Mgal/in also displays the magnitude of uncertainty in the estimates. The current estimate of the normalized ARD yield at the site is rounded to 3.6 Mgal/in to reflect this inherent uncertainty.

3.8.4 Components of Annual ARD Yield

Current operational monitoring practices maintain records of several components of the annual ARD yield. These include the toe of the Ruby waste rock dump/Ruby repository, the wet well, the Hoodoo Gulch collection system, the Heap Leach Pad, and Pond C. Available data have been compiled for water years 2000-2007.

Numerous components of the annual ARD yield are not monitored including dispersed runoff from mine waste piles and highwalls, and precipitation reporting directly to exposed pit lakes. Inflows resulting from these components contribute significantly to the site ARD yield. These inflows are termed "other" inflows, and the magnitude of these inflows is estimated based on the relationship shown below.

$$\sum \text{net inflow} = \Delta\text{storage} + \sum \text{WTP}_{\text{out}} \qquad (8)$$

And

$$\sum \text{net inflow} = \sum I_1 + \sum I_2 + \sum I_3 + \sum I_4 + \sum I_5 + \sum I_{\text{other}} \qquad (9)$$

Where:
I_1= Ruby waste rock dump
I_2= Wet Well
I_3= Hoodoo Gulch Collection System
I_4= Heap Leach Pad
I_5= Pond C
I_{other}= Other inflows

Therefore

$$\sum I_{\text{other}} = \Delta\text{storage} + \sum \text{WTP}_{\text{out}} - \sum I_1 - \sum I_2 - \sum I_3 - \sum I_4 - \sum I_5 \qquad (10)$$

Table 3.8-4 shows the measured inflows and the estimated other inflows based on the relationship shown in equation 10. Other inflows are a major component of the ARD yield at the Gilt Edge site. Exhibit 3-24 is a pie chart showing the proportion of various ARD inflows during the 2007 water year.

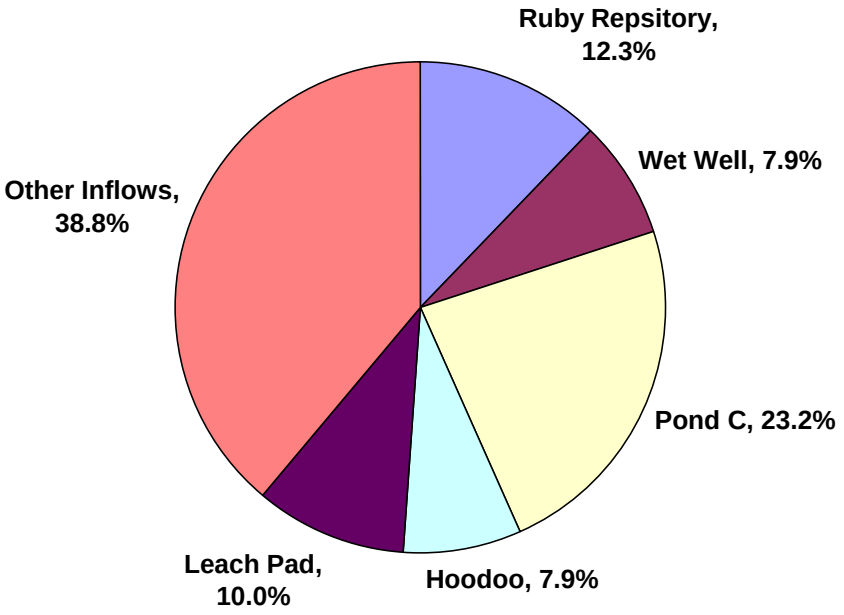


Exhibit 3-24. Pie chart summarizing measured and other ARD inflows to the site.

3.8.4.1 Estimated Ruby Repository Water Budget

The water budget for the Ruby Repository was evaluated in detail. This evaluation is available in CDM (2007a). Water reporting to the toe of the repository includes a number of components, including leakage from the diversion ditches, direct infiltration into the 9 acre uncapped area, and base flows. Based on the water budget estimate, water conveyed by the cover system and entering the dump through diversion ditch leakage is about 6 million gallons per year. This equates to approximately 43 percent of the current discharge volume from the repository. Other components of the repository discharge include runoff from adjacent undisturbed slopes (~14 percent), direct infiltration into the uncapped area of Ruby Gulch waste rock dump (~15 percent), and base flow resulting from slow draindown from the unsaturated zone and potential inflows from the bedrock aquifer (~25 percent).

3.8.4.2 Wet Well Collection System

The Wet Well collection system is an alluvial groundwater collection system located about 200 feet downgradient from the Ruby Repository. The Wet Well is a significant component of the current site ARD yields. Water quality in the Wet Well is only slightly impacted by ARD. This suggests that alluvial groundwater collected at the Wet Well contains a small component of ARD that is not contained by the primary collection facilities located at the toe of the repository. The detailed components that contribute water to the Wet Well have not been investigated.

3.8.4.3 Pond C Collection System

The Pond C collection system is a major contributor to the current site ARD yield. It is likely that water collected at this location originates in a number of ways, including inflows of alluvial groundwater from the Pond C, Process Area, and Anchor Hill alluvial aquifers; direct infiltration of precipitation onto acid generating mine waste within the basin reporting to Pond C; and run-on from adjacent undisturbed slopes within the basin. The relative contributions from these various sources have not been evaluated.

ARD inflows reporting to pond C were identified as major contributors to the site ARD yield in the 2006 water budget estimate. The runoff collection structures in upper Strawberry Gulch were modified in order to reduce ARD inflows reporting to Pond C, and monitoring of ARD inflows at Pond C was initiated in late 2006. ARD inflow rates at Pond C and monthly precipitation data for the 2007 water year are shown in Figure 3.8-1.

The term runoff, as used in this document, includes both overland flow and the component of interflow that reports within a period of days to weeks after a major precipitation or snow-melt event. Overland flow is rapidly understood as the component of runoff that flows over the land surface toward stream channels. Interflow is down-slope movement of water within the subsoil/near-surface fractured bedrock zone. Interflow can be understood in relation to common observations of increased stream flows in mountainous areas such as the Black Hills for a period of days or weeks after a large precipitation event, when overland flow either did not occur or has ceased. The primary difference between interflow, the subsurface component of runoff, and inflows from alluvial aquifers such as the Hoodoo Gulch alluvial aquifer is that flows resulting from interflow are short-term and occur only in response to snowmelt or major precipitation events.

The hydrograph (Figure 3.8-1) shows that flow rates at Pond C are strongly controlled by runoff caused by snowmelt, heavy spring precipitation, and summer thunderstorms. Snow that falls during the months of December through February in the Black Hills generally does not completely melt. During March, the spring freshet commences with melting of the snow pack and increased precipitation falling as snow and/or rain. The hydrograph (Figure 3.8-1) shows a marked increase in ARD inflows at Pond C in response to runoff caused by snow melt and increased precipitation during the spring and early summer. Runoff decreases markedly in the last quarter of the water year in response to decreased precipitation and drier soil conditions. The Pond C flow data suggest that the modified runoff collection structures did not significantly decrease the annual ARD yield during the 2007 water year. This may be a result of completion of the structures after the period when site runoff and associated ARD yield at Pond C are highest. Performance monitoring of the structures is planned during spring 2008, when the structures are likely to be more affective in reducing the site ARD yield.

3.8.4.4 Heap Leach Pad

The HLP also contributes a significant component of current site ARD yield. HLP water must be pumped from the HLP sump into the site ARD treatment system. Records of the volume of water pumped from the sump provide adequate data regarding the quantity of ARD generated on the HLP. This water results from precipitation that falls on to spent ore, construction rock stockpiles, and water treatment plant sludge located on the HLP liner. This water interacts with either acid generating rock on the pad or ARD-impacted water stored within the pad resulting in significant volumes of ARD-contaminated water.

3.8.4.5 Hoodoo Gulch

The Hoodoo Gulch ARD collection system collects ARD-impacted groundwater and surface water from the Hoodoo Gulch drainage. The collection system is located down-gradient from the Hoodoo Fill, which is a zone of ARD generating rock located in the upper portion of the Hoodoo Gulch drainage. ARD in Hoodoo Gulch discharges to the surface in a series of springs that are located several hundred feet up slope from the ARD collection system. It is likely that the springs are fed by groundwater from both the alluvial and bedrock aquifers. Hoodoo Gulch is ephemeral upslope from these springs with surface water occurring only in response to major storms or snowmelt. A paired set of monitor wells in the alluvial and bedrock systems is present in this area. The relative water levels of the wells indicate that an upward gradient is present and that ARD-affected groundwater from the bedrock aquifer flows upward into the alluvial aquifer. It is also likely that the alluvial aquifer conveys ARD generated by the Hoodoo Fill downslope towards the ARD collection system.

3.8.4.6 Other Inflows

As shown in Table 3.8-3, other inflows are the largest contributors to the current site ARD yield. These other inflows include sources such as direct precipitation on pit lakes and lined process ponds, runoff from various disturbed and undisturbed areas of the site, and potential alluvial groundwater inflows that do not report to one of the ARD monitoring points.

3.9 Land Use and Demographics

3.9.1 Demographics

The site is located in a rural area of Lawrence County approximately 4 miles south of the Town of Deadwood. A historic town called Galena is located at the eastern site boundary along Bear Butte Creek and is home to several dozen families. Numerous additional residences are dispersed in the general area south, west, and north of the site. The location of residences and associated structures in the vicinity of the site are shown in Figure 3.9-1, which is based on data provided by the Lawrence County 911 database. Lawrence County includes large areas of public land managed by the U.S. Forest Service and the U.S. Bureau of Land Management. Private land is interspersed within the public land, including the towns of Lead and Deadwood, as well as many smaller areas, such as the Town of Galena.

Private land use in the vicinity of the site is primarily residential. A few small ranches and businesses are present in the area. Private lands are subject to zoning restrictions imposed by Lawrence County. The site and the surrounding area are presently zoned as a Park Forest District by Lawrence County. Authorized land uses within the Park Forest District include detached single-family dwellings, cabins, and summer homes; transportation and utility easements, alleys, and right-of-way; public parks and/or playgrounds; historical monuments or structures; utilities substations; plant nursery; tree or crop growing areas and grazing lands; and other uses approved under county conditional use permits.

Public land use in the vicinity of the site includes recreational uses, such as hiking, hunting, and all-terrain vehicle operation and industrial uses, such as logging, hazardous fuel management, and other forest management activities. Most public land in the area is open to future mineral development under the General Mining Law, including claim staking, mineral exploration, and potentially mine development.

Demographic information for Lawrence County, South Dakota was obtained from the United States Census Bureau. As of the 2000 census, 21,802 people, 8,881 households, and 5,559 families reside in the county, with an average population density of 27 per square mile. Housing units within the county were estimated at 10,427, with an average density of 5/square kilometer (km^2) (13/square mile [mi^2]). Of the 8,881 households within the county, 28.8 percent have children under the age of 18, 51 percent are married couples living together, 8.5 percent are single mothers, 37.4 percent are classified as "non-families," and 11.5 percent have individuals living alone who are 65 years of age or older. The average household size is 2.33, and the average family size is 2.89. Age distribution within the county population is as follows: 23.1 percent under the age of 18, 13.7 percent from 18 to 24, 25.4 percent from 25 to 44, 23.1 percent from 45 to 64, and 14.7 percent who are 65 years of age or older, with the median age being 37 years.

The site is located within the Park Forest District set forth by the Lawrence County zoning regulations. Potential future land uses could include those uses authorized by the zoning regulations. A Lawrence County conditional use permit is in effect for the site, which authorized mine development. Two state large scale mine permits also were issued for development of the mine. These county and state permits contain land use requirements set forth by permit conditions.

3.9.2 Land Status of Site

A preliminary land study was completed for the site. This work incorporates a geographical information system database developed by DENR, land ownership maps recovered from former BMC files, and information regarding U.S. Forest System land in the vicinity of the site. Additional work is necessary to verify ownership of the surface and minerals estates, boundaries of patented mining claims, and the location of forest system lands within the site. The preliminary land study does provide useful information to understand the land status. The site is dominantly private lands, with U.S. Forest System land located on the north and southeast sides. The State of South

Dakota holds isolated parcels that were acquired in a Small Tracts Act purchase in 2000. Figure 3.9-2 shows existing land status data, the site boundary, and major site features. Table 3.9-1 is a list of parcels located within the site boundary, which was compiled to facilitate future land status investigations.

The majority of land within the site boundary is composed of patented mining claims. Both the surface and mineral estates are privately owned on patented mining claims. Based on available data, at least 10 different private land owners hold land within the site boundary. It is possible that the surface estate and the minerals estate were severed for patented claims within the site boundary. It is also possible that some patented mining claims were subdivided, particularly in the Galena area. Future land status work should investigate ownership of both the surface and mineral estate of patented claims within the preliminary site boundary, evaluate land records to discern if parcels were subdivided, and validate locations of the patented claims to the extent practicable. Validation of locations of patented mining claims within the major disturbance area of the site may be difficult because historical survey monuments were obliterated by mining activities.

Numerous parcels of U.S. Forest System land are present within the site boundary. U.S. Forest System land is public land administered by the USDA Forest Service. Large parcels of U.S. Forest System land are located north of Anchor Hill Pit, north and east of the HLP, northeast of the Ruby Repository collection facilities, and in the Strawberry Creek area between Strawberry Creek and Terrible Gulch. In addition, a number of small fractions of U.S. Forest System land appear to be present within the mine area. The detailed land status of these small fractions of public land may be difficult to discern because mining disturbance has obliterated patented claim monuments.

Several small parcels of state land are also present within the site boundaries. These were isolated parcels within the site that were acquired by the state through a Small Tracts Act purchase in 2000 in order to provide adequate area for construction of the Ruby Repository.

Section 4
Nature and Extent of Contamination

A major facet of the RI is characterizing the nature and extent of contamination in order 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 remedial investigations introduced in Section 2.

The discussion of nature and extent of contamination includes the following components:

- Comparison criteria
- Contaminant sources
- Groundwater
- Strawberry Creek
- Bear Butte Creek

A brief discussion of the key points of each subsection is presented below:

Comparison criteria

- These criteria are defined for the various site media in order to provide benchmarks to understand the extent of contamination at the site.
- They are based on selected preliminary remediation goals (PRGs) and applicable, relevant, or appropriate regulations (ARARs).

Contaminant Sources

- Contaminant sources are widespread within the primary mine disturbance area, and most of the estimated volume of source materials (15 million cubic yards) have the potential to generate ARD.
- There are seven categories of source materials, based on geochemical and physical characteristics (waste rock fills, HLP spent ore, exposed rock surfaces, underground mine workings, tailings, soil stockpiles, and sludge).
- ARD neutralization sludge is generated during treatment of ARD and may be a source of contaminants if stored under strongly acidic submerged environments.
- Source materials are addressed at the top of the ARD generation and transport model (Exhibit 4-1) as they are a critical component of the ARD triangle.

Groundwater

- Groundwater is one of the important migration routes for contaminant migration from the site.
- It is strongly impacted by ARD contamination in the primary mine disturbance area and can exceed groundwater comparison criteria by one to three orders of magnitude.
- Groundwater contamination is slowly migrating but has not been identified outside of the site boundary.

ARD

- Understanding the characteristics of ARD is important to understanding potential affects of remedial actions.
- Impacts within the primary mine disturbance area are extensive for both discharged and stored ARD.
- The vast majority of ARD is captured and treated, and the treated water is discharged to Strawberry Creek.

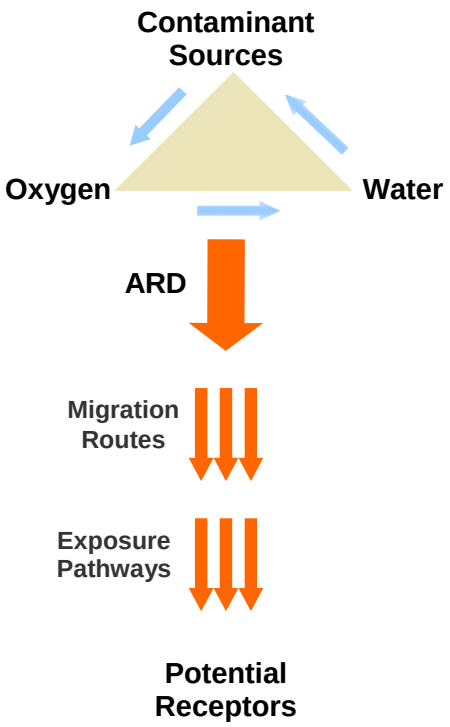


Exhibit 4-1. ARD generation and transport model

- ARD generation provides a means for contaminants originating in ARD source materials to impact migration routes and exposure pathways (Exhibit 4-1).
- A portion of ARD generated on site and stored in pit lakes cannot be treated in the current WTP, due to sulfate concentrations greater than 1,800 mg/L. EPA is currently evaluating plant upgrades in order to treat higher sulfate ARD.
- Collection systems on site operate well but are not capable of intercepting all of the ARD, and traces of ARD-related contamination are present in surface water outside of the collection system.

Strawberry Creek

- Lower Strawberry Creek is impacted by ARD generated within the primary mine disturbance area and relic mine tailings, and contamination in surface water exceeds comparison criteria on an intermittent basis.
- Stream sediments in lower Strawberry Creek are contaminated, although conditions are improving, and more data are needed to evaluate ecological risks related to the sediments.

- Groundwater-surface water interactions in lower Strawberry Creek are extensive, and ARD affected groundwater may be discharging to surface water.
- Numerous remedial actions have been competed by DENR and EPA, which provide beneficial effects to surface water quality and aquatic biota in Strawberry Creek.
- EPA is in the process of monitoring and evaluating the lower Strawberry Creek area to determine if human health or ecological risks remain and if additional remedial actions are necessary.

Bear Butte Creek

- Bear Butte Creek is located downstream from the three site drainages (Strawberry Creek, Terrible Gulch, and Ruby Gulch).
- Detectible impacts to surface water quality in Bear Butte Creek are present downstream of its confluence with Strawberry Creek.
- These impacts have caused surface water in Bear Butte Creek downstream of the confluence to exceed South Dakota Surface Water Quality Standards (SWQS) on an intermittent basis.

4.1 Comparison Criteria

In order to better understand the nature and extent of contamination at the site, the data collected during the various remedial investigations and historical data are compared to several different benchmarks, or *comparison criteria*. The comparison criteria originate from ARARs, PRGs, or characteristics of source materials that affect compliance with ARARs and PRGs (i.e. potential to generate ARD). PRGs developed for the site are described in Section 6, which summarizes the results of the human heath and ecological risk assessments. ARARs are discussed and presented in the Feasibility Study Report (CDM 2008).

EPA and DENR have not determined which ARARs will apply to the site or specifically how the ARARs and PRGs will be achieved through remedial action. These risk management decisions will be made through careful consideration of the site investigation data, human health and ecological risk assessments, National Contingency Plan (40 Code of Federal Regulations [CFR] Part 300), feasibility study, stakeholder review, and public comment.

Comparison criteria have been defined for contaminant source materials, groundwater, and surface water. The nature and extent of contamination for the various site media are evaluated by comparing data collected in the remedial investigation with respective comparison criteria for the purpose of putting the remedial investigation data into context for the reader of this report.

4.1.1 Contaminant Sources

Contaminant sources (waste rock fill material, HLP spent ore, exposed rock surfaces, underground mine workings, amended tailings, soil stockpiles, and sludge) were evaluated for total metal concentrations, soluble metal loads, and potential to generate ARD. Comparison criteria for total metal concentrations are based on surface soil PRGs developed for the low intensity recreational site user (EPA 2007). Comparison criteria for potential to generate ARD are based on a weight of evidence approach established for interpretation of acid base accounting data. Comparison criteria were not established for soluble metal loads.

Surface soil PRGs developed for the low intensity recreational site user, or hiker, are:

- **Arsenic**: 1,150 milligrams per kilogram (mg/kg)
- **Thallium:** 134 mg/kg

Two data sets were evaluated for total metal concentrations for many source materials (ie. waste rock fills, HLP spent ore, soil stockpiles). The first data set was collected during the support investigation for the BRA (CDM 2003c). These samples were collected near the surface and were sieved to provide a fine-grained sample representative of potential dust that could be generated by the source materials. The second data set was collected by CDM during other media-specific investigations. These samples were not sieved prior to analysis.

The comparison criteria are applied to either the average or median concentration of samples from the various source materials. The average concentration is used when all analytical values are above the level of detection. The median concentration is used when one or more samples have concentrations that are less than the analytical detection level.

The potential for source materials to generate ARD is evaluated based on a weight of evidence approach that considers paste pH data, ABA data, and mineralogical data. Results of ABA data are expressed in terms of neutralization to acid potential ratio (NP:AP) and net neutralization potential (NNP). The weight of evidence approach is necessary because there is no one test that can conclusively determine the potential for source materials to generate ARD (Nordstrom and Alpers 1999). Additional information regarding acid base accounting methods was presented previously in Section 2.6.

The weight of evidence approach utilizes the following metrics in order to determine potential for ARD generation:

- Acidic paste pH is strong evidence that the source material will generate acid in the future (eg. <4.5 su).
- Total and/or sulfide NNP values relative to the potential to generate acid in the future.

  - <0 t/kt $CaCO_3$ eq. indicates a high potential.
  - 0 to 20 t/kt $CaCO_3$ eq. indicates an uncertain potential.
  - >20 t/kt $CaCO_3$ eq. indicates an unlikely potential.
- NP:AP relative to the potential to generate acid in the future
  - <1 indicates a high potential.
  - 1 to 3 indicates a moderate potential.
  - 3 to 4 indicates a low potential.
  - >4 indicates unlikely potential.

These metrics are used along with an evaluation of mineralogical data in order to classify the potential for the source material to generate acid in the future.

Comparison criteria have not been established for water-soluble metal loads in source materials because of the difficulty of predicting field effluent concentrations based on laboratory extraction tests. These data are evaluated qualitatively to consider the relative potential for source materials to release contaminants to the aqueous phase during infiltration events, such as snow melt.

4.1.2 Groundwater

Groundwater comparison criteria are the site-specific groundwater quality standards (GWQS) developed by DENR. These standards include specific standards for bedrock aquifers, the Strawberry Creek alluvial aquifer and the Ruby Gulch alluvial aquifer. Groundwater monitoring well data are compared to these site-specific standards in order to identify areas with significant groundwater contamination. The GWQS are shown in Table 4.1-1.

4.1.3 Surface Water

Surface water comparison criteria are the SWQS set forth in ARSD 74:51:01. This process is intended to identify all surface water bodies that may require mitigation under future remedial actions. Evaluations of surface water within the ARD collection, conveyance, and treatment system are focused on water quality parameters that are important for water treatment evaluations. The SWQS are shown in Table 4.1-2.

4.2 Contaminant Sources

Evaluation of source materials is based on the following mine waste units:

- Waste rock fill materials, including general fills and reclamation fills
- HLP spent ore
- Exposed rock surfaces
- Underground workings
- Amended tailings
- Soil stockpiles
- Sludge

4.2.1 Waste Rock Fill Material

Numerous waste rock fill areas are present on the site. They were created during construction, mine operation, and the initial phases of mine reclamation. Waste rock fills contain rock that had to be mined to expose ore but that did not contain sufficient gold mineralization to make gold processing economic. Waste rock was also used as construction fills on the site. A good example is the Hoodoo Fill, which creates a mine haul road between Sunday Pit and the crusher area. Areas of shot muck adjacent to Anchor Hill Pit are grouped with the general fills in order to simplify the overall classification of mine waste units. Shot muck is rock that has been blasted but has not been excavated from its original location.

Waste rock fills are delineated into two groups:

- General fills
- Reclamation fills

The spatial location of these fill zones is shown in Figure 4.2-1.

Evaluation of the nature and extent of contamination in fill zones was completed in three phases. The first phase was conducted by RGC and focused on surface exposures. This program included detailed paste pH and paste TDS analyses, with a subset of samples submitted for additional analyses including total metals, modified 3:1 SPLP, ABA, and inorganic carbon. The second phase of testing was completed by CDM in 2001 and focused on subsurface sampling. All CDM samples were analyzed for paste pH, paste TDS, ABA, standard 20:1 SPLP (EPA Method 1312), and meteoric water mobility procedure. A detailed discussion of these methods is presented in Section 2.6.

The third phase of testing was also completed by CDM but in April 2007. This phase of sampling only applies to reclamation fills located around the Stormwater Pond. The focus of this investigation was to support feasibility study evaluations of potentially useful sources of soil/fill materials for site reclamation activities. Geotechnical testing was conducted on the samples, as well as geochemical testing

(paste pH and ABA). Only the geochemical data are useful for further characterizing the nature and extent of contamination in the Stormwater Pond reclamation fills and thus are described herein.

The following sections are focused on total metals, paste pH, SPLP, ABA, and inorganic carbon analyses. Additional analyses data are included in Appendix B. The discussion of general and reclamation fills includes three key components, if applicable (e.g. if data exist to describe the component):

- Total metals with potential to impact human health
- Load of stored water-soluble contaminants
- Future potential to generate acid

General information is also presented regarding fill located with Ruby Gulch waste rock dump. This fill was not specifically evaluated in site remedial investigations.

4.2.1.1 General Fills

General fills include rock that was excavated during construction of the HLP, the gold processing plant, and ancillary facilities such as road embankments and work areas. They also include waste rock fills placed during active mining of Dakota Maid and Sunday pits. Construction fills were created when rock had to be removed in order to create flat areas for construction of mine facilities. This rock was likely placed in a fill area located close to the construction cut. The largest construction cut and fill was created during construction of the HLP.

Total Analyses with Potential to Impact Human Health

A total of 14 composite samples were analyzed for areas classified as general fills as part of the support investigation for the BRA (CDM 2003c). Arsenic concentrations in these samples ranged from 69.7 mg/kg to 420 mg/kg, with an average of 168 mg/kg. Thallium was detected in 9 of the 14 samples at a concentration above the detection level of 0.86 mg/kg to 0.97 mg/kg. The maximum thallium concentration of the samples was 4.4 mg/kg, and the median concentration was 2.9 mg/kg. Concentrations of arsenic and manganese in the general fill samples do not exceed the established comparison criteria. These data are presented in Table 4.2-1.

CDM completed total metals analyses on 12 samples of general fills during the site-wide fills investigation (CDM 2003h). These data are presented in Table 4.2-2. Concentrations of arsenic in the samples ranged from 18 mg/kg to 377 mg/kg, with an average of 137 mg/kg. Thallium concentrations were less than the detection level of 1.5 mg/kg to 1.7 mg/kg in all 13 samples. Concentrations of arsenic and manganese in these samples do not exceed the established comparison criteria.

Load of Stored Water-Soluble Contaminants

Paste pH

The pH of the mine waste is the strongest control on the mobility of contaminants from mine waste fill into infiltrating water. Eighty-five paste pH samples were collected from general fill zones. This includes 75 surface samples collected by RGC and 9 subsurface samples collected by CDM. A histogram showing the paste pH data distribution is presented as Figure 4.2-2. The data generally show a skewed distribution, with more samples displaying acidic paste pH values. The skewed distribution may represent several combined distributions that relate to the specific source of the rock, such as Dakota Maid Pit, Sunday Pit, or specific cut and fill zones, such as HLP cut and fill.

Exhibit 4-2. General Fills in Hoodoo Gulch area, Facing North

Paste pH values range from 1.2 su to 7.6 su, with a median value of 3.7 su. Most of the fill samples collected from areas of general fill are either moderately or strongly acid generating, based on paste pH. The most acid generating samples were collected from the south end of the HLP fill. This rock may have been developed from rock cuts constructed during HLP construction or the rock may have been hauled to the area from other sources, such as Dakota Maid or Sunday pits.

The spatial distribution of surface paste pH values is shown on Figure 4.2-3. General spatial trends seem apparent, but it is tenuous to attempt to delineate subunits from the surface paste pH values. This is a result of uncertainty related to the subsurface extent of paste pH conditions observed at the surface and to the high degree of heterogeneity of the waste rock fill zones. Vertical variation in paste pH conditions may result from placement of more or less acid generating rock over rock with different geochemical characteristics or from varying degrees of maturity in acid generation at depth.

SPLP Analyses

CDM conducted SPLP analyses on 13 samples of general fill using the standard 20:1 solution to solid ratio. The results indicate the soluble metals and metalloids are present in the general fill, including copper, cadmium, zinc, and arsenic. Copper was detected in 12 of the 13 samples, with extract concentrations ranging from less than the detection level of 0.01 mg/L to 0.47 mg/L, and a median concentration of 0.47 mg/L. Cadmium was detected in 6 of the 13 samples, with concentrations ranging from less than 0.005 mg/L to 0.0096 mg/L. Zinc was detected in all samples, with concentrations ranging from 0.020 mg/L to 0.41 mg/L and an average concentration of 0.140 mg/L. Arsenic was detected in 3 of the 13 samples, with a maximum concentration of 0.16 mg/L. Selenium was detected in 2 of the 13 samples, with a maximum concentration of 0.009 mg/L. The remaining selenium concentrations were reported as less than 0.01 mg/L. SPLP data for the general fills are presented in Table 4.2-3.

Available paste pH and SPLP data for the general fills indicate that this rock does contain water soluble contaminants at concentrations that are problematic and that water interacting with general fills will require collection and treatment prior to discharge. This is compatible with current ARD management practices present at the site, which collect this water and convey it into the site water treatment system.

CDM collected 10 subsurface samples from various fill zones classified as general fill. The subsurface samples were grab samples collected from discrete excavator pits located in the various fill zones. The data are adequate for general evaluation of the subsurface geochemical characteristics of the rock; however, the subsurface data set is not adequate for characterization of sub-zones within the general fill. Additional geochemical data would be necessary prior to delineation of sub-zones within the general fill. This is a result of the degree of heterogeneity of the general fill piles, the relatively small number of samples, and the use of discrete point sampling methods.

Future Potential to Generate Acid

ABA samples provide information useful to understanding geochemical conditions of the general fills. Most general fills have been in place at the site for 10 to 15 years. The paste pH data described above indicate that this time period was sufficient for much of the rock to commence acid generation. The paste pH data show that the rock is generating acid. The ABA data are useful to evaluate potential future geochemical conditions and to understand variations between rock sampled at the surface and rock present in the subsurface. ABA data for samples collected from the general fill zones are shown in Table 4.2-4.

The two phases of ABA testing utilized different methods for estimation of neutralization potential. Evaluation of the general fill ABA data suggest that the method used by CDM results in generally higher estimated NP than the RGC method. This is compatible with evaluations of Jambor (2000 and 2003) and White et al. (1999), which show that the more intense digestions utilized in the Sobek (1979) method may contribute to higher estimated NP values. The finer particle size also contributes to increased neutralization potentials (Jambor 2003).

A total of 21 samples from general fill zones were evaluated for ABA, including 10 samples evaluated with the RGC method and 12 samples evaluated with the CDM method. These 21 samples represent approximately 1.6 million cy of general fills, which is not dense sample spacing. In addition, these samples were collected from discrete points within the three-dimensional piles of fill materials, so local heterogeneities within the piles may not be adequately represented by the data. The data set is adequate for the purposes of this RI, but it is important to consider the limitations of the data set and the uncertainty that these limitations cause in geochemical interpretations.

<u>Neutralization Potential</u>

The data show that neutralization potential in the general fill rock is limited. The RGC neutralization potential values range from 0 t/kt $CaCO_3$ eq. to 28 t/kt $CaCO_3$ eq., with a median of 0 t/kt $CaCO_3$ eq. The 28 t/kt $CaCO_3$ eq. value is an outlier in the

population with all other NP values less than 5 t/kt $CaCO_3$ eq. The CDM neutralization potential values range from 1 t/kt $CaCO_3$ eq. to 10 t/kt $CaCO_3$ eq., with a median of 4 t/kt $CaCO_3$ eq. The very low neutralization potential values correlate with the mineralogical composition of rock within the general fill zones. These rocks are primarily intrusive rocks with very low concentrations of acid neutralizing minerals, such as calcite ($CaCO_3$) or dolomite ($CaMg(CO_3)_2$). The apparently higher median neutralization potential in the CDM samples may be a result of dissolution of minerals in the rock that do not provide effective neutralization potential under field conditions. Samples with very low acid potential values in general fill zones may cause acid generation because the neutralization potential of the rock is so low.

Sulfur Analyses

Total sulfur concentrations in the general fill ABA samples range from 0.09 percent to 0.79 percent, with a median concentration of 0.36 percent. Sulfate sulfur in the samples ranges from 0.03 percent to 0.51 percent, with a median of 0.15 percent, and sulfide sulfur ranges from 0.06 percent to 0.50 percent, with a median of 0.23 percent. The median sulfide sulfur concentration of 0.23 percent correlates to about 0.5 percent pyrite. Figure 4.2-4 compares sulfide sulfur concentrations to paste pH values measured within the general fill and suggests that the Gilt Edge rocks produce acid even with relatively low pyritic sulfur concentrations of 0.06 percent. A sulfide sulfur concentration of 0.06 percent correlates to about 0.1 percent pyrite, which is in a range where pyrite may not be visible in rock samples without magnification. As a result, visual recognition of pyrite in hand samples of rock should not be relied on to determine whether rocks have the potential to generate acid.

Comparison of the proportion of sulfate sulfur to total sulfur in the samples suggests that the surface samples are relatively more oxidized than the subsurface samples. The percent sulfate sulfur present in surface samples collected by RGC ranges from 51 percent to 85 percent of the total sulfur, with a median of 65 percent. The percent sulfate sulfur in the subsurface samples ranges from 14 percent to 45 percent, with a median of 24 percent. Paste pH values of the surface samples are also generally more acidic than paste pH values of the subsurface samples. The proportion of sulfate sulfur in the sample is a factor of oxidation that occurred prior to mining as well as after mining, so this value is not directly representative of the maturity of the acid generating rock. The observed values support the previous observation that the subsurface rock is less mature in terms of acid generation than the surface rock. An important consideration related to these data is that paste pH values are less useful to identify acid generating rock in the subsurface and that ABA samples should be evaluated prior to delineation of non-acid generating subunits within general fill areas.

Evaluation of Acid Potential

Figures 4.2-5 and 4.2-6 show two methods of evaluating ABA data. The first method is shown in Figure 4.2-5, which compares acid potential to neutralization potential. NP:AP ratios of 1:1, 3:1, and 4:1 are shown on the chart, which correspond to the potential for the samples to generate acid. The chart shows that the CDM neutralization potential values are generally higher than the RGC values as discussed

previously. Figure 4.2-6 compares NP:AP ratio to pyritic sulfur. The charts indicate that all samples are classified with a potential to generate acid that ranges from low to high. Two samples exhibit NP:AP ratios of 2.33 to 2.49, with pyritic sulfur contents of less than 0.10 percent. One of these samples was collected from the surface, and one of the samples was collected from the subsurface. The corresponding paste pH of the surface sample is 3.5 su, which shows that the general fill rock will generate acid with NP:AP ratios in this range and very low pyritic sulfur contents of <0.10 percent. The subsurface sample exhibited a paste pH of 5.4 su at the time of sampling, which suggests that this sample was less mature than the surface sample.

The most strongly acid generating samples at the time that the paste pH analyses were conducted had paste pH values of 2.1 su and 2.2 su. These samples contain moderate sulfur concentrations of 0.36 percent and 0.43 percent, respectively. This suggests that the level of maturity of acid generation is a stronger control on pH than the sulfur content. The level of maturity is controlled by factors such as the surface area of rock particles (a factor of particle size), the grain size and crystal habit of pyrite crystals within the rock particles, and the degree of exposure to oxidation.

Potential Maturation of General Fills

Figures 4.2-7 and 4.2-8 evaluate the relative maturity of the ABA samples based on comparison of paste pH with total sulfur and NP:AP ratio. These graphs define the paste pH range of mature acid generating rock based on paste pH values observed for the most mature samples. The pathway of ARD evolution for samples with similar total sulfur and NNP values display the likely evolution pathway of acid generation in samples that were less mature at the time of sampling. Based on these evaluations, it is likely that general site fills that were moderately acid generating at the time of sampling based on paste pH will eventually become strongly acid generating and develop pH values in the range of 2.0 su to 3.0 su. Characteristics of ARD generated by the general site fills is discussed in Section 4.3, but the ABA and paste pH data suggest that the general site fills are not yet mature and that eventually these rocks will develop ARD that is more acidic than currently observed at the site. The time frame prior to maturation of the general fills is unknown.

4.2.1.2 Reclamation Fills

Reclamation fills were placed during mining conducted under State Large Scale Mine Permit 468, which included strict permit conditions intended to delineate non-acid generating rock from mining at Anchor Hill and Langley pits to use in mine construction and reclamation activities. These fills were placed in 1996 and 1997 during mining of the Anchor Hill and Langley pits. Although the success of this program in accurately delineating non-acid generating fill appears to be mixed, these fills represent a statistically distinct population for the purpose of evaluating nature and extent of contamination.

Nature and extent of contamination of reclamation fills are described first in the same manner as for general fills, by summarizing the RGC data and 2001 CDM data. Secondly, the 2007 Stormwater Pond sampling data are described. This investigation

is described separately from the remainder of the reclamation fills because the specific objectives were focused on characterizing fills in the Stormwater Pond area.

Total Analyses with Potential to Impact Human Health

Twelve composite samples were analyzed for areas classified as reclamation fills as part of the support investigation for the BRA. Arsenic concentrations in these samples ranged from 16.9 mg/kg to 131 mg/kg, with an average of 71.2 mg/kg. Thallium was detected in 9 of the 12 samples at concentration above the detection level of 0.86 mg/kg. The maximum thallium concentration of the samples was 27 mg/kg, and the median concentration was 1.45 mg/kg. The arsenic and thallium concentrations of the reclamation fill do not exceed the comparison criteria. These data are presented in Table 4.2-5.

Exhibit 4-3. Reclamation Fills in South Sunday Pit, Facing South

Thirteen samples from reclamation fills were analyzed for total metals during the site-wide fills investigation (CDM 2003h). Arsenic concentrations in the samples ranged from 29 mg/kg to 310 mg/kg, with an average of 105 mg/kg. Thallium concentrations were less than the detection level of 1.6 mg/kg to 1.7 mg/kg in 12 of the 13 samples. The maximum thallium concentration was 27 mg/kg. The arsenic and manganese concentrations do not exceed the comparison criteria. These data are presented in Table 4.2-6.

Load of Stored Water-Soluble Contaminants

Sixty-five paste pH analyses were completed on samples from the reclamation fills, including 55 surface samples collected by RGC and 10 subsurface samples collected by CDM. The reclamation fills were less acid generating at the time of sampling than the general site fills. It is likely that this is related both to the acid potential of the rock as well as the shorter time frame between mining of the rock and sampling. The reclamation fills were mined in 1996 to 1997, so they had been in place about 3 to 4 years when the RGC paste pH survey was completed in summer 2000.

Paste pH values for the reclamation fill samples range from 3.2 su to 6.8 su, with a median value of 5.3 su. The 3.2 su value appears to be an outlier in the sample population because the next lowest paste pH value is 4.1 su. A histogram showing the distribution of paste pH values from the reclamation fill samples is included as Figure 4.2-9. The values show an approximately normal distribution centered around the median.

Many of the reclamation fills, including the south Sunday Pit fill, the North Langley Pit fill, the Bunny Ear fill, and portions of the Stormwater Pond fill were covered with topsoil and revegetated after placement. Therefore, surface samples collected by RGC in these areas are not representative of the underlying fill rock. Surface samples collected in these areas are shown on Figure 4.2-3 but are excluded from the data set

representing the reclamation fills. Therefore, the geochemical data from these areas is limited to the subsurface samples collected by CDM. The sample density of the CDM sampling program is low, which causes uncertainty in evaluating these fills. All of the reclamation fills were mined from Anchor Hill and Langley pits under the permit conditions set forth in South Dakota Large Scale Mine Permit 468 and are expected to exhibit generally similar acid potential. Therefore, the geochemical characteristics of the reclamation fills are evaluated as a group.

SPLP analyses were completed on 12 samples of reclamation fills using the standard 20:1 water to solid ratio. Low levels of metals and metalloids were identified in the extract fluid, including cadmium, copper, zinc, arsenic, selenium, and lead. Copper was detected in 11 of the 12 samples, with concentrations ranging from less than the detection level of 0.01 mg/L to 1.2 mg/L. The median copper concentration in the extract fluid was 0.13 mg/L. Cadmium was detected in 5 of the 12 samples although measurable concentrations were very close to the detection level of 0.005 mg/L. Zinc concentrations ranged from 0.02 mg/L to 1.1 mg/L. SPLP data for reclamation fills are presented in Table 4.2-7.

Future Potential to Generate Acid

ABA samples for the reclamation fills were collected by both RGC and CDM. Five surface samples were collected by RGC and evaluated for ABA using the RGC method. Eleven subsurface samples were collected by CDM and evaluated for ABA using the CDM method. ABA data for the reclamation fills are shown in Table 4.2-8. The ABA samples are critical for evaluation of acid potential of the reclamation fills because of the limited time between excavation of the rock and collection of the paste pH samples.

<u>Neutralization Potential</u>

The neutralization potential of reclamation fill samples is slightly higher than the general fills. The RGC neutralization potential method was used on the five surface samples. These values range from 0.8 t/kt $CaCO_3$ eq. to 5.8 t/kt $CaCO_3$ eq., with a median neutralization potential of 2.4 t/kt.. Two of the five samples were analyzed for inorganic carbon in order to verify the NP values. These samples had RGC neutralization potential values of 3.4 t/kt $CaCO_3$ eq. and 5.8 t/kt $CaCO_3$ eq., with carbonate NP values estimated based on inorganic carbon analyses of 0.8 t/kt $CaCO_3$ eq. for both samples. The NP values of 3.4 t/kt $CaCO_3$ eq. and 5.8 t/kt $CaCO_3$ eq. are not supported by the inorganic carbon analyses, which suggests that the NP may be related to dissolution of other minerals in the NP analysis, such as silicates or oxides.

The 11 samples colleted from the subsurface were evaluated using the CDM method. This population exhibits NP values that are noticeably higher than the RGC data. The CDM samples range from 2 t/kt $CaCO_3$ eq. to 15 t/kt $CaCO_3$ eq., with a median value of 9 t/kt $CaCO_3$ eq. As discussed previously, the finer particle size and more rigorous digestion of the CDM method is likely to result in dissolution of other minerals in addition to carbonates. These minerals may dissolve in the CDM NP tests and report to the estimated NP value, but they may not represent effective neutralization capacity in the field. Local calcite veining is present in the hornblende trachyte

porphyry, so a portion of this NP may be related to dissolution of carbonate minerals. Inorganic carbon analyses were not completed on the CDM samples to estimate carbonate neutralization potential.

Sulfur Analyses

Total sulfur concentrations in the reclamation fill ABA samples are lower than the general fills. Total sulfur ranged from 0.05 percent to 0.75 percent, with a median concentration of 0.14 percent. This is about half of the sulfur concentration observed in samples of the general fill unit. The permit conditions set forth in South Dakota Large Scale Mine Permit 468 required a maximum total sulfur content of approximately 0.08 percent in rocks deemed acceptable for reclamation fills. So the ABA data from the reclamation fill samples suggest that BMC was not entirely successful in achieving the permit requirements during delineation of the reclamation fills. The lower median sulfur concentration does suggest that BMC was successful in achieving somewhat lower total sulfur concentrations in rock delineated as reclamation fill.

The proportion of total sulfur interpreted to be sulfate in reclamation fill shows similar characteristics to the general fill, with surface samples appearing to be somewhat more oxidized than subsurface samples. Sulfate sulfur concentrations in the samples range from 0.02 percent to 0.38 percent, with a median value of 0.04 percent. Sulfide sulfur ranges from less than detection to 0.56 percent, with a median value of 0.08 percent. The median sulfide concentration correlates to about 0.15 percent pyrite. The proportion of sulfur that is interpreted to be in the sulfate form ranges from 20 percent to 100 percent, with a median of 60 percent. The sulfate sulfur in the samples may result from pyrite that oxidized prior to mining in the zone of surface oxidation or pyrite that has oxidized since the rock was placed in the fill areas. So the percent oxidized sulfur can not be directly related to the level of ARD maturation in the samples.

Evaluation of Acid Potential

Evaluation of paste pH and sulfide concentration for general fills indicates that samples with sulfide sulfur concentrations as low as 0.06 percent may generate acid, so the median sulfide concentration of 0.08 percent estimated for the reclamation fills may be sufficient for the rocks to generate acid in the absence of effective neutralization potential resulting from carbonate minerals. The median sulfide concentration of 0.08 percent correlates to a pyrite concentration of about 0.15 percent, which is in a range where magnification or microscopy may be required in order to see the pyrite in rock samples. Therefore, identification of visual pyrite in hand samples may not be adequate to identify rock with potential to generate acid.

The NNP of the samples based on the total sulfur and/or sulfide sulfur fractions is one method for evaluating the potential of the reclamation fills to generate acid at some time in the future. These values are shown in Table 4.2-8. Three of the five samples analyzed by the RGC method have total NNP values of less than 0 t/kt $CaCO_3$ eq., which indicate that the samples will generate acid at some time in the future. Two of the RGC samples have total NNP values of about 1 t/kt $CaCO_3$ eq. The

samples analyzed with the CDM method exhibit a different distribution of total NNP. Three of the 11 CDM samples exhibit total sulfur NNP values that are less than 0 t/kt $CaCO_3$ eq., which indicate that these samples will generate acid. The remainder of the samples evaluated using the CDM method display total sulfur values ranging from 3 t/kt $CaCO_3$ eq. to 13 t/kt $CaCO_3$ eq. Total NNP values in the range of 0 t/kt $CaCO_3$ eq. to 20 t/kt $CaCO_3$ eq. are classified as uncertain with regard to future acid generation.

The sulfide NNP values are also included in Table 4.2-8. These values are higher than the total NNP because the sulfate sulfur fraction is not included in the acid potential calculation. However, overall conclusions regarding the potential for the rock to generate acid in the future are the same based on the sulfide NNP. Three of the five RGC samples and three of the 11 CDM samples have sulfide NNP values less than 0 and are clearly acid generating. The remainder of the samples exhibit sulfide NNP values between 0 t/kt $CaCO_3$ eq. and 20 t/kt $CaCO_3$ eq.

Evaluation of NP:AP ratios also indicate that a portion of the samples would be expected to generate acid. Three of the five RGC samples exhibit NP:AP ratios less than 1 and clearly have the potential to generate acid in the future. The RGC NP:AP values range from 0.18 to 1.55, with a median of 0.85. One RGC sample does not contain pyritic sulfur and would not be expected to generate acid. The higher NP values of the CDM samples have a large effect on the NP:AP ratios. Three of the 11 CDM samples exhibit NP:AP ratios below zero and are expected to generate acid in the future. The NP:AP ratios of the remaining CDM samples are significantly higher than the RGC samples, which results from the higher NP values and the generally low sulfide sulfur concentrations in the reclamation fill samples.

Figure 4.2-10 compares the neutralization potential to the acid potential of the RGC and CDM samples. Of the 16 samples in the reclamation fill ABA data set, 8 of the samples exhibit some potential to generate acid based on the graphical method of analysis. Two of the 16 samples are classified with a high potential to generate acid. Figure 4.2-11 compares the NP:AP ratio to sulfide sulfur and shows that the samples with very high NP:AP ratios contain low concentrations of sulfide sulfur. Six of the samples have total sulfur less or equal to 0.05 percent, and NP:AP ratios above 5:1. These samples are unlikely to generate acid in the future. The remaining 10 samples have acid potential that ranges from low to high. Seven of these samples are classified with high acid potential.

<u>Potential Maturation of Reclamation Fills</u>
Maturation diagrams for the reclamation fills are presented as Figures 4.2-12 and 4.2-13. These diagrams are interpretive because the most of the samples had not started generating significant acid at the time that the samples were collected. The diagrams show that the samples that are predicted to be strongly acid generating based on ABA data had not matured to the point that caused acid generation. This supports previous assertions that paste pH is not an adequate method for evaluating acid potential of the reclamation fills.

In summary, the potential for reclamation fill to generate acid in the future must be based on ABA data rather than paste pH because the rock has not been exposed to the environment for a long enough period for acid generation to commence. The 16 samples evaluated for ABA are a small sample set, which causes uncertainty in evaluation of geochemical characteristics of the 1.3 million cy of reclamation fills. The samples are appropriate to use in general evaluations of overall geochemical characteristics of the rock, but are not appropriate to use in delineation of sub-units.

The fact that approximately 50 percent of the 16 ABA samples have the potential to generate acid in the future does not mean that 50 percent of the 1.3 million cy of reclamation fills contain the same proportion of acid generating rock. This is a result of the small sample set and the sampling method, which focused on collection of discrete point samples within the three-dimensional piles of rock. The overall classification of the reclamation fills is moderately acid generating based on the available ABA data because it is not valid to assume that neutralization potential available in the non-acid generating rock will be sufficient or available to neutralize acid formed in other portions of the waste rock fills.

4.2.1.3 2007 Stormwater Pond Reclamation Fill Sampling

As part of a supplemental topsoil and fills investigation for the feasibility study, CDM excavated four pits and one trench within the Stormwater Pond reclamation fills, in an effort to determine their physical and chemical characteristics with depth. For each pit, CDM collected three samples at different depths, typically at 2 ft depth, middle depth, and bottom depth. For the trench, only two samples were collected, from the middle depth and bottom depth. The locations of the four pits and one trench are shown on Figure 4.2-3.

CDM measured paste pH in the field near the pit/trench for each of the depth samples. Based on visual observations, additional paste pH measurements were occasionally collected at other depths to better understand the variation in paste pH values. Paste pH was measured again for each of the three or two depth samples from each pit/trench using a more precise method in the site assay laboratory. Based on the second set of paste pH measurements, the sample with the lowest pH from each pit/trench was selected as the laboratory sample, which was then analyzed for ABA using the RGC method. Therefore, a total of five subsurface samples were analyzed for ABA.

Paste pH

Table 4.2-9a shows the paste pH results for all of the samples and their corresponding depths. As shown in the table, no significant differences between the first (field) and second (assay laboratory) sets of paste pH measurements were observed. Twenty-three field paste pH measurements and 15 assay laboratory paste pH measurements were conducted for Stormwater Pond reclamation fills. Field paste pH ranged from 3.6 su to 8.5 su, with a median of 6.1 su. Assay laboratory paste pH ranged from 4.2 su to 7.7 su, with a median of 6.2 su.

Between both field and assay laboratory paste pH, the lowest values were observed for trench 14 and pit 16. The lowest field paste pH value (3.6 su) was observed within trench 14, on the west side of the elbow shaped trench. This pH was measured at a depth of 2 ft to 3 ft where a distinct layer of strongly weathered trachyte porphyry rock was observed. All other paste pH values measured in trench 14 were 6.0 su and greater. Paste pH of trench 16 for all depths ranged between 4.1 su and 4.8 su for both field and assay laboratory measurements. This trench was located on the south side of the Strawberry Creek diversion ditch and north of the Stormwater Pond and was dug to a total depth of 14 ft.

Neutralization Potential

ABA data for the specific laboratory samples are shown in Table 4.2-9b. NP in the 2007 Stormwater Pond samples range from 0 t/kt $CaCO_3$ eq. to 2 t/kt $CaCO_3$ eq. These NP values were determined using the RGC method. In comparison to the 2001 CDM subsurface samples from the Stormwater Pond reclamation fills, the 2007 samples are much lower. As previously described, the CDM NP method may overestimate the available NP due to the more rigorous digestion method. The observations from the 2007 sampling results support this conclusion.

Sulfur Analysis

Total sulfur in the 2007 Stormwater Pond samples ranged from 0.02 percent to 0.73 percent. All of the samples except pit 18 had total sulfur concentrations greater than 0.08 percent, which is the maximum total sulfur acceptable as a reclamation fill, as set forth by the South Dakota Large Scale Mine Permit 468. Sulfide sulfur ranged from 0.01 percent to 0.70 percent while sulfate sulfur ranged from 0.01 percent to 0.04 percent.

Evaluation of Acid Potential

Figures 4.2-14 and 4.2-15 represent the comparison of NP to AP and the NP:AP ratio to the percent sulfide sulfur, respectively. Both of these figures indicate that 4 out of 5 samples are classified with a high potential to generate acid in the future. The only sample that is not shown to be potentially acid generating was collected from pit 18 at a depth of 7 ft on the south side of the Stormwater Pond. However, the RGC surface sample RF-504 collected near pit 18 is classified with a high acid generating potential while the CDM subsurface sample FM24 collected near pit 18 is classified with a moderate acid generating potential. The large variability observed between these sample sets further supports the conclusion that delineation of sub-units of reclamation fill specifically around the Stormwater Pond can not be conducted.

A comparison of paste pH data with ABA data indicates that some of the Stormwater Pond fills have partially matured and are currently producing acid while some fills have not yet matured, as exemplified by their near-neutral paste pH values. The highest sulfide sulfur percent was detected in pit 16, which also had one of the lowest paste pH measurements (4.2 su). The lower pH likely represents that fill material in this area is becoming mature in generating acid.

Conversely, the trench 14 sample (13 ft depth) also has a high sulfide sulfur content, but its corresponding paste pH is 6.0 su. As described above, a weathered zone (2 ft to 3 ft depth) of the same rock in the trench 14 sample had an acidic paste pH of 3.6 su. This empirical evidence suggests that the rock present in trench 14 is not yet mature and will generate acid in the future. Data from a third pit, pit 15, is classified with a high acid generating potential, but had paste pH measurements throughout the pit ranging from 6.4 su to 7.1 su. Therefore, the rock in pit 15 may also not yet be mature enough to produce acid.

4.2.1.4 Fill Rock Located in Ruby Gulch Waste Rock Dump

The Ruby Gulch waste rock dump contains the largest accumulation of fill rock on the site, and contains an estimated 12 million cubic yards of waste rock and spent ore. Exhibit 4-4 is an early photo showing the initial stages of construction of the waste rock dump. The natural drainage of Ruby Gulch split into two tributaries, a northern tributary (shown on right of the photo) and a southern tributary (shown on the left of the photo). BMC initially placed waste rock from Sunday and Dakota Maid pits into the southern tributary and spent ore into the northern tributary. The spent ore is ore that had been treated with cyanide solution to remove the gold. After gold processing was complete, the cyanide was neutralized and the ore was off-loaded from the HLP and was placed into the northern tributary of Ruby Gulch.

As more rock was placed into the waste rock dump, the two lobes of the dump intersected and formed one large valley fill waste rock dump in Ruby Gulch. Exhibit 4-5 is a photo of Ruby Gulch waste rock dump taken prior to construction of Ruby Repository. At that time, the lower portion of the waste rock dump was in the early stages of reclamation and had been sloped to approximately 3:1. The upper portion of the waste rock dump had not been graded and contained a mixture of exposed waste rock and spent ore.

Exhibit 4-4. Initial stages of construction at Ruby Gulch waste rock dump (looking west)

The Ruby Gulch waste rock dump began generating acid rock drainage in 1993, when a perennial discharge of ARD commenced from the toe of the waste rock dump. At the time that the site was abandoned in 1999, EPA and DENR recognized that the waste rock dump was a major source of ARD. EPA and DENR did not conduct extensive geochemical characterization of the waste rock dump for this reason. Some data are available that were collected by RGC in 2000 during their site-wide reconnaissance investigation. The RGC (2000) reconnaissance investigation was

restricted to surficial sampling, so the data can not be assumed to be representative of the geochemistry of rock at depth within the waste rock dump.

Total Analyses with Potential to Impact Human Health

RGC (2000) measured total concentrations in some surficial samples. These data are included in Table 4.2-10. The specific digestion method used in determination of total concentrations in RGC samples is unknown. Based on a comparison with data collected in EPA programs and analyzed at CLP laboratories, the RGC (2000) data tend to exhibit slightly higher metal concentrations. This may be a result of the use of a more rigorous digestion procedure in the RGC (2000) analyses.

RGC analyzed 11 samples for total metals from the Ruby Gulch waste rock dump. Arsenic in the samples ranged from 20 to 280 mg/kg, with a median of 132 mg/kg. Thallium concentrations were not analyzed in these samples. The average arsenic concentration in the samples does not exceed the established comparison criteria.

Load of Stored Water-Soluble Contaminants

RGC (2000) evaluated surface samples for paste pH and 3:1 modified SPLP. A histogram showing the distribution of paste pH of the RGC (2000) samples is presented as Figure 4.2-16. The histogram shows a bimodal population of paste pH values in the surface sample data. The minimum paste pH measured was 1.5 su and the maximum paste pH was 11 su. The high paste pH values may have been samples of stockpiled lime and fly ash that were present at the time of the RGC (2000) investigation.

Exhibit 4-5. Ruby Gulch waste rock dump configuration when site was abandoned in 1999

The RGC (2000) 3:1 modified SPLP data are shown in Table 4.2-11, and show variable concentrations of water-soluble contaminants. The highest water-soluble contaminant loads are associated with the most acidic samples.

Future Potential to Generate Acid

ABA data from the RGC (2000) surficial samples are presented in Figure 4.2-17, Figure 4.2-18, and in Table 4.2-12. ABA data from the samples show that the majority of samples are classified as acid generating. This is compatible with observational data regarding acid generation from the toe of the facility and acidic paste pH of many of the samples. Some of the surficial samples are classified as non-acid generating based on acid base accounting data. During construction of the Ruby Repository, EPA and DENR determined that although local zones of non-acid generating rock may be present in the waste rock dump, the non-acid generating rock could not be separated from the acid generating rock in a practicable and feasible manner.

The median sulfide sulfur content of the Ruby Gulch waste rock dump samples is 0.16 percent, which correlates to approximately 0.34 percent pyrite. This value is intermediate between the median sulfide sulfur concentration of 0.26 percent observed in the general fill samples and 0.16 percent identified in the reclamation fill samples. RGC (2000) speculated that the rock located at depth in the waste rock dump may contain higher concentrations of sulfide sulfur based on the construction history of the waste rock dump and other anecdotal evidence.

The ABA samples indicate that the waste dump rock has a low capacity to buffer pH changes caused by sulfide oxidation. The median NP of the samples was 2.8 t/kt CaCO3 eq., which is a negligible quantity of NP. NP values calculated from inorganic carbon analyses support the very low NP values determined in the ABA procedure. The median calculated NP of the samples based on inorganic carbon is 0 t/kt CaCO3 eq. One outlier sample exhibits an NP value of 25.8 t/kt $CaCO^3$ eq. This sample may contain some calcite veining as identified previously in the reclamation fill mined from the Anchor Hill Pit.

The ABA data collected from the surface of the Ruby Gulch waste rock dump in 2000 support previous observations that low quantities of pyritic sulfur are capable of generating acid in the Gilt Edge rock. This is a result of the very low neutralization potential of the rock and the large quantities of rock present.

4.2.2 Heap Leach Pad Spent Ore

The second source area evaluated for nature and extent of contamination is HLP spent ore. As with the fills, it was evaluated in two phases. The first phase focused on surface exposures and was conducted by RGC. The second phase was focused on subsurface spent ore and was conducted by CDM. The subsurface samples were collected by either a hollow stem auger or an excavator.

Exhibit 4-6. HLP, Facing East

The discussion of contamination at the HLP has four key components:

- Total metals with the potential to impact human health
- Load of stored water-soluble contaminants
- Future potential to generate acid
- Summary of geochemical characteristics

4.2.2.1 Total Metals with the Potential to Impact Human Health

Four composite samples of HLP spent ore were analyzed as part of the support investigation for the BRA (CDM 2003c). Arsenic concentrations in these samples ranged from 71.7 mg/kg to 391 mg/kg, with an average of 230 mg/kg. Thallium

concentrations ranged from 1.1 mg/kg to 4.5 mg/kg, with an average of 2.55 mg/kg. Neither arsenic nor thallium concentrations exceed the comparison criteria. These data are presented in Table 4.2-13.

Sixty-five samples were analyzed for total metals during the HLP investigation (CDM 2006g). The median arsenic concentration of samples collected by CDM is 94 mg/kg. The arsenic concentration of the samples ranges from 17 mg/kg to 755 mg/kg. Thallium was detected in 32 percent of the 65 samples collected by CDM. The range of concentrations is <1.10 mg/kg to 18.7 mg/kg. The median concentration is below the detection limit of approximately 1.2 mg/kg. Neither the thallium nor the arsenic concentrations in the samples exceed the comparison criteria. Total metals data are shown in Table 4.2-14.

Total cyanide was analyzed in samples collected by CDM. Cyanide was detected in 38 percent of the 65 sub-surface samples. The maximum concentration was 6.1 mg/kg, and the median concentration was below the detection level of approximately 0.13 mg/kg. It should be noted that the 6.1 mg/kg concentration is an outlier in the sample population. The next highest cyanide concentration in the sample population is 1.7 mg/kg, and the upper quartile cyanide concentration is 0.38 mg/kg. These data are included in Table 4-.2-14.

4.2.2.2 Load of Stored Water-Soluble Contaminants

The load of stored water-soluble contaminants was assessed using two types of sampling and analytical methods:

- Paste pH sampling and analysis
- SPLP sampling and analysis

Paste pH

One hundred ninety-two paste pH samples were collected and analyzed by RGC and CDM. The paste pH values range from 1.6 su to 9.9 su. The median paste pH value of the samples is 7.3 su. A histogram of the sample data is shown as Figure 4.2-19, which clearly shows a bimodal distribution. This distribution suggests the presence of two populations in the data set. Population one is circumneutral pH (i.e. between approximately 5.5 su and 8.5 su) to slightly alkaline, and population two is strongly acidic.

The data were evaluated to determine if the bimodal sample distribution corresponds to spatial or geological boundaries. This evaluation considered the loading history of the HLP and the source of the ore, which were discussed in Section 3. Data were differentiated into three zones for this analysis. The first zone is termed the lower zone. It contains Sunday Pit/Dakota Maid Pit ore that was placed on the lower two lifts of HLP cells 1 through 7. This ore came from a sulfide stockpile and from a bio-oxidation test of sulfide ore. The mass of this zone is approximately 500,000 tons (300,000 cy). The second zone is termed the upper zone. This zone includes the remaining lifts on HLP cells 1 through 7 and all of the ore on HLP cells 8, 9, and 10.

The upper zone was primarily loaded with ore from Anchor Hill and Langley pits. Approximately 300,000 tons (200,000 cy) from a low grade stockpile of rock from the Sunday/Dakota Maid pits are commingled with this rock. The upper zone constitutes the majority of the spent ore on the HLP, with an estimated mass of 2.3 million tons (1.5 million cy). The third zone includes the HLP expansion area. This zone includes all of HLP cells 11, 12, and 13. However, these cells are only loaded with approximately 10 ft of ore to serve as a cushion layer for the liner.

Forty-six paste pH samples were collected by CDM and RGC within the lower zone. The data range from 1.6 su to 9.9 su, with a median value of 6.4 su. Access to lower zone spent ore is difficult, and the majority of the samples were collected from the surface. The CDM drill holes did not intersect the lower zone as a result of auger refusal caused by large rocks within the spent ore pile. Two of CDM's trenches sampled subsurface spent ore within the lower zone. These were trenches 11 and 12. A histogram showing the distribution of paste pH data in the lower zone is included in Figure 4.2-19. The histogram shows a bimodal distribution similar to the histogram for the complete HLP data set. Nine samples compose a distinct population that is strongly acidic. The remaining 37 samples compose a second population that is circumneutral pH.

A histogram showing paste pH data from samples collected from the HLP extension area is also included in Figure 4.2-19. Extension area data constitute one sample population. Eighteen samples from the extension area were analyzed for paste pH, and pH results range from 6.2 su to 8.1 su, with a median value of 7.4 su. Paste pH data from the extension area are circumneutral pH and suggest that significant acid generation has not occurred in this zone.

The upper zone was sampled extensively with both surface and sub-surface samples. 128 samples were collected from spent ore in the upper zone. Data range from 1.7 su to 9.3 su, with a median value of 7.4 su. A histogram showing these data is included in Figure 4.2-19. The sample data constitute one population with a tail extending towards the lower pH values. The majority of data are circumneutral pH, with a few strongly acidic samples. The spatial location of the strongly acidic samples was evaluated and shows that there is no distinct spatial correlation of the low paste pH samples with distinct portions of the upper zone. This suggests that the low pH samples represent local heterogeneities or pods of acidic spent ore within a larger mass of spent ore with circumneutral paste pH values.

Interpretation of lower zone paste pH values considers the loading history, the source of the ore, upper zone paste pH data, and existing slope stability conditions on the HLP in addition to the paste pH data. As mentioned above, the lower zone was loaded with rock from a sulfide stockpile and a bio-oxidation leach test. High concentrations of pyrite and other sulfide minerals in ore at heap leach gold mines are very problematic metallurgically. The metallurgical problems may render gold production uneconomic because gold encapsulated in pyrite is not amenable to recovery by the heap leach process. In addition, the presence of excess pyrite increases consumption of cyanide, thereby increasing the cost of gold production. As a result,

rock containing significant gold with high concentrations of sulfide minerals was stockpiled. Bio-oxidation leach tests were conducted to investigate if sulfide oxidation that occurred over a period of months to years within the stockpiles liberated the gold to an extent that allowed economic gold production.

The source of this stockpiled rock was Sunday and Dakota Maid pits. Zones of strongly acid generating rock are present in the Sunday Pit/Dakota Maid Pit highwalls. This suggests that much of the ore mined from the two pits was also strongly acid generating. This interpretation is compatible with the onset of acid generation from the Ruby Gulch waste rock dump in the early 1990s, which was constructed of rock from Sunday Pit and Dakota Maid Pit. Rock mined from these pits and placed into sulfide stockpiles would be expected to contain high sulfide concentrations.

Rock in the upper zone was mined from Anchor Hill and Langley pits in 1996 and 1997. This rock was mined under permit conditions set forth in Large Scale Mine Permit 468, which were developed to mitigate acid rock drainage. These conditions included total sulfur analyses of a subset of blast holes on each bench in order to prevent placement of ore on the HLP that would generate acid. Although this program may not have been completely successful, the detailed analytical work and state oversight associated with the permit requirements would be expected to result in placement of rock with significantly lower sulfide concentrations than the sulfide stockpiles mined from Sunday Pit and Dakota Maid Pit. This is compatible with paste pH sample data from the upper zone, which show that most of the rock had not generated acid prior to the time of sampling. Paste pH data suggest that the upper zone does contain local heterogeneities or pods of acid generating spent ore .

The HLP was constructed with successive lifts of ore with a thickness of 20 ft to 30 ft. The slopes of each lift are angle of repose. Over time, numerous small scale slope failures have occurred on the HLP where upper zone spent ore has moved down-slope over the underlying lower zone slopes. In addition, it is possible that upper zone spent ore was purposefully dozed over lower zone spent ore during construction of the upper zone lifts in order to maximize the volume of ore that could be placed on the HLP.

Lower zone paste pH samples exhibit a bimodal population. Thirty-seven samples constitute the dominant population and exhibit circumneutral paste pH values. The remaining nine samples constitute a second strongly acidic population. It is proposed that these nine samples represent the lower zone population and that the other 37 samples tested upper zone rock that had either covered lower zone slopes as a result of small scale slope failures or had been dozed over the lower zone rock. The discrepancy in the sample density is a result of the difficulty of obtaining sub-surface samples from the lower zone spent ore.

This interpretation of the lower zone paste pH data is compatible with current observations of the HLP spent ore pile. Figure 4.2-20 is a photo of the west side of the HLP. The lower zone spent ore is visible in the photo based on yellowish color as

compared to the upper zone rock. This yellowish color is indicative of jarosite-group secondary precipitates on the spent ore surfaces. These precipitates form as a result of sulfide oxidation in the presence of rocks containing aluminum and potassium. The photo also shows areas where upper zone slope failures have covered lower zone rock and areas where the entire lower zone slopes appear to have been covered with upper zone spent ore.

In summary, the HLP spent ore pile was divided into three zones in order to interpret paste pH data. The lower zone contains approximately 500,000 tons (300,000 cy) of spent ore. The majority of paste pH data from the lower zone is not considered to be representative of the rock because it was collected from the surface. Surface sampling biased the data toward upper zone rock that forms a veneer over much of the lower zone. The lower zone is characterized based on nine samples collected by CDM and RGC and is strongly acidic, with paste pH values ranging from 1.6 su to 2.8 su. Samples from the upper zone and the expansion area are considered representative. The upper zone contains approximately 2.6 million tons (1.6 million cy) of spent ore. This zone is characterized by dominantly circumneutral pH values, with local pods of strongly acid generating rock exhibiting paste pH values as low as 1.7 su. The expansion area of the HLP contains approximately 5 ft to 10 ft of rock placed as a cushion layer. Paste pH data indicate that this rock was circumneutral pH at the time of sampling.

Modified SPLP Test Data

RGC conducted modified 3:1 SPLP tests on a subset of samples from their surface geochemical survey. The modified 3:1 SPLP test results vary over a wide range. Mineral acidity varies from 1.5 mg/L to 2530 mg/L $CaCO_3$ eq., with a pH titration endpoint of 8.3 su. The pH of the decant varies from 2.39 su to 8.07 su. Mineral acidity and pH measured in SPLP extract solutions correlate with the paste pH interpretation presented above. The three samples collected by RGC in the lower zone exhibit high mineral acidity and strong acidic pH. The remaining 10 samples collected from the upper zone had negligible mineral acidity and circumneutral pH. Modified SPLP data for HLP spent ore are presented in Table 4.2-15.

Mobility of toxic metals and metalloids in the modified SPLP tests ranges over three orders of magnitude. For example, the maximum concentration of copper and zinc in upper zone sample decant is 0.060 mg/L and 0.080 mg/L, respectively. The copper concentration of lower zone decants ranges from 1.77 mg/L to 24.9 mg/L, and the zinc concentration ranges from 0.295 mg/L to 2.97 mg/L. The high mobility of copper and zinc in lower zone samples is a result of liberation of trace metals from sulfide minerals caused by oxidation and the increase in metal solubility caused by acidification of the modified SPLP test decant by stored acidity in the sample.

The modified 3:1 SPLP test is useful to identify samples with potential to mobilize high concentrations of toxic metals and metalloids. However, the test is not capable of proving that spent ore will not leach toxic constituents in problematic concentrations. The limitations on modified 3:1 SPLP test interpretations are a result of:

- Different water to rock ratios of the modified 3:1 SPLP test as compared to spent ore piles
- Laboratory detection limits in relation to the water to rock ratio
- Very low regulatory compliance limits for some analytes
- Differences in the available reaction time for a 24-hour test as compared to months or years within a spent ore pile

Other Elements with Potential to Desorb into Infiltrating Water

Selenium is an element that is difficult to evaluate based on modified SPLP test data. Selenium is a metalloid that is mobile under circumneutral pH oxidizing conditions. Perel'man (1967) developed an empirical method to evaluate element mobility in the surficial environment. This method was modified by Rose et al. (1979). The method is shown below:

$$K = \frac{100M}{aN}$$

$$\begin{aligned} \text{Where: } K &= \text{Coefficient of aqueous migration} \\ M &= \text{Concentration of element in drainage (\%)} \\ N &= \text{Concentration of element in rock (\%)} \\ a &= \text{Total dissolved solids in water (\%)} \end{aligned}$$

Rose et al. (1979) provides a coefficient of aqueous migration of >10 for selenium in circumneutral pH oxidizing conditions. As discussed in a previous section, selenium was only detected in 43 percent of the HLP samples submitted for total analyses. The median of the sample population is below the detection level of approximately 1 mg/kg. Evaluation of the potential for selenium mobility from upper zone samples is based on the upper quartile total selenium concentration of 3.48 mg/kg, the average specific conductivity of the upper zone modified SPLP tests of 588 microsiemens per centimeter (µS/cm), and coefficients of aqueous migration of 10 and 20. Total dissolved solids of the upper zone modified SPLP tests were estimated by multiplying TDS by a factor of 0.95. The analysis indicates that the selenium concentration in effluents from upper zone HLP spent ore would be 19 micrograms per liter (µg/L), with K=10, and 38 µg/L, with K=20, based on the method of Perel'man (1967).

The range in potential selenium concentrations of 19 to 38 µg/L is well below the 200 µg/L detection level in the modified SPLP tests. However, the estimated selenium concentrations may cause exceedances in allowable limits. Selenium concentrations measured in HLP effluent in 2006 ranged from 8 to 53 µg/L, with a median concentration of 31 µg/L. The HLP effluent is the combined effluent from the upper and lower zones. The analysis of selenium mobility based on Perel'man (1967) suggests that the source of selenium in the combined effluent may include upper zone

circumneutral pH spent ore. This conclusion is compatible with data from other large-scale heap leach mine facilities, which show that spent ore with total selenium concentrations in the part per million range may produce effluents that exceed allowable limits (Nelson 2003).

4.2.2.3 Future Potential to Generate Acid

ABA analyses were completed on both CDM and RGC samples. CDM completed ABA analyses on all of the HLP samples. RGC completed ABA analyses on a subset of their samples. In the following analyses of ABA data, the upper zone and the expansion area zone are combined based on the similar characteristics of the spent ore. The lower zone was segregated into a separate population based on the paste pH data interpretation.

As discussed previously, HLP samples are biased toward upper zone spent ore as a result of the difficulty in collecting subsurface samples from lower zone spent ore. Eighty-five percent of the CDM ABA samples and 80 percent of the RGC ABA samples were collected in the upper zone. ABA data collected by CDM and RGC are presented in Table 4.2-16. The variability in NP between the RGC method and the CDM method has not been specifically examined for the HLP samples.

Lower zone samples are subdivided further based on whether the samples were collected from the surface of the HLP or the subsurface. This is necessary in order to account for the presence of upper zone spent ore that has covered portions of the lower zone spent ore. Interpretation of ABA data from the lower zone is based primarily on the subsurface samples. This is a conservative approach because the lower zone subsurface samples are significantly more reactive than the lower zone surface samples.

<u>Sulfur Analyses</u>

The upper zone is characterized by relatively low concentrations of pyritic sulfur. The median pyritic sulfur content is 0.29 percent, which correlates to approximately 0.5 percent pyrite. Approximately 73 percent of the sulfur interpreted as pyrite reports to the residual sulfur fraction with the remaining 27 percent reporting to the nitric acid fraction. The residual fraction is sulfur that did not dissolve under any of digestions included in the sulfur speciation analysis. The spent ore was crushed to less than 60 mesh (250 microns) to 100 mesh (149 microns) during the ABA analyses. The high proportion of pyritic sulfur reporting to the residual fraction suggests that the pyrite occurs as very finely disseminated micron-scale grains encapsulated within feldspar or quartz. Sulfur reporting to the residual fraction may also include sulfate minerals, such as jarosite or barite, which did not completely dissolve in the sulfur speciation. Interpretation of the residual fraction as 100 percent pyrite is a conservative assumption. The median pyritic sulfur content of 0.29 percent equates to an acid potential of 9 t/kt $CaCO_3$ eq.

The upper zone effluent chemistry may not be controlled by the median acid potential of the samples. Local heterogeneities or pods of spent ore with higher acid potential may ultimately control the chemistry of the pile. The 75th to 100th percentile pyritic

sulfur concentrations of the upper zone range from 0.6 to 1.3 percent sulfur, which equates to an acid potential ranging from 19 t/kt $CaCO_3$ to 41 t/kt $CaCO_3$ eq.

The upper zone contains neutralization capacity with a median NP of 11 t/kt $CaCO_3$ eq. The NP ranges from 6 to 27 t/kt $CaCO_3$ eq. It is likely that this NP is in the form of residual hydrated lime added to the ore as a processing reagent rather than naturally occurring calcite or dolomite in the ore based on available information regarding mineralogy of the rock.

The lower zone acid potential is approximately an order of magnitude higher than the upper zone based on the available samples. The median pyritic sulfur content is 2.33 percent, which equates to a pyrite content of 4.4 percent. The pyritic sulfur content ranges from 1.19 percent to 3.64 percent, which equates to 2.2 percent and 6.8 percent pyrite, respectively. The proportion of the pyritic sulfur content reporting to the residual fraction is about 11 percent, significantly lower than the upper zone. This suggests that the proportion of pyritic sulfur in the lower zone that is encapsulated in silicate minerals is also lower. The median AP of the upper zone is 72.8 t/kt $CaCO_3$ eq. The range in AP values is 37.2 t/kt $CaCO_3$ eq to 113.8 t/kt $CaCO_3$ eq.

The lower zone also has higher neutralization potentials than the upper zone, which is compatible with historic information described in Section 3.1.4.3 regarding amendment of the sulfide stockpile ore with additional hydrated lime. The median NP is 71.9 t/kt $CaCO_3$ eq., and the NP ranges from <0.3 t/kt $CaCO_3$ eq to 98 t/kt $CaCO_3$ eq.

The acid potential and neutralization potential of the upper and lower zones are evaluated graphically on Figures 4.2-21 and 4.2-22. Figure 4.2-21 shows acid potential versus neutralization potential for all ABA samples collected from the HLP. The graph also shows evaluation criteria developed for the site to discern the potential for samples to generate acid at some time in the future. Figure 4.2-22 shows the percent sulfide sulfur versus the NP:AP ratio.

Lower zone spent ore has previously been shown to be strongly acid generating based on paste pH data. Lower zone ABA data forms a distinct population on Figures 4.2-21 and 4.2-22, which supports interpretation of the lower zone as strongly acid generating. The majority of samples contain high concentrations of pyritic sulfur and insufficient neutralization potential to counteract acid production by oxidizing sulfide minerals. There are five lower zone surface sampling points shown on Figures 4.2-21 and 4.2-22 with significantly lower acid potentials. These samples are interpreted to have been collected from upper zone spent ore that forms a veneer over lower zone spent ore on portions of the HLP.

Upper zone ABA data are more difficult to interpret. The population of data points spans a range from non-acid generating to strongly acid generating, with approximately 50 percent of the data points falling below the criteria defining strongly acid generating samples. In the case of a heterogeneous spent ore pile, the median or average NP:AP ratio can not be used to predict future conditions. This is

because acid generated in one portion of the spent ore pile can not be assumed to interact with excess neutralization potential in other portions of the pile. It is likely that the upper zone will generate acid at some time in the future. Neutralization potential present in the spent ore unit is currently preventing acid drainage, with the exception of local heterogeneities or pods identified by the paste pH data. Acid generation in the remainder of the spent ore unit would be expected to commence at some unknown time in the future when this neutralization potential becomes exhausted.

4.2.2.4 Summary of Heap Leach Pad Geochemical Characteristics

HLP spent ore is differentiated into two mine waste units, the upper zone and the lower zone. The lower zone includes the lower two lifts on HLP cells 1 through 7. The mass of spent ore in the lower zone is estimated to be about 500,000 tons (300,000 cy). The upper zone includes the upper lifts on HLP cells 1 through 7, cells 8 through 10, and the 10 ft thick cushion layer located on the HLP expansion area. The mass of spent ore in the upper zone is estimated to be 2.3 million tons (1.5 million cy).

The lower zone mine waste unit is strongly acid generating. This unit is the dominant contributor to acid rock drainage that is currently collected from the HLP and transported to the Sunday Pit prior to treatment in the site WTP. The lower zone mine waste unit contains high concentrations of toxic metals and metalloids, which have been released from the rock matrix by acid generation. The lower zone mine waste unit also contains high concentrations of efflorescent iron sulfate minerals, secondary products of previous acid generation. These minerals readily dissolve in infiltrating water, releasing acidity, sulfate, iron, and other contaminants. Metals and metalloids in the lower zone are readily dissolved into infiltrating water as a result of previous liberation of contaminates from the mineral matrix and acidity released by dissolving iron sulfate minerals.

The upper zone mine waste unit is currently not acid generating, with the exception of local heterogeneities or pods within the pile. The upper zone contains high concentrations of total metals and metalloids; however, these contaminants are significantly less mobile in infiltrating precipitation because oxidation and acid generation have not yet released the contaminates from the mineral matrix, and stored soluble acidity in the form of secondary iron sulfate minerals is not present. The upper zone does have the potential to release problematic concentrations of selenium, a contaminant that is mobile in oxidizing circumneutral ph conditions. Acid generation is currently limited in the upper zone by the presence of excess neutralization capacity, likely in the form of residual hydrated lime. The upper zone contains significantly less pyritic sulfur than the lower zone , and some pyritic sulfur may be encapsulated in silicate minerals, such as feldspar and quartz. However, over time the excess neutralization capacity is expected to become exhausted, and the pile is expected to generate acid. The duration of this lag period prior to acid generation is unknown.

There is potential for the HLP spent ore units to release contaminates related to mineral processing, which is comparable for the upper and lower zone mine waste

units. Nitrate is a residual byproduct of cyanide degradation and a byproduct of ammonium nitrate fuel oil blasting agents. Nitrate and cyanide concentrations in HLP effluent are evaluated in Section 4.4.

4.2.3 Exposed Rock Surfaces

The most important exposed rock surfaces at the site are pit highwalls. Pit highwalls encompass large areas of exposed rock that include highwall exposures, safety benches, and unconsolidated rock that has spalled from the highwall and built up on the safety benches. The highwalls are known to be sources of ARD based on evaluation of paste pH and ABA data. The current rate of acid generation and the potential for the highwalls to generate acid at some time in the future varies at the different pits.

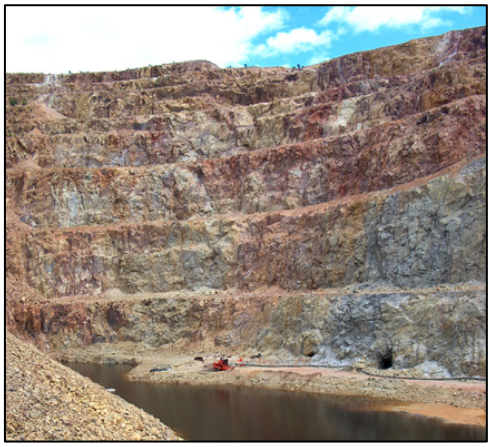


Exhibit 4-7. Exposed Rock Surfaces at Dakota Maid Pit, Facing Northeast

Highwalls at four pits were evaluated to determine nature and extent of contamination:

- Dakota Maid Pit
- Sunday Pit
- Southeast Langley Pit
- Anchor Hill Pit

Highwalls at Dakota Maid and Sunday pits were shown to be strongly acid generating in 2000 when the highwall geochemical sampling program was completed. At that time, highwalls at Langley and Anchor Hill pits were acid generating only within local zones based on paste pH data. However, the Langley and Anchor Hill pits were excavated in 1996 through 1997. This limits the usefulness of paste pH data and requires a more critical review of ABA data to predict future acid potential. The mineralogy of rocks exposed in the pit highwalls is critical to understanding and interpreting the available ABA data.

Geochemical characterization data for the pit highwalls were collected by RGC in 2000 as part of a preliminary site-wide geochemical investigation. Current interpretations of these data vary somewhat from the preliminary interpretations presented by RGC (2000). This is a result of review of the data in concert with site geology data and production history data, which were not available at the time of the preliminary investigation. Spatial variation in geochemical characteristics of pit highwalls is shown on Figure 4.2-23.

The discussion of contamination at the pit highwalls has three key components:

- Total metals with the potential to impact human health
- Load of water-soluble contaminants
- Future potential to generate acid

4.2.3.1 Dakota Maid Pit

The Dakota Maid Pit highwalls were strongly acid generating at the time of sampling, which indicates that the rocks have been exposed for sufficient time for acid generation to commence. The pit was constructed between approximately 1988 and 1992, so rocks on the pit highwalls had been exposed to weathering for a period of approximately 10 years at the time the RGC investigation was conducted. This simplifies interpretation of the geochemical data because it is not necessary to use acid base accounting data to predict whether the rocks will generate acid at some unknown time in the future.

Rocks present at Dakota Maid include trachyte porphyry as well as local zones of intrusive breccia and contact metamorphic rocks. Tracyhte porphyry is the dominant rock unit exposed in pit highwalls. Trachyte porphyry is an intrusive rock with microperthite phenochrysts occurring within a microcrystalline groundmass of potassium feldspar (Macleod 2005). Pyrite is common within trachyte porphyry, occurring as fine grained disseminated crystals and masses of fine grained crystals concentrated along fracture zones and within local pods. Local intrusive breccia zones are exposed in the pit highwalls. These breccia zones occur at the margins of larger intrusive bodies. They consist of fragmented igneous and metamorphic rocks lithified within a matrix of trachyte porphyry. The breccia zones are also commonly mineralized with pyrite. A zone of strongly altered contact metamorphic rocks is present in the southeast part of the pit. The rocks are layered sedimentary rocks that have been contact metamorphosed by the igneous intrusives and altered by hydrothermal solutions. The contact metamorphic rocks exposed in the pit are tilted steeply in relation to similar rocks located distal to Dakota Maid Pit, which suggests that the zone may be a large block of metamorphosed sediments that have been displaced during emplacement of the igneous rocks. Carbonate minerals have not been observed at Dakota Maid Pit, suggesting that available neutralization potential is limited.

Total Metals with Potential to Impact Human Health

Total metals analyses were conducted on six samples collected from the Dakota Maid Pit highwalls during the 2000 RGC investigation (RGC 2000). Data are shown in Table 4.2-17. Total arsenic concentrations in the samples ranged from 45 mg/kg to 330 mg/kg, with an average of 192.5 mg/kg; thallium was not analyzed in the RGC samples. Arsenic concentrations in this data set do not exceed the comparison criteria.

Load of Water Soluble Contaminants

Paste pH data show that all highwalls at Dakota Maid Pit are acid generating. The intensity of acid generation varies, with rocks at the top of the highwall exhibiting less acidic paste pH values than rocks exposed on the middle and lower benches. The intensity of acid generation within the middle to lower benches varies. This is related to both the local concentration of pyrite as well as the depth of oxidation. The depth of oxidation is very irregular as a result of the fracture control of hydraulic conductivity within the trachyte porphyry. Forty-four paste pH samples were collected along the highwall benches that were accessible at the time of sampling. Paste pH values range from 0.9 su to 4.5 su, with a median value of 2.5 su. Data are shown in Figure 4.2-24.

Six samples collected from the pit by RGC were submitted for the 3:1 modified SPLP analysis and total metals analyses. These data are presented in Table 4.2-18. The extraction tests indicate that the pit highwalls contain toxic metals in forms that are readily soluble in water. Cadmium was detected in one of the samples at a concentration of 0.120 mg/L. Copper concentrations ranged from 0.610 mg/L to 11.0 mg/L, with an average of 3.49 mg/L. Zinc concentrations ranged from 0.300 mg/L to 4.16 mg/L, with an average of 1.45 mg/L. Arsenic and selenium were less than the detection level of 0.200 mg/L in all samples.

Future Potential to Generate Acid

A subset of 12 samples from the paste pH sample set was submitted for acid base accounting. Neutralization potential was not identified in any of the Dakota Maid ABA samples. This indicates that very small quantities of pyrite have the potential to cause acid generation because the rock does not have the capacity to buffer changes in pH. The total NNP of the samples varies from -249 to -2 t/kt $CaCO_3$ eq. The sulfide NNP varies from -41.6 to -1.6 t/kt $CaCO_3$ eq. The NP:AP ratio for all samples was 0 because available neutralization potential was not observed. Based on the evaluation criteria presented in Section 4.1, this rock would be classified as acid generating based on both the NNP and the NP:AP ratio. This classification is supported by paste pH data. ABA data for pit highwalls are presented in Table 4.2-19.

The intensity of acid generation is largely dependant on the content of pyrite because neutralization potential is not present and the textural characteristics of the pyrite are generally similar. The pyritic sulfur content of the 12 samples submitted for ABA ranged from 0.1 percent to 1.3 percent, which corresponds to a pyrite content ranging from 0.2 percent to about 2.5 percent. The median pyritic sulfur content of the samples is 0.5 percent, corresponding to a pyrite content of about 1 percent. Locally, pyrite concentrations significantly higher than 3 percent are present, particularly within very strongly acid generating zones located on the base of the current highwall near the upper level King Adit. However, the data show that low concentrations of pyrite are capable of producing acid in rocks exposed at Dakota Maid Pit. This is attributed to the lack of acid neutralizing carbonate minerals as well as the crystal habit of the sulfide minerals, which makes them weather rapidly.

4.2.3.2 Sunday Pit

Sunday Pit highwalls are generally similar in geochemical characteristics to the Dakota Maid Pit highwalls. The Sunday Pit highwalls were also shown to be highly acid generating based on paste pH data collected during the 2000 RGC investigation. Sunday Pit was developed contemporaneously with Dakota Maid Pit during 1988 to 1992. Based on the paste pH data, the period of approximately 10 years that the pit was exposed to weathering was sufficient for acid generation to mature to a point that acidic paste pH values were observed. As described above for Dakota Maid Pit, this simplifies interpretation of the geochemical data.

The Sunday Pit contained approximately 80 million gallons (Mgal) of stored ARD when the highwalls were investigated, which corresponds to a water elevation of approximately 5,363 ft. Pit highwalls at elevations between the base of the pit at 5,260 ft to the 5,363 ft elevation have not been investigated. It is likely that these highwalls are similar in geochemical characteristics to highwalls above 5,363 ft.

Rocks exposed at Sunday Pit include trachyte porphyry and quartz trachyte porphyry. The trachyte porphyry is similar to the porphyry described for Dakota Maid Pit. The quartz trachyte porphyry is a similar rock unit with different mineralogy and composition. The quartz trachyte porphyry contains euhedral sanadine, subhedral microperthite, and subhederal quartz phenocrysts within a cryptocrystalline groundmass (MacLeod 2005). A large area of argillic alteration is exposed on the southeastern highwall of Sunday Pit. The argillic alteration is recognized by alteration of feldspar within the porphyry to clay minerals. The physical characteristics of this alteration area are significantly different from other areas of the pit; however, the argillic alteration zone is also strongly acid generating based on paste pH. Contact metamorphic rocks are not exposed within Sunday Pit. Rocks exposed at Sunday Pit do not contain carbonate minerals. Based on mineralogical data, significant neutralization potential is not present at Sunday Pit.

Total Metals with Potential to Impact Human Health

Total metals analyses were conducted on three samples collected from the Sunday Pit highwalls during the 2000 RGC investigation (RGC 2000). Total arsenic concentrations in the samples ranged from 70 mg/kg to 130 mg/kg, with an average of 93 mg/kg. Thallium was not analyzed in the RGC samples. Arsenic concentrations in this data set do not exceed the comparison criteria. All total metals data for the Sunday Pit highwalls are shown in Table 4.2-17.

Load of Water Soluble Contaminants

Paste pH data indicate that all highwalls at Sunday Pit are acid generating. Thirty-three paste pH samples were collected from highwalls at Sunday Pit. The paste pH values range from 1.5 su to 4.3 su, with a median value of 2.3 su. Three moderately acid paste pH values of 4.1 su to 4.3 su were observed on the upper benches of the north highwall. However, strongly acid paste pH values were observed in close proximity to the moderate paste pH values both along the same bench and at higher elevations within the pit. This suggests that the degree of oxidation is variable in the upper benches, which is compatible with previous observations that the depth of surface oxidation is very irregular in Sunday and Dakota Maid pits. This is attributed to the importance of fracture density in controlling hydraulic conductivity within porphyry rocks. Paste pH data for Sunday Pit are summarized in Figure 4.2-24.

Three samples from the Sunday Pit highwalls were submitted for the 3:1 modified SPLP test. These data indicate that rocks exposed on the Sunday Pit highwalls contain high concentrations of water soluble contaminants, including cadmium, copper, zinc, and arsenic. Cadmium concentrations in the 3:1 SPLP extracts ranged from 0.020 mg/L to 0.400 mg/L, with an average of 0.163 mg/L. Copper ranged from 0.070 mg/L to 5.760 mg/L, with an average of 2.583 mg/L. Zinc ranged from 0.365 mg/L to 2.640 mg/L, with an average of 1.598 mg/L. Arsenic was detected in one of the three samples at a concentration of 3.330 mg/L. However, the other two samples were less than the detection level of 0.200 mg/L. Selenium was less than the detection level of 0.200 to 0.400 mg/L in all three samples. All SPLP data for Sunday Pit highwalls are presented in Table 4.2-18.

Future Potential to Generate Acid

Six samples from the paste pH data set were submitted for ABA analyses. The total NNP of the samples ranges from -290 t/kt $CaCO_3$ eq to 0.1 t/kt $CaCO_3$ eq. The sulfide NNP ranges from -28 t/kt $CaCO_3$ eq to 1 t/kt $CaCO_3$ eq. The NP:AP ratio is 0 for four of the six samples because there was no detectable neutralization potential. Detectible neutralization potential ranging from 1 t/kt $CaCO_3$ eq to 3 t/kt CaCO3 eq. was reported for two of the samples. These two samples had NP:AP ratios ranging from 0.4 to 2.0. The NP:AP ratio of 2.0 corresponds to a paste pH value of 4.1 su, which is among the highest observed paste pH values in Sunday Pit. Inorganic carbon was also measured in this sample. The carbonate neutralization potential calculated from the inorganic carbon analysis does not correlate with the neutralization potential of 3 t/kt CaCO3 eq. derived from the ABA analysis. It is possible that another mineral is buffering the pH of the moderately acidic samples from the north wall of Sunday Pit in the 4.0 su to 4.3 su range. Buffering of these pH values in the 4.0 su to 4.3 su range may be short term and a part of the step-wise reduction in pH caused by various minerals buffering pH changes as acid conditions develop.

Based on the NNP data, all ABA samples collected from the Sunday Pit highwalls are classified as acid generating. The pyritic sulfur concentrations of the Sunday Pit ABA samples ranges from 0.04 percent to 0.9 percent, which correlates to a pyrite content ranging from trace to about 2 percent. The median pyrite content of the six samples is 0.3 percent, which correlates to about 0.6 percent pyrite. This is lower than the median

of the Dakota Maid samples of about 1 percent pyrite although the small sample size of the Sunday Pit data set is not adequate to make more than general comparisons of pyrite content for the two pits. ABA data for pit highwalls are presented in Table 4.2-19.

4.2.3.3 Southeast Langley Pit

The Southeast Langley Pit includes two areas of sidehill excavations. Interpretation of geochemical data for Southeast Langley Pit is more difficult than Dakota Maid or Sunday pits because Southeast Langley was constructed only 3 years prior to the 2000 RGC investigation of highwall geochemical characteristics. It is less likely that acid generation had matured to a point where the propensity of the rock to generate acid can be readily identified based on paste pH. So interpretation of ABA data is critical to understanding the geochemical characteristics at Southeast Langley Pit.

Rocks present at Southeast Langley Pit are substantially different than rocks at Dakota Maid or Sunday pits. The Southeast Langley Pit is located in an area of Precambrian metamorphic rocks, intrusive breccia, contact metamorphic rocks, and trachyte porphyry. Available ABA data indicate that carbonate minerals are not present at Southeast Langley Pit. The crystal habitat of pyrite within Precambrian rocks varies markedly from the porphyry rocks exposed at Dakota Maid and Sunday pits. Pyrite within Precambrian rocks is commonly associated with cleavage planes and fracture surfaces in contrast to porphyry rocks at Dakota Maid and Sunday where pyrite occurs as fine grained crystals disseminated within the rock. The general habit of pyrite within intrusive breccia and porphyry at Southeast Langley Pit is similar to Dakota Maid and Sunday.

Total Metals with Potential to Impact Human Health

Total metals analyses were conducted on five samples collected from the Southeast Langley Pit highwalls during the 2000 RGC investigation (RGC 2000) (Table 4.2-17). Total arsenic concentrations in the samples ranged from 60 mg/kg to 1,435 mg/kg, with an average of 580 mg/kg. Arsenic concentrations in this data set do not exceed the comparison criteria. Thallium was not analyzed in the RGC samples.

Load of Water Soluble Contaminants

Fourteen paste pH samples were collected from highwalls at Southeast Langley Pit. The paste pH values ranged from 2.9 su to 6.9 su, with a median value of 4.5 su. The Southeast Langley highwalls were significantly less acid generating than Dakota Maid or Sunday at the time they were sampled in 2000 (Figure 4.2-24).

Modified 3:1 SPLP tests were completed on five samples from highwalls at Southeast Langley Pit. These data are presented in Table 4.2-18. Concentrations of contaminants in the modified 3:1 SPLP extracts are generally very low. Cadmium was less than the detection level of 0.010 mg/L in all five samples. Copper was detected in four of the five samples, with concentrations ranging from less than 0.10 mg/L to 0.400 g/L. Zinc was also detected in four of five samples, with concentrations ranging from less than 0.005 mg/L to 0.073 mg/L. Arsenic and selenium concentrations were less than the detection level of 0.200 mg/L in all samples. The low concentrations of metals in the

modified 3:1 SPLP extract solutions is directly related to the relatively less mature stage of acid generation at the time samples were collected in 2000. In the event that the pit highwalls begin to generate acid in the future, the concentration of mobile contaminants would be expected to increase.

Future Potential to Generate Acid
ABA data from samples collected on the Southeast Langley Pit highwalls (Table 4.2-19) are critical to understanding the potential for the highwalls to generate acid. A subset of 12 samples from the Southeast Langley data set was submitted for ABA analyses. The total NNP for these samples ranges from -111 t/kt $CaCO_3$ eq to 1.21 t/kt $CaCO_3$ eq. The sulfide NNP ranges from -15.9 t/kt $CaCO_3$ eq to 4.96 t/kt $CaCO_3$ eq. Some neutralization potential was identified based on the ABA neutralization potential analyses, with values ranging from 0 to 5.8 t/kt $CaCO_3$ eq. However, comparison of neutralization potential from the ABA analyses with neutralization potential estimated from inorganic carbon analyses indicates that the ABA neutralization potential is not attributable to carbonate minerals. All Southeast Langley highwall samples are classified as acid generating based on the NNP. The lag period prior to development of acid conditions on the pit highwalls is unknown.

The intensity of acid generation from the Southeast Langley Pit highwalls is likely to be lower than that observed at Dakota Maid or Sunday pits. This is a result of lower overall pyrite concentrations. The pyritic sulfur content of the 12 ABA samples from Southeast Langley highwalls ranges from 0.02 percent to 0.51 percent, which corresponds to a pyrite content ranging from trace to about 1 percent. The median pyrite concentration is 0.2 percent, which is significantly lower than the median pyrite concentration at Dakota Maid Pit of 1 percent. However, pyrite within Precambrian rocks commonly occurs within specific cleavages or fractures within the rock, so it is possible that local zones are present with higher pyrite concentrations that were not sampled.

4.2.3.4 Anchor Hill Pit

The Anchor Hill Pit was constructed during the same general phase of mining as the Southeast Langley Pit. Excavation started in the first quarter of 1996 and extended to August 1997. Highwalls at Anchor Hill Pit had been exposed to weathering for a period of 3 to 4 years when the RGC geochemical sampling program was conducted. Evaluation of the geochemical characteristics of highwalls at Anchor Hill Pit is therefore dependant on interpretation of ABA data because the highwalls had not been exposed to weathering for a long enough period for acid generation to commence in some areas. Anchor Hill Pit also has distinct geological and mineralogical differences from other pits on the site, which affect interpretation of geochemical data. Highwalls at Anchor Hill Pit exhibited local zones of acid generation at the time they were sampled in 2000.

Two dominant rock types are exposed in the Anchor Hill Pit, quartz trachyte porphyry and hornblende trachyte porphyry. The quartz trachyte porphyry is exposed on the northwest highwall. The hornblende trachyte porphyry is exposed on the east and south sides of the pit. The quartz trachyte porphyry is similar in

composition to quartz trachyte porphyry exposed at Sunday Pit. However, the intensity of pyrite mineralization within the Anchor Hill quartz trachyte porphyry appears to be lower than quartz trachyte porphyry at Sunday Pit based on very limited data. The hornblende trachyte porphyry is not exposed in any of the other pits. It is composed of hornblende and plagioclase phenocrysts within a microcrystalline groundmass of potassium feldspar.

Several features of the hornblende trachyte porphyry affect interpretation of geochemical data. Local zones of calcite veining are present within the hornblende trachyte porphyry. This veining represents neutralization potential that is available to buffer changes in pH caused by sulfide oxidation. The crystal habit of pyrite within hornblende trachyte porphyry is also different from pyrite contained within other porphyry units at the site. The pyrite is coarser grained and more euhedral in crystal form, which causes it to weather more slowly than pyrite present in the other porphyry units. Both the presence of local zones of calcite veining as well as the relatively coarser and more euhedral crystal habit of pyrite tend to slow the rate of acid generation.

Total Metals with Potential to Impact Human Health

Total metals analyses were conducted on five samples collected from the Anchor Hill Pit highwalls during the 2000 RGC investigation (RGC 2000). Total arsenic concentrations in the samples ranged from 10 mg/kg to 1,400 mg/kg, with an average of 319 mg/kg. Arsenic concentrations in this data set do not exceed the comparison criteria. Thallium was not analyzed in the RGC samples. All total metals data for the Anchor Hill Pit highwalls are shown in Table 4.2-17.

Load of Water Soluble Contaminants

Thirty-two paste pH samples were collected from highwalls at Anchor Hill Pit. These data are included in Figure 4.2-24. Paste pH values range from 1.7 su to 8.1 su, with a median paste pH of 5.1 su. No acidic paste pH values were identified from the quartz trachyte porphyry unit exposed in the northwest highwall. Paste pH values from the hornblende trachyte porphyry range from strongly acid to slightly alkaline. It is likely that the more alkaline paste pH values are associated with local zones of calcite veining. Samples with both strongly acidic and circumneutral paste pH values are located in close proximity to the alkaline values. This suggests that the distribution of calcite veining is variable. It is necessary to consider this heterogeneity in mineralogical composition when interpreting geochemical data at Anchor Hill Pit.

Modified 3:1 SPLP data for Anchor Hill Pit highwalls is shown in Table 4.2-18. Five samples from the Anchor Hill highwalls were submitted for modified 3:1 SPLP analyses. Contaminant concentrations in four of the five modified 3:1 SPLP tests were relatively low, with one sample exhibiting significantly higher concentrations of mobile metals. This is a result of variation in the degree of acid generation on the Anchor Hill Pit highwalls at the time of sampling with the relatively more acid generating sample exhibiting higher concentrations of soluble contaminants. This variation is exhibited by copper and zinc concentrations in particular. Copper was detected in two of the five samples, with a median concentration of less than the

detection level of 0.010 mg/L. The copper concentration in one sample was significantly higher at 9.1 mg/L. Zinc concentrations ranged from less than 0.005 to 1.180 mg/L, with a median of 0.175 mg/L. The highest zinc concentration of 1.180 is about an order of magnitude higher than the median.

Future Potential to Generate Acid

Interpretation of ABA data is critical to evaluating geochemical characteristics at Anchor Hill Pit for several reasons: (1) the pit was excavated only 3 to 4 years prior to paste pH sampling, which is insufficient time for acid generating rock to mature to a point where paste pH is a reliable indicator of the propensity for the rock to generate acid, (2) the presence of local calcite veining will buffer pH changes and slow the rate of acidification, and (3) the relatively coarser and more euhedral crystal habit of pyrite will also decrease the rate of acid generation. Eleven ABA samples were evaluated from Anchor Hill highwalls. The total NNP ranged from -52 t/kt $CaCO_3$ eq. to 33.1 t/kt $CaCO_3$ eq., and the sulfide NNP ranged from -34 t/kt $CaCO_3$ eq. to 99 t/kt $CaCO_3$ eq. One sample had a very high neutralization potential of 100.9 t/kt $CaCO_3$ eq. Inorganic carbon data for that sample support the interpretation that this high NP is attributable to the presence of calcite and therefore represents effective neutralization capacity. ABA data for Anchor Hill Pit highwalls are included in Table 4.2-19.

The northwestern highwall has previously been classified as non-acid generating (RGC 2000). This is not supported by ABA data. Only two ABA samples were collected from the northwestern highwall. The pyritic sulfur content of one sample was very low, and this sample is classified as non-acid generating. However, the sample was collected from the top of the highwall where natural surface weathering would have oxidized any pyrite present. The other sample has a sulfide NNP of -34.1 t/kt $CaCO_3$ eq., which classifies it as strongly acid generating. This sample had a circumneutral paste pH of 5.0 su, which supports the previous assertion that the relatively short period between excavation of the pit and collection of paste pH samples makes the paste pH data less useful for understanding acid potential of the highwall. The geochemical classification of the northwest highwall is potentially acid generating because of the very low ABA sampling density and the ambiguous results.

The remaining 10 ABA samples represent the hornblende trachyte porphyry, which is exposed on the south and east highwalls. Three of these samples are classified as acid generating based on negative sulfide NNP, four samples are classified as uncertain, and three samples are classified as acid consuming as a result of high neutralization potentials. It is likely that these high neutralization potentials are a result of calcite veining. The ABA data for the hornblende trachyte porphyry validates general observation based on paste pH that acid generation from exposed hornblende trachyte porphyry will be variable. The south and east highwalls at Anchor Hill Pit are likely to generate acid; however, local non-acid generating zones may persist based on the heterogeneous distribution of calcite neutralization potential in the hornblende trachyte porphyry. It can not be assumed that excess neutralization capacity present in local zones of calcite veining will neutralize acid generation from adjacent zones of the highwalls because it is unlikely that the natural flow pathways

of precipitation interacting with the highwalls will convey all acidic drainage over zones containing calcite. It is also likely that dissolution of calcite will be hindered as a result of armoring of calcite grains with iron hydroxides, which occurs when calcite interacts with acid drainage under near-surface oxidizing conditions.

4.2.4 Underground Mine Workings

The fourth category of source area is the underground mine workings. Geochemical characteristics of rock exposed in the various underground workings at the site have not been investigated although a general evaluation can be developed based on existing data.

The primary underground workings on site include four areas:

- Upper and lower King workings
- Rattlesnake workings
- Langley Adit
- Hoodoo workings

The locations of these workings were shown previously in Figure 3.1-2.

Exhibit 4-8. Diagram of King Underground Workings in Dakota Maid Pit Area, Looking Northeast

4.2.4.1 Upper and Lower King Workings

The upper and lower level King workings are located in the general vicinity of Dakota Maid Pit. The King workings extend through geological units exposed and sampled in the Dakota Maid Pit, which include trachyte porphyry, quartz trachyte porphyry, intrusive breccia and strongly altered and mineralized Deadwood Formation sediments. These units have been shown to be strongly acid generating in exposures within the pit. Therefore, the acid potential of the King underground workings is expected to be similar.

The exposures within the underground workings have been in place since at least the late 1930s, and the rock in the upper level workings was likely unsaturated during this time. Thus, acid generation within the upper level workings may be relatively more mature, which would lead to higher concentrations of soluble products of acid generation and somewhat lower concentrations of pyrite. The lower level King workings may have been saturated during this time period. Oxidation of sulfide minerals within the lower level workings may be occurring as a result of the presence of dissolved ferric iron in groundwater; however, the degree of oxidation of sulfide minerals within lower level workings is unknown.

4.2.4.2 Rattlesnake Workings

The Rattlesnake workings are located beneath the base of Sunday Pit. These workings have been inaccessible since abandonment of the mine site as a result of ARD stored within the pit. It is likely that these workings expose rocks with similar geochemical characteristics to rocks sampled on the Sunday Pit highwalls; however, the detailed geology of the Rattlesnake workings is unknown. The upper levels of the Rattlesnake workings were excavated during development of Sunday Pit. The remaining lower level Rattlesnake workings may have been saturated during the time period following mine development, which occurred prior to the late 1930s. Saturation of sulfide minerals generally limits acid generation because the concentration of oxygen in groundwater is low and the diffusion rate of oxygen through water is slow. Dissolved ferric iron may contribute to oxidation of sulfide minerals within the Rattlesnake workings, leading to liberation of contaminants associated with the sulfide minerals into groundwater.

4.2.4.3 Langley Adit

The Langley Adit portal is located about 30 ft east of Pond E/Strawberry Pond on the slope between Sunday Pit and the Strawberry Creek drainage. This adit has not been entered to evaluate geochemical characteristics. ARD flows from this adit on an intermittent basis with pH values ranging from 2.85 to 3.29 based on three samples collected in 2000 through 2002. This suggests that the Langley workings are generally unsaturated and that acid generation is occurring within the underground workings. Based on a comparison of the location of the adit with geological data, the adit appears to penetrate along the contact zone between the quartz trachyte porphyry and trachyte porphyry. The adit may intersect a breccia zone that is mapped at the contact of the two porphyry units. Exposures of these geologic units in Dakota Maid and Sunday Pits are strongly acid generating, which is compatible with observations of acid drainage emanating from the Langley Adit.

4.2.4.4 Hoodoo Workings

The location of the Hoodoo workings is shown on Figure 3.1-2, which is based entirely on compilation of historical maps. The specific location of the portal to the Hoodoo mine is unclear as a result of numerous surface prospect pits and/or collapsed adit portals in the general area. Work has not been completed to attempt to gain access into the Hoodoo workings. No distinct point source discharge was identified, but it is possible that discharge from the Hoodoo workings contributes to alluvial groundwater, which is collected at the Hoodoo Gulch collection facility. This water is acidic and is pumped to Sunday Pit prior to treatment. The geochemical characteristics as well as the specific location of the Hoodoo workings are unknown.

4.2.5 Amended Tailings

Tailings repositories at the site were investigated to determine whether the repositories were a source of ARD. The location and general characteristics of this fifth category of source area were discussed previously in Section 3.1.

The tailings were amended with alkaline fly ash from a local coal fired power plant in order to reduce the potential for acid generation and migration of contaminants. Durkin (1994) reported that one goal of the fly ash amendment included attaining a 3:1 ratio of NP to AP and a net neutralization potential of 20 t/kt $CaCO_3$ eq. or higher. The amended tailings are covered with a low permeability clay cover that was designed to achieve a maximum permeability of 1×10^{-7} cm/sec. DENR approved plans and specifications for construction of the facilities and conducted routine inspections during construction of the tailings repositories.

Two samples of amended tailings were collected from the tailings repository located on the east side of Sunday Pit. Sample analyses included paste pH, acid base accounting, standard 20:1 SPLP tests, and total metals analyses. Two additional samples were collected from the surface of the tailings repository located in the Bunny Ear Area of the Dakota Maid Pit. Although the original intent of these samples was to evaluate the amended tailings, the samples were logged as soil. Based on the sample description, it is concluded that these samples actually came from the upper Bunny Ear topsoil stockpile. This topsoil stockpile was placed on top of the tailings repository for temporary storage during mine development activities that occurred in 1996.

The discussion of contamination in the amended tailings has three key components:

- Total metals with the potential to impact human health
- Load of water-soluble contaminants
- Future potential to generate acid

4.2.5.1 Total Metals with Potential to Impact Human Health

Total metals were analyzed in the two samples collected during the investigation (Table 4.2-20). Total arsenic concentration ranged from 112 mg/kg to 136 mg/kg. Thallium was less than the detection level of 1.7 mg/kg in both samples. Based on the limited data set, arsenic concentrations do not exceed the comparison criteria.

4.2.5.2 Load of Water Soluble Contaminants

The two samples of amended tailings were evaluated for paste pH, with values of 6.4 su and 7.9 su. The paste pH data indicate that the fly ash amendment is buffering pH changes caused by dissolution of the products of acid generation. The circumneutral pH controls solubility of metals into infiltrating water. SPLP tests were conducted on the samples. Concentrations of metals and metalloids were very low in the SPLP analyses (Table 4.2-21).

Two additional samples of fly ash amended tailings were analyzed for paste pH in the 2007 Supplemental FS Investigation. The paste pH of these samples is 6.1 su and 6.5 su. This indicates that the fly ash is buffering pH and supports the earlier data that are described above.

4.2.5.3 Future Potential to Generate Acid

ABA data (Table 4.2-22) suggest that the amended tailings have a moderate potential to generate acid in the future. Pyritic sulfur in the samples ranged from 0.52 percent to 0.81 percent in the samples, which correlates to a pyrite content of about 1 percent to 1.5 percent. Sulfate sulfur ranged from 0.31 percent to 0.49 percent. The total NNP of the samples ranged from 6.6 t/kt $CaCO_3$ eq.to 13.1 t/kt $CaCO_3$ eq., and the sulfide NNP ranges from 8.7 t/kt $CaCO_3$ eq. to 23.8 t/kt $CaCO_3$ eq. The NP:AP ratio ranges from 1.3 t/kt $CaCO_3$ eq. to 2.46 t/kt CaCO3 eq. The overall NNP of the approximately 100,000 tons of amended tailings can not be adequately characterized by two samples. However, these data suggest that the target levels of a NNP of 20 t/kt CaCO3 eq. and a NP:AP ratio of 3:1 may not have been achieved in the fly ash amendment process. Based on evaluation of the two ABA samples, there is a moderate potential that the tailings may generate acid in the future.

Potential environmental effects of future acid generation in the tailings repositories are mitigated by the presence of low permeability covers over two tailings repositories. The performance of these covers in attaining the design $1x10^{-7}$ cm/sec permeability was not evaluated in this investigation. Seepage of ARD from the toe of the repositories has not been observed during general site activities, which suggests that the cover systems are reducing infiltration of precipitation into the repositories.

4.2.6 Soil Stockpiles

The sixth category of source areas on site is the soil stockpiles. These stockpiles are resources for site reclamation and were constructed during site development activities. Their purpose is to store the topsoil and subsoil in piles to provide cover soil to use during site reclamation. Soil stockpiles that were present on the site at the time the state and EPA took over site management were evaluated by CDM, and summarized in the *Soil and Vegetation Investigation Report* (CDM 2003d). Additional evaluations of total metals data for soils include data from samples collected from reclaimed areas on the site as part of the support investigation for the baseline human health risk assessment (CDM 2003c). These areas contain formerly stockpiled soils that were used in site reclamation by BMC. A final investigation was conducted in April 2007, in conjunction with the previously described Stormwater Pond reclamation fill investigation. The focus of this investigation was specific for evaluating the chemical and physical characteristics of soil stockpile materials for use in site reclamation activities.

Many of the site soil resources were utilized during construction of the Ruby Repository. The following sections evaluate the remaining soil stockpiles as a potential source of contaminants. Additional data regarding soil quality and fertility are included in *Soil and Vegetation Investigation Report* (CDM 2003d). The remaining stockpiles include the Hoodoo Road Slope pile, the Anchor Hill pile, the Upper Bunny Ear pile, the Crusher Area pile, and the Stormwater Pond piles. The locations of these piles are shown on Figure 4.2-25.

The discussion of contamination in the soil stockpiles has three key components:

- Total metals with the potential to impact human health
- Load of water-soluble contaminants
- Future potential to generate acid

4.2.6.1 Total Metals with Potential to Impact Human Health

Six composite samples of soil were analyzed as part of the support investigation for the BRA. The samples were collected from reclaimed areas at the Sunday Pit tailings repository, an area of reclamation fills covered by soil in south Sunday Pit, and from the Upper Bunny Ear soil stockpile. The soil samples at the tailings repository and in south Sunday Pit were collected from reclaimed areas that contained soil previously stockpiled on the site. Arsenic concentrations in these samples ranged from 22.4 mg/kg to 41.9 mg/kg, with an average of 32.0 mg/kg; manganese concentrations ranged from 599 mg/kg to 1,050 mg/kg, with an average of 810 mg/kg; and lead concentrations ranged from 35.4 mg/kg to 92.5 mg/kg, with an average of 62.1 mg/kg. Thallium concentrations of the samples were all below the detection level of 0.86 mg/kg to 0.91 mg/kg. Based on the data set, manganese concentrations in the stockpiled soil exceed the comparison criteria. These data are presented in Table 4.2-23.

Total metals in 26 samples from the remaining soil stockpiles were evaluated by CDM (2003d). Summary statistics for total metals are presented in Table 4.2-24 and all data are included in Appendix B. The total metals concentrations in the soil stockpiles vary between piles. This may be a result of inherent differences between the piles as well as the heterogeneity of the piles in relation to the sample density.

Average arsenic concentrations of samples collected from the five piles ranged from 15 mg/kg to 101 mg/kg. Average lead concentrations in samples from the piles ranged from 61 mg/kg to 342 mg/kg. Average manganese concentrations of samples collected from the piles raged from 545 mg/kg to 1,325 mg/kg. Thallium concentrations were below the detection level of 0.43 to 0.60 mg/kg in all stockpiles. The highest arsenic, manganese, and lead concentrations occurred in samples collected from the Upper Bunny Ear pile, which contains approximately 84 percent of remaining soil resources.

4.2.6.2 Load of Water Soluble Contaminants

Evaluation of water soluble contaminants includes evaluation of paste pH (Table 4.2-25) and SPLP extraction tests (Table 4.2-26). Average paste pH in samples collected from the soil stockpiles ranges from 4.04 su to 5.95 su. Samples from the largest remaining soil stockpile, the Upper Bunny Ear pile, displayed an average paste pH value of 5.23 su. The SPLP data show that the concentration of mobile contaminants in soil samples is relatively low, which is a result of the moderate pH of the samples.

4.2.6.3 Future Potential to Generate Acid

ABA data are shown in Table 4.2-27. ABA analyses were conducted on 14 soil samples collected from the five remaining soil stockpiles in 2001 and on 8 soil samples collected from the Stormwater Pond and Upper Bunny Ear soil stockpiles in 2007. The CDM method for ABA analysis was utilized for the 2001 samples while the RGC method was utilized for the 2007 samples.

NP for soil stockpiles range from 0 t/kt $CaCO_3$ eq. to 15 t/kt $CaCO_3$ eq. For the two stockpiles analyzed in 2007, a comparison of NP shows that the 2001 NP values were generally higher, as expected by the more rigorous digestion method used in the 2001 NP analyses.

Sulfide sulfur concentrations range from 0.01 percent to 0.42 percent. The highest sulfide sulfur values are from surfaces of the Hoodoo Road Slope pile (0.31 percent) and Upper Bunny Ear pile (0.42 percent). Sulfide sulfur concentrations of 0.31 percent and 0.42 percent are equivalent to about 0.6 percent and 0.9 percent pyrite, respectively. Evaluations of fill material ABA and paste pH discussed in Section 4.1.2 show that sulfide sulfur concentrations in this range may cause acid generation in rocks at Gilt Edge. Additionally, note that the corresponding paste pH of the 0.31 percent sulfide sulfur sample from the surface of the Hoodoo Road Slope pile was 3.5 su, which indicates that the soil was generating acid when the sample was collected in 2001.

Figures 4.2-26 and 4.2-27 present evaluations of the acid potential versus neutralization potential and the NP:AP ratio versus percent sulfide sulfur in the soil stockpiles. Sixteen of the 22 total samples are classified with a moderate to high potential to generate acid in the future, including all samples collected from the Hoodoo Road Slope soil stockpile and all but one of the samples from the Upper Bunny Ear soil stockpile. The soil stockpiles contain large quantities of rock as discussed in Section 3.1. Based on interpretation of the ABA analyses, it is likely that this rock contains unoxidized pyrite. The moderate paste pH values that were observed at the time of sampling for some of the samples suggest that pH changes in the soil are being buffered by available neutralization potential. In the future, the soil pH is expected to decrease in response to oxidation of sulfide minerals and exhaustion of available neutralization potential.

4.2.7 Sludge

The final source area evaluated at the site is ARD neutralization sludge. The mine has produced approximately 95 Mgal of ARD per year since the early 1990s. This ARD has toxic metal and metalloid concentrations that are hundreds to thousands of times higher than permissible discharge limits. The water treatment process produces sludge, which is a slurry of water and solid precipitates produced

Exhibit 4-9. Sludge Storage Area at Sunday Pit, Looking East

when metals and metalloids precipitate from ARD in response to addition of a base, such as hydrated lime ($Ca(OH)_2$) or sodium hydroxide (NaOH). Precipitates formed from ARD neutralization reactions include amorphous to microcrystalline iron and aluminum hydroxides and/or hydroxysulfates. Other dissolved metals and metalloids, such as arsenic, cadmium, copper, and zinc, are removed by adsorption and coprecipitation with the iron and aluminum phases. As a result, these sludges contain high concentrations of metals and metalloids and represent a potential source of contamination at the site.

ARD neutralization sludge includes sludge generated by the former NaOH water treatment facilities, the current high density WTP sludge, and the Anchor Hill Pit Lake Treatability Study. Former NaOH treatment facilities include the former WTP and the hard bucket treatment systems that operated in Pond C and Hoodoo Gulch. The hard bucket system in Pond C was removed in the fall of 2004 and replaced with diversion pipelines, which convey the ARD into the site WTP circuit. The Hoodoo Gulch hard bucket system was removed in the fall of 2005 and replaced with a pump back system, which also conveys this ARD into the site WTP circuit.

Various methods of sludge management have been used by BMC, DENR, and EPA since initiation of water treatment in the early 1990s. These sludge management practices have resulted in numerous sludge disposal areas, which include pit lakes, unlined basins, and lined facilities. ARD neutralization sludge is currently present within the Anchor Hill, Dakota Maid, and Sunday pit lakes; within unlined basins in the Dakota Maid Pit and Sunday Pit remediation subareas; and within lined facilities at the Stormwater Pond and the HLP extension. All sludge from the current HDS WTP sludge has been placed within a lined area on the northeast corner of the HLP extension since water treatment at the plant commenced in 2003.

Additional sludge is present as a result of mineral processing activities. This includes cyanide neutralization sludge (from the former Neutralization Pond) and sludge that formed in the Surge Pond as a result of sedimentation along with other unknown precipitation processes. The cyanide neutralization sludge was placed into the Ruby Repository. Sludge that was originally present in the Surge Pond was removed and placed into the Sunday Pit Lake in spring 2005, effectively commingling this sludge with sludge produced by WTP activities. The Process Plant Pond sludge was sampled prior to relocation to Sunday Pit; however, currently this sludge can not be differentiated from WTP sludge in Sunday Pit because they are submerged and commingled.

CDM investigated the characteristics of sludge produced by past WTP activities and by gold processing activities over the past 6 years. Details of the CDM sludge investigation through 2006 are available in CDM (2006f). Additional sludge investigation was conducted from February through April 2007. The following sections summarize all of the results from the CDM sludge investigation, with a focus on the potential for the sludge to be a source of contaminants. However, these discussions do not include information regarding sludge previously remediated by placement in the Ruby Repository (i.e. cyanide neutralization sludge). Surge Pond

sludge data gathered as it was sampled prior to movement to Sunday Pit is included. This is the only sludge described in this section that is not ARD neutralization sludge.

The locations and estimated volumes of sludge present in the various areas of the site (as described in Section 3.1) are shown on Figure 4.2-28. Figure 4.2-29 illustrates the sampling locations of the various sludge investigations. Sludge thickness data for sludge located in the Anchor Hill, Dakota Maid, and Sunday pit lakes are shown in Figure 4.2-30. Stormwater Pond sludge thickness is a maximum of 21 ft in the deepest part of the pond. Figures 4.2-29 and 4.2-30 graphically display the pit/pond water elevations that were present at the time of sampling for submerged sludge (with the exception of the Stormwater Pond).

The discussion of nature and extent of contamination for sludge has three key components:

- Total metals with the potential to impact human health
- Load of water-soluble contaminants
- Sludge stability

4.2.7.1 Total Metals with Potential to Impact Human Health

As described above, ARD neutralization sludge contains elevated levels of total metals, including aluminum, arsenic, cadmium, copper, iron, lead, manganese, and zinc, among others. The relative amount of metals present in sludge is dependent on the metal concentrations present in the ARD treated, as well as the neutralization efficiency of the reagent ($Ca(OH)_2$ or NaOH). Neutralization efficiency is defined by the quantity of reagent utilized to neutralize ARD versus the quantity of leftover or waste reagent. Passive treatment processes, such as the hard bucket systems or in-situ pit neutralization, likely have a lower neutralization efficiency because of poor mixing. As a result, the sludge is likely to contain higher volumes of leftover reagent base, which may be reflected by higher calcium, magnesium, or sodium concentrations.

Total metals results for all of site sludge are shown in Table 4.2-28. These concentrations are compared to the comparison criteria for site soils because there are no comparison criteria for sludge as a specific medium:

- **Arsenic.** Concentrations range from 2.1 mg/kg to 2,140 mg/kg. Submerged sludge in Sunday and Dakota Maid pits have much higher arsenic concentrations than all of the other sludge sampling locations. The lowest arsenic concentrations are observed in the Anchor Hill Pit 2007 sludge samples. Locations with arsenic concentrations below the comparison criteria (85 mg/kg) include all of the Stormwater Pond sludge samples, all of the Anchor Hill Pit sludge samples (both 2001 and 2007 samples), and the sludge sample collected from the former Hoodoo Gulch Pond 1. All other site sludge arsenic concentrations are greater than the comparison criteria, as shown in Table 4.2-28.

- **Lead**. Concentrations range from 0.26 mg/kg to 338 mg/kg. The highest are observed in Sunday Pit while the lowest (e.g. less than 50 mg/kg) are in SL07 (Dakota Maid Pit), the Stormwater Pond, 2007 Anchor Hill Pit samples, and the former Hoodoo Gulch Pond 1 and Ruby Pond samples. No concentrations exceed the comparison criteria (652 mg/kg).

- **Manganese**. Concentrations range from 23 mg/kg to 16,100 mg/kg. The highest concentrations (e.g. greater than 1,000 mg/kg) are observed for Pond C, Anchor Hill Pit (2001), and Hoodoo Gulch Pond 1. The highest concentration was measured in Pond C (16,100 mg/kg) and is 32 times the comparison criteria (514 mg/kg). Locations with concentrations below the criteria include all of the Stormwater Pond and Dakota Maid Pit samples, four Sunday Pit samples, two Anchor Hill Pit samples (2007), the former Hoodoo Gulch Pond 2, and the former Ruby Pond.

- **Thallium**. Thallium was only detected for the Dakota Maid Pit sample (SL09) and the Hoodoo Gulch Pond 2 duplicate (SL12). All other samples were non-detect although a wide range of non-detect practical quantitation limits were reported (Table 4.2-28). Neither of the two detected concentrations exceeded the comparison criteria (19 mg/kg).

4.2.7.2 Load of Water Soluble Contaminants

Evaluation of water soluble contaminants includes paste pH, SPLP extraction tests, and TCLP tests. A limited amount of paste pH data are available for ARD neutralization sludge. Because of the high water content of ARD neutralization sludge (ranges from 70 percent to 95 percent water), the paste pH will be reflective of the pore water present in the sludge. Sludge present in acidic pit lakes or ponds will likely have an acidic paste pH while sludges exposed to air and no ARD (current WTP sludge) will have more basic paste pH. Paste pH for Ruby Pond sludge as it was placed in the drying impoundment near Sunday Pit was recorded at 3.2 su. The Anchor Hill Pit sludge formed after the first neutralization phase (in-situ slaked lime neutralization) of the pit treatability study was measured to have a paste pH of 3.8 su. Current WTP sludge located on the HLP extension was measured in April 2007 at a pH of 9.7 su. No other sludge paste pH data are available.

All SPLP and TCLP results are shown in Table 4.2-29. A number of soluble metals and metalloids were detected in both SPLP and TCLP leachate although generally TCLP leachate concentrations were higher. This trend is expected since TCLP is a more aggressive (i.e. lower pH) leaching procedure. Based on SPLP and TCLP data, significant concentrations of leached metals were observed for ARD neutralization sludge.

The following ranges of SPLP concentrations were observed for ARD neutralization sludge:

- **Aluminum**. Less than 0.05 mg/L to 55 mg/L

- **Arsenic**. Less than 0.005 mg/L to 0.02 mg/L
- **Cadmium**. Less than 0.005 mg/L to 0.11 mg/L
- **Copper**. Less than 0.01 mg/L to 19 mg/L
- **Iron**. Less than 0.03 mg/L to 14.3 mg/L
- **Lead**. Less than 0.002 mg/L to 0.01 mg/L
- **Manganese**. Less than 0.01 mg/L to 42 mg/L
- **Zinc**. Less than 0.01 mg/L to 5.4 mg/L

The majority of other analytes measured are non-detect or detected at low levels (Table 4.2-29). As compared to the submerged acidic pit lake sludges, lower SPLP aluminum, cadmium, copper, and zinc concentrations were observed for the samples collected from Pond C, Hoodoo Gulch ponds, Anchor Hill Pit, and the Stormwater Pond. Moreover, samples collected from Pond C and Hoodoo Gulch ponds were non-detect for a majority of the analytes measured.

The following ranges of TCLP concentrations were observed for ARD neutralization sludge:

- **Aluminum**. 0.343 mg/L to 151.5 mg/L
- **Arsenic**. Less than 0.03 mg/L to 0.31 mg/L
- **Cadmium**. Less 0.01 mg/L to 0.95 mg/L
- **Copper**. Less than 0.05 mg/L to 84 mg/L
- **Iron**. Less than 0.05 mg/L to 54 mg/L
- **Lead**. Less than 0.01 mg/L to 0.188 mg/L
- **Manganese**. 0.31 mg/L to 42.2 mg/L
- **Zinc**. Less than 0.5 mg/L to 190 mg/L

Elevated TCLP concentrations for some of the site sludge and constituents correspond with elevated total metals concentrations, including aluminum, cadmium, manganese, and zinc. These correlations were observed mostly for the former Pond C sludge and the sludge samples collected from Anchor Hill Pit in 2001. The TCLP method was developed specifically for determining if a material is a characteristic hazardous waste under Subtitle C of RCRA [40 CFR §261.24). None of the TCLP results are greater than these criteria.

4.2.7.3 Stability of ARD Neutralization Sludge

The stability of ARD neutralization sludge at the site can be determined partially from the SPLP and TCLP results presented above. Additionally, both ABA analyses and SALTs were conducted on site sludge, which provide a greater understanding of sludge stability.

The stability of ARD neutralization sludge under acidic pH environments is a concern at the Gilt Edge Mine because of the possibility of increased leaching of metals and metalloids from the sludge when in contact with acidic water. Currently sludge located in the Sunday Pit and Dakota Maid Pit have been submerged in highly acidic environments (pH 3.0 su or less) for 7 to 8years while sludge submerged in the Stormwater Pond has been located in a moderately acidic environment (pH greater than 3.0 su) for only 2 to 3 years. Sludge previously located in Ruby Pond was submerged in runoff ARD with low pH from the Ruby Repository for a period of about 4 years until it was relocated in 2005. All of the other sludges described in this section are either located in drying impoundments or in a near-neutral pH environment (Anchor Hill Pit). Sludge previously located in the Hoodoo Gulch ponds and Pond C was located in near-neutral environments as a result of the former hard bucket treatment systems.

Acid Base Accounting Results

All ABA analyses were conducted using the modified Sobek method (RGC method). ABA results for site sludge are shown in Table 4.2-30. The neutralization potential of site sludges depends on the ARD neutralization process and efficiency, and the current (or past) storage location of the sludge. Any type of ARD neutralization sludge should contain an excess amount of neutralizing base, which likely comprises most if not all of the measured NP. All sludges located in near-neutral environments at the time of sampling have a measurable amount of NP, ranging from 28 t/kt $CaCO_3$ eq. to 480 t/kt $CaCO_3$ eq. These include sludges formerly located in Pond C, Hoodoo Gulch ponds, the Surge pond, Anchor Hill Pit sludge (both the 2001 and 2007 samples), the Stormwater Pond sludge, and the current WTP sludge. Again, note that the process plant sludge is not ARD neutralization sludge; thus, high NP detected (455 t/kt $CaCO_3$ eq.) likely represents excess (unreacted) lime present in the HLP process solution. Lime was added to all ore prior to placement on the leach pad in order to maintain the pH of the mineral processing solutions above approximately 11. The highest NP values were observed for sludges produced from the hard bucket treatment system (Pond C and Hoodoo Gulch Pond 1), likely representing large amounts of excess NaOH. Hoodoo Gulch Pond 1 had a much greater NP than pond 2, which is a result of hard bucket treatment sludge depositing directly into Pond 1. Pond 2 consisted of mostly sediments and some sludge.

Conversely, sludge located in acidic low pH environments at the time of sampling have non-detect NP values (less than 1.0 t/kt $CaCO_3$ eq.). This sludge includes Sunday Pit, Dakota Maid Pit, and the former Ruby Pond. This sludge is sodium hydroxide neutralization sludge from the former WTP. Over time, the low pH ARD has consumed available NP in this sludge. The Stormwater Pond sludge is also former

WTP sludge; however, that this sludge is currently located in only moderately acidic ARD. NP values for Stormwater Pond sludge measured in 2007 range from 32.5 t/kt $CaCO_3$ eq. to 66.5 t/kt $CaCO_3$ eq., which shows that some NP would have been present in the Sunday Pit, Dakota Maid Pit, and Ruby Pond sludge prior to placement in the ARD. Based on these observations, the high NP present in the Process Plant Pond sludge was likely consumed after placement in Sunday Pit.

Total sulfur in site sludge ranges from 0.34 percent to as high as 13 percent, with an average of 3.7 percent. The highest total sulfur was observed in Dakota Maid Pit. Sulfide sulfur within sludge ranges from 0.12 percent to 7.19 percent, with an average of 1.5 percent. Note that for samples collected during the 2007 sampling event, nitric acid, hot water, and residual sulfur were not analyzed; therefore, the sulfide sulfur was computed by subtracting the hydrochloric acid soluble sulfur from the total sulfur.

Because ARD neutralization sludge is known to consist of mostly aluminum and iron hydroxides and hydroxysulfates (sulfate sulfur), the interpretation of ABA data for sludge is different than for soils or waste rock. For all other site waste rock, fills, or soils, the sulfide sulfur is interpreted as the total of nitric acid soluble sulfur and residual sulfur. Because of the known presence of pyrite in these materials, this amount of sulfur is assumed to be potentially acid generating. However, for ARD neutralization sludge, pyritic sulfur is less likely to be present. Thus, nitric acid or residual sulfur may not represent potentially acid generating materials but rather non-acid generating iron and aluminum hydroxysulfate precipitates, which did not completely dissolve in the hot water or hydrochloric acid digestions of the ABA analysis. Extremely high total sulfur concentrations present in sludge support this interpretation.

The exception to this alternate ABA interpretation is for sludge located on the bottom of pit lakes and ponds. As previously described, acid generating material from highwalls in Sunday, Dakota Maid, and Anchor Hill pits is known to spall over time, which results in deposition of rock and fines on the bottom of the pit lakes that contains pyritic sulfur. For sludges located in these pits, it is possible that some of the sulfide sulfur as described above may represent potentially acid generating pyrite. Additionally, pyrite-containing sediments may have been transported as suspended solids in effluent from the HLP or Ruby Repository over time, commingling with the sludge in the Stormwater Pond and Ruby Pond, respectively. The third source of potential sulfide sulfur is iron sulfide produced by biological reduction of iron and sulfate, which is reported to have formed during the Anchor Hill Pit Lake Treatability Study (MSE 2007). This may represent a portion of the sulfide sulfur measured in the 2007 Anchor Hill Pit sludge samples.

Figures 4.2-31 and 4.2-32 represent evaluations of AP versus NP and NP:AP ratio versus percent sulfide sulfur in sludge. Using the evaluation criteria for ABA data described in Section 4.1.1, Sunday Pit, Dakota Maid Pit, Anchor Hill Pit east, and former Ruby Pond sludge are classified with a moderate to high potential to generate acid in the future. As described above, these classifications may not be accurate for

ARD neutralization sludge alone; however, the addition of pyrite-containing sediments to sludge may contribute to potential acid generation. Visual observations noted during the 2007 sludge sampling event described the Anchor Hill Pit east sample containing mostly black sludge precipitates, as compared to the other two Anchor Hill Pit samples (a mix of black, white, and brown precipitates). White and brown precipitates may represent excess lime/calcium carbonate and hydroxysulfate compounds while the black precipitate may represent metal sulfides formed during the Anchor Hill pit bioremediation process that are potentially acid generating.

Strong Acid Leach Test Results

SALTs were conducted on ARD neutralization sludges located in Sunday, Dakota Maid, and Anchor Hill pits, and in the Stormwater Pond. SALTs were performed by the CDM subcontracted laboratory. For each sludge sample (three samples from each pit/pond), a specific mass of sludge was placed in a 1 liter plastic bottle containing ARD from the surface of Sunday Pit. Two tests were conducted for each sample, using both 5:1 and 10:1 ARD to sludge ratios by weight. Each bottle was placed on a shaker table for a period of 24 hours. After a 2-hour settling time, liquid supernatant samples were extracted from each bottle and analyzed for a number of constituents, including pH, conductivity, temperature, acidity, alkalinity, chloride, nitrate, sulfate, and dissolved metal/metalloids (aluminum, beryllium, cadmium, calcium, chromium, copper, iron, lead, magnesium, manganese, nickel, potassium, selenium, silver, sodium, and zinc). The Sunday Pit ARD sample used for the SALTs was also analyzed for these same constituents.

Analyte concentrations for the extract samples were compared to the ARD sample concentrations. The difference between the extract concentration and original ARD concentration determines the degree of leachability for each analyte. Any non-detect values were converted to one-half their detection limit in order to perform the difference calculation. A positive difference indicates that an increase in the analyte was observed during the SALT, which is interpreted to represent leaching of the analyte through desorption or dissolution reactions. A negative difference indicates that a decrease in the analyte was observed, which is interpreted to represent either adsorption or precipitation of the analyte. Using the 5:1 or 10:1 liquid to solid ratios, the positive or negative values were converted to the mass of each analyte reacted per mass of sludge (mg/kg).

SALT results for site sludge are shown in Table 4.2-31. Figures 4.2-33 through 4.2-37 illustrate the results for aluminum, cadmium, copper, iron, and zinc, shown as figures of the analyte mass reacted versus the extract pH. These results show that Sunday and Dakota Maid Pit sludges are not stable in an ARD environment. Although a slight increase in solution pH was observed after contact with sludge, significant leachate concentrations were detected in the extract samples for these sludges, including constituents such as aluminum, cadmium, copper, manganese, nickel, and zinc. Large increases in aluminum concentrations in the extract may be a result of the high aluminum concentrations in pore water (high mineral acidity has been measured on the bottom of Sunday Pit) or from aluminum hydroxysulfate compounds actually dissolving into solution. Nevertheless, large increases in cadmium, copper, nickel,

and zinc indicate that desorption processes are occurring for these metals. As shown in the figures and Table 4.2-31, the lower the pH, the greater amount of metal desorbed. Additionally, note that extract pH between the 5:1 and 10:1 tests for Sunday and Dakota Maid pits were nearly the same, which agrees with the ABA data that show these sludges have essentially zero NP to buffer the acid.

Conversely, Stormwater Pond and Anchor Hill Pit sludges are relatively more stable in an ARD environment; however, leaching of cadmium, manganese, nickel, and zinc still occurred. Aluminum, iron, and copper actually adsorbed or precipitated during all tests for these sludges (except Anchor Hill Pit east sample). Extract pH values were higher for the 5:1 tests than for the 10:1 tests. The greater amount of sludge present per ARD volume in the 5:1 test produced a higher pH extract because of more available NP. The highest extract pH (8.2 su) was observed for the Anchor Hill Pit middle sludge sample, which also has the highest NP of any sludge tested (with respect to those sludges analyzed using the SALT procedure).

Similarly, the lower pH of the 10:1 tests resulted in greater amounts of cadmium, manganese, nickel, and zinc leaching or desorbing. Nickel and zinc reactivity varied from adsorption (5:1 test) to desorption (10:1 test) for all of the Stormwater Pond samples. For the Anchor Hill Pit west sample, cadmium, manganese, nickel, and zinc had leached from the sample, whereas, the middle sample reversed to adsorption as a result of the higher NP present.

The SALT test data indicate that WTP sludge is not stable when stored in strongly acidic environments. Long-term storage of WTP sludge in submerged acidic conditions within acidic pit lakes or underground mine workings will lead to desorption and/or dissolution of COPCs sequestered in the sludge during water treatment and subsequent remobilization of these COPCs into the environment.

4.3 Nature and Extent of Contamination in Groundwater

The nature and extent of contamination in groundwater is evaluated using three methods. The first method focuses on the areal extent of individual COPC concentrations that exceed GWQS based on the site-wide groundwater sampling program conducted in April and May 2007. The second method utilizes trend analysis of individual COPC concentrations in selected wells. The third method uses Piper diagrams to evaluate major ion ratios in order to discern impacts of ARD related contamination on groundwater quality. Each of the methods has advantages and disadvantages. Application of the three methods provides a weight of evidence approach to facilitate an adequate understanding of nature and extent of contamination in groundwater.

Evaluation of Nature and Extent of Contamination in groundwater uses data collected from numerous groundwater investigations as described previously in Section 2. Table 4.3-1 summarizes the groundwater sampling events for site wells that have been considered in this analysis. All analyses discussed in this Section 4.3 are based on the dissolved concentrations of the analytes of interest.

4.3.1 Background Groundwater Quality

Estimation of background groundwater quality at the site is based on analyses of water samples from wells that are upgradient of the impacted areas of the site. Most contaminants of potential concern (COPCs) at the site occur at some background level in groundwater that has not been impacted by ARD or other mine related sources. Water quality from upgradient wells may underestimate pre-mining COPC concentrations in the pit areas. This is a result of the presence of strongly mineralized rocks in the pit areas and natural geochemical interactions between the in-situ mineralized rock and groundwater. It is possible that COPC concentrations in pre-mining groundwater within the pit areas may have been somewhat higher than estimated background water quality based on upgradient wells.

4.3.1.1 Background Water Quality in Bedrock Wells

Background groundwater quality in bedrock groundwater is estimated based on groundwater samples collected at well GWCDM28, which is located near the mine access road west of the mine disturbance area. This well was installed in April 2007 and was sampled in April 2007 and May 2007. Groundwater at this location is calcium-bicarbonate type water with circumneutral pH and low concentrations of TDS. TDS concentrations at this location were 172 and 165 mg/L for the April 2007 and May 2007 sampling events, respectively. Sulfate concentrations for these two sampling events ranged from 19.2 mg/L to 17.3 mg/L. The concentrations of COPCs in these samples were very low, with many analyses indicating COPC concentrations below the detection level. Water quality data for these samples are shown in Table 4.3-2.

4.3.1.2 Background Water Quality in Alluvial Wells

Background water quality in alluvial groundwater is estimated based on groundwater samples collected from monitor well BES-8, which is located in a small ephemeral drainage west of Anchor Hill Pit. Monitor well BES-8 has been in place for many years, and an extensive data set of water quality samples exists. This water is also calcium-bicarbonate type water with low concentrations of TDS. In April 2007, the TDS concentration of this water was 83 mg/L, and the sulfate concentration was 36.6 mg/L. Concentrations of most COPCs were below the level of detection. Data from monitor well BES-8 are also included in Table 4.3-2.

4.3.2 Ambient Groundwater Quality

DENR has evaluated ambient groundwater quality at the site based on historical groundwater quality data. Ambient groundwater quality as used in this document is defined in ARSD §74:54:02:01 as "the constituents or parameters and the concentration or measurements which describe water quality prior to a subsurface discharge." DENR utilized an analysis of ambient groundwater quality in development of GWQS based on rules set forth at ARSD §74:54:02:18. This rule establishes that ambient groundwater concentrations shall be based on a minimum of four groundwater samples collected from each applicable well within site boundaries over a 6-month period. The rule defines the ambient concentration as the arithmetic mean of these samples plus one standard deviation.

DENR estimated ambient groundwater quality at the site for the period prior to modern mining operations. Groundwater quality data collected from 1985 to 1989 were used to determine GWQS. Groundwater quality data for the Ruby Gulch alluvial aquifer were not available for the 1985 to 1989 period. GWQS for Ruby Gulch were calculated based on data collected at Ruby Gulch prior to impacts from ARD, which occurred in the early 1990s. The groundwater quality data were divided into three groups, the bedrock aquifer, Strawberry Creek alluvial aquifer, and Ruby Gulch alluvial aquifer. The data from eleven bedrock monitoring wells were combined and used to calculate ambient water quality in the bedrock aquifers. Data from six alluvial monitoring wells were combined to calculate ambient water quality standards in the Strawberry Creek alluvial aquifer, and data from one alluvial monitoring well was used to calculate ambient water quality in the Ruby Gulch alluvial aquifer.

DENR established GWQS based on ambient concentrations, state groundwater quality standards set forth in ARSD §74:54:01:04, ARSD §74:54:01:05, and EPA maximum contaminant levels and health advisories. If the ambient groundwater quality exceeded the standards, the ambient concentration was retained as the site-specific standard. The GWQS established for the site by DENR are utilized in the following sections to define nature and extent of contamination in groundwater. The GWQS set forth by DENR apply to the dissolved constituents in a sample, and were shown previously as Table 4.1-1.

4.3.3 Nature and Extent of Contamination within Bedrock Aquifers

4.3.3.1 Areal Extent of Individual Constituent Concentrations Exceeding Site-Specific Groundwater Quality Standards

Parameters that exceed GWQS at a minimum of one monitor well include pH, sulfate, total dissolved solids, aluminum, arsenic, cadmium, chromium, copper, lead, manganese, nickel, and zinc. Figure 4.3-1 presents the interpreted potentiometric surface and the extent of contamination exceeding GWQS during the April and May 2007 investigation.

Concentrations of several indicator COPCs and the interpreted areal extent of groundwater contamination exceeding GWQS for the referenced COPC are shown in Figures 4.3-2 through 4.3-5. These figures are based on monitor well samples collected during April 2007. The indicator COPCs consist of aluminum, pH, sulfate, and manganese. These COPCs were chosen because exceedances of GWQS for other COPCs are strongly correlated with exceedances of GWQS for indicator COPCs.

4.3.3.2 Evaluation of Temporal Trends in Groundwater Quality of Bedrock Wells

Evaluation of temporal trends in groundwater quality is presented for a selection of bedrock wells at the site. The temporal trends are useful to understand if changes are occurring in these wells and to evaluate the rate of change. This section is organized into subsections based on the major contributors to groundwater contamination. These subsections consist of the following.

- Groundwater quality in areas in close proximity to ARD generating fill materials and other ARD sources
- Groundwater quality in areas in close proximity to pit lakes and highwalls
- Groundwater quality in areas impacted primarily by migration of contaminated groundwater

Two figures are presented for each well evaluated in this section. The analytes included in these figures were chosen based on both the utility of the analyte as an indicator of ARD-related contamination, and the availability of data. The first figure shows pH and total dissolved solids data. These parameters are good indicators of ARD-related contamination at the site. Commonly, a concomitant increase in total dissolved solids concentrations is associated with a reduction in pH in wells impacted by ARD. This relationship is site-specific and is a result of the interactions of primary and secondary minerals within the source materials with infiltrating water. The second figure shows dissolved concentrations of arsenic, cadmium, copper and zinc. Cadmium, copper and zinc are metals that occur at high concentrations in site ARD. Arsenic is a metalloid that is observed in relatively low concentrations in site ARD but that often exceeds the GWQS.

Wells in Close Proximity to ARD Generating Fill Materials
The site is located in a groundwater recharge area near the top of the Strawberry and Ruby Gulch watersheds. Impacts to groundwater resulting from infiltration of water through ARD generating fill materials and subsequent recharge of underlying bedrock aquifers is an important mode of groundwater contamination. These types of impacts occur in areas that contain ARD generating fill rock, such as Strawberry Gulch, Ruby Gulch and Hoodoo Gulch. Bedrock groundwater quality within upper Ruby Gulch is not monitored, and this area was mitigated through construction of the Ruby Repository. Therefore, the following paragraphs present data from bedrock wells located in close proximity to ARD generating fill materials in Strawberry Gulch and Hoodoo Gulch.

<u>Strawberry Gulch</u>
Monitor well GW-4 is located in an area of acid generating fills approximately 200 feet southeast of the Surge Pond. Groundwater quality data collected in April 2007 indicates that this well exceeds GWQS for manganese and lead. Temporal trends in groundwater quality data for the period of 1990 to the present are shown on Figures 4.3-6 and 4.3-7. ARD impacts to this well have not been major for most of the period of record. Temporal data exhibit circumneutral pH, moderate concentrations of TDS, and relatively low metals concentrations. Recent data indicates an increase in TDS concentrations from about 200 mg/L to 850 mg/L. These data suggest that relative ARD impacts to this well are increasing.

Monitor well GW-5 is located within Strawberry Gulch very close to Pond C. Based on April 2007 sampling data and Piper diagram analysis, this well is impacted by ARD related contamination. This well exceeds GWQS for aluminum and manganese.

Temporal data for GW-5 are presented in Figures 4.3-8 and 4.3-9 for the period extending from 1990 to the present. A very notable increase in TDS concentration occurred at this well during the time period of 1997 to 1999. It is possible that this increase is related to construction of Pond C and initiation of solid sodium hydroxide water treatment within Pond C. This process included detention of treated water within Pond C to allow settling of solids precipitated in the treatment process. The pond of treated water in Pond C would have increased the downward hydraulic gradient between the near surface alluvial system and the bedrock system sampled at GW-5. Arsenic, cadmium, copper, and zinc concentrations are relatively low in this well and generally do not exceed the GWQS.

Monitor well GW-6 is located on the lower end of Strawberry Gulch approximately 200 feet downstream from Pond E/Strawberry Pond. Based on the April 2007 sampling data, this well exceeds GWQS for manganese and pH. The Piper diagram analysis also indicates that this well is impacted by ARD-related contamination. Temporal data for the period of 1990 to the present are presented in Figures 4.3-10 and 4.3-11. pH at this well was in the range of approximately 6 to 7 su for the period of record. TDS concentrations increased from a range of approximately 200 mg/L to 300 mg/L to a range of approximately 600 mg/L to 700 mg/L in the mid 1990s. TDS concentrations have been variable over the last 7 years, with concentrations ranging from approximately 300 mg/L to 1600 mg/L. Concentrations of arsenic, cadmium, copper, and zinc are relatively low as compared to other ARD affected wells. Cadmium and arsenic concentrations in this well exceed the GWQS on an intermittent basis, with the highest values occurring during 2001 to 2004. Current cadmium and arsenic concentrations in this well are lower than values observed during 2001 to 2004. The cause of this variation is unknown.

Hoodoo Gulch

Bedrock well GWCDM10 is located in Hoodoo Gulch several hundred feet downslope from the ARD generating fill rock in the Hoodoo Fill and about 200 feet upslope from the alluvial groundwater collection facility in Hoodoo Gulch. Based on April 2007 groundwater quality data, this well exceeds GWQS for pH, TDS, sulfate, aluminum, cadmium, manganese, nickel, and zinc. Temporal data for the period of 2002 to the present are shown in Figures 4.3-12 and 4.3-13. The data indicate that groundwater at this location was impacted by ARD-related contamination at the time the well was installed. pH values range from approximately 3 su to 5 su, with no apparent trends. TDS concentrations have also remained approximately constant at a concentration of about 1,300 mg/L . Concentrations of cadmium and zinc have also remained at similar levels over the period of record. Cadmium and zinc concentrations have exceeded the GWQS for the period of record. Arsenic and copper concentrations do not exceed GWQS based on recent data.

Wells in Close Proximity to Pit Lakes and Highwalls

Groundwater quality in close proximity of pit lakes contains high concentrations of COPCs. It is likely that this is a result of several factors, including communication of ARD stored within the pit lakes with groundwater and infiltration of ARD-impacted water through highwalls to groundwater.

Anchor Hill Pit

Monitor well GE-MW-08 is located approximately 100 feet east of Anchor Hill Pit. Monitor well GE-MW-08 is located in an area that formerly contained strongly acid generating shot muck, which was removed and placed into the Ruby Repository. Impacts to this well are likely related to a number of factors, including the pit lake, the shot muck, and water infiltrating through pit highwalls. The well is strongly impacted by ARD as demonstrated by the April 2007 data and the piper analysis. The well exceeds GWQS for pH, TDS, sulfate, aluminum, cadmium, lead, manganese, and zinc. Some of these COPCs are orders of magnitude above GWQS. Temporal data for GE-MW-08 are shown in Figures 4.3-14 and 4.3-15. pH values in the well are on a declining trend, with current values in the approximate range of 3.0 su to 4.5 su. TDS concentrations range from approximately 2,800 mg/L to 5,000 mg/L over the period of record. Cadmium and zinc concentrations in the well have remained relatively constant during the period of record and have consistently exceeded the GWQS. Cadmium concentrations are about two orders of magnitude above the GWQS and zinc concentrations are about one order of magnitude above the GWQS.

Sunday Pit Lake

The Sunday Pit Lake currently contains very concentrated ARD solutions, and the Sunday Pit highwalls expose rock that is strongly acid generating. Sunday Pit has stored ARD since the mid 1990s. The Sunday Pit area was also used for ARD evaporation and sludge disposal. Each of these factors likely contributes to ARD-related contamination in groundwater. Monitor well GWCDM03 is located southwest of Sunday Pit. Groundwater in this area is strongly impacted by ARD and exceeds GWQS for pH, TDS, sulfate, aluminum, arsenic, cadmium, chromium, copper, lead, manganese, nickel, and zinc. Concentrations of several of these analytes are orders of magnitude above the GWQS . Temporal data for the period of 2000 to the present for this well are shown in Figures 4.3-16 and 4.3-17. TDS concentrations increased markedly during 2001 to 2003 from approximately 4,000 mg/L to approximately 18,000 mg/L. TDS was not measured in this well during the period of late 2003 to 2007. The TDS concentration measured in April 2007 was significantly lower at approximately 5,400 mg/L. pH values have been consistently acidic, ranging from approximately 2.5 su to 3.5 su over the period of record. Groundwater quality at GWCDM03 is the most strongly impacted groundwater on the Gilt Edge site.

Dakota Maid Pit Lake

Monitor well GWCDM02 is located approximately 100 feet southwest of Dakota Maid Pit. Dakota Maid Pit contains a small pit lake as well as large expanses of strongly acid generating highwalls. Dakota Maid Pit also contains stored WTP sludge. GWCDM02 is strongly impacted by ARD-related contamination . Based on April 2007 data, the well exceeds GWQS for pH, TDS, sulfate, arsenic, aluminum, cadmium, manganese, nickel, and zinc. Temporal trends in groundwater quality data are shown on Figures 4.3-18 and 4.3-19 for the period of late 2002 to April 2007. pH values have remained relatively stable in the range of 3.5 su to 5 su for this period. An apparent increasing trend is present for TDS, with concentrations increasing from about 2,600 mg/L to 4,800 mg/L over the period of record. This increase may be related to maturation of acid generating rock exposed on highwalls, maturation of acid

generating fill materials, or dissolution of sludge stored within the strongly acid environment of the pit lake. Concentrations of arsenic, cadmium, copper, and zinc are variable over the period of record, but significant trends are not apparent.

Wells in Areas Impacted Primarily by Migration of Contaminants in Groundwater
Major fracture zones are potential conduits for groundwater flow. Monitor wells were developed on the site to evaluate groundwater characteristics in the vicinity of the major fracture zones. Five monitor wells were drilled at an angle across major fracture zones in order to provide the best chance of intersecting the zones. One pre-existing well, GWCDM14, is located very close to the trend of one of the fracture zones. These wells provide valuable information regarding potential contaminant migration in fracture zones. Water quality data from these wells indicates that ARD is migrating in the general trend of these fracture zones.

The first angle well drilled was GE-MW-15, which was designed to intersect the Selway Northeast fracture zone in an area northeast of Sunday Pit between Sunday Pit and Ruby Gulch. Groundwater at this location is moderately acidic, with pH of approximately 5 su, elevated concentrations of ARD-related metals, and TDS concentration of 2,100 mg/L. Based on April 2007 data, the well exceeds GWQS for pH, TDS, sulfate, aluminum, cadmium, manganese, nickel, and zinc.

Monitor well GE-MW-16 is was drilled from upper Hoodoo Gulch in a northwest direction toward the Selway Northeast fracture zone. Water quality at this well is also impacted by ARD-related contamination, including strongly acidic pH of 2.8 su to 3.0 su, high concentrations of ARD-related metals, and TDS concentrations of 4,600 to 5,600 mg/L. Based on the April 2007 data, groundwater at this well exceeds GWQS for pH, TDS, sulfate, aluminum, arsenic, cadmium, chromium, copper, lead, manganese, nickel, and zinc. Temporal data for the period extending from 2004 through 2007 are shown in Figures 4.3-20 and 4.3-21. Based on available data, it appears that ARD impacts to groundwater at GE-MW-16 are on an increasing trend.

Data collected from GE-MW-16 during April and May 2007 indicate that groundwater at this location contains elevated nitrate concentrations. These data were shown previously in Table 4.3-2. Elevated nitrate concentrations are also present in monitor well GWCDM03, which is impacted by communication with ARD stored in Sunday Pit. The primary source of nitrate at the site is degradation of cyanide in HLP spent ore. Effluent from the HLP is periodically pumped to Sunday Pit as part of routine site management activities. The presence of elevated nitrate concentrations in GE-MW-16 suggests that Sunday Pit Lake may be a source of contaminants present at GE-MW-16 and that contaminant migration in groundwater is occurring along the trend of the Selway Northeast fracture zone toward Strawberry Creek.

Monitor well GE-MW-17 was drilled on the south side of Sunday Pit and was designed to intersect the Rattlesnake fracture zone. Groundwater quality at this well is strongly impacted by ARD-related contaminants, including strongly acidic pH, high concentrations of toxic metals, and TDS concentrations of approximately 3,600 mg/L. This suggests that ARD-related contamination is migrating along the trend of

the Rattlesnake fracture zone southwest of Sunday Pit. Based on the April 2007 data, groundwater at GE-MW-17 exceeds GWQS for pH, TDS, sulfate, aluminum, cadmium, copper, lead, manganese, nickel, and zinc. Significant temporal trends in groundwater quality at this location are not apparent based on available data.

Monitor well GE-MW-18 is located on the west side of Strawberry Creek near the confluence of Cabin Creek and Strawberry Creek. This well was targeting the western-most extent of the Rattlesnake fracture zone. Water quality at GE-MW-18 meets site-specific standards, with circumneutral pH, only trace concentrations of toxic metals, and moderate sulfate concentrations. This well was drilled from the west side of Strawberry Creek and it may be upgradient of effects from the Rattlesnake fracture zone based on potentiometric surface shown previously in Figure 4.3-1.

Monitor well GE-MW-19 is located very close to the Oro Fino Shaft on the southernmost extent of the projected Selway northeast fracture zone. Groundwater at this location is circumneutral pH and contains low concentrations of toxic metals. However, the sulfate concentration of the water ranges from approximately 600 to 1,300 mg/L. This well is located very close to the Oro Fino Shaft, which is the site water supply for WTP make-up water, sewer water, and other purposes. A cone of depression is present in this area surrounding the Oro Fino Shaft during times when groundwater is being extracted from the Oro Fino Shaft. It is possible that the cone of depression around the Oro Fino Shaft is causing treated water flowing down Strawberry Creek to infiltrate into groundwater at this location. This is discussed further in Section 4.5, which focuses on groundwater-surface water interactions in the Strawberry Creek area.

Monitor well GWCDM14 is located approximately 500 feet downstream of the Oro Fino Shaft on the north side of Strawberry Creek. Although this well was not drilled during the fracture zone investigation, it is located very close to the projected extent of the Selway Northwest fracture zone in an area where groundwater was shown to discharge to Strawberry Creek (Kimball et al. 2005). The Selway Northwest fracture appears to be a conjugate fracture zone, which intersects the Selway Northeast fracture zone in the vicinity of Southeast Langley Pit. Groundwater quality data collected at GWCDM14 indicates a clear trend of increasing ARD-related impacts to groundwater quality in the area.

Figures 4.3-22 and 4.3-23 show trends of selected water quality parameters at well GWCDM14 for the period of 2004 through 2007. The figures show that concentrations of ARD-related contaminants at this location have been increasing significantly over the last several years. Based on April 2007 data, groundwater at this location exceeds GWQS for pH, TDS, sulfate, aluminum, arsenic, cadmium, manganese, nickel, and zinc. Several of these constituents exceed GWQS by several orders of magnitude. The pH of GWCDM14 is ranged from about 5.2 su to 6.0 su during 2004 through 2007. Dissolved iron concentrations are very high at about 500 mg/L, which indicate that groundwater conditions are reducing and that iron is in the ferrous (Fe^{+2}) oxidation state.

Wells Monitoring Downgradient Contaminant Migration
Wells are in place to monitor the leading edge of groundwater contamination in the Strawberry Creek/Hoodoo Gulch area, Ruby Gulch, and Terrible Gulch. The following paragraphs describe groundwater quality conditions at these locations.

Strawberry Creek/Hoodoo Gulch
Two wells in the Strawberry Creek area were installed in April 2007 to monitor the leading edge of groundwater contamination, GWCDM22 and GWCDM23. GWCDM22 is located in lower Hoodoo Gulch just above the confluence of Hoodoo Gulch and Strawberry Creek. GWCDM23 is located approximately 1,500 feet downstream of this location on the north side of Strawberry Creek. Groundwater quality at GWCDM22 in lower Hoodoo Gulch is relatively good quality, with neutral pH and low concentrations of dissolved solids. However, groundwater at this location exceeds GWQS for arsenic and manganese. Groundwater quality at GWCDM23 meets all GWQS. Temporal trends in groundwater quality at these wells will be monitored in the future.

Ruby Gulch
Monitor well GW-9A is located approximately 400 feet downslope from the Ruby Repository. The purpose of this well is to detect migration of contaminants from Ruby Repository. Groundwater quality at GW-9A does not exceed GWQS and impacts of ARD related contamination have not been identified.

Terrible Gulch
Monitor well GWCDM24 was installed in Terrible Gulch in April 2007 to detect potential migration of contaminants in groundwater. Groundwater quality at GWCDM24 is very good and no indications of contaminant migration toward Terrible Gulch have been identified.

4.3.3.3 Evaluation of Major Ion Concentrations

Ratios of major cations and anions in groundwater can be used as a fingerprinting method to evaluate changes in groundwater quality related to migration of COPCs. Figures 4.3-24 through 4.3-31 are Piper diagrams that display the ratios of major cations calcium, magnesium, sodium, and potassium and major anions bicarbonate, carbonate, chloride, and sulfate. Graphical evaluation of groundwater quality in Piper diagrams is a useful method to understand the extent of ARD impacts to groundwater. In application of this method, the major ion ratios of background and ARD-impacted groundwaters are evaluated first. This is followed by evaluation of various areas of the site to identify impacts to groundwater quality attributed to ARD-related contamination. Data from samples collected in the site-wide groundwater quality monitoring program conducted in April and May 2007 are used in this analysis.

Figures 4.3-24a and 4.3-24b show Piper diagrams for the background well, GWCDM28, and several wells that are clearly impacted by ARD-related contamination. A marked difference in the Piper diagrams for the two groups of samples is apparent. ARD impacts result in a change from the background calcium-

bicarbonate type water to calcium-sulfate type water. Impacts of ARD at the site are readily identified based on the location of data points in the lower right portion of the Piper diagram plot. The increase in the relative concentration of sulfate in the water as compared to carbonate plus bicarbonate is a result of acid generation, which releases sulfur from pyrite, decreases pH, and reduces the solubility of carbonate and bicarbonate. As groundwater becomes increasingly impacted by ARD, the data points move from the carbonate-bicarbonate portion of the Piper diagram to the sulfate portion of the diagram as shown in Figure 4.3-24. Evaluation of the ratios of major ions in this manner provides information regarding groundwater contamination that may not be immediately apparent when considering ion concentrations separately.

Wells Located on Northern Margin of Primary Mine Disturbance Area
A Piper diagram showing major ion ratios for wells located on the northern margin of the primary mine disturbance area is shown on Figure 4.3-25. These wells consist of GWCDM26, GWCDM25, and GW-10A. GWCDM26 is located northeast of Anchor Hill Pit, GWCDM25 is located northeast of the HLP, and GW-10A is located near the HLP expansion within the upper portion of Ruby Repository. GW-10A is dry during some portions of the year, but groundwater was present during the April 2007 sampling program. . Groundwater at wells GWCDM25 and GWCDM26 may be slightly impacted by ARD based on evaluation of the Piper diagrams. Groundwater quality at GW-10A appears to be somewhat more impacted, because the water contains higher sulfate concentrations as compared to carbonate-bicarbonate concentrations. Based on the Piper diagram analysis, none of the wells on the northern margin of the Site is impacted to the extent of the ARD-affected wells depicted in Figure 4.3--24b. Wells located on the northern margin of the site do not contain individual constituent concentrations that exceed GWQS.

Wells Located in Vicinity of Anchor Hill Pit
A Piper diagram showing wells near Anchor Hill Pit is shown as Figure 4.3-26. Anchor Hill Pit contains stored ARD pumped into the pit during 2006 and 2007 as well as water remaining in storage from the Anchor Hill Pit Lake Treatability Study. Figure 4.3-26 includes monitor well BED-8, which is located west of Anchor Hill Pit, and monitor well GE-MW-08, which is located east of Anchor Hill Pit. Comparison of the Piper diagram in Figure 4.3-26 with the diagram presented in Figure 4.3-24 suggests that both wells are somewhat impacted by ARD-related contamination. The upgradient well BED-8 shows the relative concentration of sulfate as compared to carbonate+bicarbonate to be slightly higher than background conditions.. Groundwater quality at GE-MW-08 is strongly impacted by ARD-related contamination, which is compatible with the location of the well downgradient from the pit lake. These data indicate that groundwater surrounding the Anchor Hill Pit Lake is hydraulically connected with stored ARD in the pit lake. This conclusion is also supported by the close relationship of water levels in the wells surrounding the pit lake with the pit lake water elevation, which was discussed previously in Section 3.6.

Wells located in Vicinity of Sunday and Dakota Maid Pits

A Piper diagram showing wells located adjacent to Sunday and Dakota Maid pits is shown as Figure 4.3-27. These wells are strongly impacted by ARD-related contamination as demonstrated by the presence of sulfate as the dominant anion. The regional potentiometric surface map shown in Figure 4.3-1 indicates that the Sunday Pit Lake forms a mound in the regional water table. This creates a hydraulic gradient causing ARD to migrate from the pit lake into surrounding groundwater. ARD-related impacts to groundwater in this area may also be a result of infiltration of water through fractures into acid generating bedrock, which results in recharge of groundwater by ARD-impacted water. This process was observed during underground investigations of the upper level King workings where strongly acidic water was observed to be flowing through the vadose zone via fractures and underground mine voids (BOR 2000b). The Piper diagram analysis suggests that the pit lake is in communication with surrounding groundwater at Sunday and Dakota Maid pits. This is compatible with the correlation of monitor well water levels with pit lake elevations, which was discussed previously in Section 3.6.

Wells in Strawberry Gulch Area

Figure 4.3-28 is a Piper diagram showing in the Strawberry Gulch area. In a direction proceeding from the north end of Strawberry Gulch toward the south, these wells consist of GW-4, GW-5, GWCDM01, GWCDM02 and GW-6. The Piper diagram analysis indicates that all of these wells are impacted by ARD-related contamination. Two wells appear to be relatively less impacted, GW-4 and GW-6. GW-4 is a well in the bedrock aquifer located on the north end of Strawberry Gulch. This well is located on the west side of Strawberry Gulch upgradient of the highly acid generating general fills in the Strawberry Gulch area. GW-4 may be impacted by general fills in the Process Plant area or by COPCs migrating from Anchor Hill Pit Lake. Impacts to groundwater at well GW-4 appear to have occurred during the period after approximately January, 2000 based on TDS data shown in Figure 4.3-6. Well GW-6 is a bedrock well located on the southern end of Strawberry Gulch. As discussed in Section 3.6, this well is located in an area that has an upward gradient with groundwater moving from the bedrock aquifer up into the alluvial aquifer. This may tend to limit migration of ARD-related groundwater from the shallow alluvial aquifer into the bedrock aquifer.

Wells in Hoodoo Gulch Area

Major ion concentrations of wells in the Hoodoo Gulch area are displayed on Figure 4.3-29. Wells GE-MW-06, GE-MW-16, GWCDM09, and GWCDM10 are strongly impacted by ARD-related contamination. As discussed in Section 3.6, an upward gradient is present between the deep well in Hoodoo Gulch, GWCDM10 and the shallow well, GWCDM09. Both wells are strongly impacted by ARD-related contamination. This contamination may be related to migration of contamination from the Sunday Pit area or to ARD that is generated upslope in the Hoodoo Gulch fill. Wells GWCDM21 and GWCDM22 are less impacted by ARD although the location of the major anion data points suggests that these wells are slightly impacted by ARD. Wells GWCDM21 and GWCDM22 were drilled in April 2007 and have been

sampled twice as shown in Table 4.3-2. The data indicate that these wells exceed GWQS for arsenic and manganese, which supports the Piper diagram interpretation.

Wells in Strawberry Creek Area

Groundwater quality in wells along Strawberry Creek is evaluated in Figure 4.3-30. This diagram includes wells extending from the Cabin Creek area to just upstream of the confluence of Strawberry Creek with Bear Butte Creek. The Piper diagram analysis indicates that ARD impacts in Strawberry Creek wells vary. Three wells located in the middle and lower portions of Strawberry Creek, GWCDM22, GWCDM23 and BED-14, are less impacted by ARD-related contamination. Based on the Piper diagram, GWCDM23 is not impacted by ARD-related contamination. This well is a bedrock well located on the north side of Strawberry Creek between the Boomer Gulch and Hoodoo Gulch drainages. The Piper diagram interpretation is supported by evaluation of contaminant concentrations shown in Table 4.3-2, which shows that concentrations of COPCs do not exceed GWQS. Well BED-14 also appears to be unimpacted by ARD-related contamination. This is a bedrock well located in the lower Strawberry Creek drainage just upstream of the confluence of Strawberry Creek and Bear Butte Creek.

Wells Located Downstream of Ruby Repository

Figure 4.3-31 is a Piper diagram evaluating bedrock wells in Ruby Gulch downstream from the Ruby Repository collection facilities. Well GW-9A is located approximately 500 feet downgradient of the collection facilities. The purpose of GW-9A is to detect migration of COPCs from Ruby Repository. Evaluation of the Piper diagram suggests that groundwater quality at well GW-9A is not significantly impacted by migration of COPCs from Ruby Repository. Well BED-15 is located just upstream of the confluence of Ruby Gulch with Bear Butte Creek. The major anion ratios of this well show a minor sulfate signature, which may be a result ARD impacts.

4.3.4 Nature and Extent of Contamination within Alluvial Aquifers and the Waste Dump Water Bearing Unit

Alluvial aquifers are relatively local in extent and are restricted to the base of major drainages, such as Strawberry Gulch, Hoodoo Gulch, and Ruby Gulch. The Waste dump water bearing unit occurs within alluvial sediments and overlying waste rock fill within the Ruby Repository, and is not a natural alluvial aquifer. Nature and extent of contamination in the following areas is discussed in this section:

- Strawberry Gulch alluvial aquifer
- Lower Strawberry Creek alluvial aquifer
- Hoodoo Gulch alluvial aquifer
- Waste Dump water bearing unit
- Ruby Gulch Alluvial Aquifer

4.3.4.1 Current Extent of Contamination in Alluvial Aquifers

Extent of Individual Constituent Concentrations Exceeding GWQS

ARD-related contamination is present within all alluvial aquifers in the primary mine disturbance area. The interpreted extent of contamination in alluvial aquifers is presented on Figure 4.3-32, which is based on groundwater samples collected during April and May 2007. These data are included on Table 4.3-2. The Strawberry Gulch alluvial aquifer, the Hoodoo Gulch alluvial aquifer and the Waste Dump water bearing unit are strongly impacted by ARD-related contamination. Groundwater quality within the lower Strawberry Creek alluvial aquifer also exceeds GWQS; however, this contamination may be related to the WTP discharge and subsequent communication between Strawberry Creek and the alluvial aquifer adjacent to the creek.

Evaluation of Groundwater Quality

Strawberry Gulch Alluvial Aquifer

The Strawberry Gulch alluvial aquifer extends from the approximate location of Pond E/Strawberry Pond upstream to the area north of the Stormwater Pond. Strawberry Gulch contains large quantities of acid generating fill rock, and the Strawberry Gulch alluvial aquifer is extensively impacted by ARD related contamination.

A Piper diagram evaluating major element concentrations based on April 2007 sampling data is shown as Figure 4.3-33. This diagram shows the five alluvial wells located within Strawberry Gulch, GW-2A, GW-3, GW-7, GWCDM11 and GWCDM12. As shown on the figure, groundwater at all alluvial wells is calcium-sulfate type water, which is an indicator of ARD-related impacts. Based on the Piper diagram, monitor wells GW-2A and GW-7 are somewhat less impacted than GW-3, GWCDM11, and GWCDM12. The Piper diagram analysis is supported by data regarding individual constituent concentrations.

GW-2A is located near the Stormwater Pond in an area containing reclamation fills. Groundwater quality in GW-2A exceeded GWQS for pH in one of two samples collected during 2007. The pH of the samples is very close to the applicable criteria of 6.5 su. Sulfate is elevated in the well as compared to background conditions but does not exceed the GWQS. As discussed in Section 4.2, reclamation fills are currently acid generating only in local zones and do not contain a large load of soluble contaminants. The groundwater data from GW-2A support this evaluation and suggest that fill rock in this area is not releasing contaminant loads in quantities that cause groundwater quality at this location to exceed GWQS.

Temporal trends in groundwater quality at GW-2A are shown in Figures 4.3-34 and 4.3-35 for the period extending from late 1996 to 2007. The well was not sampled during 2001 through 2006. Total dissolved solids concentrations during 1996 through 1999 were variable, ranging from less than 200 mg/L to approximately 1,100 mg/L. pH has remained in the range of 6.0 su to 6.5 su for the period of record, which is below the lower limit of the GWQS. Copper and zinc concentrations increased slightly during the period of 1997 through early 2000. This may be related to placement of the Stormwater Pond fill.

GW-3 is located adjacent to Pond C, which collects ARD affected alluvial groundwater and surface water and conveys it into the site WTP. Alluvial groundwater at GW-3 exceeds GWQS for pH, sulfate, aluminum, cadmium, manganese, nickel, and zinc. Temporal trends in groundwater quality at GW-3 are shown in Figures 4.3-36 and 4.3-37. An increasing trend in cadmium, copper, and zinc concentrations and a concomitant decreasing trend in pH is apparent during the period extending from 1990 to 2000. A decreasing trend in metals concentrations is apparent during 2006 and 2007 although cadmium and zinc concentrations remain well above GWQS. The pH is currently buffered in the 4.0 su to 4.5 su range.

GWCDM11 and GWCDM12 are located between Dakota Maid Pit and Strawberry Gulch. These wells are also impacted by ARD. GWCDM11 exceeds GWQS for pH, TDS and sulfate. GWCDM12 exceeds GWQS for those parameters as well as cadmium and manganese. Temporal trends in groundwater quality at GWCDM11 are shown in Figures 4.3-38 and 4.3-39. TDS is on an increasing trend in this well and pH is currently buffered in the 6.0 su to 6.5 su range. No clear trends are apparent in metals concentrations. Temporal trends in groundwater quality at GWCDM12 are shown in Figures 4.3-40 and 4.3-41. No apparent trends are present for pH and TDS. Cadmium, copper, and zinc concentrations are on an increasing trend in GWCDM12.

GW-7 is located downstream of Pond C below the Strawberry Gulch collection facilities. Based on data collected in April and May 2007, groundwater at this location exceeds GWQS for pH and cadmium. The pH is slightly acidic, with values of 5.62 and 6.04 su, and the cadmium concentration is 0.007 mg/l. Other constituents meet GWQS at this location. Temporal trends in groundwater quality at GW-7 are shown in Figures 4.3-42 and 4.3-43. Arsenic, cadmium, copper, and zinc concentrations have been on a decreasing trend in this well since the early 1990s. pH was on an increasing trend over the same time period. It is possible that groundwater quality at this location is improving as a result of removal of relic tailings in 1993 and continued operation of ARD collection facilities at Pond C, Pond D, and Pond E/Strawberry Pond.

<u>Lower Strawberry Creek Alluvial Aquifer</u>
The lower Strawberry Creek alluvial aquifer is generally continuous with the Strawberry Gulch alluvial aquifer. The delineation between the two aquifers is based on the location of the ARD collection facilities in Strawberry Gulch as well as the relationship between the bedrock and alluvial aquifers. The Strawberry Gulch alluvial aquifer is perched above the bedrock aquifer and a downward gradient is present causing groundwater to flow from the alluvial aquifer into the underlying bedrock aquifer. Downstream from GW-7, this relationship changes and an upward vertical gradient is present causing water to flow from the bedrock aquifer into the alluvium and into Strawberry Creek. In addition, tailings removal activities conducted in Strawberry Creek during 1993 excavated a slot through the lower Strawberry Creek alluvium to bedrock, which drains the alluvium and causes much of the alluvium to be unsaturated. Alluvial wells in lower Strawberry Creek are monitoring groundwater quality within the upper weathered zone of the bedrock, but the alluvial aquifer is not a distinct perched aquifer.

Major ion concentrations of lower Strawberry Creek wells are shown on a Piper diagram included as Figure 4.3-44. This diagram shows that the wells are calcium-sulfate type water, which was used previously to identify ARD affected groundwater. The high sulfate concentration of groundwater in the lower Strawberry Creek wells may be a result of interaction of treated water that is discharged down Strawberry Creek rather than migration of ARD in groundwater. The current treatment process does not remove sulfate from the ARD, and the treated water contains high concentrations of sulfate and other total dissolved solids, such as calcium and magnesium. The signature of treated water is calcium-sulfate type water with high concentrations of TDS, circumneutral pH, and low concentrations of heavy metals, such as cadmium, copper, and zinc. These impacts extend to monitor well BES-14, which is located next to the creek just upstream from the confluence of Strawberry Creek with Bear Butte Creek.

Based on 2007 data, monitor well BES-11 exceeds GWQS for sulfate only. Temporal trends in groundwater quality at BES-11 are shown in Figures 4.3-45 and 4.3-46. The pH of BES-11 was relatively stable during the period of 1990 to the present, ranging from approximately 6.0 su to 7.8 su. The pH has met the GWQS since 1995. An increase in TDS from less than 500 mg/L to a general range of approximately 1,000 mg/L to 2,400 mg/L occurred in 1995. This may be related to commencement of full-scale ARD treatment at the site and discharge of treated water down Strawberry Creek.

Monitor well BES-14 is located on the north side of Strawberry Creek, just upstream of the confluence of Strawberry Creek with Bear Butte Creek. Based on 2007 data, BES-14 exceeds GWQS for sulfate and TDS. Figures 4.3-47 and 4.3-48 show temporal trends in groundwater quality at BES-14. Groundwater data from BES-14 also display a marked increase in TDS occurring in mid 1995 when TDS increased from less than 500 mg/L to greater than 1,000 mg/L although the well was sampled less frequently than BES-11. The TDS concentration in BES-14 was below 500 mg/L during one sampling event in mid 2003. This corresponds to a period when the site WTP was not discharging, which extended from August 2002 to September 2003. Significant trends are not present in metals concentrations and pH at BES-14.

The BES-11 and BES-14 data support the hypothesis that this contamination is a result of discharge of treated water from the site WTP. Alluvial groundwater quality at these locations exhibits the characteristic signature of treated water, and temporal variations in groundwater quality correspond to periods of WTP operation. It is likely that alluvial groundwater along Strawberry Creek is in communication with surface water and that the treated water either recharges alluvial groundwater or discharges from groundwater depending on seasonal fluctuations in the water table and the flow rate of Strawberry Creek.

<u>Hoodoo Gulch Alluvial Aquifer</u>
The upper portion of the Hoodoo Gulch alluvial aquifer is strongly impacted by ARD-related contamination. Alluvial groundwater in this area is captured in the Hoodoo Gulch ARD collection system and is pumped to Sunday Pit prior to treatment in the

site WTP. Monitor well GWCDM09 is located in the alluvial aquifer upstream of this collection point. Well BES-17 is located in the lower portion of the alluvial aquifer just upstream from the confluence of Hoodoo Gulch with Strawberry Creek. Major ion concentrations of the two Hoodoo Gulch alluvial wells are plotted on a Piper diagram included as Figure 4.3-49, which is based on data collected in April 2007. The Piper diagram suggests that both wells are impacted to some extent by ARD-related contamination.

Based on 2007 data, groundwater at GWCDM09 is strongly acidic and exceeds GWQS for pH, TDS, sulfate, aluminum, cadmium, manganese, nickel, and zinc. Temporal trends in groundwater quality at GWCDM09 are shown in Figures 4.3-50 and 4.3-51. Over the period of record of 2002 to the present, pH, TDS, and metals concentrations have been approximately stable. The pH is currently buffered in the range of 3 su to 4 su and TDS ranges from approximately 1,100 to 1,600 mg/L.

Groundwater at BES-17 meets GWQS, with the exception of manganese and arsenic. Groundwater quality at BES-17 displays slightly elevated sulfate concentrations as compared to background conditions. Temporal trends in groundwater quality at BES-17 are shown in Figures 4.3-52 and 4.3-53. Significant trends are not apparent in pH or metals concentrations. Arsenic has exceeded the GWQS on an intermittent basis over the period of 1990 to the present. An increase in TDS from approximately 200 mg/L to approximately 450 mg/L is apparent starting in 1998. This suggests that groundwater quality at BES-17 may be changing in response to upgradient ARD sources.

<u>Waste Dump Water Bearing Unit and Ruby Gulch Alluvial Aquifer</u>
Alluvial groundwater within the Waste Dump water bearing unit is strongly impacted by ARD as shown by discharge from the Ruby Repository and groundwater quality at monitor well GW-8. Two additional alluvial wells, GW-8A and BES-15, are located downgradient from the Ruby Repository in order to detect releases of ARD from the collection facilities at the toe of the repository. Figure 4.3-54 is a Piper diagram comparing major ion concentrations in GW-8, GW-8A and BES-15. GW-8 is an alluvial well within the waste dump water bearing unit, which is strongly impacted by ARD related contamination. The Piper diagram analysis suggests that the Ruby Repository collection facilities are performing adequately in preventing downgradient migration of ARD in the Ruby Gulch alluvial aquifer.

Temporal data for monitor well GW-8 is shown as Figures 4.3-55 and 4.3-56. These graphs show the characteristic groundwater impacts that are associated with ARD at the site. In the early 1990s, a concomitant decrease in pH and increase in total dissolved solids is apparent on Figure 4.3-55. Figure 4.3-56 shows that this trend is temporally associated with increases in cadmium, copper, and zinc concentrations. Figures 4.3-57 and 4.3-58 show temporal data for monitor well GW-8A, which is located approximately 400 feet downgradient of the collection facilities. ARD impacts are not present at this monitor well.

Surface water sampling location CP003 is also located in Ruby Gulch below the collection facilities. Surface water at this location is discharged from a small spring

below the collection facilities. This is a discharge point for alluvial groundwater. Surface water collected at this location is impacted by ARD. This suggests that monitor well GW-8A is not measuring the same water that discharges as a spring at CP003 and that the collection facilities at Ruby Repository are not entirely effective in preventing migration of ARD in the alluvial aquifer of Ruby Gulch. Water quality at CP003 is discussed in Section 4.4, which is focused on water quality of ARD sources, including Ruby Repository.

4.4 Acid Rock Drainage

This section focuses on ARD within the site collection, conveyance, and treatment system and includes all mine pits, waste rock fill areas, amended tailings facilities, processing facilities, and underground workings. Discussions of ARD water quality are focused on evaluation of parameters that affect water treatment requirements, such as pH, total dissolved solids, sulfate concentrations, mineral acidity, and representative total recoverable toxic metal and metalloid concentrations.

The sulfate concentration of ARD is currently a critical parameter with regard to ARD concentrations. The existing site WTP is not capable of treating ARD containing greater than 1,800 mg/L sulfate. Treatment of ARD containing greater than 1,800 mg/L sulfate causes adverse scaling of sand filters within the plant and quickly causes total shutdown of the plant. EPA is currently considering options to modify the plant to allow treatment of ARD containing sulfate concentrations greater than 1,800 mg/L.

Extensive monitoring of surface water quality at the site was completed as part of various remedial investigations and routine operational monitoring data. Figure 4.4-1 shows the surface water sampling locations that are discussed in this remedial investigation report. This map includes surface water sampling locations that are described in this section as well as Sections 4.5 and 4.6, which are focused on areas outside of the ARD collection, conveyance and treatment system.

SWQS that are used to evaluate nature and extent of contamination in surface water are shown in Table 4.1-2. These standards are used in this section as well as Sections 4.5 and 4.6. Water quality data described in this section are compared to the WTP effluent standards, where applicable. These standards are used as a basis for comparison because the majority of ARD sources described in this section are within the site water treatment system. EPA and DENR have not determined which ARARs will apply to the site or specifically how the ARARs and PRGs will be achieved through remedial action. These risk management decisions will be made through careful consideration of the site investigation data, human health and ecological risk assessments, National Contingency Plan (40CFR Part 300), feasibility study, stakeholder review, and public comment.

Virtually all surface water within the primary mine disturbance area is collected and conveyed into the site water treatment system. The sources of this water include discharges from groundwater at underground mine portals and ARD springs,

interaction of precipitation with exposed source materials, and direct precipitation on ARD storage facilities. The collected water is acidic calcium-sulfate water with high concentrations of total dissolved solids, sulfate, and toxic metals and metalloids. This water is collected from various areas and conveyed to storage facilities prior to treatment.

Evaluation of ARD is described into two categories:

- ARD sources
- Stored ARD

Evaluation of available information regarding ARD sources is important to provide an understanding of the range of ARD chemistry that is produced at the site. Water chemistry of stored ARD on the site is dependant on the overall chemistry of individual ARD sources reporting to the storage facility as well as site ARD management activities, such as commingling of WTP sludge with stored ARD and partial treatment of ARD completed during the Anchor Hill Pit Lake Treatability Study.

Metal and metalloid concentrations presented in Section 4.4 are the total concentration of the metal in the effluent. Additional analyses, including dissolved analyses of some contaminants, are included in Appendix B.

4.4.1 ARD Sources

ARD from seven sources are discussed below:

- Heap Leach Pad
- Ruby Repository
- Hoodoo Gulch
- Langley Adit
- King Adit
- Wood Weir
- Other Sources

4.4.1.1 Heap Leach Pad

Water infiltrating HLP spent ore as a result of precipitation flows through the rock and collects on the HLP liner. This water flows along the liner toward the southwest and collects in a sump area on the southwest corner of the HLP. The HLP contributed 10.0% of the total ARD generated on the site during the 2007 water year. This sampling location is called HLP EFFLUENT as shown on Figure 4.4-1. This effluent is periodically pumped to the Stormwater Pond for temporary storage. Ultimately the

water is pumped to Sunday Pit and commingled with other ARD stored in Sunday Pit prior to treatment. HLP effluent water quality is routinely monitored as part of operational monitoring at the site. Operational monitoring data provide an excellent opportunity to understand the effect of HLP spent ore on water quality. The geochemistry of the spent ore is changing as the rock equilibrates with the surface environment. Therefore, recent HLP effluent data are most useful to understand current conditions.

The effluent is moderately acidic and shows clear indications of sulfide oxidation occurring within the HLP. The median pH of 2006 samples is 3.35 su. The effluent pH was buffered at approximately 4.5 su during 2004 and early 2005. In May 2005, the pH dropped to approximately 3.3 su. This stepwise pattern of pH reductions is common in acidifying mine waste piles. It is caused by pH buffering resulting from dissolution of various minerals. Currently, the HLP appears to be buffered in the 3.3 su range. In time, pH of HLP effluent is expected to decrease to the 2.0 su to 3.0 su range observed in mature acid drainage at other areas of the mine site.

Numerous contaminants related to ARD are detected in HLP effluent. The effluent exceeds SWQS for numerous metals, metalloids, and physical parameters related to ARD, including arsenic, cadmium, copper, nickel, selenium, zinc, and total dissolved solids. HLP effluent also contains elevated concentrations of selenium, a contaminant mobile under circumneutral pH oxidizing conditions.

Cyanide is present in the HLP effluent in trace quantities. Cyanide is subject to natural degradation in leach pad environments (Smith et al. 1999), and cyanide was rinsed from the pad as a result of influxes of precipitation since gold processing ceased in the late 1990s. As a result, cyanide concentrations are decreasing in HLP effluent. Cyanide analyses include total cyanide and WAD cyanide. Cyanide occurs in numerous forms in leach pad environments, including free cyanide (CN^-) and numerous cyanide complexes. WAD cyanide analyses detect cyanide in the form of free cyanide as well as dissolved cyanide complexes of zinc, cadmium, copper, nickel, and silver. Total analyses include free cyanide; WAD cyanide complexes; and strong complexes of iron, cobalt, and gold (Smith et al. 1999).

Cyanide was measured in HLP effluent during seven sampling events in 2006. Total cyanide was detected in five of seven of seven sampling events in 2006. The median concentration of the samples is 0.014 mg/L, and the concentrations range from <0.01 mg/L to 0.085 mg/L. WAD cyanide was detected in one of the seven samples. The minimum and median concentrations are below the detection level of 0.01 mg/L and the maximum concentration is 0.029 mg/L. Potential toxicity to humans from cyanide in site surface water was evaluated in the draft BRA (EPA 2006b). This analysis considered a total cyanide concentration of 0.48 mg/L. Cyanide was not found to be a driver of human health risk at this concentration level. The SWQS applies to WAD cyanide only, and sets forth an acute limit of 0.022 mg/l and a chronic limit of 0.0052 mg/l. The maximum WAD cyanide concentration observed in 2006 exceeds the SWQS.

Nitrate is a product of cyanide degradation and residual ammonium nitrate fuel oil (ANFO) blasting agents. The stored mass of nitrate in the HLP is a product of residual cyanide left in HLP spent ore as well as residual blasting agents. This stored mass is being depleted as HLP effluent is pumped from the HLP to the site water treatment system. In 2006, nitrate concentrations in HLP effluent ranged from 35.1 to 250 mg/L, with a median value of 126 mg/L. SWQS include nitrate standards of 50 mg/L and 88 mg/L for the 30-day average and daily maximum values, respectively. The median nitrate concentration in 2006 HLP effluent samples exceeds the SWQS.

4.4.1.2 Ruby Repository

Ruby Repository is a significant source of ARD at the site, providing 20.2 percent of the total ARD yield in the 2007 water year. These ARD inflows include water that is collected in the primary collection facility at the Ruby Repository toe and water that reports to the Wet Well, a backup system intended to collect leakage from the primary facility. ARD collected at the primary collection facility accounted for 12.3 percent of site ARD inflows, and the Wet Well accounted for an additional 7.9 percent of the total ARD yield in the 2007 water year. Contaminants present in both of these sources originate at the Ruby Gulch waste rock dump; however, contaminant concentrations in water from the primary collection facility are substantially higher than the Wet Well.

Ruby Repository Toe

The water discharging from the toe of the repository is strongly acidic, with pH values generally ranging from 2.5 su to 3.0 su, high mineral acidity and high concentrations of toxic heavy metals, such as cadmium, copper, and zinc, as well as elevated concentrations of arsenic and other metals and metalloids. Water discharging from the toe of the repository also contains trace concentrations of cyanide and nitrate, which are residual gold processing reagents that are mobilizing out of HLP spent ore that was placed into the waste rock dump. This water is consistently several orders of magnitude above SWQS for a number of parameters.

The toe of the waste rock dump was sampled 10 times between 2000 and 2003. Water samples collected from the waste rock dump toe during that time period are among the most acidic of any sources on the site. Mineral acidity ranged from 5,100 mg/L to 8,710 mg/L, with an average of 6,746 mg/L; sulfate ranged from 7,300 mg/L to 17,000 mg/L, with an average of 10,450 mg/L; total dissolved solids ranged from 9,500 mg/L to 16,260 mg/L, with an average of 12,766; cadmium ranged from 0.263 mg/L to 1.130 mg/L, with an average of 0.604 mg/L; and zinc ranged from 6.33 mg/L to 34.0 mg/L. Arsenic was present in the samples, with concentrations ranging from 0.713 mg/L to 4.480 mg/L and an average concentration of 1.723 mg/L. Selenium was only detected in 2 of the 10 samples at concentrations above the detection level of 0.0034 mg/L to 0.0048 mg/L. The maximum selenium concentration was 0.020 mg/L.

Changes in water quality at the waste rock dump toe resulting from construction of Ruby Repository are currently being evaluated based on water samples collected from the toe of the Ruby Repository. The data suggest that construction of the repository has reduced the overall concentration of ARD discharged from the facility. Current

sulfate concentrations range from 907 mg/L to 1,200 mg/L, cadmium concentrations range from 0.102 mg/L to 0.194 mg/L, copper concentrations range from 4.5 mg/L to 6.67 mg/L, and zinc concentrations range from 2.42 mg/L to 4.29 mg/L. Arsenic concentrations range from <0.005 mg/L to 0.006 mg/L and selenium concentrations range from 0.005 to 0.008 mg/L. The observed improvement in ARD water quality from Ruby Repository is supported by data from alluvial monitor well GW-8, which is located within the repository. Data from GW-8 were discussed previously in Section 4.3.3.

Trace concentrations of residual mineral processing reagents are present in the Ruby Gulch waste rock dump discharge. WAD and total cyanide were analyzed eight times since EPA and the state took over the site. Total cyanide was less than the detection level of 0.0016 mg/L to 0.005 mg/L for three of the eight sampling events. The maximum total cyanide concentration was 0.0135 mg/L. WAD cyanide concentrations were below the detection level of 0.005 to 0.012 in all samples. The chronic SWQS applies only to WAD cyanide and is 0.0052 mg/L. Nitrate, a residual product of cyanide degradation and residual ANFO blasting agents, was analyzed once at the waste rock dump toe. A nitrate concentration of 26 mg/L was reported for a sampling event in February 2002. This concentration is below the SWQS of 50 mg/l.

Wet Well

The current ARD collection facilities present at Ruby Gulch waste rock dump were completed in early 2006. These facilities include a subsurface collection gallery at the toe of the waste rock dump, the Wet Well, and ancillary pumping infrastructure. The configuration of the Wet Well was complete in October 2005. Work completed between October 2005 and early 2006 consisted of upgrades to the pumping infrastructure, which did not affect water chemistry. Therefore, water quality data collected from the Wet Well after October 2005 are most representative of current water quality conditions. The Wet Well sampling location is called WET WELL or OPCDM09 in the site database.

The pH of the water collected in the Wet Well is monitored daily; however, water chemistry data are not collected on a routine basis. Available data suggest that the Wet Well water contains a component of ARD from Ruby Gulch waste rock dump that has mixed with alluvial groundwater from other sources. An opportunity sample of the Wet Well water was collected on April 9, 2007 to provide some information regarding the chemistry of the water. The pH of water collected in the Wet Well generally ranges from about 4.5 su to 6.5 su, which is significantly higher than the range of pH values observed at the toe of the repository. Water chemistry data from April 9, 2007 was slightly impacted by ARD-related contaminants. The pH of the water was 6.65 su, which does not exceed SWQS. Cadmium slightly exceeded the SWQS, with a concentration of 0.007 mg/L.

Sampling Location CP003

Sampling location CP003 is within Ruby Gulch approximately 500 ft below the Wet Well. Surface water flow at this location is intermittent, and flows generally cease during the driest months of the year. The flow rate at this location is generally less

than 10 gpm as described in Section 3. Figures 4.4-2 through 4.4-5 display water quality data for pH, cadmium, copper, and zinc, respectively. The non-detect cadmium concentrations in Figure 4.4-3 are shown as one-half the detection limit. The most important period of record for this sampling location is after October 2005 when construction was completed at the Wet Well. The data indicate that the water is circumneutral pH and within applicable pH SWQS of 6.0 su to 9.5 su. However, trace concentrations of cadmium, copper, and zinc are present in the water, which regularly exceed SWQS. Sampling location CP003 is the only location discussed in this section that applies to water not collected within the site water treatment system, therefore Ruby Gulch SWQS are used for comparison rather than WTP effluent SWQS.

One additional surface water quality sampling site is present in Ruby Gulch just upstream from the confluence of Ruby Gulch and Bear Butte Creek. This site is discussed in a later section focused on Bear Butte Creek.

4.4.1.3 Hoodoo Gulch

The Hoodoo Gulch collection system is also an important source of ARD on the site. In the 2007 water year, it accounted for 7.9 percent of the total ARD yield on the site. Prior to fall 2005, ARD at Hoodoo Gulch was treated using sodium hydroxide hard buckets. In fall 2005, the hard bucket system was removed and a new collection system was constructed to convey this water to the site ARD treatment system as set forth in the interim ROD for water treatment (EPA 2001a).

Water quality data at Hoodoo Gulch are limited to six samples collected from 2000 to 2003 and one sample that was collected on January 16, 2006. The Hoodoo Gulch sampling location is called SWCDM27 in the site database and on Figure 4.4-1. In 2006, Hoodoo Gulch ARD was moderately acidic (pH of 3.7), with sulfate concentrations of 978 mg/L and very low dissolved iron concentrations. Dissolved copper, cadmium, and zinc concentrations were 2.08 mg/L, 0.102 mg/L, and 4.07 mg/L, respectively.

During the 2000 through 2003 sampling events, pH ranged from 3.77 su to 4.29 su, with a median of 4.03 su; sulfate ranged from 976 mg/L to 1,600 mg/L, with an average of 1,158 mg/L; acidity ranged from 230 mg/L as $CaCO_3$ to 550 mg/L as $CaCO_3$, with an average of 328 mg/L as $CaCO_3$; cadmium ranged from 0.098 mg/L to 0.179 mg/L, with an average of 0.135 mg/L; copper ranged from 1.87 mg/L to 3.03 mg/L, with an average of 2.42 mg/L; and zinc ranged from 2.96 mg/L to 5.53 mg/L, with an average of 4.05 mg/L. Concentrations of arsenic and selenium in the 2000 to 2003 samples were low. Arsenic was detected in four of the six samples, with a maximum of 0.008 mg/L, and selenium was below the detection level of 0.003 to 0.0048 in all samples.

ARD discharging at Hoodoo Gulch is less concentrated than ARD discharged from Ruby Repository. This may be a result of somewhat less acid generating rock as well as the level of maturity of acid generation. A major source of ARD collected at the Hoodoo collection system is general fill rock present in the upper reaches of the Hoodoo Gulch drainage. General fill rock on the site was shown previously to be in

the process of maturing and in time poorer water quality is expected to result from interaction of infiltrating rain and snow with the rock.

4.4.1.4 Pond C

ARD inflows reporting to Pond C account for a large proportion of the total ARD yield. During the 2007 water year, Pond C accounted for 23.2% of the total site ARD yield. Water quality at Pond C was monitored monthly during May, June and July, 2007. The data indicate that ARD reporting to Pond C is moderately acidic (pH 4.4-4.7 su) and that associated dissolved solids concentrations are lower than other ARD sources at the site. During the 2007 sampling events, sulfate concentrations ranged from 466 mg/l to 645 mg/l, copper concentrations ranged from 0.457 mg/l to 0.838 mg/l, cadmium concentrations ranged from 0.080 mg/l to 0.162 mg/l and zinc concentrations ranged from 2.62 to 4.21 mg/l. The flow characteristics of Pond C were described previously in Section 3.8.4.3. The data indicate that ARD inflows at Pond C dominantly result from the surface and subsurface components of runoff. Pond C has a relatively large drainage basin and portions of the drainage basin do not contain ARD-generating source materials. The ARD chemistry data suggest that mixing of ARD with relatively clean waters from other parts of the basin may be diluting the concentration of ARD reporting to Pond C.

4.4.1.5 Langley Adit

The Langley Adit discharges ARD from the adit portal on an intermittent basis. The flow rate and flow duration of ARD discharges are not monitored. The adit was observed to discharge during months of May, June, September, and October during 2000 through 2003. The adit has not been monitored since that time. The flow rate is generally on the order of about 10 gpm based on anecdotal visual observations.

The adit discharge was sampled five times during the time period of 2000 to 2003. This sampling location is called OPCDM16 in the site database and Figure 4.4-1. The discharge is acidic and requires collection and treatment prior to discharge. The pH values from the sampling events ranged from 2.59 su to 3.29 su, with a median pH of 2.86 su. Mineral acidity ranged from 430 mg/L $CaCO_3$ to 1,250 mg/L $CaCO_3$, with an average of 743 mg/L $CaCO_3$. Sulfate ranged from 620 mg/L to 1,560 mg/L, with an average of 1,050 mg/L, and total iron ranged from 63 mg/L to 204 mg/L, with a median of 107 mg/L.

The water also contains trace metal and metalloid concentrations that exceed SWQS. Total cadmium ranged from 0.064 mg/L to 0.084 mg/L, with an average of 0.070 mg/L; total copper ranged from 10.7 mg/L to 16.8 mg/L, with an average of 12.8 mg/L; and total zinc ranged from 1.93 mg/L to 2.72 mg/L, with an average of 2.35 mg/L for the five sampling events. Metalloids arsenic and selenium are also present at problematic concentrations in ARD discharged from Langley Adit. Total arsenic concentrations ranged from 0.044 mg/L to 0.699 mg/L, with an average of 0.298 mg/L for the five sampling events. Total selenium was less than detection of 0.003 mg/L to 0.0048 mg/L for two of the five sampling events. The maximum selenium concentration was 0.032 mg/L, and the median concentration was 0.008 mg/L.

4.4.1.6 King Adit

The King Adit was sampled on two occasions in 2000. This sampling location is called OPCDM15 in the site database and on Figure 4.4-1. The King Adit is hydrologically connected with Dakota Maid Pit through a series of fracture zones. However, it is likely that the water chemistry of the King Adit discharge is affected by water-rock interactions that occur along the flow path of water from the pit lake into the adit as well as water that enters the underground workings from other sources. In October 2000, the King Adit was explored, and highly acidic water was observed to be entering the adit through an abandoned raise within the adit as well as through fractures. A raise is a subsurface excavation that extends upward from a drift or a stope. This raise was in poor condition and was not explored as a result of safety hazards. Three samples were collected from ARD entering the underground workings during this investigation.

Based on the two samples collected, the King Adit is highly acidic and contains high concentrations of toxic metals and metalloids. The pH was measured only during the September 24, 2000 sampling event and was 2.31 su. Sulfate concentrations for the June and September sampling events were 6,700 mg/L and 7,600 mg/L, respectively. Cadmium concentrations were 0.563 mg/L and 1.490 mg/L, copper concentrations were 94.6 mg/L and 133.0 mg/L, zinc concentration were 15.9 mg/L and 33.4 mg/L, arsenic concentrations were 1.720 mg/L and 1.150 mg/L, and selenium concentrations were 0.437 mg/L and 0.144 mg/L, respectively.

4.4.1.7 Wood Weir

The Wood Weir is a spring located between Sunday Pit and the upper Strawberry Creek area. The Wood Weir discharges ARD at a rate that varies from 0 to 30 gpm. The average discharge rate has been about 5 gpm since EPA and the state took over site management in 2000. The Wood Weir flow rate appears to increase in response to increased water storage in Sunday Pit. Although the flow in the Wood Weir appears to be related to the elevation of water within Sunday Pit, the water chemistry of the Wood Weir is different than Sunday Pit, suggesting that this water interacts with rock surfaces along a flow path between Sunday Pit and the Wood Weir discharge. The Wood Weir discharge was sampled on several occasions in 2000 through 2003 by UOS and CDM.

The Wood Weir sampling location is called OPCDM03 in the site database and on Figure 4.4-1. The Wood Weir discharge is strongly acidic, with pH values ranging from 2.2 su to 2.95 su and mineral acidities ranging from 2,200 mg/L $CaCO_3$ eq. to 4,900 mg/L $CaCO_3$ eq. The median field pH of eight sampling events between 2000 and 2003 was 2.50 su. Average mineral acidity of three sampling events during 2000 to 2001 was 3,243 mg/L $CaCO_3$ eq. Sulfate concentrations for five sampling events between 2000 and 2001 ranged from 2,950 mg/L to 8,400 mg/L, with an average concentration of 5,984 mg/L. Total dissolved solids concentrations of three sampling events between 2000 and 2001 ranged from 4,400 mg/L to 8,700 mg/L, with an average of 6,833 mg/L.

Concentrations of toxic metals and metalloids are high in the Wood Weir discharge. Metals and metalloids were analyzed in five samples collected between 2000 and 2001. Cadmium concentration ranged from 0.226 mg/L to 1.240 mg/L, with an average of 0.735 mg/L. Copper concentrations ranged from 25.9 mg/L to 109 mg/L, with an average of 77.8 mg/L. Zinc concentrations ranged from 4.84 mg/L to 29.8 mg/L, with an average of 19.1 mg/L. Arsenic ranged from 0.093 mg/L to 1.950 mg/L, with an average of 0.596 mg/L; and selenium ranged from 0.004 mg/L to 0.032 mg/L, with an average of 0.176 mg/L.

4.4.1.8 Other Sources

Numerous other sources of ARD-impacted water are present at the site, including waste rock fill areas, pit highwalls, Ruby Repository diversion ditches, and areas of relatively unimpacted water that flows onto areas containing ARD. These sources contribute significantly to the ARD yield although the ARD chemistry and inflow volume resulting from the other sources are not well understood. During the 2007 water year, it is estimated that other sources contributed 38.5 percent of the total ARD yield.

4.4.2 Stored ARD

ARD is stored within four primary locations at the site:

- Sunday Pit Lake
- Dakota Maid Pit Lake
- Anchor Hill Pit Lake
- Stormwater Pond

The chemical characteristics of the stored water are a result of both ARD inflows into the storage facilities and ARD management activities that have occurred over the past approximately 15 years. The specific ARD chemistry of the pit lakes changes in response to climatic conditions at the site as well as site management activities, so chemical analyses must be considered as a snapshot in time. The available data demonstrate general characteristics of the ARD storage facilities that are important in developing an understanding of nature and extent of contamination. Recent pit lake chemical data are shown in Table 4.4-1.

4.4.2.1 Sunday Pit

Sunday Pit is the primary ARD storage facility at the site, with an operational capacity of approximately 60 Mgal. Sunday Pit receives water that is pumped from ARD collection facilities at Ruby Repository, Hoodoo Gulch, Strawberry Gulch, and the HLP. Sunday Pit also receives ARD inflows from pit highwalls, fill areas, and direct precipitation on the surface of the pit lake. Sunday Pit is highly stratified with strongly acidic water at the base of the pit lake and relatively more dilute ARD on the surface of the pit lake. Pit lake stratification is routinely monitored as part of site

operation and maintenance activities. Spring inflows dilute ARD concentrations each year and result in lower ARD concentrations on the surface of the pit lake.

Figure 4.4-6 shows the stratification of the pit lake based on sulfate concentrations. Sulfate was specifically tracked in the pit lake because of operational issues related to gypsum scaling within the WTP. The concentrations display a trend that applies to all dissolved solids within the pit lake, with significantly more concentrated ARD solutions occurring at the base of the lake. This stratification appears to be relatively stable based on monitoring data, and seasonal mixing or turnover of water in the lake has not occurred. The driving forces for seasonal turnover of the pit lake result from water density changes caused by seasonal temperature fluctuations and wind effects. The lack of turnover at Sunday Pit may be related to the significantly higher density of the deeper water that results from high total dissolved solids concentrations. Total dissolved solids concentrations at the lake surface were 2,540 mg/L based on samples collected on February 6, 2007. Concentrations increased steadily with depth, and a TDS concentration of 8840 mg/L was measured from a sample collected at the base of the pit.

The acidity of the ARD stored in Sunday Pit Lake increases significantly with depth. pH values from the February 2007 sampling event ranged from 3.16 su at the surface of the pit lake to 2.87 su at the base of the pit lake. Mineral acidity increased from 368 mg/L $CaCO_3$ eq. to 3,530 mg/L $CaCO_3$ eq. Major components of mineral acidity include aluminum, iron, and manganese. Aluminum concentrations increase from 42.9 mg/L at the surface to 617 mg/L at the base of the pit lake. Iron concentrations increase from 27.4 mg/L to 438 mg/L, and manganese concentration increase 4.76 mg/L to 35.2 mg/L. Mineral acidity is directly related to the consumption of reagents in the WTP, so water at the base of the pit lake is harder to treat and more expensive to treat than water at the surface of the pit lake. Currently, the site WTP is not capable of treating ARD stored in the lower portions of Sunday Pit.

Concentrations of toxic contaminants also increase significantly with depth in Sunday Pit. The presence of concentrated ARD in the base of Sunday Pit exacerbates the potential for adverse groundwater impacts. Based on the February 2007 data, cadmium concentrations increased about two orders of magnitude with depth in Sunday Pit, with a surface concentration of 0.091 mg/L and concentration at depth of 1.26 mg/L. Copper showed a similar trend, with a surface concentration of 6.12 mg/L and a concentration at depth of 136 mg/L. Zinc concentrations increased from 12.3 mg/L to 39.4 mg/L at depth. Concentrations of metalloids arsenic and selenium also increased significantly with depth. The arsenic concentration on the surface was 0.022, and the arsenic concentration at depth was 0.38 mg/L. The selenium concentration on the surface was 0.09 mg/L, and the concentration at depth was 0.055 mg/L.

The cause of stratification of ARD within Sunday Pit is not well understood. It is currently thought that three factors may contribute to formation of the stratified layers. The first is variation in the density of ARD that flows into the pit lake from the various sources. As described previously, ARD from the Ruby Repository is more acidic and contains a higher concentration of dissolved solids than ARD from the

Hoodoo Gulch collection facility. So water that is pumped into the pit from Ruby Repository may tend to sink further in the pit lake than water pumped from Hoodoo Gulch. The second potential cause is related to a past ARD management practice of evaporating ARD using large turbomisters that sprayed ARD over the Sunday Pit area. The evaporation process was successful in removing large volumes of water from the site water treatment system, but the process also resulted in precipitation of efflorescent acid salts on pit highwalls and other surfaces within the pit. These salts are readily soluble in precipitation events and contain the products of acid generation, such as iron, sulfate, and toxic metals and metalloids. In a rain event, these salts would dissolve and flow into the pit, increasing the load of dissolved solids in the stored ARD. The third potential cause is dissolution of the stored WTP sludge in the base of the pit. The stability of sludge stored under the strongly acidic conditions of the pit lake was discussed previously in Section 4.2.7.

4.4.2.2 Dakota Maid Pit

The Dakota Maid Pit contains a relatively small volume of ARD in comparison to Sunday Pit. The maximum water level in Dakota Maid Pit is controlled by discharge from the King Adit, and the Dakota Maid Pit is substantially shallower than Sunday Pit as a result of the side-hill pit configuration adjacent to Strawberry Gulch. The operational storage capacity of Dakota Maid Pit is only 15 Mgal. As a result, stratification within Dakota Maid Pit Lake is less pronounced. The Dakota Maid Pit Lake is not sampled routinely although some water chemistry data are available. It is unknown if the pit lake turns over seasonally. The Dakota Maid Pit is significantly shallower than Sunday Pit, with a depth of 15 ft, and it is more exposed to wind, so it is possible that the pit lake mixes at various times of the year.

The most recent sampling data from Dakota Maid Pit Lake were collected on August 3, 2005. Sulfate concentrations increased from 4,830 to 7,160 mg/L over a depth of 15 ft. Aluminum, iron, and manganese concentrations also increased, with concentrations ranging from 252 mg/L to 489 mg/L, 845 mg/L to 1690 mg/L, and 11.1 mg/L to 11.4 mg/L, respectively. Cadmium, copper, and zinc also increased with depth within the pit lake. The increased concentrations with depth that were apparent during the August 3, 2005 sampling event may be related to dissolution of stored WTP sludge in the base of the pit. Based on the concentrations of sulfate in Dakota Maid pit, none of the ARD stored in the pit is treatable in existing WTP.

4.4.2.3 Anchor Hill Pit

The Anchor Hill Pit Lake also exhibits marked stratification, but the origin and chemistry of the stratified layers are different as compared to Sunday Pit Lake. The Anchor Hill Pit Lake was the site of an EPA pit lake treatability study, which occurred between 2001 and 2006. During this test, approximately 70 Mgal of ARD and HLP effluent were pumped into the pit, and a treatability study was initiated to attempt to treat the water in-situ using a combination of chemical and biological methods. The test included in-situ neutralization of the contaminated water using a combination of lime and sodium hydroxide and biological sulfate reduction facilitated through addition of a carbon source to the pit lake. A portion of the biologically treated water

was discharged from the site during 2005 and 2006. However, approximately 52 Mgal of this water was only partially treated and did not meet site discharge criteria. In late April 2006, the site received about 4 ft of heavy wet snow, which caused a major adverse impact on the overall site water balance. The available ARD storage capacity in Sunday Pit was exceeded, and it was necessary to pump ARD from Sunday Pit to Anchor Hill Pit for storage prior to treatment. Currently, the Anchor Hill Pit Lake is stratified with a layer of ARD overlying a deeper layer of water that was partially treated in the treatability study. As a result of mixing that occurred when the ARD was pumped into Anchor Hill Pit in 2006, the volume of circumneutral pH biologically treated water in the pit decreased to approximately 23 Mgal.

Figure 4.4-7 shows a series of depth profiles for specific conductivity, temperature, oxidation reduction potential, pH, and dissolved oxygen collected in November 2006. The location of the chemocline that separates the upper and lower layers of water within Anchor Hill Pit is shown on the profiles charts. In November 2006, the chemocline location was at an approximate depth of 50 ft. It is unknown if the chemocline will remain in place until the water is treated at some future date or if the upper and lower layers of water stored within Anchor Hill Pit Lake will eventually mix.

The upper layer of water within Anchor Hill Pit is ARD generated on the site in spring 2006. The Anchor Hill pit was sampled in August 2006. Three samples were collected from the upper zone at depths of 5 ft, 20 ft, and 35 ft. The pH of the 20 ft and 35 ft samples was 3.19 su and 3.25 su, respectively. The pH of the 20 ft samples was 1.48 su, which is a strongly acid pH value for the Gilt Edge site. It is unknown why this layer of very acidic water was present at the 20 ft depth during this sampling event. Sulfate concentrations and mineral acidity also showed this layering. Sulfate concentrations ranged from 1,530 mg/L to 3,310 mg/L, with an average of 2,220 mg/L; mineral acidity ranged from 258 mg/L to 3,390 mg/L, with an average of 2,220 mg/L; iron concentrations ranged from 15.3 mg/L to 39 mg/L; and aluminum concentrations ranged from 35.8 mg/L to 37.2 mg/L, with an average of 24.8 mg/L. Other metals and metalloids were not analyzed during this sampling event but would be expected to occur at similar concentrations to other ARD on the site. Previous sampling data for the upper zone of Anchor Hill Pit are included in Appendix B.

The lower zone of Anchor Hill Pit exhibits significantly different water quality. This water is circumneutral pH, with high concentrations of sulfate and total dissolved solids and relatively low concentrations of the toxic heavy metals. The pH of the lower zone ranged from 7.66 to 7.97 during the August 2006 sampling event. The iron concentration of the water ranged from 2.11 to 16.3 mg/L, with an average concentration of 8.55 mg/L. Water within the lower zone of Anchor Hill Pit is more reduced than the upper zone as a result of the treatability study, which allows iron to remain in solution at circumneutral pH as ferrous iron (Fe^{+2}). Sulfate concentrations of the water ranged from 2,020 mg/L to 2,160 mg/L, with an average of 2,087 mg/L. A more complete chemical analysis was conducted on May 19, 2006. Data from this sampling event display the low metals concentrations present in this lower layer with cadmium, copper, and zinc concentrations of <0.001 mg/L, 0.008 mg/L, and 0.101

mg/L, respectively. The concentration of metalloids arsenic and selenium were <0.005 mg/L and 0.018 mg/L, respectively. Although the water contains low metals concentrations, the total dissolved solids concentration is high. The total dissolved solids concentration was 3,250 mg/L, and the sulfate concentration was 1,950 mg/L. Additional chemical data for the Anchor Hill Pit Lake are included in Appendix B.

4.4.2.4 Stormwater Pond

The Stormwater Pond is currently used for storage of HLP effluent, which is pumped from the sump on the southwest corner of the HLP into the Stormwater Pond on an intermittent basis. The chemistry of the Stormwater Pond is similar to the chemistry of the HLP effluent, which was discussed in a previous section. The extent of interaction between the stored ARD in the Stormwater Pond and the sludge stored within the pond is unknown.

4.5 Strawberry Creek Area

This section describes the nature and extent of contamination in the Strawberry Creek area, which includes a discussion of the following:

- Surface water
- Stream sediments
- Relic tailings
- Groundwater-surface water interactions

4.5.1 Surface Water

Surface water quality in Strawberry Creek was historically measured at compliance point CP001, located approximately 100 ft downstream from the confluence of Boomer Gulch and Strawberry Creek. Additionally, a number of water quality sampling locations are present along the creek and within the major tributaries to the creek, which include Cabin Creek, Hoodoo Gulch and Boomer Gulch. An additional sampling location is present at the WTP effluent discharge location. All of these sampling locations are shown in Figure 4.4-1. Since EPA and DENR took over the site, surface water quality was measured at some or all of these locations during the following sampling events:

- Low-flow synoptic sampling in October 2000, high-flow synoptic sampling in May 2001, and low-flow synoptic sampling in September 2001
- Quarterly operational monitoring sampling from 2002 through 2006
- Weekly WTP influent and effluent operational monitoring during discharge periods

In addition to the sampling investigations mentioned above, the United States Department of the Interior and United States Geological Survey conducted a low-flow

synoptic sampling investigation on Strawberry Creek in June 2003. Since the main focus of this investigation was to quantify the effect of contaminated groundwater on the creek, the results of this investigation are discussed in Section 4.5.4, Groundwater-Surface Water Interactions.

The following sections describe the water quality derived from all of these investigations. With exception to the synoptic sampling events, water quality data presented are limited to August 2002 through December 2006. The August 2002 date was chosen to illustrate the effects of implementing the Interim ROD for Water Treatment Operations (EPA 2001a) as well as current effects of WTP effluent discharge on Strawberry Creek water quality.

4.5.1.1 Water Treatment Plant Effluent

WTP effluent has been discharged in the upper reaches of Strawberry Creek prior to and since EPA and DENR took over the site. The discharge is located on Strawberry Creek approximately 260 ft upstream from the confluence of Cabin Creek. All WTP effluent data are included in Appendix B, with the sampling location name denoted as WTP-OUT, TREATEDEFF, WWTP EFFLUENT, or WTP EOP in the database. Sampling of the influent and effluent took place on a weekly basis, with exception to periods when the plant was shut down and no discharge occurred.

Data derived from the WTP effluent sampling location names WTP-OUT, TREATEDEFF, and WWTP EFFLUENT may have been collected in the WTP rather than at the end-of-pipe location on Strawberry Creek. These samples were also collected near the shutdown and startup periods; therefore, water may not have been discharged into the creek at those times.

During the period of record discussed in this section, the following shutdown and startup operational periods are noted:

- Beginning of August 2002 through end of September 2003: No treated water was discharged into Strawberry Creek. The HDS treatment plant was being constructed during this time period.

- End of September 2003 through end of August 2004: Regular treated water was discharged into Strawberry Creek using the new HDS treatment plant.

- End of August 2004 through end of September 2005: No treated water was discharged into Strawberry Creek. The treatment plant was shut down due t a lack of available ARD to treat as a result of drought conditions and sequestration of stored ARD in the Anchor Hill pit for the treatability test.

- October 2005 to present: Regular treated water was discharged into Strawberry Creek. Shutdown during this most recent period occurred infrequently and for limited time periods. Although the weekly discharge volume varied over this period, some quantity of treated water was discharged by the end of every weekly period.

Water quality parameters measured at the WTP effluent varied over the years, but for a majority of samples, the following parameters were analyzed: pH, conductivity, temperature, turbidity, TSS, TDS, alkalinity, ammonia, nitrate, nitrite, sulfate, hardness, WAD cyanide, and dissolved and/or total recoverable metals/metalloids (e.g. aluminum, arsenic, calcium, cadmium, chromium, copper, iron, lead, magnesium, manganese, mercury, nickel, selenium, silver, and zinc). Water quality results from this location are compared to the WTP effluent SWQS shown previously in Table 4.1-2. Parameters that are greater than these standards are determined and discussed below.

During the period of record discussed in this section, the following parameters were identified to be greater than the WTP effluent SWQS: ammonia, nitrate, conductivity, TSS, TDS, and dissolved cadmium, chromium, copper, and selenium. Concentrations of dissolved copper, dissolved selenium, and TSS are shown in Figures 4.5-1 through 4.5-3, respectively. SWQS for dissolved copper were computed based on the sample's hardness. Discharge hardness levels are generally greater than 400 mg/L $CaCO_3$, ranging from 195 mg/L $CaCO_3$ to 1,530 mg/L $CaCO_3$. A further discussion of WTP effluent and Strawberry Creek hardness is presented in Section 4.5.1.2. Note that the chronic standard for cadmium (0.64 µg/L) and selenium (4.6 µg/L) are less than their respective laboratory detection limits (1.0 µg/L for cadmium and 5.0 µg/L for selenium). As a result, non-detect results may or may not exceed the chronic standards for these constituents. To reflect this graphically, non-detect selenium concentrations are shown as one-half the detection limit on Figure 4.5-2. Cadmium concentrations are not presented in a figure. For a total of 121 samples collected and analyzed for cadmium, 111 samples were non-detect. All of the detected samples are greater than the SWQS; however, only 1 out of the 10 detected samples were above 1.0 µg/L.

During the most recent operational period (October 2005 to present), only one dissolved copper sample was measured above the SWQS, in August 2006. Selenium concentrations were nearly always greater than the SWQS; however, the site has an interim waiver on the selenium WTP effluent standard. Similarly, the site has an interim waiver on TDS standards and conductivity standards by association. Both TDS and conductivity are nearly always greater than their respective SWQS.

TSS concentrations detected above the 24-hour composited sample standard (10.0 mg/L) and grab sample maximum standard (17.5 mg/L), as shown in Figure 4.5-3, mostly occurred during the September 2003 through August 2004 operating period, or near the shutdown and startup periods. Elevated nitrate concentrations above the SWQS were observed from December 2003 through July 2004. High WTP influent nitrate levels during this period were also observed (data not shown). The presence of nitrate at that time in the influent/effluent is likely the result of residual ANFO present in the Ruby Repository and HLP effluents, which were periodically pumped into the treatment plant system. The remaining parameters measured above WTP effluent SWQS are limited to relatively infrequent spikes. Ammonia was detected above the SWQS in February 2006, and three chromium measurements were above the hexavalent chromium chronic standard (11 µg/L) in July and August of 2004.

4.5.1.2 Compliance Point CP001

Water quality and flow have been measured at CP001 weekly since 1993; however, only data after July 2002 are presented in this section. Water quality parameters measured at CP001 are similar to the WTP effluent parameters, with the exception of conductivity and TDS, which were not regularly measured at CP001. Water quality results from this location are compared to the SWQS shown in Table 4.1-2. Parameters measured above these standards are determined and discussed below. All water quality data are included in Appendix B.

Hardness

Although hardness is not a constituent included in the SWQS, it is important to note that current discharges into Strawberry Creek are directly affecting the hardness level of the stream, which in turn affects some of the dissolved metal criteria, as described in Section 4.1.

Figure 4.5-4 illustrates hardness concentrations and weekly WTP discharge volumes since August 2002. Daily hardness concentrations are calculated as a function of the measured dissolved calcium and magnesium concentrations. Historically (pre-2002), Strawberry Creek hardness has been high (i.e. > 200 mg/L $CaCO_3$). Analysis of the WTP effluent into Strawberry Creek shows that elevated levels of calcium and magnesium are consistently present, and as a result, Strawberry Creek hardness measured at CP001 has been shown to increase dramatically during WTP discharge periods. Upon conversion of the WTP to an HDS plant in September 2003, residual calcium levels in the WTP effluent further increased.

During construction of the new HDS WTP (from August 2002 until the end of September 2003), the average stream hardness at CP001 was 286 mg/L $CaCO_3$. During the regular WTP operating period from September 2003 through August 2004, the average stream hardness increased to 1,182 mg/L $CaCO_3$. From August 2004 through September 2005 during WTP shutdown, the average hardness again decreased to 349 mg/L $CaCO_3$. Spikes in hardness (greater than 1,000 mg/L $CaCO_3$) were observed in March and August 2005 when Anchor Hill Pit water (hardness of greater than 1,000 mg/L $CaCO_3$) was being discharged into Strawberry Creek. From October 2005 until December 2006, regular WTP discharge had again increased the average stream hardness to 881 mg/L $CaCO_3$.

During the mid-April through June 2006 time period, significant drops in CP001 hardness were observed while large volumes of WTP effluent were being discharged. As indicated in the Strawberry Creek hydrograph (Figure 3.5-3), flow rate during this time period was extremely high due to increased stormwater runoff and snowmelt freshwater additions to the creek, which diluted the CP001 water quality. One additional drop in hardness was observed during October 2006. This hardness fluctuation corresponds with the Pilot Scale Surge Pond Gypsum Precipitation Test in which WTP effluent was re-routed to either the Sunday Pit or the Surge Pond for a period of 6.5 days rather than discharged into Strawberry Creek.

This historical comparison indicates that the natural stream hardness is below 400

mg/L $CaCO_3$, which is the maximum hardness used in calculating hardness dependent SWQS. The calcium rich WTP discharge is increasing the stream hardness.

Cadmium
Daily total recoverable and dissolved cadmium results for CP001 are illustrated in Figure 4.5-5. The detection limit for cadmium is 1.0 µg/L. Samples that are non-detect are shown as one-half the detection limit on Figure 4.5-5 in order to distinguish between non-detect values and detected values at the 1.0 µg/L concentration. Since the chronic SWQS for cadmium is less than detection limit, non-detect values shown may or may not be greater than the standard.

Generally, spikes in dissolved cadmium concentrations were observed during the spring to early summer seasons, with some samples exceeding the acute SWQS . Precipitation and stream flow are much higher during this season; therefore, the seasonal cadmium fluctuations are most likely due to increased load from stormwater runoff rather than from WTP effluent. WTP effluent data presented in Section 4.5.1.1 showed that elevated cadmium concentrations were not present during these periods. Figure 4.5-5 also indicates that the difference between total recoverable and dissolved cadmium concentrations is minimal, which suggests that increased cadmium is due primarily to increased dissolved loads.

Copper
Daily total recoverable and dissolved copper results for CP001 are illustrated in Figure 4.5-6. Copper concentrations were greater than the chronic SWQS in November and December 2003, January 2004, and May 2006. Spikes in copper concentrations during the spring to early summer months were also observed. Although the frequency of copper detections above the SWQS is limited, elevated copper concentrations at CP001 are evident during WTP operational periods. During the shutdown period from August 2004 through October 2005, a decrease in dissolved and total copper concentrations was observed. The seasonal fluctuations of copper are not as evident as for cadmium because of the WTP effluent influence.

Selenium
Daily total recoverable and dissolved selenium results for CP001 are illustrated in Figure 4.5-7. As for cadmium, non-detect selenium samples are shown as one-half the detection limit. Dissolved selenium was measured only twice since August 2002, with one result in June 2004 greater than the chronic SWQS. Note that the SWQS for selenium are not dependent on the sample's hardness, and the chronic standard is less than the laboratory detection limit (5 µg/L). Elevated total recoverable selenium concentrations were observed only during WTP operational periods.

Zinc
Daily total recoverable and dissolved zinc results for CP001 are illustrated in Figure 4.5-8. One zinc sample was greater than the acute and chronic SWQS in May 2003. Variations in zinc concentrations are similar to cadmium, with more consistent spring to early summer spikes. Minimal zinc is present in the WTP effluent; therefore, no effect by the WTP effluent on CP001 zinc is observed.

Total Suspended Solids

The TSS daily results for CP001 are illustrated in Figure 4.5-9. One TSS sample was greater than the daily maximum SWQS (158 mg/L) in June 2005. Note that the TSS surface water SWQS for Strawberry Creek are much higher than the WTP effluent criteria. No correlation between elevated WTP effluent TSS and CP001 TSS is observed.

4.5.1.3 Synoptic Sampling Investigations and 2002 Quarterly Monitoring

Synoptic sampling data from Strawberry Creek and its tributaries helps to further identify the nature and extent of contamination from mine-related activities. A measurement report of the synoptic sampling investigations and 2002 quarterly operational monitoring, *Strawberry Creek and Bear Butte Creek Surface Water, Sediment, and Bank Material Measurement Report* (CDM 2003f) was created in 2003. This report describes the results of the three synoptic sampling investigations conducted in 2000 and 2001 as well as the quarterly operational monitoring data collected in 2002. The quarterly operational monitoring program for Strawberry Creek and its tributaries is conducted to assure compliance with the SWQS during water treatment and to define the nature and extent of contamination. This program monitors water quality within Strawberry Creek and its three major tributaries, Cabin Creek, Hoodoo Gulch, and Boomer Gulch. A summary of the findings of these investigations is presented in this section.

All water quality data for the synoptic sampling investigations and 2002 quarterly operational monitoring are located in Appendix B. Table 4.5-1 shows the applicable sampling locations discussed in this section. Water quality parameters measured during these investigations include the same parameters described in Sections 4.5.1.1 and 4.5.1.2. Additional parameters include sodium, potassium, fluoride, chloride, bromide, and dissolved/total recoverable antimony, barium, beryllium, cobalt, silica, strontium, thallium, and vanadium.

Not all locations were sampled for each of the sampling events due to field conditions and/or direction by EPA. Deviations from the analytical parameter lists for respective SAPs for these investigations were discussed in Section 2.5.3.1. Due to the historic nature of these data (e.g. pre-HDS treatment plant installation), water quality parameters are not compared to the SWQS.

The eight sampling events during this period can be divided into two groups: WTP effluent and no WTP effluent. The treatment plant was discharging to Strawberry Creek during October 2000 (synoptic), May 2001 (synoptic), and May 2002 (quarterly). Effluent was not discharged into Strawberry Creek during the remainder of the sampling events (September 2001 [synoptic], February 2002 [quarterly], April 2002 [quarterly], August 2002 [quarterly], and October 2002 [quarterly]).

This section includes discussions of the following:

- pH
- Conductivity
- Oxidation-reduction potential
- Major anions and cations
- Metals/metalloids
- Physical parameters and nutrients

pH

Figure 4.5-10 illustrates laboratory and field pH measurements collected within Strawberry Creek for each of the sampling events. The WTP effluent is a well-buffered water due to the treatment process and can absorb a substantial amount of ARD without showing a significant impact. In other words, ARD entering Strawberry Creek via groundwater or ARD generated in sediments or bank material will have little impact to the water quality due to the buffering capacity under this type of flow regime. Conversely, during sampling events when the WTP was not discharging to Strawberry Creek, there appeared to be two distinct regions where an ARD source is contributing to Strawberry Creek. This was more evident during these sampling events because of the lower buffering capacity of the water within Strawberry Creek. The regions where ARD is contributing to Strawberry Creek are above the confluence with Cabin Creek and above the confluence with Hoodoo Gulch.

Overall, pH ranged from 4.5 su to 9.7 su. Fluctuations of greater than 0.5 pH units were observed for some of the sampling events. The major mechanisms responsible for pH changes within the creek are acidic groundwater contribution (lowering pH), oxidation of sulfidic relic tailings within the streambed and/or bank material (lowering pH), and dilution by tributaries (raising pH). Further discussions of relic tailings and groundwater interactions with Strawberry Creek are discussed in Sections 4.5.3 and 4.5.4, respectively.

Conductivity

Figure 4.5-11 shows laboratory and field conductivity measurement results for all sampling events. The WTP effluent contains a large amount of dissolved solids (e.g., ions) that are capable of carrying a charge (i.e., method by which conductivity is measured). These dissolved solids are mostly sodium (from the former sodium hydroxide WTP) and sulfate. During the sampling events when the WTP was discharging to Strawberry Creek, the conductivity decreased as the water flowed downstream and was diluted by tributaries and groundwater inflow. When the WTP was not discharging to Strawberry Creek, the conductivity measurements either increased as the water flowed downstream or remained relatively constant with distance downstream.

Oxidation-Reduction Potential

The ORP field measurements from sampling locations within Strawberry Creek are illustrated in Figure 4.5-12. ORP is a relative measure of the abundance of easily freed electrons within a solution. A reduced solution (low ORP) will readily give up its electrons to oxidized constituents (e.g., ferric iron, dissolved oxygen, manganese (IV), etc.) with which it comes in contact. Conversely, an oxidized solution (high ORP) will strip electrons from reduced constituents (e.g., ferrous iron, sulfide, manganese (II), etc.) with which it comes in contact. ORP can help with interpreting results by indicating if a water is reducing or oxidizing. In many cases, this field measurement can be used to determine if the water is in intimate contact with the atmosphere or if all the oxidants present have been consumed by abiotic or microbiologically mediated reactions.

The ORP results indicate that there is an influence above the confluence with Hoodoo Gulch that is causing the ORP to reduce in Strawberry Creek. However, the influence is short lived, and the ORP rebounds before the confluence with Boomer Gulch. This reduction in ORP may be an indication of groundwater entering the creek and/or oxidation of relic tailings within the alluvial material releasing reduced constituents (e.g., ferrous iron, manganese (II), etc.) to the creek.

Major Anions and Cations

- **Major cations (calcium, magnesium, sodium, and potassium) (Figure 4.5-13).** During the three sampling events when the WTP was discharging (i.e., October 2000, May 2001, and May 2002), the major cation profiles were nearly identical, with sodium dominating the solution followed by calcium, magnesium, and potassium. Because of the high initial concentrations of major cations caused by the WTP effluent, only minor dilution occurred at the confluences with Cabin Creek or Boomer Gulch. When the WTP was not discharging, the contributions from both Cabin Creek and Boomer Gulch were much more evident. During these sampling events, the highest concentrations of cations were observed upstream of Cabin Creek and between Cabin Creek and Boomer Gulch, which is consistent with the varying trends of pH and conductivity. Note that sample data from the February and April 2002 sampling events are insufficient to be included in the general conclusions for non-WTP discharge sampling events due to the lack of locations sampled.

- **Major anions (sulfate, chloride, total alkalinity, and fluoride) (Figure 4.5-14).** Anions were not analyzed during the April 2002 sampling event. The most significant changes in anion concentrations occurred due to dilution of Strawberry Creek by Cabin Creek and Boomer Gulch, as well as an increase in alkalinity by Boomer Gulch. As with major cations, WTP effluent caused an increase in major anion concentrations. Note that the chloride concentration during the May 2001 sampling event was higher than any other due to the addition of ferric chloride within the treatment plant.

The results from the furthest downstream location on Strawberry Creek (i.e., SWCDM32 or CP001) are plotted in a Piper diagram shown in Figure 4.5-15. The

cations are plotted on the left triangle based on the relative milliequivalents of each cation, and the anions are plotted on the right triangle using the same approach. The points on both the cation triangle and the anion triangle that represent one sample are projected onto the diamond section of the Piper diagram where the points within the diamond represent both the cation and anion makeup. The concentric rings around the points on the diamond represent the calculated total dissolved solids concentration (scale on left of diagram). Samples in Strawberry Creek are dominated by sodium and sulfate especially during the sampling events when the plant was discharging. During the May 2001 sampling event, when ferric chloride was added in the WTP, the contribution from chloride increased substantially and was slightly greater than 10 percent. When there was no WTP discharge to Strawberry Creek, the relative contribution from carbonate+bicarbonate increased to between 5 percent and 15 percent. During these same sampling events, sodium plus potassium became less dominant while the calcium to magnesium ratio remained relatively constant.

Metals

Total recoverable and dissolved concentrations of aluminum, cadmium, copper, manganese, and zinc within Strawberry Creek are illustrated in Figures 4.5-16 through 4.5-20, respectively. These five metals were chosen to be included in this discussion, rather than other metals, because of their concentrations within Strawberry Creek in comparison to the SWQS or their abundance within the creek (e.g., aluminum and manganese).

- **Aluminum**. Concentration profiles within Strawberry Creek (Figure 4.5-16) during the sampling events indicate that the majority of aluminum within the creek is associated with the particulate phase. Total concentrations within Strawberry Creek were relatively high during the fall 2000 sampling event due to an upset in treatment operations, which caused additional aluminum, among other constituents, to be released to Strawberry Creek. During the spring 2001 sampling event, the total concentrations were lower than in the previous sampling event. However, the dissolved aluminum constituted a greater proportion of the total.

  During the sampling events when the WTP was not discharging, aluminum concentrations at location SWCDM23 (directly upstream from the confluence with Cabin Creek) were much higher than at other locations. These results, along with many other parameters/elements measured at this sampling location, indicate this region of Strawberry Creek is being influenced by ARD-impacted inflows. The dilution of Strawberry Creek by Cabin Creek substantially reduced aluminum concentrations below the confluence.

- **Cadmium**. Concentration profiles within Strawberry Creek (Figure 4.5-17) during the sampling events indicate that nearly all of the cadmium present is dissolved, and the concentrations decreased as Strawberry Creek approached Bear Butte Creek. Note that non-detect cadmium concentrations for Figure 4.5-17 are not shown as one-half the detection limit. For all sampling events over the 2-year period, concentrations ranged from non-detect to 13 µg/L for all locations except

SWCDM23. Similar to aluminum, spikes in cadmium were observed at this location for the three sampling events when no WTP discharge occurred, with concentrations ranging from 35 µg/L to 72 µg/L.

- **Copper**. Concentration profiles in Strawberry Creek (Figure 4.5-18) during the sampling events were similar to the aluminum concentrations profiles. The majority of copper present in Strawberry Creek was associated with the particulate phase for most of the creek. Both the total and dissolved concentrations decreased as Strawberry Creek approached Bear Butte Creek. Notice that during the non-WTP discharge sampling events, the concentrations increased between the first sampling location and the confluence with Cabin Creek.

- **Manganese**. Concentration profiles in Strawberry Creek (Figure 4.5-19) during the sampling events all showed an overall decrease with distance. However, during each sampling event, concentrations increased upstream from the confluence with Hoodoo Gulch. Similar to all other metals mentioned, an increase in the manganese concentration prior to the confluence with Cabin Creek was observed. Nearly all of the manganese is present as dissolved species within Strawberry Creek.

- **Zinc**. Concentrations profiles in Strawberry Creek (Figure 4.5-20) during the sampling events basically showed a decreasing trend with distance. However, in a majority of the sampling events, dissolved concentrations were greater than the total concentrations, indicating analytical difficulties. However, these data were validated and deemed usable. In all concentration profiles, there was a zinc increase directly upstream from the confluence with Hoodoo Gulch, similar to what was noted for manganese concentrations. Also, the same spike in zinc concentrations was also observed at SWCDM32. No major influence on Strawberry Creek zinc concentrations was observed from the WTP effluent.

Physical Parameters and Nutrients

- **TDS**. Concentrations in Strawberry Creek are illustrated in Figure 4.5-21. The TDS trends within Strawberry Creek are nearly identical to the conductivity trends (Figure 4.5-11), with decreasing concentrations as Strawberry Creek approaches Bear Butte Creek, when the WTP is discharging, and an increasing trend during the sampling events when the WTP was offline. The dilution effects from the Strawberry Creek tributaries are more pronounced during the non-WTP discharge sampling events.

- **TSS**. Concentrations within Strawberry Creek are illustrated in Figure 4.5-22. The TSS concentrations during the fall 2000 sampling event showed a decreasing trend with distance from the outfall except for a spike in TSS directly below the confluence with Hoodoo Gulch. The TSS profiles for the remainder of the sampling events showed spikes around the confluence with Cabin Creek and around the confluence with Hoodoo Gulch.

- **Nitrate/nitrite**. Concentrations within Strawberry Creek are illustrated in Figure 4.5-23. The source of nitrate/nitrite within Strawberry Creek is likely degradation of cyanide and/or ANFO, which is present in WTP effluent. The nitrate/nitrite concentrations display a decreasing trend as Strawberry Creek approaches Bear Butte Creek during periods when the WTP is discharging because the elevated concentrations originally present in the WTP effluent are diluted by tributary and groundwater inflows into Strawberry Creek.

4.5.1.4 2003 through 2006 Quarterly Operational Monitoring

Water quality parameters measured for the 2003 through 2006 quarterly operational monitoring are similar to the CDM synoptic sampling and 2002 quarterly sampling parameters. For the period of record described herein, variations in water quality parameters and sampling locations occur between different sample dates as a result of changing work assignments and/or direction by EPA. All water quality data for the quarterly operational monitoring is located in Appendix B.

Table 4.5-1 presents the list of sampling locations and months of samples collected. Two quarterly sampling events were conducted in 2003, one in January and one in August. The January 2003 sampling event included a condensed list of locations compared to the synoptic and quarterly sampling conducted from 2000 through 2002. The August sampling event, however, included the full list of locations compared to the previous sampling.

Starting in 2004 through 2006, the quarterly operational monitoring sampling list included the following locations: SWCDM11 and SWCDM32 on Strawberry Creek and OPCDM06 and SWCDM31 as tributaries (Hoodoo Gulch and Boomer Gulch, respectively). Note that only two quarterly sampling events were conducted in 2004. As described in Section 2.5.3.1 for the O&M surface water investigation, data for SWCDM11 and OPCDM06 from 2004 through 2006 are not considered usable for describing nature and extent of contamination, as a result of the two locations being possibly switched during sampling events.

In addition to the locations presented above, the quarterly operational monitoring program included monthly sampling at BMRCK01, CLVT01 and HD01. Monthly monitoring for these locations occurred either between the quarterly sampling or on the same months as the quarterly sampling; however, not all months were sampled under this program for these locations.

The following discussion of water quality includes five subcategories:

- 2003 quarterly sampling
- CLVT01
- HD01
- BMRCK01/SWCDM31

- 2004 through 2006 SWCDM32

2003 Quarterly Sampling

This subsection discusses the water quality gathered from the two quarterly sampling events conducted in 2003 on Strawberry Creek and its tributaries. No WTP effluent was being discharged during these two sampling events. Locations sampled during the 2003 quarterly investigations are shown in Table 4.5-1. The pH for the 2003 quarterly sampling remained within acceptable limits set forth by the SWQS; therefore, data are not shown with respect to distance along Strawberry Creek. All TDS and TSS concentrations for Strawberry Creek and its tributaries were below the SWQS.

Dissolved and total recoverable aluminum, iron, cadmium, copper, manganese, and zinc concentrations are illustrated in Figures 4.5-24 through 4.5-29, respectively. Results are shown with respect to distance along Strawberry Creek, similar to that shown in Section 4.5.1.3. Note that the SWQS are not included on these figures and that cadmium non-detect concentrations are not shown as one-half the detection limit. In general, a decrease in all water quality constituents is observed as water moves further downstream toward Bear Butte Creek. For the January 2003 investigation, spikes in iron, manganese and zinc concentrations were observed at SWCDM10 between Cabin Creek and Hoodoo Gulch. These spikes are possibly due to an influx of ARD-impacted groundwater. Note that similar spikes in these constituents were observed at SWCDM10 for the non-WTP discharge sampling events described in the previous section.

For the August 2003 investigation, the highest concentrations of all of the metals shown in Figures 4.5-24 through 4.5-29 were observed near the upstream end of Strawberry Creek (locations SWCDM23 and SWCDM06), with the exception to iron. Since the treatment plant was shutdown during this sampling period, higher concentrations of these metals may be the result of ARD-impacted groundwater influx (as evident from the 2000 through 2002 sampling) and/or a result of discharge from the 36-inch culvert (location CLVT01). Water quality at location CLVT01 is discussed in the next section. Dissolved cadmium, copper, and zinc concentrations were greater than SWQS for this area of the creek. The concentrations of these constituents decreased between Cabin Creek and Hoodoo Gulch. This may be attributable to dilution by tributaries, groundwater inflows or adsorption.

All of the remaining constituents applicable to the SWQS that were measured (alkalinity, ammonia, WAD cyanide, nitrate/nitrite, and dissolved arsenic, cadmium, copper, lead, nickel, and selenium) were either non-detect or near their respective detection limits for a majority of the samples.

CLVT01

CLVT01 represents the freshwater diversion discharge into Strawberry Creek, which is located upstream of the WTP effluent. This location has been sampled since October 2002 with an irregular monthly frequency. Figure 4.5-30 illustrates the pH for CLVT01 over the period of record. pH values range from 5.5 su to 7.9 su, with a noticeable

decline in 2005 and 2006 below the lower bound SWQS. This time period represents the accelerated deterioration of the old 36-inch culvert freshwater diversion line. Over time, an increased amount of ARD-impacted water had been seeping into the culvert, resulting in poor water quality of the freshwater diversion. This culvert was replaced in September 2006; however, no water quality data are available after the replacement of this culvert in 2006 due to lack of flow within the culvert.

Figure 4.5-31 illustrates the hardness and sulfate concentrations. Note the limited data set available for sulfate. Elevated hardness is a result of increased dissolution of calcium and magnesium concentrations by ARD. Compared to the WTP effluent, CLVT01 sulfate and hardness are generally lower.

The remainder of constituent concentrations measured support the conclusion that ARD-impacted water was present in the freshwater diversion. Figure 4.5-32 illustrates the dissolved and total recoverable aluminum and iron concentrations. Although iron concentrations are generally low or less than the detection limit (50 µg/L), elevated aluminum is evidence of ARD, particularly in the winter of 2005 to 2006. Figures 4.5-33 through 4.5-36 illustrate the dissolved and total recoverable concentrations for cadmium, copper, selenium, and zinc, respectively. The highest dissolved concentration for each of these constituents was observed in the winter of 2005 to 2006, corresponding to the more acidic pH present and higher aluminum concentrations. Dissolved concentrations for each of these parameters were consistently greater than the SWQS.

The remainder of measured constituents applicable to the SWQS (TSS, ammonia, WAD cyanide, nitrate/nitrite, and dissolved lead) were either non-detect or near their respective detection limits.

HD01

Location HD01 is the exact same location as OPCM06 on Hoodoo Gulch just prior to entering Strawberry Creek. The HD01 location name was utilized in between quarterly sampling events. Historically, this location represents the effluent from the hard bucket treatment system within Hoodoo Gulch. This system was removed in the fall of 2005 and replaced with the Hoodoo collection system. The period of record for this location extends from March 2003 through present. Figure 4.5-37 illustrates the pH for HD01 over the period of record, showing pH values range from 4.8 su to 8.0 su. The low pH of 4.8 on May 1, 2006 may represent leakage of ARD not captured by the collection system. Note that since Hoodoo Gulch is not classified as a marginal coldwater fishery like Strawberry Creek, its pH SWQS are different than Strawberry Creek. The upper and lower bounds for Hoodoo Gulch are 9.5 su and 6.0 su, respectively.

Figure 4.5-38 illustrates the hardness and sulfate concentrations. Note the limited data set available for sulfate. Since 2002, hardness has consistently stayed near 400 mg/L. Sulfate concentrations are lower than that present in the WTP effluent or in Strawberry Creek during WTP discharge periods.

Figures 4.5-39 through 4.5-42 illustrate the dissolved and total recoverable concentrations for aluminum and iron, cadmium, copper, and zinc, respectively. Some of the samples were greater than the SWQS for cadmium, copper, and zinc as shown on the figures. With exception to dissolved iron, the highest dissolved and total recoverable concentrations for all these constituents were observed on May 1, 2006. These high metal concentrations correspond with the acidic pH measured for that sample, evident of possible ARD leakage into Strawberry Creek. The remainder of measured constituents applicable to the SWQS (TSS, ammonia, WAD cyanide, nitrate/nitrite, dissolved lead, and dissolved selenium) were either non-detect or near their respective detection limits.

BMRCK01/SWCDM31

BMRCK01 is located next to SWCDM31 in Boomer Gulch. Starting on the first quarterly date for 2005, the location BMRCK01 replaced SWCDM31 during all subsequent quarterly sampling events for Boomer Gulch sampling. Prior to 2005, BMRCK01 was sampled in between quarterly sampling events. SWCDM31 quarterly data from 2004 (two samples) are discussed in this section. The period of record presented extends from December 2002 through December 2006.

Overall, water quality at BMRCK01 is better than that observed at all previously discussed locations. Boomer Gulch has not been affected by mine-related discharges, and as a result, helps to dilute effluent in Strawberry Creek prior to reaching CP001 and Bear Butte Creek. Figure 4.5-43 illustrates the hardness and sulfate concentrations. Note the limited data set available for sulfate. The average hardness over the period of record is 124 mg/L as $CaCO_3$, much lower than Strawberry Creek, even during non-discharge periods. Figure 4.5-44 shows the dissolved and total recoverable iron and aluminum concentrations for comparison to other tributaries and locations on Strawberry Creek. As shown, both iron and aluminum concentrations are much lower than other locations shown previously.

The only sample detected to be greater than the SWQS for BMRCK01 is dissolved zinc on December 4, 2006 (188 µg/L). The source of zinc in the December 2006 sample is unknown. All dissolved zinc samples prior to this date were non-detect (except 58 µg/L detected on July 6, 2004). All of the remaining constituents applicable to the SWQS that were measured (TSS, ammonia, WAD cyanide, nitrate/nitrite, and dissolved arsenic, cadmium, copper, lead, nickel, and selenium) were either non-detect or near their respective detection limits for a majority of the samples.

2004 Through 2006 SWCDM32

Location SWCDM32 is downstream from CP001, just prior to the confluence with Bear Butte Creek. The period of record for this location extends from 2000 through present; however, only data from 2004 through 2006 are discussed below. Data from 2000 to 2002 were discussed in Section 4.5.1.3, and 2003 data were discussed in the 2003 Quarterly Sampling section.

Figure 4.5-45 illustrates the hardness and sulfate concentrations measured throughout the period of record. Although the frequency of sample data are much less than CP001, similar spikes in hardness were observed during discharge periods. Similar

concentrations of other metals, such as cadmium, copper, selenium, and zinc were also observed between CP001 and SWCDM32, with SWCDM32 concentrations being only slightly lower in some cases. Due to the limited data set, these constituents are not shown in a figure; however, the following high concentrations were observed on May 16, 2005: cadmium dissolved (5 µg/L) and total recoverable (6 µg/L), copper dissolved (12 µg/L) and total recoverable (33 µg/L), selenium dissolved (9 µg/L) and total recoverable (9 µg/L), and zinc dissolved (124 µg/L) and total recoverable (183 µg/L).

The only measurable parameters greater than the SWQS are dissolved selenium and cadmium, and TSS (583 mg/L on November 18, 2005). The SWCDM32 sample dates that were greater that the chronic SWQS for selenium and cadmium correspond with the same sample dates as CP001.

Dissolved and total recoverable aluminum and iron are shown in Figure 4.5-46. Note the high total recoverable aluminum and iron concentrations observed on May 16, 2005. This spike corresponds to similar CP001 data.

4.5.2 Stream Sediments

Sediment samples were collected during some of the synoptic sampling investigations mentioned previously as well as during the May 2002 quarterly sampling. Sediment sampling locations are the same as the surface water sampling locations; however, the terms SW in SWCDM and OP in OPCDM are replaced with SD and OPSD. Figure 4.4-1 shows the sediment sampling locations, illustrated as the corresponding surface water sampling location.

4.5.2.1 Synoptic Sampling and May 2002 Quarterly Sampling

Figure 4.5-47 illustrates the total concentrations of arsenic, cadmium, copper, lead, mercury, and zinc within the Strawberry Creek sediment. The remaining total metal/metalloid and total cyanide results are shown in Table 4.5-2 (a through d). These six parameters were selected for discussion because they represent the metals that are directly related to poor sediment quality and potential for a detrimental impact to the water quality within Strawberry Creek. Note that sediment results for the Strawberry Creek tributaries (SD05, OPSD02, SD25, SD27, OPSD06, and SD31) are not shown on Figure 4.5-47 but are displayed in Table 4.5-3.

The results show that:

- **Arsenic**. Arsenic concentrations (Figure 4.5-47a) appear to be increasing throughout Strawberry Creek. At all locations sampled during the May 2002 sampling event, the arsenic concentrations within the sediment were higher than during the previous three sampling events. The reason for this apparent increase in arsenic is not known. None of the arsenic concentrations in sediment were above the comparison criteria for sediment, which is the same as for soils.

- **Cadmium**. Cadmium concentrations (Figure 4.5-47b) do not show a discernable trend with distance from the WTP outfall or time.

- **Lead**. Lead concentrations (Figure 4.5-47d) appear to be increasing or remaining relatively constant, with respect to time.

- **Mercury**. The majority of the mercury concentrations (Figure 4.5-47e) were below the reporting limit shown. Mercury was only detected in sediments during the fall 2001 sampling event, with exception to sampling location SD28 during the spring 2001 sampling event.

- **Copper and Zinc**. Copper and zinc concentrations (Figures 4.5-47c and 4.5-47f, respectively) show an increase above Cabin Creek followed by a decrease between Cabin Creek and Hoodoo Gulch.

- **Thallium**. Thallium concentrations are not shown in a figure although nearly all of the concentrations measured were non-detect and below the comparison criteria. A maximum concentration of 1.9 mg/kg was detected.

4.5.2.2 Sediment Acid-Base Accounting Results

Strawberry Creek sediment ABA results are shown in Table 4.5-4. Sediments were only analyzed for ABA parameters during the first sampling event (fall 2000). Figure 4.5-48 illustrates the sulfur composition of the samples collected.

The total sulfur concentrations were substantially higher at sampling locations SD07, SD08, and SD24 than the remaining sampling locations within Strawberry Creek. Notice that the difference is primarily due to the increased amount of water-soluble and acid-soluble sulfates. This large amount of sulfate sulfur is probably due to the abundance of WTP precipitates that had settled within this region of Strawberry Creek. The amount of sulfide sulfur increases slightly with distance from the WTP outfall. The percent sulfide sulfur (HNO_3 and residual fractions) is plotted versus the NP:AP ratio in Figure 4.5-49. All of the Strawberry Creek sediment results indicate that they are not likely to generate acid, based on the criteria previously described in Section 4.2.

4.5.3 Relic Tailings

Mitigation actions that removed tailings from the Strawberry Creek drainage in 1993 and 1994 did not completely remove tailings located along the banks of Strawberry Creek extending downstream from the general area of Cabin Creek to at least the confluence with Hoodoo Gulch. In this area, BMC utilized heavy equipment to excavate a slot through the tailings to the approximate depth of the alluvium-bedrock interface. Tailings excavated from this slot were hauled to the site, amended with fly ash, and placed into repositories. Tailings that were located along the banks of this slot were not disturbed. These tailings represent a potential source of acidity and metals to Strawberry Creek.

Tailings that remain on the banks of Strawberry Creek are readily identified based on visual and chemical characteristics. The tailings are visually recognized as accumulations of sand-sized rock fragments, with color ranging from yellow-orange to reddish. The grain size of the tailings is a result of beneficiation, which occurred

during mineral processing activities. The color of the tailings results from the presence of secondary iron oxide and/or iron hydroxide minerals. The tailings deposits that remain in Strawberry Creek range from relatively homogeneous accumulations of tailings to mixtures of tailings with natural alluvium and organic matter. These mixtures result from natural stream depositional processes and soil development, which have occurred over the last approximately 70 years. The tailings deposits are acid generating and exhibit moderate to low paste pH values. Unconsolidated sediments that contain a fraction of tailings are difficult to recognize visually. These zones are recognized by low paste pH values as compared to nearby less impacted soils.

Geochemical characteristics of the tailings were evaluated in several phases between 2000 and 2003. The most detailed investigation was conducted during 2003 when 128 samples were collected from 32 transects. The transects were orientated perpendicular to Strawberry Creek at intervals of approximately 100 ft, encompassing the area extending from Cabin Creek to Hoodoo Gulch. These transects are shown on Figure 4.5-50. Four samples were collected from each transect at a depth of 2 to 6 inches. Tailings samples were not collected from depths exceeding 6 inches. Therefore, the tailings samples are biased toward the surficial deposits, which are more likely to be affected by surficial weathering process, colluvial sedimentation, and soil development. All transect samples were evaluated for visual characteristics and paste pH. A subset of samples with the lowest paste pH values were submitted for additional laboratory analyses, including total metals and cyanide, SPLP extraction tests, and ABA.

Samples of Strawberry Creek bank material were also collected during an investigation conducted in 2000. In this investigation, a total of 18 bank material samples were collected from both banks of Strawberry Creek. One sample was collected on the left and right bank of each sample point indicated on Figure 4.5-50 (sample points indicated by BM__). The location of samples collected in 2000 along the banks of Strawberry Creek correspond to the same locations as in-stream sediment and surface water samples collected in 2000 (Sections 4.5.1.3 and 4.5.2). The following evaluation of Strawberry Creek tailings includes evaluation of data collected in both investigations. Additional information regarding these investigations is included in CDM (2007f).

As with the source areas discussed in Section 4.2, the discussion of relic tailings in Strawberry Creek includes three key components:

- Total metals with potential to impact human health
- Load of water soluble contaminants
- Future potential to generate acid

4.5.3.1 Total Metals with Potential to Impact Human Health

All TAL metals as well as total cyanide were evaluated in the 2000 and 2003 sampling programs. Seven samples were evaluated in the 2003 program, and 18 samples were evaluated in the 2000 program. The samples were evaluated by ICP-AES with the EPA Method 3050b digestion. The 2003 samples were a subset of 128 transect samples that were based on samples with the lowest paste pH values. The 2003 total metals samples are therefore biased toward most acid generating samples. All of the 2000 samples were analyzed for total metals, so the 2000 sample set is not biased toward the most acid samples.

Comparison of total metals with potential to impact human health in 2000 and 2003 samples suggests that the biased population of 2003 samples does not significantly bias the 2003 data. Arsenic in the 2000 sample set ranged from 43.7 mg/kg to 221 mg/kg, with a median of 136 mg/kg. The 2003 sample set shows similar values, which range from 122 mg/kg to 299 mg/kg, with a median of 175 mg/kg. Thallium concentrations in 2000 samples ranged from less than the detection limit of approximately 1 mg/kg to 2.8 mg/kg, with a median value of 1.6 mg/g. Thallium concentrations in 2003 samples ranged from 1.6 mg/kg to 3.7 mg/kg, with a median of 2.05 mg/kg. None of these medians is greater than the comparison criteria for soil.

Other metals analyzed in the 2000 and 2003 sampling programs are shown in Table 4.5-5 and 4.5-6. Iron is generally enriched in the samples, which is also evident based on visual characteristics. Iron concentrations in the 2003 samples ranged from 3.2 to 6.1 percent.

4.5.3.2 Load of Water Soluble Contaminants

Acidity is an important control on the load of water soluble contaminants in the tailings deposits. One hundred thirty-two samples were evaluated for paste pH during the 2003 sampling program. Paste pH values ranged from 2.8 su to 7.6 su, with a median of 4.7 su. These values were from samples visually classified as tailings, tailings/soil mixture, soil, and road fill. Histograms of paste pH data from subsets of the 2003 data based on the visual classifications are shown in Figure 4.5-51. Samples classified as tailings or tailings/soil have moderate to low pH values. This population is skewed toward more acidic pH values in the general range of 3.6 su to 4.0 su. A few samples classified as tailings/soil exhibited circumneutral paste pH values. Histograms of samples classified as soil or road fill constitute a distinct sample population, exhibiting slightly acidic to circumneutral pH. Paste pH samples classified as soil ranged from 3.5 su to 7.2 su, with a median value of 5.0 su. Paste pH samples classified as road fill ranged from 4.9 su to 7.6 su, with a median value of 6.0 su.

Evaluation of paste pH data from the 2003 transect samples presented above show that the visual classification is generally capable of identifying areas where tailings are present. The presence of skewed distributions with high pH samples classified as tailings and a few low pH samples classified as soil suggests that the visual identification was not entirely successful in delineating areas impacted by tailings.

Therefore, a paste pH cut-off of 4.5 su was developed based on evaluation of the tailings-impacted and non-impacted data sets. Samples with a paste pH of 4.5 su or less were classified as tailings and tailings-impacted soils. These geographic locations of samples with paste pH of less than 4.5 su were used to compile the spatial distribution of tailings and tailings-impacted soils along the banks of Strawberry Creek from the general area of Cabin Creek to the confluence of Hoodoo Gulch. This interpreted spatial distribution is shown in Figures 4.5-52, 4.5-53a, 4.5-53b, and 4.5-53c. Note that paste pH values collected from the transect sampling are indicated on Figures 4.5-53a, 4.5-53b, and 4.5-53c.

SPLP analyses were completed on the same subset of seven samples from the 2003 data set as selected for total analyses. These samples were selected based on acidic paste pH values. Metal solubility is strongly controlled by pH, so the bias of the seven samples selected for SPLP analyses toward the most acidic samples is likely to select samples with high concentrations of soluble contaminants. The less acidic samples that were excluded from SPLP analyses would be more likely to exhibit lower concentrations of water-soluble metals. It is likely that the selected subsample of the 2003 sample set is generally representative of tailings and tailings-impacted soils although the subset is not a statistically valid subset of the entire 2003 sample population.

Figure 4.5-54 shows SPLP results for aluminum, copper, iron, lead, manganese, and zinc on a logarithmic scale for the subset of 2003 samples. Results for arsenic, barium, cadmium, chromium, mercury, selenium, and silver were all either non-detect or near the detection limits. Low concentrations of copper, iron, manganese, lead, and zinc were present in the SPLP extract solution. The data indicate that the tailings have the potential to contribute to metals loading to Strawberry Creek in the event of intermittent flushes of water through the tailings deposits. The 20:1 solids to liquids ratio of the SPLP test is substantially different from field conditions where the liquids to solids ratio may be on the order of 0.05 to 1 to 0.5 to 1. Therefore the SPLP extract metals concentrations can not be compared directly to surface water quality standards.

4.5.3.3 Future Potential to Generate Acid

Interpretation of ABA data is less critical for the Strawberry Creek tailings because the tailings are currently acid generating. ABA data for the tailings samples are summarized in Figures 4.5-55 and 4.5-56. Note that samples collected from both the 2000 and 2003 investigations are included on these figures. Tables 4.5-7 and 4.5-8 show the ABA results for the 2003 and 2000 investigations, respectively. As discussed previously, the 2003 data subset was selected based on samples with acidic paste pH values. The ABA data support the paste pH data, indicating that the samples do have the potential to generate acid.

Eighteen samples of Strawberry Creek bank material were submitted for ABA analyses during the 2000 sampling program. This data set is more representative of the bank material because samples were not selected based on acidic paste pH. The

total NNP of these samples ranges from -19 t/kt $CaCO_3$ eq. to 17 t/kt $CaCO_3$ eq., with a median of -4 t/kt $CaCO_3$ eq. The sulfide NNP ranges from -17 t/kt $CaCO_3$ eq. to 78 t/kt $CaCO_3$ eq., with a median of -2 t/kt $CaCO_3$ eq. The NP:AP ratio of the samples ranges from 0.1 to 14.8, with a median of 0.8. These data indicate that 50 percent of the samples are strongly acid generating and that the remainder of the bank material is somewhat less acid generating. It cannot be assumed that acid produced within zones of acid generating tailings will interact with neutralization potential that may be present in relatively less acid generating zones. It therefore must be concluded that the tailings do have the potential to generate acid in the future and that the products of acid generation have the potential to impact surface water quality within Strawberry Creek.

The current hydrogeological characteristics of the areas of tailings and tailings-impacted soils along Strawberry Creek affect temporal characteristics of potential adverse impacts to surface water in Strawberry Creek. Excavation of the slot through the tailings deposits extending to the approximate alluvium-bedrock interface has provided a mechanism to dewater the tailings deposits by gravity drainage into the stream. It is likely that most of the tailings deposits are unsaturated during much of the year. The tailings are exposed to surface oxidation, and water flow through the tailings is controlled by the infiltration rate of precipitation through the piles. It is likely that products of acid generation, including acidity and metals, are stored within the tailings during much of the year and that on an intermittent basis these products of acid generation are flushed into the stream on a short-term basis. This may cause impacts from the tailings to the aquatic ecosystem; however, impacts would likely be short term, related to large precipitation events or snow melt rather than continuous discharges of contaminants into the ecosystem.

4.5.4 Groundwater-Surface Water Interactions

Evaluation of groundwater-surface water interactions in the Strawberry Creek area utilizes data collected from surface water investigations, groundwater investigations, and a very detailed investigation completed by USGS (Kimball et al. 2006). Data collected from surface water and groundwater investigations in the Strawberry Creek area were discussed previously in Sections 3.3 and 3.5. Results of the USGS investigation are summarized in this section, and the USGS data are combined with data presented in Section 3.3 and 3.5 to provide an overall evaluation of the effect of groundwater-surface water interactions on the nature and extent of contamination in the Strawberry Creek area.

Important groundwater-surface water interactions affecting nature and extent of contamination in the Strawberry Creek area include the following:

- Surface and groundwater interactions along, and within, Strawberry Creek include ARD inflow from localized groundwater seeps, remnant tailings and surface inflow from Hoodoo Gulch. Non-ARD affected inflows are observed from Cabin Creek, Boomer Gulch and other groundwaters. Attenuation of ARD contamination along the length of Strawberry Creek is the result of significant

buffering capacity within the treated water discharge, sorptive reactions with iron precipitates, and dilution.

- Local infiltration of WTP effluent into groundwater occurs in the vicinity of the Oro Fino Mine in response to intermittent drawdown of the water level in the mine as a result of pumping to provide make-up water for the WTP. During periods when the WTP is not operating, this relationship changes with groundwater recharging surface water in the creek.

- Discharge of ARD-impacted groundwater to surface water was identified in the portion of Strawberry Creek immediately upstream of Hoodoo Gulch. This may be related to migration of ARD-related contaminants along the Selway Northwest and Selway Northeast fracture zones.

- Infiltration of WTP effluent from surface water into the near-surface alluvial aquifer adjacent to the creek appears to occur in the vicinity of monitor well BES-14.

4.5.4.1 Summary of USGS Investigation

The USGS investigation was conducted on June 26 and June 27, 2003 and utilized a chemical tracer method. The investigation included sampling of seeps, springs, and tributaries contributing surface water to Strawberry Creek. *USGS Scientific Investigations Report 2006-5006* (Kimball et al. 2006) provides a detailed discussion of the results of this investigation. The investigation provided data regarding the rate of inflow to the creek from surface water tributaries, identifiable seeps, and dispersed subsurface inflows from groundwater. The investigation also evaluated the chemical characteristics of these inflows. The focus of the investigation was identification of potential impacts to the creek resulting from migration of contaminants from the mine along major fracture zones extending from the Sunday Pit area to Strawberry Creek. The USGS investigation is a detailed snapshot of conditions that were present at the site in June 2003.

The site WTP was not operating between August 2002 and September 2003, so the plant had not discharged for approximately 10 months prior to the USGS investigation. Semi-passive treatment systems at Hoodoo Gulch and Pond C were operating at the time. These systems raised the pH of ARD by passing the ARD stream over solid sodium hydroxide, allowed for precipitation of solids in settling ponds, and discharged the water directly to Strawberry Creek and Hoodoo Gulch. Discharges from the Pond C system to Strawberry Creek at the upstream end of the USGS area of investigation were identified as the largest single metal load entering Strawberry Creek.

The USGS investigation determined that on the days of the test, the discharge in Strawberry Creek increased by 401 gpm between the discharge culvert located in Strawberry Creek just upstream from the confluence of Cabin Creek with Strawberry Creek and a point just upstream from the confluence of Strawberry Creek with Bear Butte Creek. Discharge at the upstream end of the study reach was 43 gpm. Tributary

inflows from Cabin Creek, Boomer Gulch and Hoodoo Gulch accounted for inflows of 154 gpm. An increase in the discharge of 247 gpm resulted from inflows from small springs and dispersed subsurface inflows. These data display the importance of groundwater discharge to surface water in providing base flow to Strawberry Creek.

The USGS study identified primary loading of cadmium, cobalt, nickel, and zinc occurring from the mine discharge and secondary loading occurring in the vicinity of the Oro Fino Mine Shaft and at two locations approximately 200 meters downstream. The WTP was not discharging during the USGS investigation, but discharges were occurring from the Pond C area into Strawberry Creek. The two downstream locations are spatially correlated with the intersection of the Selway Northwest fracture zone with Strawberry Creek. The USGS investigation determined that loading resulting from the inflows adjacent to Oro Fino Shaft and Selway Northwest fracture zone did not appear to have a substantial impact on surface water quality in Strawberry Creek.

USGS evaluated the inflow chemical data using cluster analysis, which is a statistical method intended to identify groups of samples with multivariate data that have similar characteristics. USGS identified four inflow groups designated as Group 1 though Group 4, with concentrations of most analytes ranging from low in Group 1 to high in Group 4. Median concentrations of sulfate, iron, manganese, and zinc in Groups 1 through 4 demonstrate this relationship.

- Sulfate ranged from 38.4 mg/L to 1,360 mg/L
- Iron ranged from less than detection to 34.8 mg/L
- Manganese ranged from 0.008 to 6.490 mg/L
- Zinc ranged from 0.047 mg/L to 2.540 mg/L

Groups 3 and 4 were the most impacted by mine-related contaminants. Group 3 included the mine discharge, inflows near Oro Fino Shaft and inflows from Hoodoo Gulch. Group 3 also included inflows from the north side of the stream that USGS thought may be related to water from the Rattlesnake fracture zone. Group 4 included inflows occurring in the vicinity of the Selway Northwest fracture zone. The Group 4 inflows exhibited the highest metal concentrations of the inflows sampled in the USGS investigation.

4.5.4.2 Evaluation of Identified Groundwater-Surface Water Interactions

Attenuation of ARD-related Contaminants

The dominant effect of groundwater-surface water interactions in Strawberry Creek is attenuation of dissolved contaminant concentrations in surface water. This is demonstrated by USGS data as well as data collected during a series of synoptic sampling events conducted by CDM (Figures 4.5-10 through 4.5-23). Attenuation of dissolved contaminant concentrations along Strawberry Creek is likely related to several mechanisms. These include dilution resulting from inflows at Cabin Creek,

Hoodoo Gulch and Boomer Gulch (223 gpm in June, 2003), dispersed inflows from groundwater (178 gpm in June 2003), the buffering capacity of treated water, and sorption to iron precipitates.

USGS demonstrated attenuation of dissolved contaminant mass loading in addition to attenuation of contaminant concentrations in Strawberry Creek. This suggests that sorption of dissolved contaminants to particulates is an important mechanism that attenuates dissolved contaminant loads along Strawberry Creek. Flocculation and settling of these particulates may sequester metals from suspension within the water column to the stream sediments.

Local Infiltration of Treated Water in Vicinity of Oro Fino Mine Shaft
Groundwater within the Oro Fino Mine is used for the site water supply. A pumping station is present at the shaft collar, which controls a submersed pump within the mine shaft. A major use of this facility is to supply make-up water for the site WTP to use for lime slaking and mixture of flocculent solutions. Water from Oro Fino Shaft is also used for general purposes on the mine site. The WTP currently uses Oro Fino water at a rate of approximately 15 gpm. Oro Fino water was also used for dust control during construction of the Ruby Repository in 2002 through 2003. Figure 4.5-57 shows temporal variations in the water table elevation in the paired well set BED-11/BES-11, which is located near the Oro Fino Mine Shaft. This figure demonstrates that pumping of Oro Fino Mine during active WTP operations causes a cone of depression that affects groundwater at BES-11 and BED-11. When the plant is running, a downward hydraulic gradient is present causing surface water from Strawberry Creek to recharge groundwater. It appears that the groundwater table rebounds during periods when the WTP is not operating. During these periods, an upward hydraulic gradient is present causing groundwater inflows to Strawberry Creek.

USGS completed their investigation during a period when the WTP was not running and an upwards hydraulic gradient was present, causing groundwater to discharge into Strawberry Creek. Based on the USGS cluster analyses, inflows in the Oro Fino area were classified as Group 3 inflows along with water at the mine discharge and Hoodoo Gulch. The mine discharge and Hoodoo Gulch were releasing treated ARD during this period. This water is circumneutral pH with low concentrations of heavy metals and high concentrations of sulfate and total dissolved solids. This water generally complied with discharge requirements of the Early Action Interim ROD of site water treatment, but the water exceeds site-specific groundwater standards for sulfate, electrical conductivity, and total dissolved solids.

Strawberry Creek inflows in the vicinity of Oro Fino Mine sampled by USGS did contain measurable concentrations of base metals. These metals may be related to oxidation of sulfide minerals within Oro Fino Mine or to interaction of groundwater with relic tailings. The intermittent pumping and drawdown of the Oro Fino Shaft would exacerbate oxidation and subsequent rinsing of contaminants from exposed rock surfaces within the mine. Relic tailings located on the banks of Strawberry Creek

are acid generating. Rinsing of soluble contaminants from relic tailings may also contribute to the base metal load observed by USGS.

As discussed in Section 4.3, groundwater in the vicinity of Oro Fino Mine exceeds site-specific standards. Based on evaluation of groundwater-surface water interactions in the Oro Fino Mine area, it is possible that contamination present within the bedrock groundwater system at this location is a result of infiltration of treated water into the cone of depression formed by pumping water from the Oro Fino Mine rather than migration of ARD-related contaminants in groundwater from the primary mine disturbance area.

Discharge of ARD-Impacted Groundwater to Surface Water in the Area Upstream from Hoodoo Gulch

A hypothesis that ARD-impacted groundwater is migrating through major fracture zones and discharging to surface water in a local area upstream from the confluence of Hoodoo Gulch with Strawberry Creek is supported by several lines of evidence, including USGS data, CDM synoptic sampling data, groundwater water quality data, geological data, and visual observations. The effect that this groundwater discharge is having on surface water quality in Strawberry Creek is incompletely understood, and additional surface water quality sampling in the area is in progress to evaluate whether this discharge is impacting compliance with surface water quality standards or causing unacceptable ecological risks.

USGS classified two inflows in this area as Group 4 based on cluster analyses. Group 4 inflows are the most-impacted inflows identified in the USGS investigation. These inflows contained the highest concentrations of most metals, the highest concentrations of sulfate and lower pH than other inflows. USGS also identified the greatest increase in colloidal iron concentrations at this location. Colloidal iron concentrations in Strawberry Creek decreased rapidly below Hoodoo Gulch, suggesting that dissolved iron entering Strawberry Creek upstream of Hoodoo Gulch is rapidly precipitating and depositing within stream sediments. Colloidal metals are particulate metals that are suspended in the water column. They are determined based on the difference between the filtered metals concentration and the total concentration. USGS also identified that colloidal copper concentrations were higher than dissolved copper concentrations in the vicinity of the Selway Northwest fracture zone. This suggests that dissolved copper was being sequestered into the solid phase through adsorption to colloidal iron precipitates.

CDM conducted a series of synoptic sampling investigations that included Strawberry Creek as discussed in Section 4.5.1.3. Figure 4.5-12 displays ORP measurements collected during the synoptic sampling investigations. A distinct reduction in ORP is apparent in this portion of Strawberry Creek during all synoptic sampling events. This is compatible with the discharge of ARD-impacted groundwater containing reduced iron into the stream. Rapid oxidation of this iron would lead to a decrease in the measured ORP in this portion of the stream. Oxidation of this iron under the circumneutral pH conditions present in Strawberry Creek would lead to rapid precipitation of iron hydroxide minerals. Figures 4.5-19, 4.5-20, and 4.5-25 display

concentrations of manganese, zinc, and iron in Strawberry Creek. These figures show that concentrations of these metals in surface water increased in this portion of Strawberry Creek.

Visual evidence in this portion of Strawberry Creek also supports the data provided by the USGS and CDM investigations. Seeps are present adjacent to Strawberry Creek in this area with associated blooms of orange-colored iron hydroxide precipitates. The abundance of these precipitates on the streambed increases markedly at this location and extends downstream past the confluence with Hoodoo Gulch to the general area of Boomer Gulch. The precipitates result from precipitation of iron, settling of the precipitates, and episodic transport of precipitates downstream.

Groundwater data from monitor well GWCDM14 support data interpretations presented above and suggest that the water chemistry observed in Strawberry Creek is a result of discharge of ARD-impacted groundwater to surface water. GWCDM14 is a bedrock monitoring well located within the Precambrian hydrogeologic unit. Figures 4.3-22 and 4.3-23 display concentrations of arsenic, cadmium, copper and zinc, TDS, and pH in well GWCDM14. The data show that groundwater at GWCDM14 is slightly acidic, with pH values ranging from about 5.2 su to 6.0 su. The groundwater at GWCDM14 contains very high concentrations of cadmium and zinc and elevated concentrations of copper. Figure 4.5-58 shows temporal variations in dissolved iron and pH in GWCDM14. Groundwater at this location contains high concentrations of iron at a slightly acidic pH. This indicates that the iron is in the ferrous oxidation state (Fe^{+2}) and that groundwater at this location is reduced. Discharge of this groundwater into oxidized surface water would result in rapid oxidation of ferrous iron to ferric (Fe^{+3}), and precipitation of iron hydroxides. This is compatible with data described previously that was developed from the USGS investigation, the CDM synoptic sampling programs, and the visual evidence.

Monitor well GWCDM14 is spatially associated with the Selway Northwest fracture zone, which extends from the Strawberry Creek area northwesterly to the approximate location of Langley Pit. The Selway Northwest fracture zone intersects the Selway Northeast fracture zone, which extends northeasterly from Southeast Langley pit to the Sunday Pit area. The geological and hydrogeological characteristics of these fracture zones were discussed previously in Sections 3.4.2 and 3.6.2.

Groundwater along the Selway Northeast fracture zone near Sunday Pit is strongly impacted by ARD-related contamination as shown by groundwater quality data collected at GE-MW-16, which was discussed previously in Section 4.3.3. The data from GE-MW-16 demonstrate a nitrate signature in addition to ARD impacts, which suggests a potential connection with ARD stored in Sunday Pit. ARD stored in Sunday Pit exhibits this nitrate signature as a result of storage of HLP and Ruby repository effluent, which contain nitrate from cyanide and ANFO degradation. Migration of contaminants in groundwater from the Sunday Pit area to Strawberry Creek via the Selway Northeast and Selway Northwest fracture zones may contribute to the observed ARD-impacted groundwater discharges into Strawberry Creek. These discharges may also be attributable to ARD generation in the Southeast Langley Pit

area and migration toward Strawberry Creek along the Selway Northwest fracture zone. A nitrate signature is not present in groundwater at monitor well GWCDM14, based on 2007 sampling data (Table 4.3-2). This suggests that ARD impacts to groundwater at GWCDM14 may be attributable to ARD generation at SE Langley Pit rather than migration of ARD from Sunday Pit.

USGS determined that the inflows to Strawberry Creek in this area did not appear to have a substantial impact on Strawberry Creek water quality based on their detailed investigation conducted on June 23 and 24, 2003. However, the USGS investigation represents a snapshot in time. Evaluations of temporal variations in groundwater quality at GWCDM14 shown in Figures 4.3-22, 4.3-23, and 4.5-58 show that the water quality at GWCDM14 is deteriorating and that increased impacts of ARD-related contamination are present. This suggests that migration of ARD-related contaminants in groundwater is occurring from relatively more impacted areas of the site toward Strawberry Creek. This is compatible with the potential contaminant migration directions shown on Figure 4.3-1. The very high cadmium and zinc concentrations in groundwater at GWCDM14 also indicate that these metals are also likely to be discharging to surface water. It is unknown if discharges of cadmium and zinc from groundwater at this location are impacting compliance with surface water quality standards or causing unacceptable ecological risks. Additional monitoring of surface water quality at this location should be considered in order to determine the magnitude of effects to surface water quality.

Infiltration of WTP Effluent into Alluvial Groundwater in Lower Strawberry Creek Area

As discussed previously, treated water discharged under the Early Action Interim ROD for site water treatment contains elevated levels of total dissolved solids and sulfate. Groundwater quality data presented in Figures 4.3-47 and 4.3-48 for alluvial monitor well BES-14 display a similar chemical signature. Alluvial groundwater at this location exceeds GWQS for sulfate, electrical conductivity, total dissolved solids, and sulfate. It is likely that the alluvial groundwater at this location is in communication with surface water discharged from the site WTP and that treated water moves either into or out of the alluvial system depending on the relative water levels alluvial groundwater and surface water in Strawberry Creek. The impacts to alluvial groundwater quality are not present at monitor well BED-14, the paired bedrock well at this location. This supports the interpretation that the observed impacts to alluvial groundwater are related to communication between alluvial groundwater and surface water rather than offsite migration of ARD-related contaminants through groundwater.

4.6 Bear Butte Creek

Bear Butte Creek is a perennial stream with a large drainage basin upgradient of the site tributaries. Strawberry Creek is a perennial tributary, and Terrible Gulch and Ruby Gulch are intermittent tributaries to Bear Butte Creek. Bear Butte Creek surface water is calcium-bicarbonate water with circumneutral pH, moderate TDS concentrations, and low toxic metal and metalloid concentrations.

Surface water quality in Bear Butte Creek was evaluated in specific remedial investigations conducted from 2000 to 2002 and as part of an operational monitoring program that has been conducted from 2000 through the present. The remedial investigations conducted between 2000 and 2002 evaluated Bear Butte Creek, Strawberry Creek, and several tributaries in detail. Results of these investigations provide a detailed overview of the creek based on conditions that existed during 2000 to 2002. Major changes in site environmental control infrastructure have been instituted since 2002, including construction of a new WTP; construction of new ARD collection systems at Ruby Gulch, Hoodoo Gulch, and Pond C; and abandonment of the use of sodium hydroxide reagents at the site. These changes have improved surface water quality in water discharged from the site. Operational monitoring data are less detailed than the remedial investigations conducted during 2000 to 2002, but the operational monitoring data provide the best information regarding the performance of existing environmental control infrastructure and current impacts to Bear Butte Creek.

Based on current data, surface water quality in Bear Butte Creek is not being impacted by site discharges to an extent that causes the water to significantly exceed SWQS. Operational monitoring data indicate that the site discharge flowing into Bear Butte Creek via Strawberry Creek does cause occasional exceedances in chronic and acute SWQS for cadmium and copper within Bear Butte Creek. The site also causes measurable increases in hardness and sulfate concentrations in Bear Butte Creek.

The discussion of the nature and extent of contamination in Bear Butte Creek focuses on recent data because important remedial actions have been completed at the site over the period of 2001 to 2006, which beneficially affect water quality in Bear Butte Creek. Historical data regarding Bear Butte Creek water quality are available in Appendix B. This evaluation focuses on the following data:

- Synoptic sampling investigations and 2002 quarterly operational monitoring
- 2003 through 2006 quarterly operational monitoring

4.6.1 Synoptic Sampling Investigations and 2002 Quarterly Monitoring

The CDM synoptic sampling investigations described in Section 4.5.1 (Strawberry Creek) included portions of Bear Butte Creek. A summary of the findings of these investigations relevant to Bear Butte Creek is presented in this section.

All water quality data for the synoptic sampling investigations and 2002 quarterly operational monitoring are located in Appendix B. Table 4.6-1 shows the applicable sample locations discussed in this section. Some sampling dates and locations do not include all of the parameters listed above because of field conditions. Deviations from the analytical parameter lists for respective SAPs for these investigations are discussed in Section 2.

- **pH (Figure 4.6-1).** Overall, pH measurements varied between 7.4 su and 8.6 su. During any one sampling event, pH varied less than 0.5 pH units. No significant impact by Strawberry Creek was evident.

- **Conductivity (Figure 4.6-2).** Overall, the sampling events indicate that the conductivity in Bear Butte Creek was substantially impacted by Strawberry Creek during 2000 to 2002. The magnitude of the impact is directly related to whether the WTP was discharging during the sampling event and the flow within both Bear Butte Creek and Strawberry Creek.

- **Oxidation-Reduction Potential (Figure 4.6-3).** The ORP results were relatively stable; however, during the spring 2001 sampling event, the ORP varied greatly (150 to 325 millivolts [mV]), with no discernable trend. The lowest ORP results occurred during the summer 2002 sampling event.

- **Major Cations and Anions.** All of the major cations, especially sodium (Figure 4.6-4) increase below the confluence with Strawberry Creek. The increase was less significant when the WTP was not discharging to Strawberry Creek although a substantial increase in sodium was present during every sampling event. The major anion (i.e., sulfate, chloride, total alkalinity, and fluoride) concentrations are shown in Figure 4.6-5. Sulfate concentrations increased substantially during all sampling events due to the contribution to Bear Butte Creek by Strawberry Creek. Fluoride also increased substantially during most of the sampling events, namely when the WTP was discharging. Chloride concentrations increased substantially during the spring 2001 sampling event when ferric chloride was being used within the WTP. Alkalinity was not affected by the contribution from Strawberry Creek.

  The results from above the confluence with Strawberry Creek (i.e., SWCDM33) and at the end of the study area (i.e., SWCDM40) for the sampling events are plotted in a Piper diagram shown in Figure 4.6-6. The Piper diagram indicates that Bear Butte Creek above Strawberry Creek is classified as a calcium-bicarbonate water, whereas, below Strawberry Creek it is a sodium-sulfate water. This analysis indicates that Strawberry Creek is altering the major ion composition of Bear Butte Creek.

- **Trace Metals/Metalloids.** Total and dissolved manganese concentrations are shown in Figure 4.6-7. Manganese was chosen out of the 21 trace metals analyzed because it is the only trace metal that is significantly impacted by Strawberry Creek. During the sampling events, when the WTP was discharging to Strawberry Creek, manganese concentrations increased substantially where the majority of the manganese added was dissolved. In all of these sampling events (e.g., fall 2000, spring 2001, and spring 2002), the manganese concentration decreased with distance from the confluence with Strawberry Creek. During the other sampling events, the manganese concentrations remained relatively constant.

- **Physical Parameters and Nutrients (Figure 4.6-8).** During every sampling event, TDS increased immediately downstream of the confluence with Strawberry Creek, except for the fall 2002 sampling event. When the WTP was discharging to Strawberry Creek (i.e., fall 2000, spring 2001, and spring 2002), the maximum TDS concentration was measured at the first sampling location below the confluence with Strawberry Creek. When the WTP was not discharging, the maximum TDS concentration was measured at the furthest downstream sampling location within Bear Butte Creek. The nitrate + nitrite concentrations within Bear Butte Creek are illustrated in Figure 4.6-9. During all of the sampling events, an increase occurred within Bear Butte Creek downstream from the confluence with Strawberry Creek

4.6.2 2003 through 2006 Quarterly Operational Monitoring

The quarterly operational monitoring program for Bear Butte Creek and its tributaries is conducted to assure compliance with standards for surface waters leaving the site. This program monitors water quality within Bear Butte Creek and at the three major tributaries to Bear Butte Creek, Strawberry Creek, Terrible Gulch, and Ruby Gulch. For the period of record described in this section, variations in analytes and sample locations occur between different sample dates as a result of changing work assignments and/or direction by EPA. All water quality data for the quarterly operational monitoring is located in Appendix B. Table 4.6-1 presents the list of sample locations and dates of samples collected.

Data are discussed for each of the following four sampling locations:

- SWCDM33
- SWCDM34
- SWCDM35
- SWCDM37

Only one quarterly sampling event was conducted in 2003 during the month of January. It included locations SWCDM33, SWCDM34, and SWCDM40. Additionally, samples were collected monthly from SWCDM34 throughout the year. Starting in 2004 through 2006, the quarterly operational monitoring sampling list included SWCDM34 on Bear Butte Creek and SWCDM35 and SWCDM37 as tributaries (Terrible Gulch and Ruby Gulch, respectively). Monthly samples were also collected from SWCDM34 from 2004 through 2006.

4.6.2.1 SWCDM33 Water Quality

SWCDM 33 is a control station located on Bear Butte Creek just upstream from the confluence of Strawberry Creek. This site was sampled once during 2003 and has not been sampled since that time. The sample is calcium-bicarbonate type water with circumneutral pH, moderate hardness, and low concentrations of metals. Indicators of potential impacts of ARD, such as sulfate, iron, aluminum, or other metals are not

present in significant quantities. This water meets applicable surface water quality standards.

4.6.2.2 SWCDM34 Water Quality

SWCDM 34 is an important monitoring point located on Bear Butte Creek downstream of the confluence of Strawberry Creek. Strawberry Creek receives discharge from the site WTP, which causes measurable effects to surface water quality in Bear Butte Creek. The WTP discharge is calcium-sulfate type water with high TDS concentrations. The WTP discharge water quality was discussed previously in Section 4.5.1, which focused on Strawberry Creek and tributaries to Strawberry Creek. The flows within Bear Butte Creek are significantly higher than Strawberry Creek as described in Section 3. This provides significant attenuation capacity, which attenuates concentrations of dissolved solids flowing into Bear Butte Creek from Strawberry Creek.

Figure 4.6-10 displays sulfate and hardness concentrations at SWCDM34 for the time period from 2002 to the present. During this time period, the site WTP was shut down for two extended periods of approximately 1 year each. The first period occurred while the old sodium hydroxide plant was removed and the current high density sludge lime plant was being constructed. The second period was a result of the site water balance. This provides an opportunity to evaluate the effects of Strawberry Creek on Bear Butte Creek during times when the plant was discharging and during times when the plant was not discharging. The data show that during times when the plant is discharging, the water quality at SWCDM34 exhibits increased hardness and increased total dissolved solids concentrations. This is directly attributable to discharge of high TDS calcium-sulfate type water from the site WTP.

Hardness within Bear Butte Creek is not significantly affected by Strawberry Creek during times when the WTP is not discharging and exhibits values ranging from about 100 mg/L $CaCO_3$to 235 mg/L $CaCO_3$, which is comparable to hardness measured at the upstream control site, SWCDM33, of 140 mg/L $CaCO_3$ in January 2003. The hardness within Bear Butte Creek below Strawberry Creek increases to about 300 mg/L $CaCO_3$ to 800 mg/L $CaCO_3$ while the WTP is discharging. The effect of Strawberry Creek on hardness in Bear Butte Creek is highest during low flow because the proportion of water entering the stream from other sources is relatively lower as compared to WTP discharge.

Figures 4.6-11 through 4.6-14 display concentrations of cadmium, copper, zinc, and aluminum/iron in Bear Butte Creek at site SWCDM34, respectively. Aluminum and iron concentrations are elevated as compared to the January 2003 data collected from the control site. Dissolved and total aluminum concentrations were 0.035 mg/L and 0.044 mg/L, respectively at the control site in January 2003. As shown on Figure 4.6-14, concentrations of aluminum and iron below the confluence of Strawberry Creek are somewhat higher, with maximums of 0.499 mg/L and 0.635 mg/L, respectively. Concentrations of copper and cadmium within Bear Butte Creek at SWCDM34 are generally below applicable hardness dependant limits; however, occasional exceedances of the chronic cadmium standard and chronic and acute copper

standards have been measured. With the exception of these intermittent exceedances, concentrations of cadmium, copper, and zinc are generally less than the detection level, although non-detect cadmium concentrations are not shown as one-half the detection limit on Figure 4.6-11.

4.6.2.3 SWCDM35 Water Quality

SWCDM35 is located on Terrible Gulch, just upstream of the confluence of Terrible Gulch with Bear Butte Creek. Water quality data from this site indicate that site contaminants are not impacting water quality in surface water discharged from Terrible Gulch. The data set at SWCDM35 is limited to the period of 2004 through the present. During this time, cadmium was below the detection level of 0.005 mg/L in all samples. Copper was below the detection level in all dissolved analyses and was detected in only one of eight samples evaluated for total metals at a trace concentration of 0.007 mg/L. Zinc concentrations were less than detection in all samples. Iron and aluminum are present in the SWCDM35 samples at very low concentration as shown on Figure 4.6-15.

4.6.2.4 SWCDM37 Water Quality

SWCDM37 is located in lower Ruby Gulch, just above the confluence with Bear Butte Creek. The Ruby Gulch waste rock dump and the ARD collection facilities located at the toe of the dump are located about 3,500 ft upstream of SWCDM37. SWCDM37 data collected during the time period of spring 2004 to the present suggest that ARD in the upper portion of Ruby Gulch may be affecting water quality in lower Ruby Gulch. Figures 4.6-16 through 4.6-19 illustrate the total recoverable and dissolved aluminum/iron, cadmium, copper, and zinc concentrations, respectively. Figure 4.6-20 shows the hardness and sulfate concentrations. Cadmium concentrations on Figure 4.6-17 that are less than the detection level are not shown as one-half the detection limit.

The data indicate that zinc concentrations in the samples exceeded chronic or acute surface water quality standards on three of six sampling events. These elevated zinc concentrations are associated with elevated sulfate concentrations, which are an indicator of ARD-related contamination. Cadmium concentrations were all less than detection and copper concentrations were above detection only during one sampling event during this time frame. Intermittent exceedances in surface water quality standards are also present at sample site CP003, which is located about 3,000 ft upstream from SWCDM37, as discussed in Section 4.4.1.

This page left intentionally blank.

Section 5
Fate and Transport

Evaluation of fate and transport of contaminants is based on results of site physical characteristics, source characteristics, and extent of contamination investigations. This section provides a discussion of the important factors involved in fate and transport of metals, metalloids, and cyanide at the site.

The discussion covers the components of the ARD generation and transport model (Exhibit 5-1) that extend from contaminant sources to migration routes. The final two components of the model (exposure pathways and receptors) will be described in Section 6, which focuses on the human health and ecological risk assessments.

The discussion of fate and transport includes the following subsections:

- Site conditions
- Potential routes of migration
- Contaminant release mechanisms
- Fate and persistence of contaminants in the environment

A brief discussion of key points of each subsection is presented below:

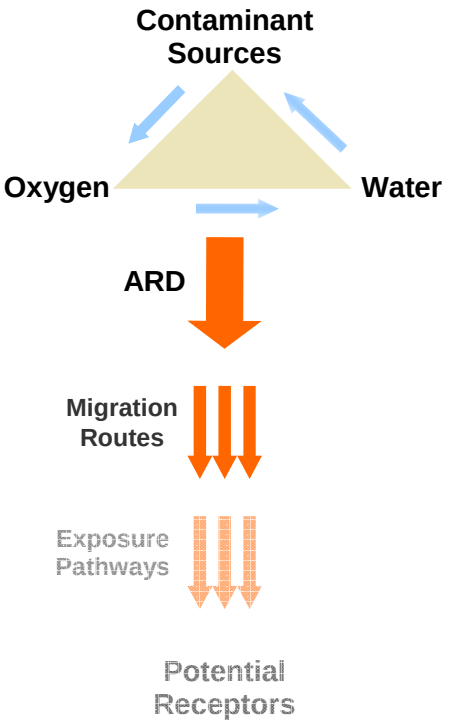


Exhibit 5-1. ARD generation and transport model

Site Conditions

- The Gilt Edge ore deposit contains natural enrichments of metals and metalloids.
- Rocks enriched in metals were exposed by mining at the site, and weathering of these rocks in the surficial environment causes ARD.
- The fate and transport model describes mechanisms that control release of contaminants from source materials and migration of these contaminants in surface water.
- The fate and transport model is an important component of the site conceptual model (presented in Section 1).

Potential Routes of Migration

- Four potential migration routes exist on site (atmospheric, surface water, groundwater, and groundwater/surface water interactions).
- Atmospheric migration is insignificant.
- Surface water migration would be very significant if existing ARD management systems failed.
- Groundwater and groundwater/surface water interactions present problems.

Contaminant Release Mechanisms

- The primary occurrence of metals and metalloids on site is in solid mineralogical forms.
- Sulfide oxidation and acid generation release metals and metalloids from their solid form, which increases mobility of the contaminants in the environment.
- Residual mineral processing reagents are present in spent ore and are a potential cause of cyanide and nitrates in HLP and Ruby Repository effluent.
- Water treatment plant sludge may also result in contamination of surface and groundwater, depending on the hydrogeochemical environment in which it is stored.

Contaminant Fate and Persistence

- Contaminant mobility primarily occurs in the aqueous phase, and the primary control is pH.
- Factors controlling contaminant mobility include development of secondary acidity, solubility in receiving waters, and sorption on solid particles.
- In most cases, increasing pH reduces metal solubility and causes precipitation, and even small changes in pH can have significant impacts on metal and metalloid sorption.
- Six methods of natural degradation have worked to reduce cyanide concentrations in spent ore to low levels and have resulted in nitrate (as a byproduct of degradation) in HLP and Ruby Repository effluent.

5.1 Site Conditions

Mineral deposits are naturally occurring enrichments of metals and metalloids. When the content of one or more metals is sufficient to render mining and mineral processing economic, a mineral deposit is referred to as an *ore deposit*. Commonly, other metals and/or metalloids are present in elevated concentrations in addition to the economic metal. The Gilt Edge deposit was a gold and silver ore body. It contains

elevated concentrations of numerous trace metals and metalloids, such as arsenic, selenium, sulfur, cadmium, copper, and zinc.

Metals and metalloids in an ore deposit are commonly found in the solid phase. Adverse environmental impacts related to mining are associated with transformation of solid phase metals and metalloids into forms that are mobile and potentially toxic to humans and ecological receptors. Crushing and grinding during mining and mineral processing may cause metals to mobilize in the form of very fine grained particulates that can be transported by wind or water. These particulates may cause adverse impacts to human and ecological receptors through ingestion or inhalation. Other processes result in partial or complete dissolution of metals and/or metalloids from the solid phase, which provides a mechanism for contaminant migration into groundwater and surface water. These processes increase the mobility of contaminants in the environment and, therefore, increase the potential for impacts to human and ecological receptors.

A fate and transport model is presented in Figures 5.1-1 and 5.1-2. It incorporates the primary mechanisms that lead to release of contaminants from source materials and their subsequent fate and transport in the environment. As mentioned previously, ARD is an important mechanism in this process.

Acid generating source materials contain minerals that are unstable in the surface environment. These source materials were discussed in Sections 3 and 4 and include:

- Areas of acid generating fill rock
- HLP spent ore that has been crushed and exposed to mineral processing solutions
- Exposed rock surfaces (e.g., pit highwalls)
- Underground mine workings
- Amended tailings repositories
- Relic mine tailings in the Strawberry Creek area
- Soil stockpiles

Other source materials include stored ARD, contaminated ground and surface waters, and water treatment plant sludge. These sources are a direct result of interaction of precipitation with acid generating source rock and the difficulty of managing the environmental problems that result from ARD.

The initial phase of acid generation at the site is ingress of oxygen and infiltration of oxygenated meteoric waters into acid generating rock piles, exposed rock surfaces, and underground mine workings. This results in oxidation of pyrite and other sulfide minerals, release of contaminants from the rock, mobilization of acid metal-laden solutions, and development of secondary acidity.

ARD runoff from the source materials flows to numerous areas, many of which are captured to the extent feasible and stored in pit lakes until the ARD can be treated in the water treatment plant. The volume of ARD runoff is supplemented by additional inflows of clean water and direct precipitation on the pit lakes. Clean water inflows that interact with stored ARD, acid generating fill rock, or acid generating exposed rock surfaces become contaminated and add to the balance of contaminated water that must be treated.

ARD has also contaminated site groundwater by infiltration into alluvial and bedrock aquifers. The current volume of stored ARD exacerbates contaminant migration into groundwater because the stored water in the pit lakes creates a groundwater mound and provides a hydraulic gradient for ARD to move from the pits into groundwater. Near-surface alluvial groundwater is captured at Strawberry Gulch, Hoodoo Gulch, and Ruby Gulch and is conveyed to the Sunday Pit Lake. The deeper bedrock groundwater has impacted an area extending south and east of the mine site. Much of this water moves slowly in the crystalline and Precambrian hydrologic units. Primary permeability of the bedrock aquifers is low and groundwater movement occurs through secondary permeability in the form of fractures and fracture zones. ARD-impacted groundwater in the vicinity of the Selway Northwest fracture zone discharges to surface water in Strawberry Creek, causing precipitation of iron hydroxide within the stream bed and potentially impacting surface water quality.

The HLP also contains a large volume of acid generating spent ore. This rock was processed to remove the gold and is still in place on the liner system. The liner system reduces the potential for HLP spent ore to affect to groundwater. ARD that is generated by the leach pad is collected in a sump and pumped into the site water treatment circuit.

Underground workings are present in the Dakota Maid Pit, Sunday Pit, and Hoodoo Fill remediation subareas. The lower level workings are subsurface pools of ARD. Although these pools may influence contaminant migration into groundwater, they do not cause surface discharges of ARD. The King and Langley adits discharge ARD to surface water in Strawberry Gulch. A third ARD spring is present at the Wood Weir, which may be related to underground mine workings. Other ARD springs discharging to surface water occur at Hoodoo Gulch and Ruby Gulch.

Water treatment plant sludge is currently stored under strongly acid conditions in mine pit lakes at Sunday Pit, Dakota Maid Pit, and within the Stormwater Pond. Water treatment plant sludge is also stored at Anchor Hill Pit Lake, a surface repository in Dakota Maid Pit, a surface repository adjacent to Sunday Pit, and on the HLP leach pad. This sludge was generated by site environmental management activities that have taken place over the last approximately 12 to 15 years. Sludge is also a source of contamination because it contains the toxic metals and metalloids that were removed from ARD during water treatment.

Interim environmental controls collect ARD from surface water and groundwater and pump it to one of the pits for storage and treatment. These controls prevent

potentially catastrophic releases of contaminants. They also require personnel to be on site 24 hours per day 7 days a week. Approximately 95 million gallons of ARD are generated at the site in an average year and require treatment. Releases of ARD-related contaminants may be occurring that are not collected by the site environmental control infrastructure. These potential releases include slow contaminant migration in groundwater, groundwater/surface water interactions in the Strawberry Creek area, and ARD seeps in the Ruby Gulch area.

5.2 Potential Routes of Migration

Four potential routes of migration were evaluated in this RI:

- **Atmospheric**. Inhalation and incidental ingestion of particulates is a potential route of migration for site contaminants. The potential for this pathway to cause adverse impacts beyond the primary mine disturbance area is relatively low because the particle size of most source materials is large.

- **Surface Water**. Major surface water discharges from the site are being controlled through interim environmental controls that collect ARD and convey it into the site water treatment plant circuit. As long as these interim environmental controls are actively managed and maintained, catastrophic releases to surface water are unlikely. In the event that these interim environmental controls fail for any reason, there would be a high potential for migration of contaminated surface water into cold water fisheries in Strawberry Creek and Bear Butte Creek.

- **Groundwater Pathway.** ARD-related contaminants are migrating in groundwater at the site. The rate of contaminant migration is controlled by the transmissivity of the aquifers, the hydraulic gradient, and other factors. Secondary permeability related to major fracture zones is an important control on contaminant migration in groundwater. Important areas with regard to contaminant migration in groundwater include the Hoodoo Gulch, Langley Pit, and Strawberry Creek areas.

- **Surface Water/Groundwater Interactions.** Surface water/groundwater interactions are common especially in the Strawberry Creek area. In the area near Langley Pit and Hoodoo Gulch, contaminants appear to migrate along the Selway Northeast and Selway Northwest fracture zones toward the Strawberry Creek drainage. Contaminant migration along this pathway has the potential to impact surface water quality and aquatic habitat within Strawberry Creek.

5.3 Contaminant Release Mechanisms

This section describes the origin of contaminants at the site and the mechanisms that cause release of these contaminants into the environment. The major environmental issue on the site is ARD, which results from naturally occurring enrichments in rock that have been exposed by mining. These contaminants include acidity, metals, and metalloids. Low concentrations of nitrate and cyanide are present, which result from the use of cyanide in the mineral processing circuit and ANFO blasting agents. Metals

and metalloids are also present in water treatment plant sludge, which results from environmental remediation activities.

5.3.1 Primary Occurrence of Metals and Metalloids

The primary occurrence of metals and metalloids at the site are solid mineralogical forms. Prior to mining, these metals and metalloids were sequestered within the solid phase. The BRA (EPA 2006a) identifies potential human health risks in source materials that are driven by arsenic, manganese, thallium, and lead. These are elements that may be naturally enriched in gold deposits (Smith and Huyuk 1999). Arsenic, lead, and thallium are chalcophile elements that tend to concentrate in sulfide minerals. These elements may occur in unoxidized site ore as substitutions in the pyrite mineral lattice (FeS_2); as trace base metal sulfide minerals, such as chalcopyrite ($CuFeS_2$), sphalerite (ZnS), or galena (PbS); or as dominant constituents in trace sulfosalt minerals, such as arsenopyrite ($AsFeS_2$). Manganese is a lithophile element that tends to concentrate in silicate minerals. It also occurs as manganese oxide, which is an alteration mineral phase that may be associated with gold enrichments.

Several metals not discussed above have been identified with potential to impact human health or ecological risk in other media, such as surface water and groundwater (EPA 2001b and 2006a). These metals include aluminum, cadmium, chromium, copper, lead, mercury, nickel, silver, and zinc. In addition, selenium has been identified as a potentially problematic constituent in mine waters. Aluminum is a major rock-forming element that constitutes about 8 percent of the earth's crust (Smith and Huyuk 1999). On site, it is found in aluminum-silicate minerals, such as orthoclase feldspar ($KAlSi_3O_8$), a primary component of trachyte porphyry and quartz-trachyte porphyry rocks. Cadmium, copper, lead, mercury, nickel, silver, and zinc are elements that tend to accumulate in sulfide minerals. They are often associated with gold enrichments (Smith and Huyuk 1999). Selenium is a metalloid that is commonly associated with sulfide minerals. Selenium may substitute for sulfur in the mineral lattice of sulfide minerals, such as pyrite, or in secondary sulfate minerals formed by oxidation of pyrite. Chromium is an element that is not generally associated with gold enrichments, and its concentration in site rocks is not significantly enriched above normal crustal levels based on a comparison with geological background concentrations provided by Rose et al. (1979). However, under the strongly acid conditions present at the site, the trace concentrations of chromium are mobilized into ARD at concentrations that exceed South Dakota Surface Water Quality Standards.

5.3.2 Sulfide Oxidation and Acid Generation

Acid generation is dependant on the balance of acid generating minerals and acid neutralizing minerals within exposed rock. ARD occurs when the amount of acid generation exceeds the capacity of neutralizing minerals in the rock to buffer pH changes.

Oxidation of the mineral pyrite is the primary cause of acid generation at the site. This process involves a series of linked geochemical and microbially mediated reactions, which result in dissolution and/or alteration of sulfide minerals into soluble forms. During pyrite oxidation, electrons are transferred from sulfur and iron to oxygen, providing a flow of electrons that is harnessed as an energy source by bacteria (Younger et al. 2002). Microbial oxidation of pyrite is catalyzed by a consortium of autotrophic and heterotrophic microorganisms (Nordstrom 2003).

The initial reaction can be summarized as follows:

$$2FeS_2 + 7O_2 + 2H_2O \rightarrow 2Fe^{2+} + 4SO_4^{2-} + 4H^+$$

This reaction represents the average stoichiometry of the overall oxidation process, which likely involves a number of linked geochemical and biochemical reaction steps.

In the presence of water with sufficient dissolved oxygen or when in contact with the atmosphere, the ferrous iron produced during pyrite oxidation will oxidize to ferric iron.

$$2Fe^{2+} + \frac{1}{2}O_2 + H^+ \rightarrow 2Fe^{3+} + H_2O$$

At pH values above approximately 3, the ferric iron may precipitate as iron hydroxide, which produces additional acidity. Mine workings often achieve solubility equilibrium with iron hydroxide because the kinetics of the precipitation reaction are rapid in relation to the retention time (Younger et al. 2002). This reaction produces the common red to orange precipitates often observed at mine sites.

$$2Fe^{3+} + 6H_2O \Leftrightarrow 2Fe(OH)_3 + 6H^+$$

Ferric iron that does not precipitate may oxidize additional pyrite as shown below. This is one factor involved in the rapid increase in the rate of acid generation once pH conditions decrease to approximately 3 and ferrous iron remains in solution. This reaction also provides for pyrite oxidation under saturated conditions in the presence of ferric iron.

$$14Fe^{3+} + FeS_2 + 8H_2O \rightarrow 2SO_4^{2-} + 15Fe^{2+} + 16H^+$$

In the process of pyrite oxidation, toxic metals and metalloids that were present as substitutions in the pyrite crystal structure are released from the solid form and become mobile and bioavailable.

Oxidation of other metal sulfides in the ARD source materials may not generate acid, but it does serve to release toxic metals associated with these phases into the environment. Some relevant examples are presented below for the ore minerals sphalerite, galena, millerite, greenockite, covellite, and chalcopyrite, respectively.

$$ZnS + 2O_2 \rightarrow Zn^{2+} + SO_4^{2-}$$
$$PbS + 2O_2 \rightarrow Pb^{2+} + SO_4^{2-}$$
$$NiS + 2O_2 \rightarrow Ni^{2+} + SO_4^{2-}$$
$$CdS + 2O_2 \rightarrow Cd^{2+} + SO_4^{2-}$$
$$CuS + 2O_2 \rightarrow Cu^{2+} + SO_4^{2-}$$
$$CuFeS_2 + 4O_2 \rightarrow Cu^{2+} + Fe^{2+} + 2SO_4^{2-}$$

The kinetics of these oxidation reactions are strongly controlled by the size of the mineral particles because the reactions take place at the interface between the solid phase and the aqueous phase. Other controlling factors include crystal morphology, crystal surface texture, porosity, and degree of aggregation with other minerals. As a result, the rate of sulfide oxidation is very difficult to predict (Younger et al. 2002).

Minerals with the capacity to neutralize acidity may dissolve and buffer pH changes in ARD source materials mitigating generation of ARD. ARD is very corrosive and has the capacity to dissolve a large number of rock-forming minerals. However, the relative kinetics of acid generation versus acid neutralization render most rock forming minerals ineffective in buffering pH changes caused by pyrite oxidation. Only the carbonate minerals dissolve fast enough to provide effective neutralization potential to buffer pH changes caused by pyrite oxidation. The most important acid neutralizing minerals are the carbonates calcite ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$. Relevant neutralization reactions for calcite and dolomite are presented below.

$$CaCO_3 + H^+ \Leftrightarrow Ca^{2+} + HCO_3^-$$
$$CaMg(CO_3)_2 + 2H^+ \Leftrightarrow Ca^{2+} + Mg^{2+} + 2HCO_3$$

Rocks with significant concentrations of carbonate minerals may prevent or delay the onset of acid generation caused by pyrite oxidation. A lag period prior to acid generation may result from the time required for acid generation in the rock to overcome the available neutralization capacity. Under oxidizing conditions, ferric iron present in the ARD solution will precipitate as iron hydroxides on carbonate mineral surfaces as a result of the alkaline microenvironment present at the interface between the solid and aqueous phases. This process results in armoring the carbonate mineral grains with iron hydroxide precipitates, which decreases the effectiveness of the minerals in preventing ARD.

5.3.3 Residual Processing Reagents

Mining and mineral processing may introduce additional contaminants into source materials. These include cyanide, products of cyanide degradation, lime, and residual blasting agents. The most important site contaminants in this category are cyanide and nitrate. Residual mineral processing reagents are present in spent ore. The other source materials were not subjected to mineral processing, so they are unlikely to contain cyanide. Trace concentrations of nitrates may be present in all blasted materials as a result of residual ammonium nitrate fuel oil blasting agents.

5.3.4 Water Treatment Plant Sludge

Water treatment sludge at Gilt Edge includes sludge generated by the former sodium hydroxide water treatment facilities as well as the current high-density sludge WTP. The water treatment process uses hydrated lime ($Ca(OH)_2$) or sodium hydroxide (NaOH) to increase the pH of ARD and cause metals to precipitate from solution. These are widely used methods of ARD treatment and reduce metal concentrations through precipitation of amorphous to microcrystalline iron and aluminum hydroxides and/or hydroxysulfates. Other dissolved metals and metalloids, such as arsenic, cadmium, copper, and zinc are removed by adsorption and coprecipitation with the iron and aluminum phases.

Iron and aluminum hydroxides and/or hydroxysulfates are relatively stable at circumneutral pH. However, the propensity for adsorbed or coprecipitated toxic metals or metalloids to desorb under various disposal scenarios is unknown. SPLP extraction tests were completed on sodium hydroxide sludges (Section 4.2.7.2). The SPLP test evaluates the potential for contaminants to be mobilized by a weakly buffered acidic solution resembling rain water, and some contaminants dissolved in the tests.

Under strongly acidic conditions, it is likely that the sludge would tend to dissolve. Solubility of aluminum and iron increases significantly at low pH. Solubility of toxic metals and metalloids adsorbed and coprecipitated with the iron and aluminum phases also increases significantly at low pH. McDonald and Webb (2006) evaluated stability of sludge generated by treatment of a simulated ARD solution with lime in strongly acidic environments by conducting extraction tests in sulfuric acid solutions with varying pH. They found that iron began leaching at a pH of 3 su and that 40 percent of the iron had been dissolved by pH of 2 su to 2.5 su. Aluminum began leaching at pH 4.5 su, and 60 to 70 percent of the aluminum had dissolved at a pH of 2 su to 2.5 su. Virtually all of the adsorbed copper and 100 percent of the adsorbed zinc had dissolved by a pH of 2 su to 2.5 su.

Geochemical equilibrium modeling was conducted to evaluate the stability of mineral phases with water treatment plant sludge in the stored ARD within Sunday Pit. Primary solid phases in Gilt Edge sludge are thought to be basalumanite, schwertmannite, ferrihydrite, and/or aluminum hydroxide. Nordstrom and Alpers (1999) suggest that initial iron and aluminum phases that precipitate upon rapid neutralization of ARD are amorphous basaluminite ($Al_4(SO_4)(OH)_{10} \cdot 5H_2O$) and a schwertmannite-like phase ($Fe_8O_8(SO_4)(OH)_6$) formed from substitution of sulfate in

ferrihydrite ($Fe_5HO_8 \cdot 4H_2O$). Geochemical equilibrium modeling indicates that schwertmannite, basaluminite, ferrihydrite, and aluminum hydroxide are undersaturated in Sunday Pit ARD and would tend to dissolve. Persistence of large quantities of sodium hydroxide water treatment plant sludge in Sunday Pit suggests that the rate of sludge dissolution is relatively slow. The presence of water with extremely high mineral acidity in the base of the pit lake may be related to sludge dissolution.

Strong acid leach tests were conducted on water treatment plant sludge in order to evaluate its stability under acid conditions. As discussed previously (Section 4.2.7.3) these tests indicate that the contaminants are mobilized from the sludge in 24-hour bottle roll tests using ARD as an extraction fluid. The mechanisms responsible for the observed contaminant mobilization are desorption and dissolution.

5.4 Contaminant Fate and Persistence

Evaluation of contaminant fate and persistence at the site includes an assessment of:

- The mobility of metals and metalloids
- The various degradation mechanisms of cyanide

5.4.1 Metal and Metalloid Mobility

The capacity of metals and metalloids released from source materials as a result of oxidation to move through the environment after dissolution is referred to as *mobility*. It occurs primarily in the aqueous phase and is controlled by precipitation, sorption and dissolution reactions.

Important controls on metal and metalloid mobility include:

- **Development and dissolution of secondary acidity**. Secondary sources of acidity that develop in unsaturated waste rock and spent ore piles, highwalls, and underground workings as a result of precipitation/dissolution of mineral phases
- **Metal and metalloid solubility in receiving waters**. The capacity of metals and metalloids in solution to precipitate in response to changes in solution composition caused by mixture with unimpacted waters
- **Metal and metalloid sorption on solid particles**. A mechanism by which dissolved metals and metalloids are sequestered to the solid phase via surface interactions with sorbents (e.g., iron hydroxide)

5.4.1.1 Development of Secondary Acidity

Acidity and metals/metalloids released by acid 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. Temperatures of 180° Fahrenheit have been observed in steam fumaroles exiting a valley fill waste rock dump in South Dakota as a result of pyrite oxidation (Durkin 1992). The heat generated by acid generation contributes to evaporation of fluids within unsaturated zones of actively oxidizing waste rock and spent ore piles. When the solubility limit for sulfate and hydroxysulfate minerals is reached, products of acid generation (e.g., H^+, 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 spent ore piles, on surfaces of rock highwalls or underground mine workings, or within non-acid generating rock or soil exposed to ARD solutions. These minerals essentially represent "freeze 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.

The 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). The minerals romerite, coquimbite, and rhomboclase were identified in samples collected by the BOR at the site (Gobla 2002).

Another common group of secondary minerals found at acid generating sites is alunite-jarosite group minerals, which are often recognized as accumulations of bright yellow precipitates on the surfaces of acid generating rock. These yellow colored precipitates are particularly apparent on exposed surfaces of the lower zone leach pad spent ore at the site. The specific mineralogical composition of the alunite-jarosite group minerals cannot be identified without laboratory analyses. Alunite-jarosite group minerals may also form acid upon dissolution. Detailed discussion of secondary minerals associated with acid drainage is included in Nordstrom and Alpers (1999).

Dissolution of secondary acidity may have profound effects on the chemistry of mine drainage as well as the performance of remedial actions. A common effect of

secondary acidity in large waste rock piles is correlation of the most concentrated ARD solutions with periods of highest ARD discharge. This is contrary to cursory evaluations, which may suggest that high flows would dilute ARD discharging from the waste rock piles. The high infiltration rate into the waste rock pile changes the hydrologic characteristics of the pile, facilitates flow through portions of the pile that are not often flushed, and dissolves secondary acidity within the pile. Another implication of secondary acidity is that flooding of underground mines and open pits may not result in short-term improvements in water quality because flooding results in dissolution of secondary acidity present within formerly unsaturated void spaces (Nordstrom and Alpers 1999). Relocation of acid generating rock within open pits that will eventually become saturated will dissolve secondary acidity and produce concentrated ARD solutions.

5.4.1.2 Metal Solubility

Acidity is a primary control on the solubility of metals at the site. The low pH conditions caused by ARD increase the solubility of metals, such as iron, aluminum, cadmium, copper, and zinc. Neutralization of ARD, either by addition of a base during water treatment or through mixing with unimpacted waters, reduces the solubility of metals and causes precipitation.

Most metals are *amphoteric* – meaning that they exhibit solubility minima under circumneutral pH conditions with increased solubility under both acidic and alkaline conditions. The point of minimum solubility varies depending on the metal as well as the oxidation state. Figure 5.4-1 displays the solubility of aluminum and iron hydroxide minerals at varying pH. These types of experiments are conducted under ideal conditions using pure solutions of the metals of interest. Solubility controls in solutions containing mixtures of various ions may deviate from ideal conditions displayed on diagrams such as Figure 5.4-1.

Other metals that occur in mining-related contamination generally precipitate from solution as the pH increases. The point where the metals begin to precipitate is characteristic of the specific metals. Figure 5.4-2 displays the solubility equilibrium of several mine-related contaminants 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. 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.

Metal ions do not exist in a single ionic phase when dissolved. They form many different dissolved species by combining with other ions in solution. The combined ions are called *complexes*. Relevant examples of aqueous complexes include hydroxide complexes (e.g., $ZnOH_2^{+)}$, sulfate complexes (e.g., $ZnSO_{4(aq)}$), and carbonate complexes (e.g., $ZnCO_{3(aq)}$). Complexes that contain a single metal ion are referred to as *mononeuclear complexes*. *Polynuclear complexes* also occur that contain more than one metal ion, such as $Zn(OH)_6^{2+}$ (Younger et al. 1999). An estimate of molar concentrations of various aqueous complexes present in ARD stored in Sunday Pit based on equilibrium geochemical equilibrium modeling is presented in Table 5.3-1.

Geochemical equilibrium modeling is attaining more widespread use in evaluating solubility controls in mine drainage environments (eg. Alpers and Nordstrom 1999, Ptacek and Blowes 2003). The high concentrations of sulfate, protons, and metals cause uncertainties in equilibrium geochemical modeling as a result of ion interactions in concentrated acidic solutions. Additional uncertainties are caused by lack of thermodynamic data for many of the secondary minerals that precipitate. Some of these secondary minerals constitute secondary acidity and were discussed previously in Section 5.4.1.1.

Solubility of ferric iron in ARD is an important control on overall solution chemistry because iron hydroxide precipitates are important in attenuating dissolved concentrations of other mine-related contaminants through adsorption. Iron is also a major component of ARD solutions occurring at concentrations up to 500 mg/L. Ferric iron begins to precipitate from site ARD solutions at a pH values exceeding approximately 3 su. Precipitation of ferric iron also occurs within Strawberry Creek in response to dilution of inflowing ARD-impacted groundwater seeps by circumneutral pH water within the stream. This precipitation reaction occurs very rapidly in response to an increase in solution pH to greater than approximately 3 su to 3.5 su.

5.4.1.3 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 or by mineral processing 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. The most important adsorbent materials within mine environments are iron hydroxides and oxides, such as iron hydroxide ($Fe(OH)_3$), goethite (FeOOH), and hematite (Fe_2O_3). This is a result of the abundance of iron produced during oxidation of pyrite, which contains 46.6 percent iron by weight and the common occurrence of iron hydroxides and iron oxide as alteration minerals in ore deposits and soils developed from these deposits. Neutralization of ARD produces large quantities of ferrihydrite precipitates, which precipitate very readily in response to pH changes caused by base addition or mixing of ARD with circumneutral pH waters.

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 sorbate 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 dominant control on adsorption within mine environments is pH.

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 dominantly positive, which increases the tendency for anions, such as arsenate and selenate, to adsorb. At neutral to alkaline pH, the surface charge is dominantly 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 dominate. At solution pH values below the point of zero charge, anion adsorption would tend to dominate. The point of zero charge for several adsorbent species is shown as Table 5.4-1.

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 5.4-3) (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.

The adsorption curves presented in Figure 5.4-3 are pertinent to understanding fate and transport of contaminants discharging from groundwater into Strawberry Creek in the area directly upstream of Hoodoo Gulch. In this area, groundwater seeps are readily apparent as blooms of iron hydroxide precipitates within discrete seeps along the northern bank of stream. Iron hydroxide precipitates are also present within the stream bed extending from this area downstream for several hundred meters. Groundwater data from a bedrock well directly adjacent to the seeps indicate that dissolved cadmium and zinc are also present in the groundwater entering the stream.

The pH of Strawberry Creek generally ranges from about 7.5 to 8.0. In this range, cadmium and zinc are not likely to be 100 percent adsorbed to the iron hydroxide precipitates, and attenuation of these contaminants by adsorption is likely to be incomplete. An opportunity sample was collected from this area of the stream in February 2007 when the water treatment plant was not discharging. This sample exhibited dissolved cadmium concentrations of 0.004 mg/L and dissolved zinc concentrations of 0.477 mg/L. These concentrations are compatible with the concepts presented above. Additional sampling is required to develop an adequate understanding of the potential for groundwater seeps in the area to affect surface water chemistry. However, the example does exhibit the importance of adsorption processes in understanding the fate and transport of site contaminants.

Adsorption curves for several anionic species (Figure 5.4-4) show that anions tend to adsorb at under acidic conditions, in contrast to the cationic species. The figure also

shows the effect of redox conditions on adsorption for selenium. As shown on the curves, the more oxidized form of selenium (selenate) is more mobile than selenite. In addition, in strongly alkaline conditions, selenium is less likely to be sequestered in a solid phase as a result of adsorption. This is pertinent to consideration of selenium concentrations observed in effluent from the leach pad. During active gold production, mineral processing solutions containing cyanide were maintained at a pH of approximately 11 in order to prevent cyanide from forming the very toxic gas hydrogen cyanide (HCN). Crushing of the ore as well as irrigation of the ore with mineral processing solutions also would tend to oxidize the ore. Because selenium was released from the ore as a result of chemical weathering, the oxidized conditions and alkaline pH would both tend to make it more mobile in leach pad solutions.

5.4.2 Cyanide Degradation

Cyanide concentrations in site effluents are currently at trace concentrations, as discussed in Section 4. This is a result of the natural degradation of cyanide in near-surface oxidizing conditions.

The mechanisms of natural cyanide degradation include:

- Hydrolysis and volatilization
- Oxidation of HCN and cyanide ion (CN^-)
- Hydrolysis/saponification
- Aerobic biodegradation
- Thiocyanate formation
- Cyanide compound dissociation metal-cyanide complexation

These reactions tend to attenuate cyanide concentrations in the leach pad. They are discussed below.

5.4.2.1 Hydrolysis and Volatilization

The hydrolysis of cyanide ion to HCN is pH dependent; and, at pH of approximately 9.36, concentrations of CN^- and HCN are roughly equal. However, with rinsing activities following HLP operations, meteoric inputs, and the dissolution of carbon dioxide within the HLP, a gradual decrease in pH is anticipated, resulting in HCN formation. HCN is a colorless gas or liquid with a boiling point of 25.7 degrees Celsius and a vapor pressure of 630 millimeters of mercury (mm Hg) at 20 degrees Celsius (Smith and Mudder 1999). As such, it is quickly volatized into the atmosphere and represents a significant mechanism in the removal of cyanide and HLP detoxification.

5.4.2.2 Oxidation of HCN and CN^-

Oxidation of HCN generates hydrogen cyanate (HCNO), which readily hydrolyzes to form ammonia and carbon dioxide. Depending on pH, the ammonia may form ammonium compounds or be further oxidized to nitrate. These reactions are:

$2HCN + O_2 \rightarrow 2HCNO$ (Reaction 1)

$HCNO + H_2O \rightarrow NH_3 + CO_{2(g)}$ (Reaction 2)

$NH_3 + H^+ \rightarrow NH_4^+$ (Reaction 3)

$NH_4^+ + 2O_2 \rightarrow NO_3^- + 2H^+ + H_2O$ (Reaction 4)

Oxidation of CN^- is less likely and requires a mineralogical, bacteriological, or ultraviolet catalyst with the product being cyanite ions (CNO^-).

5.4.2.3 Hydrolysis/Saponification

With further reductions of pH within a heap leach environment, HCN can be hydrolyzed to generate formate, as either formic acid or ammonium formate, per the following reactions:

$HCN + 2H_2O \rightarrow NH_4COOH$ (Ammonium Formate)

$HCN + 2H_2O \rightarrow NH_3 + HCOOH$ (Formic Acid)

Based on work completed by Hoecker and Muir (1987), the proportion of cyanide degradation because of saponification is minor under oxidative conditions.

5.4.2.4 Aerobic Biodegradation

Under aerobic conditions, Towill et al. (1978) reported that cyanide salts are quickly converted biologically to ammonia and ultimately nitrate. These reactions are very similar to the aforementioned oxidation reactions, with the only difference being that a biological enzyme is used to convert HCN to hydrogen cyanate. Studies have shown that cyanide soil concentrations of up to 200 mg/kg are readily converted to inorganic nitrogen and that substituting cyanide for commercial fertilizers (e.g., ammonium nitrate) has a similar positive result on plant growth rates (Fuller 1984).

A consistent end product in the degradation of cyanide is the formation of inorganic nitrogen (i.e., ammonia and nitrate) regardless of reaction type. As a result, and as is commonly observed within heap leach environments, decreasing cyanide concentrations are balanced by a concomitant increase in inorganic nitrogen levels.

5.4.2.5 Thiocyanate Formation

Free cyanide (i.e., CN^-) can react with various forms of sulfur (e.g., sulfide, hydrogen sulfide, polysulfides, and thiosulfate) in the environment to generate thiocyanate ions (CNS^-). Of the aforementioned sulfur forms, polysulfides (S_2) and thiosulfate (S_2O_3) are the two forms most likely to react with cyanide per the following reactions:

$S_x^{2-} + CN^- \rightarrow [S_{(x-1)}]^{2-} + SCN^-$ (Reaction 5)

$$S_2O_3^{3-} + CN^- \rightarrow SO_3^{2-} + SCN^- \qquad \text{(Reaction 6)}$$

Under aerobic conditions, sulfite (SO_3^{2-}) as identified within Reaction 6 is further oxidized to sulfate (SO_4^{2-}). Thiocyanate is a relatively stable and less toxic form of cyanide and is typically effective in removing cyanide from a heap environment. However, with elevated sulfide concentrations, acidic conditions may occur which would favor the formation of hydrogen cyanide and increase the degree of disassociation of heavy metal-cyanide compounds.

5.4.2.6 Cyanide Compound Dissociation

Cyanide can form a wide range of simple salts/compounds with a range of monovalent and divalent cations. Examples of such simple salts include NaCN, KCN, $Ca(CN)_2$, $Hg(CN)_2$, $Zn(CN)_2$, CuCN, $Ni(CN)_2$, and AgCN. In solution, these simple salts will disassociate, releasing free metal cations and cyanide ion. In environments where the pH is less than 9.36, formation of hydrogen cyanide is favored and dissociation of free metals is favored and results in subsequent leaching.

5.4.2.7 Metal-Cyanide Complexation

Twenty-eight elements can form complexes with cyanide of varying solubilities and stabilities. At pH values of ≤ 4.5 and/or ultraviolet exposure, many metallo-cyanide complexes will dissociate into free cyanide and the respective metals.

This page left intentionally blank.

Section 6
Risk Assessment

A baseline human health risk assessment, an ecological risk assessment (ERA), and a screening level ecological risk assessment (SERA) have been performed. The BRA evaluated the potential for adverse human health and environmental effects to occur from exposure to site-related contaminants. The ERA and SERA assessed the risk of adverse effects to ecological receptors as a result of exposure to site-related chemicals.

This section is pertinent to the "Exposure Pathways" and "Potential Receptors" portion of the ARD generation and transport model shown as Exhibit 6-1.

A brief discussion of key points of each subsection is presented below:

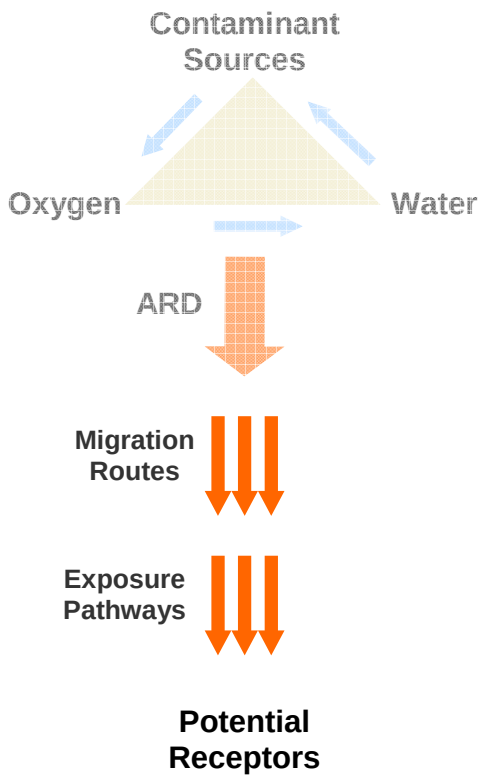


Exhibit 6-1. ARD generation and transport model

<u>Baseline Human Health Risk Assessment</u>

- Uses COPCs to conduct an *exposure assessment* for soil, surface water, groundwater, sediment, and fish tissue.
- Potential human receptors include on site (all-terrain vehicle [ATV] riders, hikers, residents, commercial workers, and construction workers) and off site (children, fishermen, and residents) users.
- Depending on the media and receptor, COPCs include arsenic, manganese, thallium, aluminum, cadmium, copper, iron, lead, antimony, chromium, and zinc.
- The *toxicity assessment* determined the potential for each COPC to cause adverse effects (cancer and non-cancer), and the *risk characterization* estimated the likelihood and nature of potential health effects that may occur as a result of exposure to COPCs.
- *PRGS* for surface water, sediment, and groundwater and *remedial action levels* (RALs) for soils were developed.

- Potential unacceptable future risks are ingestion of thallium and arsenic in soil by onsite construction workers; ingestion of arsenic, lead, and other metals in groundwater; and ingestion of thallium in surface soil by commercial workers.

- Risks were also unacceptable in current and future scenarios for ATV riders (soil) and residents (soil and groundwater), but these scenarios are not allowed by EPA and would not be allowed in the future.

Ecological Risk Assessment

- The ERA calculated risks to aquatic receptors, terrestrial plants and organisms, and wildlife using COPCs, exposure assessment, and toxicity assessment.

- Three line-of-evidence approaches are used (where applicable) to assess risk: hazard quotients (HQs), site-specific toxicity tests, and observations of population and community demographics.

- An external review draft of the *Biological Monitoring Report* commissioned by EPA for Strawberry Creek was submitted in January 2007 and concluded that conditions had improved noticeably, but the sediment continues to pose a risk to benthic organisms, and the benthic community has not recovered.

- Risks are high for aquatic receptors in Strawberry Creek, Hoodoo Gulch, and Ruby Gulch.

- For terrestrial plants and wildlife, risks from surface soil contamination are of concern in the Riparian Area of Strawberry and Bear Butte creeks and in the Mine Source Area.

- For wildlife receptors, risks from surface water and soil are high in the Riparian Area along Strawberry Creek, Ruby Gulch, and downstream Bear Butte Creek.

Information from these assessments is summarized herein. It has been extracted from *Draft-Final Baseline Human Health Risk Assessment for the Gilt Edge Mine Site* (EPA 2006a), the *Final Baseline Ecological Risk Assessment for the Gilt Edge Mine Site* (EPA 2003), the *Biological Monitoring Report for the Gilt Edge Mine* (EPA 2007b), and *Human Health Preliminary Remediation Goals and Remedial Action Levels for Recreational Visitors and Residents at the Gilt Edge Mine Site* (EPA 2006b). No additional information or conclusions outside of those documents cited have been presented in this document.

6.1 Baseline Human Health Risk Assessment

The BRA includes the following elements:

- COPCs

- Exposure assessment

- Toxicity assessment

- Risk characterization
- PRGs and RALs

These elements are discussed in the following subsections.

6.1.1 Identification of Chemicals of Potential Concern

The BRA identified COPCs that exist in the environment at concentration levels that might be of potential health concern to humans and which are or might be derived, at least in part, from site-related sources using the procedure shown in Figure 6-1. COPCs were identified for evaluation of risks to human receptors from soil, groundwater, surface water, sediment, and fish tissue.

As part of the evaluation, chemicals not likely to contribute significant risks to humans are eliminated. Chemicals that *might* be of potential concern are assigned to one of two groups:

- Those that lack the data needed to perform a quantitative evaluation (these are addressed qualitatively)
- Those that have sufficient data to allow quantitative evaluation

Identification of COPCs is based on a conservative process. Thus, some chemicals are identified as COPCs that are actually of little or no concern, but no chemical of authentic concern is overlooked.

For the COPC selection procedure, the following steps were performed:

- Step 1: Eliminate chemicals for which no toxicity values are available. Risk from chemicals for which EPA has not established toxicity values can not be evaluated quantitatively and so these chemicals were either evaluated semi-quantitatively or were assigned to the qualitative COPC category.
- Step 2: Eliminate chemicals detected but whose maximum value is below a level of concern. If a chemical is detected at least once, but the maximum detected concentration is well below the level of health concern, that chemical may be eliminated from further consideration. This screening was performed using risk-based concentration (RBC) values from EPA Region 3 (EPA 2005a). Target risk levels were set to an HQ value of 0.1 and a cancer risk level of 1E-06. EPA Region 3 does not have RBC values for either sediment or surface water; residential soil and tap water RBCs were used, respectively, to screen chemicals in these media.
- Step 3: Eliminate chemicals with a detection frequency < 5 percent. In accordance with EPA (1989), a chemical may be eliminated from the quantitative risk assessment if it is detected only infrequently (<5 percent) in a site medium. In the Gilt Edge risk assessment, chemicals with a detection frequency ≥ 5 percent were

retained and those with a detection frequency < 5 percent were eliminated from further consideration.

Table 6-1 lists the COPCs identified for quantitative evaluation. COPCs identified for qualitative evaluation are presented in Table 6-2.

6.1.2 Exposure Assessment

The exposure assessment identifies scenarios through which a receptor could contact COPCs in site media and estimates the extent of exposure. An exposure point is an area where a receptor (worker, visitor, or resident) may be exposed to one or more environmental media. The risk assessment model for human exposure (RAM), Figure 6-2, illustrates media of concern, exposure pathways, and human populations that were evaluated in the BRA. Media selected for evaluation in the BRA were soil, groundwater, surface water, sediment, and fish tissue. The exposure units for the site are presented in Tables 6-3 and 6-4.

6.1.2.1 Soil

In the BRA, the site was divided into five exposure units as shown in Figure 6-3. These large areas may be representative of the area a recreational visitor (ATV rider, hiker) may use when visiting the site. The five soil exposure units are Anchor Hill and ponds (AH&P), heap leach pad (HLP), Ruby Gulch waste rock dump (RGWRD), pits and crusher area (PCA), and Langley pit (LP).

6.1.2.2 Groundwater

Concentrations of metals in groundwater vary from well to well. Thus, exposure and risk from metals in groundwater will vary depending on the precise location where a hypothetical future drinking water well might be installed. For this reason, risks from groundwater were evaluated on a well-by-well basis.

6.1.2.3 Surface Water, Sediment, and Fish Tissue

Concentrations of metals in surface water and sediment may vary between surface water bodies and can be influenced by confluences with other tributaries, exposure units for surface water, sediment fish tissue based on a surface water body (e.g., pit lake, pond), or reach-by-reach basis. Smaller stream segments may also be representative of the area that a recreational user may cover while wading or fishing at the site.

6.1.2.4 Potential Receptors

The BRA evaluated human populations most likely to be exposed and includes hypothetical future residents, commercial workers, construction workers, and current and future recreational visitors. Specifically, the risk was estimated for the following populations:

- Onsite ATV riders. Total risks from ingestion and inhalation of surface soil

- Onsite hikers. Total risks from incidental ingestion of onsite surface soil, sediment, and surface water during recreational activities
- Onsite residents (hypothetical future). Total risks from the incidental ingestion of soil and groundwater
- Onsite commercial workers (current or hypothetical future). Total risks from ingestion of groundwater and soil at some locations
- Onsite construction workers (current or hypothetical future). Total risks from ingestion and inhalation of surface and sub-surface soil at the site
- Offsite children. Total risks from playing in offsite drainages and ingestion of surface water and sediment
- Offsite recreational fishermen. Total risks from ingestion of sediment, surface water, and fish in offsite drainages
- Offsite residents (current or hypothetical future). Total risks from ingestion of groundwater

The likelihood of an ATV rider being exposed is low or non-existent because current future land use is for recreational use, and this designation does not support ATV riders. In addition, EPA will most likely use institutional and physical controls (e.g., fencing) to prohibit ATV riders and prevent damage to existing and future waste rock caps and covers. Thus, ATV-rider exposure is hypothetical. Likewise, EPA will not allow for residential land use at the site and, therefore, residential exposure and risk do not exist.

6.1.3 Toxicity Assessment

The purpose of the toxicity assessment is to review and summarize the potential for each of the COPCs to cause adverse effects in exposed individuals. The toxic effects of a chemical generally depend on its inherent toxicity, the pathway of exposure, exposure frequency and duration, and the level of exposure.

A toxicity assessment for a chemical identifies what adverse health effects the chemical causes and how the appearance of these adverse effects depends on exposure level. The toxicity assessment process is usually divided into two parts: the first characterizes and quantifies the non-cancer effects of the chemical while the second addresses the cancer effects of the chemical.

6.1.3.1 Non-Cancer Effects

Essentially all chemicals can cause adverse health effects if given at a high enough dose. However, when the dose is sufficiently low, typically no adverse effect is observed. Thus, in characterizing the non-cancer effects of a chemical, the key parameter is the dose at which an adverse effect first becomes evident. Doses below this “threshold” are considered to be safe while doses above the threshold are likely

to cause an effect. Based on a thorough review of all available data, EPA identifies a reference dose (RfD) to be used as a conservative estimate of the threshold. The RfD is an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime.

6.1.3.2 Cancer Effects

For cancer effects, the toxicity assessment process has two components. The first is a qualitative evaluation of the weight of evidence that the chemical does or does not cause cancer in humans. For chemicals which are considered known or possible human carcinogens, the second part of the toxicity assessment is to describe the carcinogenic potency of the chemical. This is done by quantifying how the number of cancers observed in exposed animals or humans increases as the dose increases. Typically, it is assumed that the dose response curve for cancer has no threshold, arising from the origin and increasing linearly until high doses are reached. Thus, the most convenient descriptor of cancer potency is the slope of the dose-response curve at low doses (where the slope is still linear). This is referred to as the slope factor (SF), which has dimensions of risk of cancer per unit dose.

6.1.3.3 Toxicity Values

All toxicity values (RfD and SF values) used in the risk assessment were derived by EPA and were obtained either from the on-line database referred to as "IRIS" (Integrated Risk Information System) from EPA's Health Effects Assessment Summary Tables (HEAST) or from interim recommendations from EPA's Superfund Technical Assistance Center operated by the National Center for Environmental Assessment (NCEA).

6.1.3.4 Adjustments for Relative Bioavailability

Accurate assessment of human exposure to ingested metals requires knowledge of the amount of metal absorbed from the gastrointestinal tract into the body. This information is especially important for environmental media, such as soil or mine wastes, because metals in these media may exist, at least in part, in a variety of poorly water soluble minerals and may also exist inside particles of inert matrix, such as rock or slag. These chemical and physical properties may tend to influence (usually decrease) the absorption (bioavailability) of the metals when ingested.

In general, the most reliable means for obtaining absorption data on a metal that is present in a particular soil or mine waste is to study the rate and extent of absorption of the metal when the material is fed to an appropriate test animal. However, such *in vivo* studies are slow and costly, and no results exist for soils from the site.

In vivo testing of arsenic in soil and mine waste has been conducted at a variety of other sites in the Rocky Mountain West (EPA 2005b). Based on an analysis of relative bioavailability (RBA), which is the ratio of absorption from the study medium compared to absorption from site medium, in 26 test materials, an RBA of 0.5 was selected for use in this risk assessment and is considered a generally conservative

default value for arsenic in soil. In the absence of site-specific data, the RBA for all chemicals in all media was assumed to be 1.0 (EPA 1989), with the exception of lead where EPA (1994b) recommended default RBA for lead in soil of 0.6.

6.1.4 Risk Characterization

The risk assessment characterizes risks to current and future human populations of concern, consisting of residents, commercial workers, construction workers, and recreational visitors. It was performed to estimate the likelihood and nature of the potential effects to human health that may occur as a result of exposure to the COPCs at the site.

6.1.4.1 Basic Approach for Characterizing Non-Cancer Risks

For most chemicals, the potential for non-cancer effects is evaluated by comparing the estimated daily intake (DI) of the chemical over a specific time period with the RfD for that chemical derived for a similar exposed period. This comparison results in a non-cancer HQ, as follows:

$$HQ = DI / RfD$$

where:

HQ = Hazard quotient

DI = Daily intake (milligrams per kilogram [mg/kg]-day)

RfD = Reference dose (mg/kg-day)

If the HQ for a chemical is equal to or less than one (1E+00), it is believed that there is no appreciable risk that non-cancer health effects will occur. If an HQ exceeds 1E+00, there is some possibility that non-cancer effects may occur although an HQ above 1E+00 does not indicate an effect will definitely occur. This is because of the margin of safety inherent in the derivation of all RfD values. However, the larger the HQ value, the more likely it is that an adverse effect may occur.

If an individual is exposed to more than one chemical, a screening-level estimate of the total non-cancer risk is derived simply by summing the HQ values for that individual. This total is referred to as the hazard index (HI). If the HI value is less than 1E+00, non-cancer risks are not expected from any chemical, alone or in combination with others. If the screening level HI exceeds 1E+00, it may be appropriate to perform a follow-on evaluation in which HQ values are added only if they affect the same target tissue or organ system (e.g., the liver). This is because chemicals that do not cause toxicity in the same tissues are not likely to cause additive effects.

In the case of lead, risks are evaluated using a somewhat different approach. In brief, mathematical models are used to estimate the distribution of blood lead values in a population of people exposed to lead under a specified set of conditions. Health risks are judged to be acceptable if there is no more than a 5 percent chance that an exposed individual (a child or a woman of child-bearing age) will have a blood lead level that

exceeds 10 micrograms per deciliter (µg/dL). For convenience, this probability is referred to as P10.

6.1.4.2 Basic Approach for Characterizing Cancer Risks

The excess risk of cancer from exposure to a chemical is described in terms of the probability that an exposed individual will develop cancer because of that exposure by age 70. For each chemical of concern, this value is calculated from the daily intake of the chemical from the site, averaged over a lifetime [daily intake lifetime (DIL)]), and the SF for the chemical, as follows (EPA 1989):

$$\text{Excess Cancer Risk} = 1 - \exp(-\text{DIL} \bullet \text{SF})$$

Excess cancer risks are summed across all chemicals of concern and all exposure pathways that contribute to exposure of an individual in a given population. The level of total cancer risk that is of concern is a matter of personal, community, and regulatory judgment. In general, EPA considers excess cancer risks that are below about 1 in 1,000,000 to be so small as to be negligible and risks above 1 in 10,000 to be sufficiently large that some sort of remediation is desirable. Excess cancer risks that range between 1 in 10,000 and 1 in 1,000,000 are generally considered to be acceptable although this is evaluated on a case by case basis.

6.1.4.3 Risk Estimates for Onsite ATV Riders

Table 6-5 summarizes the total risks to hypothetical ATV riders from ingestion and inhalation of surface soil although this activity is prohibited. As seen, the total risks are below a level of concern to central tendency exposure (CTE) individuals in all exposure areas but may be above a level of concern to a reasonable maximum exposure (RME) individual for non-cancer effects in all exposure areas and cancer effects in one exposure area (LP).

Non-cancer risks at all locations are primarily due to the inhalation of manganese. Ingestion of thallium also contributes to the non-cancer risks at two areas (AH&P and LP). Risks from lead are below a level of concern at all locations. Cancer risks are due to ingestion of arsenic, with additional contributions from the inhalation pathway. Results indicate that levels of thallium, arsenic, and manganese in onsite soils may pose a risk to ATV riders who visit the site for recreation.

6.1.4.4 Risk Estimates for Onsite Hikers

Table 6-6 presents the total risks to hikers from the incidental ingestion of onsite surface soil, sediment, and surface water during recreational activities. Total non-cancer and cancer risks to a CTE individual are below a level of concern at all locations but exceed a level of concern to an RME individual at several locations. Non-cancer risks are driven by the incidental ingestion of metals in surface water, with additional contributions from the ingestion of surface soil, with the exception of the AH&P area of the site and at three surface water/sediment exposure units (reach LA, LCPD and PDC) within the pits and crusher area of the site. For exposures that occur in the AH&P area of the site, non-cancer risks are driven by the incidental ingestion of thallium in surface soil.

Non-cancer risks in the southwestern area of the PCA exposure unit (at surface water/sediment exposure units LA, LCPD, and PDC) are driven by both thallium and arsenic in surface soil. Cancer risks exceeding a 1E-04 level of concern are driven by arsenic in surface water, with additional contributions from arsenic in sediment at some locations. Risks to hikers from lead are not of concern at any location. These results indicate that risks from exposure to surface water, sediment, and surface soil at the site are likely to be below a level of concern for most recreational visitors but could be of potential concern to individuals with RME exposures if exposure were to occur repeatedly in some locations.

6.1.4.5 Risk Estimates for Onsite Residents

Table 6-7 summarizes the total risks to hypothetical future onsite residents from the incidental ingestion of soil and groundwater. Non-cancer risks are above a level of concern at all locations. At most locations, they are driven by ingestion of groundwater, with additional contributions from soil ingestion. At two locations (well BED-8 and GE-MW-06), non-cancer risks are driven by the ingestion of thallium in surface soil, with additional contributions from groundwater ingestion. Non-cancer risks from groundwater ingestion are driven by several metals (arsenic, cadmium, chromium, copper, iron, antimony, zinc, manganese, aluminum, and thallium) in both the dissolved and total fractions; whereas, non-cancer risks from soil ingestion are driven by arsenic and thallium. Risks from lead would be of concern to residents at some locations due to the concentration of dissolved and total lead in groundwater.

Total cancer risks exceed a 1E-04 at all locations for a resident with RME exposure and at several locations for a resident with CTE exposure. Cancer risks are due to the ingestion of arsenic in both surface soil and groundwater. The exposure pathway contributing the maximum cancer risk varies from location to location. These results indicate that concentrations of arsenic, lead, and other metals in soil and groundwater would be of concern to hypothetical future residents.

6.1.4.6 Risk Estimates for Onsite Commercial Workers

Table 6-8 summarizes the total risks to hypothetical future onsite commercial workers. Non-cancer risks to a worker with both CTE and RME exposures exceed a level of concern at all locations, with one exception (well GW-10A). These risks are almost entirely due to the ingestion of groundwater, with additional contributions from soil at some locations.

The chemicals driving non-cancer risks from groundwater ingestion vary from location to location and include arsenic, cadmium, chromium, copper, iron, antimony, zinc, manganese, aluminum, and thallium in both the dissolved and total fractions. The non-cancer risk driver for the soil ingestion exposure pathway is thallium. Risks from lead exceed EPA's health based goal (P10<5 percent) for a pregnant worker at three locations (wells CDM03b, CDM04b, and GE-MW-08) due to ingestion of dissolved or total lead in groundwater.

Total cancer risks exceed a 1E-04 level of concern at most locations for workers with RME exposure to site media and, at a few locations, for an individual with CTE

exposure. These risks are driven by the groundwater ingestion pathway due to concentrations of dissolved and total arsenic.

These results indicate that concentrations of arsenic and lead and other metals in groundwater and the concentration of thallium in surface soil would be of concern to commercial workers under a future land use scenario.

6.1.4.7 Risk Estimates for Onsite Construction Workers

Table 6-9 summarizes the total risks to hypothetical future construction workers from ingestion and inhalation of surface and sub-surface soil at the site. Non-cancer risks are above a level of concern at all locations while cancer risks are not of concern at any location.

The non-cancer risks are due almost entirely to ingestion of thallium, with additional contributions from arsenic at two areas (HLP and LP). Risks from lead are below a level of concern at all locations. These results indicate that levels of thallium and arsenic in soil may pose a risk to onsite construction workers during future excavation or maintenance work at the site.

6.1.4.8 Risk Estimates for Offsite Children

Table 6-10 presents the total risks to children playing in offsite drainages from surface water and sediment. Total non-cancer and total cancer risks are below a level of concern at all locations. Risks from lead are also below a level of concern at all locations. These results indicate that there is little risk to children or other recreational visitors who may have contact with surface water or sediment along offsite creeks and drainages.

6.1.4.9 Risk Estimates for Offsite Recreational Fishermen

Table 6-11 summarizes the total risks to recreational fisherman from the ingestion of sediment, surface water, and fish in offsite drainages. As seen, non-cancer and cancer risks from surface water and sediment are below a level of concern at all locations. At this location, the total cancer risks exceed a level of concern for an RME individual from the ingestion of arsenic in surface water. Risks from lead are below a level of concern at all locations. These results indicate there is little risk to recreational fisherman from ingestion of fish or who may have contact with surface water or sediment along offsite creeks.

6.1.4.10 Risk Estimates for Offsite Residents

Table 6-12 summarizes risks to current or hypothetical future residents from ingestion of groundwater from offsite wells located mainly along creeks and channels that drain from the site. Results are presented both for dissolved metals (Panel A) and for total metals (Panel B).

Non-cancer risks are above a level of concern for many well locations, both for a CTE and RME receptor, for both dissolved and total metals. This risk is attributable to numerous chemicals, including arsenic, cadmium, copper, iron, manganese,

antimony, and thallium, with the relative contribution varying from well to well. Lead risks are not above a level of concern based on dissolved or total metals, with the exception of one well (BED-19). The concentration of lead in the total fraction at this location exceeds EPA's health based goal (P10 < 5 percent). This suggests that the water contains suspended particulate matter, which would be of potential concern if not filtered or allowed to settle before ingestion.

Cancer risks for both dissolved and total metals exceed 1E-04 for RME receptors at a number of wells, with all values exceeding 1E-05. This risk is due to arsenic in the groundwater. These results indicate that ingestion of groundwater from wells on the site is likely to pose unacceptable levels of non-cancer and cancer risk in most locations due to the presence of numerous dissolved and suspended metals.

6.1.5 Uncertainties

Quantitative evaluation of the risks to humans from environmental contamination is frequently limited by uncertainty regarding a number of key data items, including concentration levels in the environment, the true level of human contact with contaminated media, and the true dose-response curves for non-cancer and cancer effects in humans. This uncertainty is usually addressed by making assumptions or estimates for uncertain parameters based on whatever limited data are available. Because of these assumptions and estimates, the results of risk calculations are themselves uncertain, and it is important for risk managers and the public to keep this in mind when interpreting the results of a risk assessment. In most cases, assumptions employed in this risk assessment to deal with uncertainties were intentionally conservative; that is, they are more likely to lead to an overestimate rather than an underestimate of risk.

6.1.6 Preliminary Remediation Goals and Remedial Action Levels

The HHRA evaluated exposures and risks to recreational hikers from ingestion of surface soil, surface water, and sediment and evaluated exposure and risk to recreational ATV riders from ingestion of surface soil and the inhalation of dust in air. Exposure and risks to hypothetical future residents were also evaluated from the ingestion of surface soil and ingestion of groundwater.

The following chemicals of concern and exposure scenarios/land uses were identified and evaluated in the *Human Health Preliminary Remediation Goal and Remedial Action Levels for Recreational Visitors and Residents at the Gilt Edge Mine Site* (EPA 2006b).

<u>Recreational Land Use</u>

ATV rider:	Arsenic, manganese, and thallium in surface soil
Hiker:	Arsenic and thallium in surface soil
Hiker:	Aluminum, arsenic, cadmium, copper, iron, manganese, and thallium in surface water

Residential Land Use

Resident: Arsenic, lead, and thallium in surface soil

Resident: Aluminum, antimony, arsenic, cadmium, chromium, copper, iron, lead, manganese, thallium, and zinc in groundwater

6.1.6.1 Preliminary Remediation Goals

Using the COPCs, PRGs for surface water, sediment, and groundwater for recreational visitors and future residents were developed. PRGs were developed based on results of the BRA and are described in detail in *Memorandum, Human Health Preliminary Remediation Goals and Remedial Action Levels for Recreational Visitors and Residents at the Gilt Edge Mine Site* (EPA 2006b). RALs were developed for site soil.

PRGs are the average concentration of a chemical in an exposure unit associated with the target risk level such that the concentrations at or below the PRG do not pose an unacceptable risk. Recreational visitor and future residents PRGs are dependent on the input values used in the calculation and include human exposure parameters and toxicity values. PRGs may need to be recalculated if any assumptions for these input values change. Table 6-13 summarizes the PRGs for recreational visitors and hypothetical future residents.

6.1.6.2 Remedial Action Levels

An RAL is the maximum concentration of a contaminant that can be left in place in soil at an exposure unit such that the average concentration (or 95th percentile upper confidence limit of the average) within the exposure unit is at or below the PRG. Recreational visitor and future residents RALs are dependent on the input values used in the calculation and include human exposure parameters, toxicity values, concentrations of metals in clean fill, and the data sets of contaminants at the exposure unit.

Soil is the preliminary medium that EPA is considering remediating for protection of human health. Table 6-14 summarizes the surface soil RALs for the site.

6.2 Ecological Risk Assessment

The ERA assesses risks for ecological receptors for conditions that were present from July 1995 to June 2002. Current conditions were changed from that present in 2002 as a result of two primary events:

- The Ruby Waste Repository was filled and capped.
- The wastewater treatment system that discharged treated mine waste water from the site to Strawberry Creek was completely replaced.

The original wastewater treatment system was a sodium (or aluminum) hydroxide addition system that primarily raised the pH of mine waters prior to discharge. The new wastewater treatment system came online in September of 2003 and is a lime

(bicarbonate) addition system. Thus, the description of baseline risks for aquatic and terrestrial receptors that follows may not reflect current site conditions. To evaluate current site conditions in Strawberry Creek, EPA commissioned a study group to collect information on the aquatic environment in Strawberry Creek to understand if risks for aquatic receptors remain at unacceptable levels. An external review draft of the Biological Monitoring Report was submitted in January 2007. Results of the biological monitoring are presented in Section 6.2.7 along with recommendations for further monitoring.

6.2.1 Identification of Chemicals of Concern

The purpose of the baseline ERA is to describe the likelihood, nature, and extent of adverse effects to ecological receptors resulting from exposure to contaminants released at the mine and to surrounding areas as a result of site activities. This information, along with other relevant information, is used by risk managers to make decisions whether remedial actions are needed to protect ecological receptors and the environment.

This ERA is completed according to current EPA guidance for ecological risk assessments (EPA 1992, 1997, 1998). For the site, the ERA process was initiated by performing a SERA in January of 2001 (EPA 2001b). The SERA concluded that risks from site-related chemicals could not be excluded for any of these ecological receptors and identified data needed for the completion of a more detailed evaluation. The ERA report is organized into nine sections, including introduction, site characterization, nature and extent of contamination, problem formulation, risks to aquatic organisms, risks to terrestrial plants and soil invertebrates, risks to wildlife receptors, uncertainties, and references.

6.2.2 Exposure Assessment

Available site data are divided into two conceptual categories:

- **Mine Source Area.** Refers to data collected within the boundaries of the mine site and workings. Areas of potential ecological exposure are further divided into a number of reaches, including several locations that are not believed to be impacted by site-related releases and that serve as reference areas. These reaches and reference areas are listed below.

- **Riparian Area**. Riparian Area refers to data collected in surface water drainages (surface water, sediment, soil, and biological tissue) outside of the boundary of the mine site and workings. All samples from Strawberry Creek, Hoodoo Gulch, and Ruby Gulch are considered to be Riparian Area. Surface material within this area is composed of fill material, waste rock, and some soil (surface and subsurface).

EPA has compiled a master database of all results with the assistance of CDM. The ERA uses a subset of data from this master database (as of the date of this document) with some additions and modifications.

Figure 6-4 presents the ecological site conceptual model for the ERA. There are a number of complete exposure pathways by which ecological receptors may come into contact with site-related contamination. It is not feasible to evaluate exposures and risks for each avian and mammalian species potentially present at the site. For this reason, specific wildlife species are identified as surrogates (representative species) for the purpose of estimating exposure and risk. The surrogate species at the site are representative of other species with similar dietary preferences and feeding guilds. The surrogate species at this site include the masked shrew (*Sorex cinereus*), the American robin (*Turdus migratorius*), the belted kingfisher (*Ceryle alcyon*), the mink (*Mustela vison*), the deer mouse (*Peromyscus maniculatus*), and the bobwhite quail (*Galliformes phasiadinae*).

Assessment endpoints are explicit statements of the characteristics of the ecological system that are to be protected. Assessment endpoints are either measured directly or are evaluated through indirect measures. Measurement endpoints represent quantifiable ecological characteristics that can be measured, interpreted, and related to the valued ecological components chosen as the assessment endpoints (EPA 1992, 1997). Table 6-15 describes the assessment and measurement endpoints used to interpret potential ecological risks for the site. Measurement endpoints can be divided into three basic categories based on the line of evidence approach that they use. These lines of evidence are: HQs, site-specific toxicity tests (SSTTs), and observations of population and community demographics.

Each of the approaches has advantages and limitations, and conclusions based on only one method of evaluation may be misleading. The best approach for deriving reliable conclusions is to combine the findings across all of the line-of-evidence methods for which data are available, taking the relative strengths and weaknesses of each method into account. If the methods all yield similar conclusions, confidence in the conclusion is greatly increased. If different methods yield different conclusions, then a careful review must be performed to identify the basis of the discrepancy and to decide which approach provides the most reliable information.

6.2.3 Risk to Aquatic Receptors

Based on the ecological site conceptual model, three exposure pathways are quantitatively evaluated using the various methods:

- Direct contact with contaminants dissolved and/or suspended in surface water
- Direct contact with contaminants in sediment
- Exposure of fish by all pathways combined based on tissue levels of contaminants in fish tissue

6.2.3.1 Direct Contact with Contaminants in Surface Water

This pathway is most applicable to fish, but is also applicable to benthic organisms that reside in the uppermost portion of the sediment substrate. All three lines of evidence are used to evaluate risks to aquatic receptors from direct contact exposure

to surface water. These lines of evidence include the HQ calculations, the toxicity testing of surface water, and the biological community data (benthic invertebrate and fish). The findings from the lines of evidence evaluated for exposures of aquatic receptors to COPCs in surface water are summarized below.

Line of Evidence - HQ Calculations Based on Surface Water Concentrations

- For Strawberry Creek, acute toxicity (risk) is associated with aluminum, cadmium, copper, and zinc and to a lesser extent chromium, manganese, and selenium; chronic toxicity (risk) is associated with cadmium and to a lesser extent calcium and manganese, aluminum, cobalt, copper, selenium, and sodium.

- For Hoodoo Gulch, acute toxicity is associated with aluminum, cadmium, copper, and zinc and to a lesser extent manganese; chronic toxicity is associated with aluminum and manganese and to a lesser extent beryllium, cadmium, cobalt, copper, and nickel.

- For Ruby Gulch, acute toxicity is associated with aluminum, cadmium, copper, and zinc although to a lesser extent compared to Strawberry Creek and Hoodoo Gulch; chronic toxicity is associated with cadmium.

- For Bear Butte Creek, only moderate acute risks are identified associated with copper downstream of Strawberry Creek.

Line of Evidence - Direct Toxicity Testing

- For Strawberry Creek, surface water toxicity testing identified that site surface waters are significantly toxic and reduced both the survival and growth of fathead minnows in all samples tested.

- For Bear Butte Creek, surface water samples were not toxic to fathead minnows.

Line of Evidence - Population Observation Benthic Community Structure

- For Strawberry Creek, the benthic macroinvertebrate community is severely or moderately impaired compared to reference stations.

- For Bear Butte Creek, the benthic macroinvertebrate community is slightly impaired relative to reference stations.

Line of Evidence - Population Observation Fish Community Structure

- For Strawberry Creek, the fish community is impaired relative to upstream Bear Butte Creek in that some types of fish are absent or severely limited in number although there does appear to be some recovery at the station located just above the confluence with Bear Butte Creek.

- For Bear Butte Creek, the fish community does not appear to be impaired downstream of Strawberry Creek compared to upstream.

Based on these lines of evidence, it is concluded that site-related COPCs in surface water pose an unacceptable risk to aquatic receptors in Strawberry Creek. Based on

the weight of evidence, risks associated with COPCs in surface water are not predicted for Bear Butte Creek. This conclusion is based on the observations that (1) the HQ values calculated for Bear Butte Creek do not predict risk, (2) toxicity tests do not demonstrate toxicity, and (3) the benthic macroinvertebrate community is only slightly impaired and this impairment may be associated with sediment contamination.

An evaluation was completed to identify which of the COPC concentrations could explain the observed toxicity. The results of the definitive surface water tests are compared to known toxicity level (LC50) values for each of the COPCs identified as being significantly correlated with the observed toxicity (cadmium, calcium, cobalt, magnesium, manganese, nickel, selenium, sodium, sulfate, and TDS. The toxicity of the sample(s) is not explained by concentrations of calcium, cadmium, magnesium, nickel, selenium, sodium, and TDS. Cobalt, manganese, and sulfate are identified as possible contributors to toxicity. The toxicity of the Strawberry Creek surface water samples represents the effects of the mixture of COPCs, including possible antagonistic, synergistic, and/or additive effects between individual components. The toxicity of the mixture is represented directly by the measured results of tests with the surface water samples but may not be well represented by the individual single-compound results. In other words, our comparison of single contaminant LC50 values may not be a good measure of the overall toxicity. In making these comparisons, it is assumed that the single COPC is the sole cause of toxicity, and its toxicity is not affected by other COPCs.

Interpretation of the cause of toxicity is also confounded by the following factors: (1) the analyses of the COPCs in the test water samples represent the state of the sample at the time of collection and may not represent the actual exposure conditions in the test beakers after manipulation in the laboratory and (2) toxicity could be associated with a constituent or multiple constituents that were not analyzed for in the test samples.

In order to develop a tool for assessing major ion toxicity, Mount et al. (1997) performed a series of acute toxicity tests with three freshwater species on solutions enriched with varying combinations of major ions. Results of these tests were incorporated into multivariate logistic regression models that predict survival of the three test species based on major ion concentrations. Using this model, the predictive toxicity for Strawberry Creek associated with TDS components is much less than that observed. This comparison infers that toxicity observed for the water samples cannot be explained by TDS alone and clearly indicates the presence of another toxicant(s). As previously stated, toxicity may be caused by constituents(s) that were not analyzed for in the surface water samples. Historic use of polymers (surfactants) has been documented for the wastewater treatment system prior to discharge to Strawberry Creek. These organic chemicals are a possible cause of the observed toxicity in surface water samples. It is not possible to confirm the exact cause of toxicity. To confirm a specific cause(s) or to ensure that future discharges of treated effluent are not toxic, site-specific toxicity testing is recommended in addition to monitoring for COPC concentrations and water quality parameters.

6.2.3.2 Direct Contact with Contaminants in Sediment

This pathway is most applicable to benthic macroinvertebrate species that live buried within the sediment substrate. Three lines of evidence are available to evaluate risks from sediments to benthic organisms. The findings from the lines of evidence are summarized below.

Line of Evidence - HQ Calculations

- For Strawberry Creek, risks are categorized as severe for benthic organisms exposed to cadmium, copper, lead, and zinc in sediment; high for silver; and moderate for aluminum and manganese.

- For Hoodoo Gulch, risks are categorized as severe for benthic organisms exposed to cadmium, copper, lead, silver, and zinc and moderate for manganese.

- For Ruby Gulch, risks are categorized as high for benthic organisms exposed to copper. Risks associated with cadmium are moderate.

- For Bear Butte Creek (downstream) risks are categorized as severe for benthic organisms exposed to cadmium, copper, and zinc and high for lead and silver.

Line of Evidence - Direct Toxicity Testing

- For Strawberry Creek, very high toxicity was observed in sediment toxicity testing (very low survival of *H. azteca (6* to 30 percent compared to 70 to 100 percent in controls) in September 2000 and October 2001.

- For Bear Butte Creek, toxicity was not observed in the sediment toxicity testing.

Line of Evidence - Population Observations Benthic Community Structure

- For Strawberry Creek, the benthic macroinvertebrate community is severely or moderately impaired compared to reference stations.

- For Bear Butte Creek, the benthic macroinvertebrate community is slightly impaired relative to reference stations.

In summary, based on a weight of evidence approach, it is concluded that COPCs in sediments are adversely impacting benthic organisms in Strawberry Creek. For downstream Bear Butte Creek, the HQs predict toxicity but none was observed in sediment testing, and the benthic macroinvertebrate community is only slightly impaired relative to reference. Risks to aquatic receptors in Bear Butte Creek from exposure to COPCs in sediment are not considered to be significant.

In order to increase the usefulness of the weight of evidence evaluation, the sediment toxicity testing results are compared to concentrations of COPCs in the sediment samples. This analysis identifies copper ($p < 0.0001$; $R2 = 0.93$) in the sediment samples as a possible cause of the toxicity observed.

6.2.3.3 Exposure of Fish by All Pathways (based on tissue levels of contaminants in fish tissue)

One line of evidence (tissue-based HQ values for fish) is available to evaluate risks to aquatic receptors (fish) from all aquatic exposure pathways combined (surface water, sediment, and dietary exposure). The findings from this line of evidence are summarized below.

Line of Evidence - HQ Calculations Based on Fish Tissue Burdens

- For cadmium, risks are identified as severe in Strawberry Creek and downstream Bear Butte Creek and are minimal for lead and chromium.

Based on this line of evidence, it is concluded that risks to fish from COPCs in all media (surface water, sediment, and diet) are significant in Strawberry Creek and downstream Bear Butte Creek associated with cadmium.

6.2.3.4 Overall Conclusion Regarding Risks to Aquatic Receptors

The weight of evidence combined across all observations indicates that risks to aquatic receptors from site-related COPCs are high in Strawberry Creek, Hoodoo Gulch, and Ruby Gulch. Unacceptable risks do not extend downstream into Bear Butte Creek.

6.2.4 Risk to Terrestrial Plants and Soil Organisms

Based on the ecological site conceptual model, the following exposure pathways are selected for quantitative evaluation:

- Direct contact of plant roots with chemicals in surface soils
- Direct contact with soils by soil invertebrates

Only one line of evidence (the HQ approach) is available to evaluate risks to plants and soil invertebrates from COPCs in soils. The findings from this line of evidence on concentrations measured in soil are summarized below.

- For Strawberry Creek, risks are categorized as severe for plants and soil invertebrates exposed to copper and silver in soils, high for selenium and thallium, and moderate for zinc.
- For Bear Butte Creek, risks are categorized as high for plants and soil invertebrates exposed to copper and zinc and moderate for silver and thallium.
- For Mine Source Area soils, certain soil, fill, and waste rock samples have HQ values greater than 1 for arsenic, copper, lead, zinc, thallium, silver, and selenium.

Based on this line of evidence, it is concluded that risks from site-related contaminants in surface soil are of concern in the Riparian Area of Strawberry Creek and Bear Butte Creek and in the Mine Source Area. Risks for riparian soils are associated with copper, silver, thallium, and zinc. Risks for Mine Source Area soils are associated with arsenic, copper, lead, selenium, silver, thallium, and zinc. Use of HQ

values to interpret risks does not consider environmental factors that may influence the toxicity of COPCs in soils to plants and soil invertebrates.

For lead and copper in soils, it is possible to more accurately predict the toxicity of soils based on the measured pH and organic carbon content of the soils using a data set and regression equations developed by Suave et al (2000). Suave et al. (2000) developed regression equations to predict toxicity to plant and soil organisms from copper and lead. Using the measured bulk metal concentrations and soil pH, the free metal concentrations in the soil solution are estimated. The free metal activity is then used to predict the expected inhibition of the plant and soil organism communities and microbial processes. A 25 percent inhibition corresponds to the level at which most organisms will begin to exhibit adverse effects and represents the threshold for the beginning of ecosystem toxicity (Suave et al. 2000). A 50 percent inhibition represents a drastic impact on the ecosystem, with major impacts on microbial processes, moderate impacts to organisms of average sensitivity, and alterations of plant productivity and species competition (Suave et al. 2000).

The predictive model (equation) was applied to the data for fill material, soil stockpiles, and waste rock for copper and lead. The results are sorted conceptually into three categories:

- Low (low inhibition <10 percent)
- Medium (from 10 to 30 percent inhibition)
- High (>30 percent inhibition)

The results indicate that most fill material samples are not toxic, but most waste rock and soil stockpile samples are toxic.

6.2.5 Risk to Wildlife Receptors

Exposure of wildlife receptors may occur through ingestion of contaminated surface water while drinking, ingestion of contaminated soil or sediment while feeding, and ingestion of contaminated food web items. It is not feasible to evaluate exposures and risks for each avian and mammalian species potentially present. For this reason, specific wildlife species are identified as surrogates (representative species) for the purpose of estimation of exposure and risk in the ERA (Exhibit 6-1).

Exposure of wildlife receptors for Riparian Areas for each COPC in each medium (surface water, soil, sediment, and fish) within each exposure reach is based on the 95 percent upper confidence limit (UCL) of the mean concentration or the maximum concentration, whichever is lower. The 95 percent UCL is calculated based on the assumption that concentration values within each reach are distributed lognormally. Non-detects are evaluated by assuming a concentration value equal to one-half the detection limit. For exposures related to ingestion of plants and soil invertebrates, site-specific measurements of COPC concentrations in these food items are not available for the site. COPC concentrations in plants and soil invertebrates are estimated based

on available equations that relate the soil concentration of the COPC to the concentration in food type.

Exhibit 6-2. Surrogate Species at the Site and Exposure Pathways Evaluated

Surrogate Species	*Feeding Guild*	*Exposure Pathways Evaluated*
Riparian Areas		
Mink	Mammalian piscivore	Ingestion of surface water, sediment, and fish
Belted Kingfisher	Avian piscivore	
Masked Shrew	Mammalian insectivore	Ingestion of surface water, soil, and soil invertebrates
American Robin	Avian omnivore	Ingestion of surface water, soil, plants, and soil invertebrates
Deer Mouse	Mammalian omnivore	
Bobwhite quail	Avian herbivore	Ingestion of surface water, soil, and plants
Mine Source Area		
Deer mouse	Mammalian omnivore	Ingestion of soil, fill material, waste rock, and plants
Bobwhite quail	Avian herbivore	

Exposures for wildlife to the Mine Source Area (the mine workings) are evaluated in the same manner as risks for terrestrial receptors (plants and soil invertebrates) by sampling location. COPC concentrations in plants are estimated in the same manner as for the Riparian Areas.

Toxicity reference values (TRVs) for terrestrial wildlife (mammals and birds) were derived by EPA for the calculation of ecological soil screening levels (Eco-SSLs). Using specific procedures for the Eco-SSLs, one mammalian and one avian TRV are derived and expressed as mg contaminant per kg body weight. The TRV derivation procedures extract and plot two different toxicity values. The first value is the exposure dose that is not associated with any adverse effects to the test organism. This is referred to as the No Observed Adverse Effect Level (NOAEL). The second value is the reported exposure dose that causes an observable adverse effect and is referred to as the Lowest Observed Adverse Effect Level (LOAEL).

NOAEL and LOAEL values are grouped by six types of endpoints (biochemical, behavior, pathology, reproduction, growth, and mortality). The TRV value, in most cases, is equal to the geometric mean of the NOAEL for growth and reproductive effects or the highest bounded NOAEL lower than the lowest bounded LOAEL for growth, reproduction, or survival. For contaminants where Eco-SSL TRVs are not available, TRVs are derived from other literature sources.

The TRVs for wildlife are expressed in units of ingested dose. However, the toxicity from an ingested dose depends on how much of the ingested dose is actually absorbed, which in turn depends on the properties of both the contaminant and the exposure medium. Ideally, toxicity studies would be available that establish empiric TRVs for all site media of concern (water, food, soil, sediment). However, most laboratory tests use either food or water as the exposure medium, and essentially no studies use soil or sediment. Therefore, in cases where a TRV is based on a study in which the oral absorption fraction is different than what would be expected for a site medium, it is necessary to adjust the TRV to account for the difference in absorption.

For inorganic COPCs, available data on cadmium and manganese suggest that absorption from the diet is about half that from water (IRIS 2002). Based on this, when toxicity data for inorganic COPCs are available from studies in food or water, but not both, the RBA for a contaminant in food compared to that for water or other soluble forms (e.g., capsule) is assumed to be 0.5 (50 percent). That is:

TRVwater = TRVdiet A 0.50

TRVdiet = TRVwater or capsule / 0.50

In the absence of any site-specific data, it is assumed that contaminants in soil and sediment are absorbed to the same degree as contaminants in food. It is considered likely that this approach may tend to overestimate exposure and risk from ingestion of soil, but this is not known for certain.

Inspection HI values for each surrogate species and each riparian exposure reach reveal the following main conclusions:

- Risks are above a level of concern in Strawberry Creek for ingestion of aluminum in surface water; incidental ingestion of arsenic and lead in soil; ingestion of arsenic, cadmium, lead, selenium, and thallium in soil invertebrates; and ingestion of antimony, arsenic, lead, and thallium in plants.

- Risks are above a level of concern in Ruby Gulch for ingestion of aluminum in surface water, cadmium and chromium in soil invertebrates, and antimony in plants.

- Risks are below a level of concern in HooDoo Gulch for all wildlife receptors.

- Risks are above a level of concern in downstream Bear Butte Creek for ingestion of antimony and lead in plants and ingestion of arsenic, cadmium, lead, and vanadium in soil invertebrates.

Inspection of HQs for the Mine Source Area reveals the following:

- Some location-specific HQs for surface soil or fill material samples are within a level of concern (> 1) that is higher than the range of possible background soil concentrations, and there are risks associated with the ingestion of manganese, selenium, vanadium, lead, and zinc in plants and the incidental ingestion of arsenic in the soil and/or fill material.

- Some location-specific HQs (waste rock only) are within a level of concern that is higher than the range for background, and there are associated risks with the ingestion of antimony, chromium, and molybdenum in plants and the incidental ingestion of antimony and lead in waste rock.

- HQs for all remaining COPCs for all samples and sample types are below a level of concern with either HQ values of < 1 or less than background conditions.

Only one line of evidence is available to evaluate risks for wildlife. A summary of the risk evaluation is provided below.

Line of Evidence - HI Calculations Based on COPC Concentrations Measured in Soil, Water, and Diet

- For Strawberry Creek (Riparian Area), risks are above a level of concern for ingestion of aluminum in surface water; incidental ingestion of arsenic and lead in soil; ingestion of arsenic, cadmium, lead, selenium, and thallium in soil invertebrates; and ingestion of antimony, arsenic, lead, and thallium in plants.

- For Ruby Gulch (Riparian Area), risks are above a level of concern for ingestion of aluminum in surface water; ingestion of cadmium and chromium in soil invertebrates; and ingestion of antimony in plants.

- For Hoodoo Gulch (Riparian Area), risks are above a level of concern for incidental ingestion of aluminum in sediment.

- For downstream Bear Butte Creek, risks are above a level of concern for ingestion of antimony and lead in plants and ingestion of arsenic, cadmium, lead, and vanadium in soil invertebrates.

HQ Calculations Based on COPC Concentrations Measured in Surface Soil, Subsurface Soil, Fill Material, Waste Rock, and Plants

- For the Mine Source Area, risks are above a level of concern for ingestion of manganese, selenium, vanadium, lead, and zinc in plants and the incidental ingestion of arsenic in environmental media (soil, surface soil, waste rock, or fill material).

- For the Mine Source Area, risks are above a level of concern for exposures to waste rock (but not other waste material types) for ingestion of antimony, chromium, and molybdenum in plants (growing on the waste rock) and the incidental ingestion of antimony and lead in waste rock.

Based on this line of evidence, it is concluded that risks from COPCs in surface water and soil are of concern to wildlife receptors in the Riparian Area along Strawberry Creek, Ruby Gulch, and downstream Bear Butte Creek.

6.2.6 Uncertainties

Quantitative evaluation of ecological risks is generally limited by uncertainty regarding a number of important data. This lack of knowledge is usually circumvented by making estimates based on whatever limited data are available or by making assumptions based on professional judgment when no reliable data are available. Because of these assumptions and estimates, the results of the risk calculations are themselves uncertain, and it is important for risk managers and the public to keep this in mind when interpreting the results of a risk assessment. The following text summarizes the key sources of uncertainty influencing the results of this ERA.

6.2.6.1 Uncertainty in the Nature and Extent of Contamination

Representativeness of Samples Collected

Concentration levels of COPCs in environmental media are often quite variable as a function of location and may also vary significantly as a function of time. Thus, samples collected during a field sampling program may or may not fully characterize the spatial and temporal variability in actual concentration levels. At this site, all field samples were collected in accordance with sampling and analysis plans that specifically sought to ensure that samples were representative.

However, in some locations and for some media, the number of samples collected was relatively small. Thus, some uncertainty remains as to whether the samples collected provide an accurate representation of the distribution of concentration values actually present.

Accuracy of Analytical Measurements

Laboratory analysis of environmental samples is subject to a number of technical difficulties, and values reported by the laboratory may not always be exactly correct. However, all data used in this risk assessment had sufficient accompanying quality assurance data to ensure that results were within acceptable bounds for accuracy and precision. The magnitude of analytical error is usually small compared to other sources of uncertainty although the relative uncertainty increases for results that are near the detection limit.

6.2.6.2 Uncertainty in Exposure Assessment

Exposure Pathways Not Evaluated

Exposure pathways selected for quantitative evaluation in this ERA do not include all potential exposure pathways for all ecological receptors. Exposure pathways *not* evaluated in this ERA include:

- Ingestion of prey items and sediments by benthic invertebrates
- Ingestion of water, sediment, and prey items by fish

- Dermal exposure of wildlife to soil, sediment, and surface water

Omission of these pathways will tend to underestimate total risk to the exposed receptors. However, most of these exposure pathways are likely to be minor compared to other pathways that are evaluated, and the magnitude of the underestimation is not likely to be significant.

Contaminants Not Detected
Any contaminant that was never detected in a site medium is not evaluated in exposures of receptors to that medium. However, in some cases, the analytical detection limit is too high to expect the contaminant would be detected even if it were present at a level of concern.

Contaminants in this category are assigned to the qualitative COPC list (Type 2). A few such contaminants exist at the site. Omission of these contaminants could result in an underestimation of risk. However, the magnitude of the error is likely to be low because, if the contaminant is actually site related or if it is present at a level of substantial concern, it likely occurs at levels above the detection limit at least a few times. Thus, while the hazard from Qualitative Type 2 COPCs is unknown, it is probably not large enough to cause a substantial underestimation of risk.

Exposure Area Concentration Values
For exposures that are based on the average concentration across many samples rather than exposures that are based on individual samples (this is the case for most wildlife species), the desired input parameter is the true mean concentration of a contaminant within a medium, averaged over the area where exposure occurs. In this assessment, rather than using the sample mean, exposure is based on the 95 percent UCL of the mean or the maximum value (whichever was lower). This approach is much more likely to overestimate than underestimate true risk, and this is a source of conservatism in the risk estimates.

Wildlife Exposure Factors
The intake (ingestion) rates for food, soil, water, and sediment used to estimate exposure of wildlife at the site are derived from literature reports of intake rates, average body sizes, dietary compositions, consumption rates, and metabolic rates by receptors at other locations or from measurements of laboratory-raised organisms. These values may or may not serve as appropriate models for site-specific intake rates of wild receptors at this site. Moreover, the actual dietary composition of an organism will vary daily and seasonally. In addition, some wildlife receptor-specific intake rates are estimated by extrapolation from data on a closely related species or by use of allometric scaling equations (scaling of intake rates based on body weights). This introduces further uncertainty into the exposure and risk estimates. These uncertainties could either under- or overestimate the actual exposures of wildlife to COPCs in water, sediment, soil, and diet.

Absorption From Ingested Doses
The toxicity of an ingested contaminant depends on how much of the contaminant is absorbed from the gastrointestinal tract into the body. However, the actual extent of contaminant absorption from ingested media (soil, sediment, food, and water) is usually not known. The hazard from an ingested dose is estimated by comparing the dose to an ingested dose that is believed to be safe, based on tests in a laboratory setting. Thus, if the absorption is the same in the laboratory test and the exposure in the field, then the prediction of hazard will be accurate. However, if the absorption of contaminant from the site medium is different (usually lower) than occurred in the laboratory study, then the hazard estimate will be incorrect (usually too high). In this assessment, estimates of wildlife exposure due to incidental soil and sediment ingestion conservatively assume a relative bioavailability of 100 percent for all contaminants. This assumption is expected to overestimate contaminant doses to wildlife, since absorption efficiencies for many contaminants (especially metals) are lower in site media (especially soil and sediment) than in most laboratory studies.

6.2.6.3 Uncertainties in Effects (Toxicity) Assessment

Representativeness of Receptors Evaluated
Risk characterizations for aquatic receptors are based on a generalized set of species found in freshwater aquatic communities. However, not all of these species are likely to occur at this site. Thus, HQ values above 1E+00 may reflect risks to species that are absent at the site, and risks to species that are actually present at the site may be lower. Risks to wildlife are assessed for a small subset of the species likely to be present in the areas surrounding the Gilt Edge Mine. The representative wildlife species used for quantitative evaluation at this site were selected to represent a range of taxonomic groups and life history types of species likely to occur in the area. These species may not, however, represent the full range of sensitivities present. The species selected may be either more or less sensitive to contaminant exposures than typical species located within the area.

Absence of Toxicity Data for Some Contaminants
No reliable toxicity benchmark could be located for a number of contaminants detected in one or more samples of site media. Contaminants in this category are assigned to the qualitative COPC list (Type 1). A number of such contaminants exist. The inability to evaluate hazard from these contaminants could result in an underestimation of risk, but the magnitude of the error is likely to be low. This is because absence of a toxicity benchmark for a contaminant is often due to the fact that toxicological concern over that contaminant is low. That is, contaminants that lack benchmarks are often considered to be relatively less hazardous than those for which benchmarks do exist. To the extent that this is true (even though there are likely some exceptions to this rule), risks from Qualitative Type 1 COPCs at this site are likely not of substantial concern.

Extrapolation of Toxicity Data Between Receptors
Toxicity data are not available for all of the species of potential concern at the site. Thus, it is sometimes necessary to estimate toxicity values for a receptor by

extrapolating toxicity data across similar species. This extrapolation may either overestimate or underestimate the risk to the actual receptor, depending on whether the actual receptor is less sensitive or more sensitive than the species for which data are available. The direction of the error introduced by this extrapolation is unknown but could be significant in some cases.

Extrapolation of Toxicity Data Across Dose or Duration
In some cases, TRV data are available only for high dose exposures, and extrapolation to low doses (similar to those that actually occur at the site) is a source of uncertainty. Likewise, some TRVs are based on relatively short-term exposures, and extrapolation to long-term conditions is uncertain, especially for chemicals that tend to build up in the exposed organism. When such extrapolations are necessary, it is customary to include an "uncertainty factor" in the derivation of the benchmark to account for the extrapolation. In general, the uncertainty factor is likely to be somewhat too large, so the benchmarks derived in this way are often conservative (overly protective).

Extrapolation of Toxicity Data from Laboratory to Field Conditions
Even when data are available for a species of concern at the site, the data are usually generated under laboratory conditions, and extrapolation of those data to free-living receptors in the field is uncertain. In some cases, site-specific factors may tend to modify (often decrease) the toxicity of contaminants in surface water, sediments, and soil. For example, metals in surface water may be bound to soluble organic materials that reduce the tendency for the metal to bind to respiratory structures of fish or benthic organisms. Similarly, the presence of organic matter in soil, along with other substances, may have a significant influence on actual toxicity. Thus, risks based on literature-derived toxicity factors may sometimes overestimate risk from site media.

6.2.6.4 Uncertainties in Risk Characterization

Interactions Among Contaminants
Most toxicity benchmark values are derived from studies of the adverse effects of a single contaminant. However, exposures to ecological receptors usually involve multiple contaminants, raising the possibility that synergistic or antagonistic interactions might occur. However, data are not adequate to permit any quantitative adjustment in toxicity values or risk calculations based on inter-contaminant interactions. In accordance with EPA guidance, effects from different COPCs are not added unless reliable data are available to indicate that the two (or more) chemicals act on the same target tissue by the same mode of action. At this site, HQ values for each COPC are not added across different contaminants. If any of the other COPCs at the site act by a similar mode of action, total risks could be higher than estimated.

Estimation of Population-Level Impacts
Assessment endpoints for the receptors at this site are based on the sustainability of exposed populations, and risks to some individuals in a population may be acceptable if the population is expected to remain healthy and stable. However, even if it is possible to accurately characterize the distribution of risks or effects across the members of the exposed population, estimating the impact of those effects on the population is generally difficult and uncertain. The relationship between adverse

effects on individuals and effects on the population is complex, depending on the demographic and life history characteristics of the receptor being considered as well as the nature, magnitude, and frequency of the contaminant stresses and associated adverse effects. Thus, the actual distribution of HQ values that will lead to population-level adverse effects will vary from receptor to receptor, and use of a single criterion (80 percent below 1E+00) may not be appropriate. For this ERA, risks are estimated for the individual organism and as such may overestimate risks for the population.

6.2.6.5 Summary of Uncertainties

Table 6-16 summarizes the various sources of uncertainty in this ERA along with a qualitative estimate of the direction and magnitude of the likely errors attributable to the uncertainty. Based on all of these considerations, the HQ and HI values calculated and presented in this ERA should be viewed as having substantial uncertainty. Because of the inherent conservatism in the derivation of many of the exposure estimates and toxicity benchmarks, these HQ and HI values should generally be viewed as being more likely to be high than low, and should be interpreted in a weight-of-evidence approach based on other types of available information as well.

6.2.7 Biological Monitoring Report

In 2004, EPA commissioned a biomonitoring study to determine if site conditions have improved along Strawberry Creek as a result of using a new lime-based water treatment plant that discharged directly to the creek. Data collected in 2004 are compared to biomonitoring data collected in 2000 and 2001. Data collected during the study include concentration of metals in surface water and sediment pore water samples, site-specific information on surface water and sediment toxicity, and population and community studies of the benthic invertebrates community and fish populations. This study approach was consistent with the three lines of evidence presented in the baseline ERA.

The evaluation of time trends and current status of the aquatic species in Strawberry Creek required consideration of all the available lines of evidence, integrated into a weight of evidence conclusion. In general, downstream locations along Strawberry Creek have improved in surface water quality as demonstrated by HQ calculations and toxicity tests. Fish surveys indicate that the fish community is apparently healthy in the lowest reach of Strawberry Creek immediately above the confluence with Bear Butte Creek. The fish community is limited in the upper reaches of Strawberry Creek about the Boomer Gulch confluence. However, the limited fish community may be a result of metal contamination, habitat factors (physical barriers, lack of adequate prey, etc.), or both.

Data show that benthic communities have increased over time along the entire Strawberry Creek reach, except at SC-4 (upstream of Hoodoo Gulch confluence). The benthic community has not yet fully recovered and may reflect sediment as well as surface water conditions along Strawberry Creek.

Data collected during the 2004 biomonitoring suggest that surface water quality in Strawberry Creek is tending to improve in reaches downstream of Cabin Creek, but that some degree of impairment may still remain upstream from the confluence with Hoodoo Gulch.

Lines of evidence used for surface water impact determination include:

- Surface water concentrations
- Surface water HQ values
- Site-specific fish toxicity tests
- Benthic community surveys

To evaluate the risk associated with sediment to the benthic organisms present in Strawberry Creek, the standard lines of evidence were used:

- HQ values for bulk sediments
- Site-specific sediment toxicity tests
- Site-specific benthic community surveys

Based on all lines of evidence, EPA determined that, for sediments present in Strawberry Creek, conditions improved noticeably between 2000 to 2001 and 2004. However, the sediment continues to pose a risk to benthic organisms, and the benthic community is not recovered yet.

It should be noted that because the water treatment plant was not discharging during the 2004 sampling event, questions regarding the comparability of data collected during 2004 to current still exist. EPA has commissioned additional biomonitoring of Strawberry Creek to be performed in the spring and fall of 2007. Data collected from these sampling events will be used to update the site model and will be used to further define PRGs and remedial approaches, if any, for Strawberry Creek.

6.2.8 Ecological Preliminary Remediation Goals

No PRGs have been developed for the site at this time. Additional monitoring will be performed and the data evaluated, and if applicable, PRGs will be developed with this complete data set.

Section 7
Summary and Conclusions

This section summarizes the results of the preceding sections of the RI, reviews the site conceptual model, and summarizes source materials and contamination within the remediation subareas. It is organized as follows:

- Purpose and background (presented in Section 1)
- Data collection, evaluation, and usability (presented in Section 2)
- Physical characteristics (presented in Section 3)
- Nature and extent of contamination (presented in Section 4)
- Fate and transport (presented in Section 5)
- Risk assessments (presented in Section 6)
- Summary of site conceptual model
- Summary of source materials and contamination within remediation subareas

7.1 Purpose and Background

Key points of Section 1 are:

- Mining has occurred intermittently since the late 1800s. The site has been extensively disturbed by mining and mineral processing operations, and most of the disturbance was created by large-scale open pit mining between 1986 and 1999.
- Many features associated with development remain, including open pits, underground mine workings, HLP, waste rock dumps, and ARD management systems.
- The former owner/operator abandoned the site in 1999, and EPA now manages the site (including the water treatment system) under the Superfund program.
- The site is divided into three OUs. This RI addresses all three operable units, which encompass all remaining source materials and contamination within the site boundary.

The portion of the site that contains the largest accumulation of source materials has been subdivided into 15 remediation subareas. Key points of Section 2 are:

- DQOs were established for all of CDM's investigations and some of the other investigations after site historical data were screened for usability and data gaps

were identified to determine 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.

- DQOs were developed for site fills and soils, HLP, groundwater, surface water, groundwater-surface water interactions, tailings, sediment and stream bank material, sludges, and process plant equipment.

- The precision and representativeness of the field and laboratory analytical process were evaluated to ensure the data used were of high quality and useable for the RI.

- For some data, the validation/evaluation procedure was modified to include additional information about the primary qualifier that can be used to determine applicability of data to specific study objectives.

- All data were evaluated for the RI and FS to determine whether data were acceptable for all purposes, selected purposes, or were unusable, and most were determined to be usable for its intended purpose.

- Data sources include historic analytical data collected by the agencies and consultants for BMC, analytical data collected for the RI for EPA, and analytical and non-analytical data collected tangential to the RI by other entities that are useful to the RI.

- Evaluation of ARD involves the use of specialized analytical methods (total analysis, paste pH, extraction tests, acid base accounting, and inorganic carbon testing).

7.2 Site Physical Characteristics

Key points of Section 3 are:

Remediation Subareas

- Subareas are an organizational strategy to describe major site features, such as mine pits, waste rock dumps, stockpiles, underground workings, and water treatment facilities.

- The subareas correspond to the FS, which addresses potential remedial technologies applicable to areas with interrelated features that require integrated remedial strategies.

- The mining process removed rock from deep within the earth where oxygen is limited, increased its surface area through crushing and other processes, and placed it (in dumps, fills, etc.) in a near-surface oxygen rich environment.

- Exposure to air is an important component of the ARD generation and transport model (Exhibit 7-1) and is represented by the term “oxygen.”

ARD Collection and Conveyance Facilities

- ARD is generated at numerous locations in the primary mine disturbance area, and a complex network of pumping stations, pipelines, and storage facilities was developed in order to collect the ARD and prevent catastrophic discharge into streams and drinking water sources.

- Site collection facilities capture most surface water at the site and convey it to Sunday Pit where the water is stored prior to treatment in the WTP.

- Although major releases are prevented, the system does allow smaller releases to surface water and underlying groundwater.

- These systems address the ARD portion of the ARD generation and transport model (Exhibit 7-1).

Climate

- The amount, timing, and potential for above average precipitation are critical factors necessary to evaluate ARD management and storage requirements.

- The site gets a significant amount of annual precipitation (rain, 29 inches, and snow, 139 inches), and the total annual precipitation for 95 percent of the water years was less than 40 inches.

- April, May, and June are the wettest months, with median monthly precipitation of 3.27, 3.61, and 3.33 inches, respectively.

- Departures from average precipitation are important to understanding the site (e.g., a precipitation record of 14.84 inches was set in May 1965).

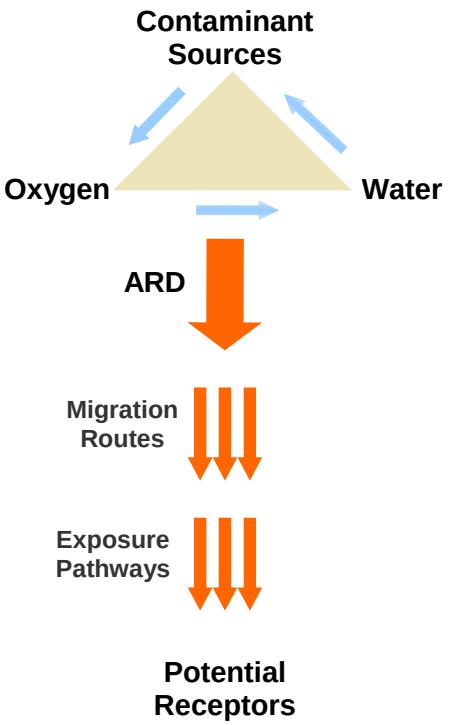


Exhibit 7-1. ARD generation and transport model

- The evaluation of climate addresses the water component of the ARD generation and transport model (Exhibit 7-1).

Geology

- The site is a highly mineralized area with widespread pyrite mineralization and natural enrichments of metals, important factors contributing to ARD generation.

- The geologic structure is complex and includes major areas of folding and fractures that influence infiltration of precipitation and fate and transport of contaminants in groundwater.

- The geology evaluation addresses the Source Material and Migration Routes components of the ARD model (Exhibit 7-1).

Surface Water

- Surface water is important to the potential migration of ARD-related contaminants and exposure of ecological receptors to contamination.
- Surface water bodies within and downstream of the site include perennial (Strawberry Creek and Bear Butte Creek), intermittent (Hoodoo and Ruby Gulches), and ephemeral streams.
- The site is a headwater area that contributes flow to coldwater fisheries in the two perennial streams.
- Surface water is a potential migration route into sensitive karst-hosted aquifers downstream of the site, which are drinking water sources for residential and municipal wells.
- ARD collection systems are present in Ruby and Hoodoo gulches.
- The evaluation of surface water is particularly relevant to the Migration Routes portion of the ARD model (Exhibit 7-1).

Groundwater

- Groundwater is contaminated in the primary mine disturbance area, and understanding its physical characteristics is critical to understanding the potential for contamination to migrate and affect potential human or ecological receptors.
- The site has bedrock and alluvial aquifers, and groundwater velocity ranges from about 50 to 100 feet annually in the Strawberry Creek area.
- An uncontrolled discharge of ARD could impact groundwater in a broad area extending eastward toward Sturgis and encompassing several regional aquifers (Madison and Minnelusa) that are used as private and municipal water sources.
- The evaluation of groundwater is pertinent to the Migration Routes portion of the ARD model (Exhibit 7-1).

Groundwater-Surface Water Interactions

- Groundwater-surface water interactions are extensive, control migration of ARD on and off site, and are important in understanding potential risks to receptors.
- Significant interactions include discharges of ARD from flooded underground mine workings and from springs to surface water.
- Dakota Maid Pit water is directly connected to groundwater, and the Sunday and Anchor Hill pits also appear to be connected although not as directly.

- Bear Butte Creek averages a 100 percent loss of stream flow as it enters one of three loss zones, and these losses recharge the Madison aquifer throughout the year and also the Minnelusa aquifer (during periods of high stream flow).

- This discussion is germane to Migration Routes on the ARD model (Exhibit 7-1).

Site Water Balance

- The water balance defines an annual expected ARD yield (103 million gallons for average precipitation) and the normalized ARD yield (3.6 million gallons/inch of precipitation).

- Estimated inflows have ranged from 123 million gallons (2007 water year) to 42 million gallons (2004 water year).

- The estimated rate of ARD collected from groundwater in the areas of primary mine disturbance is 69 gpm (36 million gallons annually).

- Approximately 112 gpm of ARD is collected from surface water runoff and direct precipitation on pit lakes and ponds.

- Water balance data allow impacts of wet years to be estimated, including ARD required for collection, storage, and treatment, to prevent a catastrophic release.

- The water balance addresses the ARD portion on the ARD model (Exhibit 7-1).

Land Use and Demographics

- Land data are useful for issues related to final land use and institutional controls and are part of the evaluation of Potential Receptors.

- Site land is mostly private, with some federal land and isolated parcels of state-owned land acquired to provide for construction of the Ruby Repository.

- Nearby private land is mostly residential but includes a few small ranches and businesses.

- Nearby public land is used for recreation (hiking, hunting, and ATV operation) and industry (logging and forest management activities).

- Land use and demographics address potential receptors shown on Exhibit 7-1.

7.3 Nature and Extent of Contamination

Key points of Section 4 are:

Comparison Criteria

- These criteria are defined for the various site media in order to provide benchmarks to understand the extent of contamination at the site.

- They are based on selected PRGs and ARARs.

Contaminant Sources

- Contaminant sources are widespread within the primary mine disturbance area, and most of the estimated volume of source materials (15 million cubic yards) have the potential to generate ARD.

- There are seven categories of source materials, based on geochemical and physical characteristics (waste rock fills, HLP spent ore, exposed rock surfaces, underground mine workings, tailings, soil stockpiles, and sludge).

- ARD neutralization sludge is generated during treatment of ARD and may be a source of contaminants if stored under strongly acidic submerged environments.

- Source materials are addressed at the top of the ARD generation and transport model (Exhibit 7-1) as they are a critical component of the ARD triangle.

Groundwater

- Groundwater is one of the important routes for contaminant migration from the site.

- Groundwater is strongly impacted by ARD contamination in the primary mine disturbance area and can exceed comparison criteria by one to three orders of magnitude.

- Groundwater contamination is slowly migrating but has not been identified outside of the site boundary.

ARD

- Understanding the characteristics of ARD is important to understanding potential effects of remedial actions.

- Impacts within the primary mine disturbance area are extensive for both discharged and stored ARD.

- The majority of ARD is captured and treated, and the effluent is discharged to Strawberry Creek.

- ARD generation provides a means for contaminants originating in ARD source materials to impact migration routes and exposure pathways (Exhibit 7-1).

- A portion of ARD generated on site and stored in pit lakes can not be treated in the current water treatment plant, so EPA is currently evaluating plant upgrades.

- Collection systems on site operate well but are not capable of intercepting all of the ARD, and traces of ARD-related contamination are present in surface water outside of the collection system.

Strawberry Creek

- Lower Strawberry Creek is impacted by ARD generated within the primary mine disturbance area and relic mine tailings, and contamination in surface water exceeds comparison criteria on an intermittent basis.
- Stream sediments in lower Strawberry Creek are contaminated, although conditions are improving, and more data are needed to evaluate ecological risks related to the sediments.
- Groundwater-surface water interactions in lower Strawberry Creek are extensive, and ARD affected groundwater is likely discharging to surface water.
- Numerous remedial actions have been completed by DENR and EPA, which provide beneficial effects to surface water quality and aquatic biota in Strawberry Creek.
- EPA is in the process of monitoring and evaluating the lower Strawberry Creek area to determine if human health or ecological risks remain and if additional remedial actions are necessary.

Bear Butte Creek

- Bear Butte Creek is located downstream from the three site drainages (Strawberry Creek, Terrible Gulch, and Ruby Gulch).
- Detectible impacts to surface water quality in Bear Butte Creek are present downstream of its confluence with Strawberry Creek.
- These impacts have caused surface water in Bear Butte Creek downstream of the confluence to exceed comparison criteria on an intermittent basis.

7.4 Fate and Transport

Key points of Section 5 are:

Site Conditions

- The Gilt Edge ore deposit contains natural enrichments of metals and metalloids.
- Rocks enriched in metals were exposed by mining at the site, and weathering of these rocks in the surficial environment causes ARD.
- The fate and transport model describes mechanisms that control the release of contaminants from source materials and migration of these contaminants in surface water and is an important component of the site conceptual model.

Potential Routes of Migration

- Four potential migration routes exist on site (atmospheric, surface water, groundwater, and groundwater-surface water interactions).
- Atmospheric migration is insignificant.

- Surface water migration is currently controlled by ARD collection and treatment technologies but would be very significant if the control systems failed.

- Groundwater and groundwater-surface water interactions present problems.

Contaminant Release Mechanisms

- The primary occurrence of metals and metalloids on site is in solid mineralogical forms.

- Sulfide oxidation and acid generation release metals and metalloids from their solid form, which increases mobility of the contaminants in the environment.

- Residual mineral processing reagents are present in spent ore and are a potential source of cyanide and nitrates in the surficial environment.

- Water treatment plant sludge may also result in contamination of surface and groundwater, depending on the hydrogeochemical environment in which it is stored.

Contaminant Fate and Persistence

- Contaminant mobility primarily occurs in the aqueous phase, and the primary control is pH.

- Methods of mobility include development of secondary acidity, solubility in receiving waters, and sorption on solid particles.

- Increasing pH reduces metal solubility and causes precipitation, and even small changes in pH can have significant impacts on metal and metalloid sorption.

- Six methods of natural degradation have worked to reduce cyanide concentrations in spent ore to low levels and have resulted in nitrate (as a byproduct of degradation) in HLP effluent.

7.5 Risk Assessments

Key points of Section 6 are:

Baseline Human Health Risk Assessment

- Uses COPCs to conduct an *exposure assessment* for soil, surface water, groundwater, sediment, and fish tissue.

- Potential human receptors include on site ATV riders, hikers, residents, commercial workers, and construction workers and off site children, fishermen, and residents).

- Depending on the media and receptor, COPCs include arsenic, manganese, thallium, aluminum, cadmium, copper, iron, manganese, lead, antimony, chromium, and zinc.

- The toxicity assessment determined the potential for each COPC to cause adverse effects (cancer and non-cancer) and the risk characterization estimated the likelihood and nature of potential health effects that may occur as a result of exposure to COPCs.

- PRGs for surface water, sediment, and groundwater and RALs for soils were developed.

- Potential unacceptable future risks are ingestion of thallium and arsenic in soil by onsite construction workers; ingestion of arsenic, lead, and other metals in groundwater; and ingestion of thallium in surface soil by commercial workers.

- Risks were also unacceptable in current and future scenarios for ATV riders (soil) and residents (soil and groundwater), but these scenarios are not allowed by EPA and would not be allowed in the future.

Ecological Risk Assessment

- The ERA calculated risks to aquatic receptors, terrestrial plants and organisms, and wildlife using COPCs, exposure assessment, and toxicity assessment.

- Three line-of-evidence approaches are used (where applicable) to assess risk: HQs, site-specific toxicity tests, and observations of population and community demographics.

- An external review draft of the *Biological Monitoring Report* commissioned by EPA for Strawberry Creek was submitted in January 2007 and concluded that conditions had improved noticeably, but the sediment continues to pose a risk to benthic organisms and the benthic community has not recovered.

- Risks are high for aquatic receptors in Strawberry Creek, Hoodoo Gulch, and Ruby Gulch.

- For terrestrial plants and wildlife, risks from surface soil contamination are of concern in the Riparian Area of Strawberry and Bear Butte Creeks and in the Mine Source Area.

- For wildlife receptors, risks from surface water and soil are high in the riparian area along Strawberry Creek, Ruby Gulch, and downstream Bear Butte Creek.

7.6 Summary of Site Conceptual Model

The current SCM incorporates components of a fate and transport model that is presented in Section 5, and components of a risk assessment model that is presented in Section 6. A graphical representation of the current SCM is presented in Exhibit 7-2. This model incorporates the current understanding of the contaminant sources, migration routes, exposure pathways, and potential receptors.

Source materials shown on Exhibit 7-1 are primarily sources of contaminants that interact with oxygen and water to form ARD. These sources consist of the following:

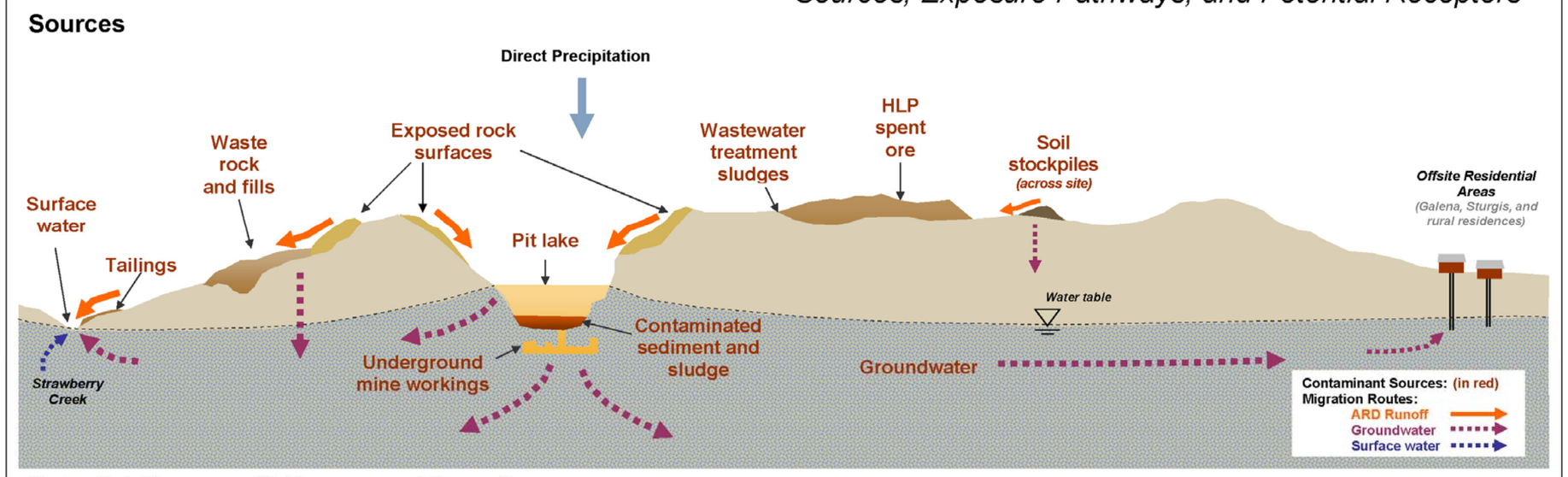
- **Waste rock and fills** are waste rock dumps and other fills that contain broken unconsolidated rock that forms ARD at the site. The broken and unconsolidated nature of the waste rock and fills exacerbates ARD generation because of the large amount of surface area that is exposed to weathering.

- **Exposed rock surfaces** are rock surfaces that are exposed in highwalls, safety benches, and other rock exposures (bedrock) at the sites. The reduced surface area of exposed rock surfaces as compared to waste rock and fills decreases the relative potential for ARD generation. However, exposed rock surfaces remain an important source of ARD on the site.

- **HLP spent Ore** is spent ore that is present on the HLP. ARD generated by spent ore on the HLP is contained by the liner system that was originally used to contain cyanide solutions used in the gold extraction process.

- **Soil stockpiles** are piles of stockpiled topsoil and subsoil that are a resource for reclamation. These piles are potentially acid generating as a result of the widespread occurrence of the mineral pyrite at the site.

Exhibit 7-2
Gilt Edge Site Conceptual Model
Sources, Exposure Pathways, and Potential Receptors

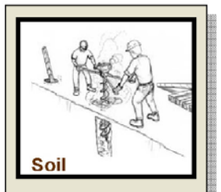


Potential Exposure Pathways and Receptors

Offsite Recreational Fisherman
- Ingestion of and/or dermal contact with sediments and surface water
- Ingestion of fish

Offsite Resident
- Groundwater ingestion
- Ingestion of and/or dermal contact with sediments and surface water

Onsite Resident
- Groundwater ingestion
- Ingestion of and/or dermal contact with surface soil
- Ingestion of terrestrial food items

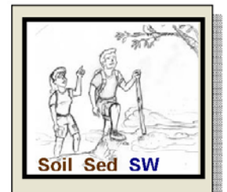


Onsite Construction Worker
- Inhalation/ingestion of and/or dermal contact with surface and subsurface soil

Onsite Commercial Worker
- Inhalation/ingestion of and/or dermal contact with surface soil
- Groundwater ingestion

Onsite ATV Rider*
- Inhalation/ingestion of and/or dermal contact with surface soil

* Recreational visitors



Onsite Hiker*
- Inhalation/ingestion of and/or dermal contact with surface soil
- Ingestion of and/or dermal contact with sediments and surface water

* Recreational visitors

Wildlife (Aquatic/ Terrestrial)
- Ingestion of vegetation, soil, and surface water
- *Dermal contact with surface water, sediment, and soil*

- **Tailings** are the sand textured mine wastes left on the site by the old timers. Some of the tailings on the site have been remediated by previous actions, although some ARD generating tailings remain on the site.

One additional source material is present on the site, which does not have the potential to generate ARD.

- **ARD treatment sludge** contains the toxic metals that have been removed from ARD during treatment. ARD treatment sludge is a potential source of contaminants depending on the environment in which it is stored.

Migration routes included in the SCM consist of ARD runoff, surface water migration, and groundwater migration.

- **ARD runoff** occurs when precipitation interacts with ARD source materials. The runoff dissolves secondary acidity and metals that were released from the rock by acid generation and transports these contaminants as ARD.

- **Surface water migration** occurs when ARD reaches area streams and contaminants are transported by surface water in either the dissolved or particulate form.

- **Groundwater migration** occurs when the ARD is transported along with groundwater through site aquifers.

The final components of the SCM are potential exposure pathways and receptors. Exposure pathways describe the processes by which a potential receptor could contact contaminated media, such as surface water or groundwater. Receptors define groups of humans (or other organisms) that could be impacted by site contaminants via one of the exposure pathways. The SCM evaluates eight receptors:

- Offsite recreational fisherman
- Offsite resident
- Onsite resident
- Onsite construction worker
- Onsite commercial worker
- Onsite all-terrain vehicle rider
- Onsite hiker
- Wildlife

One to three exposure pathways are evaluated for each receptor. The exposure pathways include ingestion, inhalation, and dermal contact of various types of

contaminated media, such as surface water, groundwater, soil, contaminated sediments, and contaminated fish.

7.7 Summary of Source Materials and Contamination within Remediation Subareas

Exhibit 7.3 summarizes the results of the RI with respect to the remediation subareas. The table shows the types of contaminant sources that are present within the remediation subareas and the remediation subareas that cause direct impacts to Strawberry Creek, Bear Butte Creek, and/or groundwater.

Exhibit 7-3. Remediation Subareas and their Associated Contaminant Sources, Surface Water Impacts, and Groundwater Impacts

Remediation Subarea	Contaminant Sources						Surface Water			Ground-water
	Acid-Gen. Waste Rock and Fill	HLP Mine Waste	Exposed Acid-Gen. Bedrock	Tailings	Sludge	Mine Work-ings	ARD	Straw-berry Creek	Bear Butte Creek	
Anchor Hill Pit	X	NA	X	NA	X	NA	X	NA	NA	X
Dakota Maid Pit	X	NA	X	NA	X	X	X	NA	NA	X
Hoodoo Fill	X	NA	NA	NA	NA	X	X	X	NA	X
Heap Leach Pad	X	X	NA	NA	X	NA	X	NA	NA	NA
Langley Benches	X	NA	X	NA	NA	NA	X	X	NA	X
Process Plant	X	NA	NA	NA	X	NA	X	NA	NA	X
Ruby Repository	X	NA	X	NA	NA	NA	X	NA	X	X
Lower Strawberry Creek	NA	NA	NA	X	X	NA	X	NA	X	X
Strawberry Gulch	X	NA	NA	NA	NA	NA	X	X	NA	X
Stormwater Pond	X	NA	NA	NA	X	NA	X	NA	NA	X
Sunday Pit	X	NA	NA	NA	X	X	X	NA	NA	X
Union Hill Upland	X	NA	NA	NA	NA	NA	X	NA	NA	X
Upper South Ruby	X	NA	NA	NA	NA	NA	X	NA	NA	X
Water Treatment Plant	NA	NA	NA	NA	X	NA	X	X	NA	NA
Groundwater	See Note									

Note: Groundwater contamination crosses boundaries of most remediation subareas as discussed in Section 4.3.

This page left intentionally blank.

Section 8
References

Alpers, C.N., Nordstrom, D.K. 1999. *Geochemical Modeling of Water-Rock Interactions in Mining Environments, 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. 289-315.

CDM. 2000a. *Draft Field Sampling Plan for URS Mid-September 2000 Sampling Event, Gilt Edge Mine NPL Site, Lawrence County, South Dakota*. September.

_____. 2000b. *Draft Quality Assurance Project Plan for URS Mid-September 2000 Sampling Event, Gilt Edge Mine NPL Site, Lawrence County, South Dakota*. September.

_____. 2000c. *Draft Sampling and Analysis Plan for Low Flow Synoptic Surface Water and Sediment Sampling, Autumn 2000, Gilt Edge Mine, Lawrence County, South Dakota*. October.

_____. 2001a. *Draft Sampling and Analysis Plan for Fill Material Sampling – Fall 2001, Gilt Edge Mine NPL Site, Lawrence County, South Dakota*. October.

_____. 2001b. *Final Sampling and Analysis Plan for Heap Leach Pad Investigation – Fall 2001, Gilt Edge Mine Superfund Site, Lawrence County, South Dakota*. February.

_____. 2001c. *Final Sampling and Analysis Plan for Soil and Vegetation Investigation, Gilt Edge Mine NPL Site, Lawrence County, South Dakota*. October.

_____. 2001d. *Final Sampling and Analysis Plan for Sludge Sampling at the Sunday Pit, Dakota Maid Pit, Pond C and Hoodoo Gulch Ponds Fall 2001, Gilt Edge Mine NPL Site, Lawrence County, South Dakota*. August.

_____. 2001e. *Sampling and Analysis Plan for Cyanide Neutralization Sludge Sampling - Fall 2001, Gilt Edge Mine NPL Site, Lawrence County, South Dakota*. September.

_____. 2001f. *Final Sampling and Analysis Plan for Groundwater Sampling, Spring 2001, Gilt Edge Mine, Lawrence County, South Dakota*. May.

_____. 2001g. *Final Sampling and Analysis Plan for Quarterly Surface Water, Groundwater, and Sediment Sampling, Gilt Edge Mine NPL Site, Lawrence County, South Dakota*. September.

_____. 2001h. *Final Focused Feasibility Study for Gilt Edge Mine Site; Interim Water Treatment Operations Operable Unit 2, Lawrence County, South Dakota*. September.

_____. 2002a. *Sampling and Analysis Plan, Surface Soils Investigation to Support Human Health Risk Assessment, Gilt Edge Mine Superfund Site, Lawrence County, South Dakota*. May.

_____. 2002b. *Final Sampling and Analysis Plan for Monitoring Well Rehabilitation and Installation, Gilt Edge Mine, Lawrence County, South Dakota*. March.

_____. 2002c. *Final Sampling and Analysis Plan for Merrill-Crowe Gold Recovery Circuit, Gilt Edge Mine NPL Site, Lawrence County, South Dakota*. May.

_____. 2002d. *Bauxsol Treatability Study Report (2001), Gilt Edge Mine NPL Site, Lawrence County, South Dakota*. August.

_____. 2002e. *Final Technical Memorandum for the Lime HDS Pilot Plant Testing Report, Gilt Edge Mine NPL Site, Lawrence County, South Dakota*. February.

_____. 2002d. *Draft Technical Memorandum for the Metals Coordination Pilot Plant Testing Report, Gilt Edge Mine NPL Site, Lawrence County, South Dakota*. January.

_____. 2003a. *Draft Sampling and Analysis Plan for Site Management Operations, Gilt Edge Mine NPL Site, Lawrence County, South Dakota*. June.

_____. 2003b. *Draft Sampling and Analysis Plan for Tailings Present in Strawberry Creek*. November.

_____. 2003c. *Interim Status Report, Total Metals Concentrations in Surface and Subsurface Soils*, *Gilt Edge Mine NPL Site, Lawrence County, South Dakota*. March.

_____. 2003d. *Draft Interim Status Report, Soil and Vegetation Investigation, Gilt Edge Mine NPL Site, Lawrence County, South Dakota*. March.

_____. 2003e. *Draft Interim Status Measurement Report, Merrill-Crowe Gold Recovery Circuit, Gilt Edge Mine NPL Site, Lawrence County, South Dakota*. February.

_____. 2003f. *Draft Interim Status Report, Strawberry Creek and Bear Butte Creek Surface Water, Sediment, and Bank Material Measurement Report, Gilt Edge Mine NPL Site, Lawrence County, South Dakota.* January.

_____. 2003g. *Draft Interim Status Report, Groundwater Characterization Report, Gilt Edge Mine NPL Site, Lawrence County, South Dakota.* January.

_____. 2003h. *Interim Status Report, Fill Material Sampling Report, Gilt Edge Mine NPL Site, Lawrence County, South Dakota.* March.

_____. 2004a. *Sampling and Analysis Plan Addendum to Sampling and Analysis Plan for Sludge Sampling at the Sunday Pit, Dakota Maid, Pond C, and Hoodoo Gulch Ponds Fall 2001 for the Surge Pond*. March.

_____. 2004b. *Revised Final – Sampling and Analysis Plan for Additional Groundwater Characterization and Fill Confirmation*. February.

_____. 2004c. *Preliminary Feasibility Study Report, Gilt Edge Mine Site Operable Unit 1*. November.

_____. 2006a. *Final Sampling and Analysis Plan for Groundwater Aquifer Pumping Test, Gilt Edge Mine, Lawrence County, South Dakota*. July.

_____. 2006b. *Interim Status Report, Bauxsol Trench System Treatability Study Report, Gilt Edge Mine NPL Site, Lawrence County, South Dakota*. August.

_____. 2006c. *2006 Draft Field Report, ViroMine™ Permeable Reactive Barrier Treatability Study, Gilt Edge Mine NPL Site, Lawrence County, South Dakota*. August.

_____. 2006d. *2006 Interim Status Report, Multi-Cell Wasterock Treatability Study Report, Gilt Edge Mine NPL Site, Lawrence County, South Dakota*. August.

_____. 2006e. *Draft Memorandum, Ruby Repository Diversion Test Summary*. November.

_____. 2006f. *Draft Report, Sitewide Sludge Measurement Report, Gilt Edge Mine NPL Site, Lawrence County, South Dakota*. November.

_____. 2006g. *HLP Interim Remedial Investigation, Gilt Edge Mine Superfund Site, Lawrence County, South Dakota*. November.

_____. 2007a. *Draft Technical Memorandum, Estimation of Ruby Waste Rock Dump Water Budget Before and After Installation of Low-Permeability Cover*. January.

_____. 2007b. *Final Sampling and Analysis Plan for Supplemental Feasibility Study Investigation, Gilt Edge Mine NPL Site, Lawrence County, South Dakota*. March.

_____. 2007c. *Sampling and Analysis Plan Addendum to Sampling and Analysis Plan for Sludge Sampling at the Sunday Pit, Dakota Maid, Pond C, and Hoodoo Gulch Ponds Fall 2001 for the Stormwater Pond, Dakota Maid Pit, Sunday Pit, and Anchor Hill Pit*. February.

_____. 2007d. *Final Sampling and Analysis Plan for Groundwater Remedial Investigation, Gilt Edge Mine NPL Site, Lawrence County, South Dakota*. March.

_____. 2007e. *Groundwater Data Summary, Gilt Edge Mine Superfund Site, Lawrence County, South Dakota*. February.

_____. 2007f. *Draft Report, Strawberry Creek Bank Tailings Measurement Report, Gilt Edge Mine NPL Site, Lawrence County, South Dakota*. March.

_____. 2008. *Draft Report, Feasibility Study Report for the Gilt Edge Mine Superfund Site, Operable Unit 1 (OU1), Gilt Edge Superfund Site, Lawrence County, South Dakota*. August.

Driscoll, D.G., Hamade, G.R., and Kenner, S.J. 2000. *Summary of Precipitation Data Compiled for the Black Hills Area of South Dakota, Water Years 1931-98: U.S. Geological Survey Open-File Report 00-329*.

Driscoll, D.G., Carter, J.M., Williamson, J.E., Putnam, L.D. 2002. *Hydrology of the Black Hills Area, South Dakota, Water resources Investigations Report 02-4094, US Geological Survey*.

Durkin, T. 1992. Senior Hydrologist, DENR, Minerals and Mining Program. Personal communication.

Durkin. 1994. *Acid Mine Drainage: Reclamation at the Richmond Hill and Gilt Edge Mines, South Dakota*. EPA Seminar Publication no. EPA/625/R-95/0071994, Seminar Series: Managing Environmental Problems at Inactive and Abandoned Metals Mine Sites.

Enecotech Inc. 1988. *Draft Hydrologic Baseline Field Studies and Preliminary Description of the Existing Hydrologic Environment – Brohm Mining Corporation, Gilt Edge Sulfide Project*. May.

Fuller, W. 1984. *Cyanide in the Environment with Particular Attention to the Soil, Cyanide and the Environment: v.I.* Colorado State University. Fort Collins, Colorado, p. 19-46.

Freeze, R.A. and Cherry, J.A. 1979. *Groundwater*. Prentice Hall, Inc. Englewood Cliffs, New Jersey.

Gobla, M. 2006. Design Engineer, BOR, Denver, Colorado. Personal communication.

_____. 2002. Design Engineer, BOR, Denver, Colorado. Personal communication.

Hight P. 2001. Senior Operator, Gilt Edge Mine Site, CDM. Personal communication.

_____. 2006. Senior Operator, Gilt Edge Mine Site, CDM. Personal communication.

Hoecker, W. and D. Muir. 1987. *Degradation of Cyanide: The AusIMM Adelaide Branch, Research and Development in Extractive Metallurgy*.

Hortness, J.E., and Driscoll, D.G. 1998. *Streamflow Losses in the Black Hills of Western South Dakota: U.S. Geological Survey Water-Resources Investigations Report 98-4116*. p. 99.

Hydro-Engineering. 1994. *Groundwater Hydrology at Brohm's Gilt Edge Mine*. Prepared for BMC. March.

IRIS. 2002. Integrated Risk Information System. On-line toxicity database created and maintained by USEPA. Available at http://www.epa.gov/iriswebp/iris/index.html.

Jambor, J.L., Dutrizac, J.E., Chen T.T. 2000. *Contribution of Specific Minerals to the Neutralization Potential in Static Tests*. Proceedings from the Fifth International Conference on Acid Rock Drainage. p. 551-565.

Jambor, et. al. 2003. *Environmental Aspects of MINE WASTES, Short Course Series Volume 31*. Prepared by the Mineralogical Association of Canada.

Kimball, B.A., Runkel, R.L., Walton-Day, K., Williamson, J.E. 2006. *Quantification of Mass Loading to Strawberry Creek near the Gilt Edge Mine, Lawrence County, South Dakota, June, 2003, Scientific Investigations Report 2006-5006*. June.

Langmuir, D. 1997. *Aqueous Environmental Geochemistry, Pearson Education, Prentice Hall, Inc.* p. 350.

Lawrence, R.W. 1990. *Prediction of the Behavior of Mining and Processing Wastes in the Environment*. In Doyle, F. (ed), Proceedings of the Western Regional Symposium on Mining and Mineral Processing Wastes: Society for Mining, Metallurgy, and Exploration, Inc., Littleton, Colorado.

MacLeod, R.J. 1986. *The Geology of the Gilt Edge Area, Northern Black Hills of South Dakota*. Masters Thesis, South Dakota School of Mines and Technology.

Macleod R. 2005. *Dakota Maid Geologic Study*. Prepared for CDM Denver, CDM. January.

McDonald, D.M., Webb, J.A. 2006. *Prediction of Sludge Composition and Water Quality From Lime Neutralization of ARD*.

Malo et. al. 2001. *Gilt Edge Mine NPL Site Lawrence County, South Dakota Final Report for the Climatic Evaluation*. December.

Mount, D.R., Gulley, D.D., Hockett, J.R., Garrison, T.D., Evans, J.M. 1997. *Statistical models to predict the toxicity of major ions to Ceriodaphnia dubia, Daphnia magna, and fathead minnows (Pimephales promelas*). *Environ. Toxicol. Chem*. 16:2009-2019.

MSE. 2001. *Quality Assurance Project Plan for Bioremediation of Pit Lakes (Gilt Edge Mine)*. Mine Waste Technology Program. Activity III, Project 34. Prepared for: U.S. EPA and U.S. Department of Energy. February.

_____. 2003. *MWTP Project 29 Final Report – Remediation Technology Evaluation at the gilt Edge Mine, SD*. Prepared for the USEPA and USDOE.

_____. 2007. Reserved for MSE final Report – Anchor Hill Pit Treatability Study, unpublished at the time of submittal of this RI report.

Munshower, F. F. 1993. *Practical Handbook of Disturbed Land Reclamation*. Lewis Publishers, Boca Raton. p. 8 – 10.

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.

Nichol, C. Smith, J., and Beckie, R. 2000. *Hydrologic Behavior of Unsaturated Waste Rock: An Experimental Study, in Proceedings from Fifth International Conference on Acid Rock Drainage, Society for Mining, Metallurgy, and Exploration, Littleton, Colorado*. p. 215-224.

Nordstrom, D.K. 2003. *Effects of Microbiological and Geochemical Interactions in Mine Drainage, in Environmental Aspects of Mine Wastes*. Jambor, J.L., Blowes, D.W., and Ritchie, A.I.M. editors, Short Course Series Volume 31, Mineralogical Association of Canada, p. 227-238.

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, Littleton, CO., p. 133-154.

Ohm, M. 2006. Cave Specialist, Wind Cave National Monument, Hot Springs, South Dakota. Personal communication.

Perel'man, A.I. 1967. *Geochemistry of Epigenesis*. Plenium Press. New York, p. 266.

Ptacek, C.J., Blowes, W.D. 2003. *Geochemistry of Concentrated Waters at Mine-Waste Sites, in Environmental Aspects of Mine Wastes*. Jambor, J.L., Blowes, D.W., and Ritchie, A.I.M. editors, Short Course Series Volume 31, Mineralogical Association of Canada, p. 239-260.

Rahn, P.H. 1971. *The hydrologic significance of the November 1968 dye test on Boxelder Creek, Black Hills, South Dakota*. Proceedings, South Dakota Academy of Science, Vol. 50, p. 52-56.

_____. 1985. *Groundwater Stored in the Rocks of Western South Dakota and Wyoming (2d ed.)*. Geological Society of America, Field Trip Guidebook, American Geological Institute.

RGC. 2000. *Geochemical Field Reconnaissance Survey of the Gilt Edge Mine, South Dakota*. August.

Rose, A.W., Hawkes, H.E., Webb, J.S. 1979. *Geochemistry in Mineral Exploration*. Academic Press, Harcourt Brace Jovanovich Publishers, London, p. 549-581.

Smith, A.C.S., Mudder, T. 1999. The Environmental Geochemistry of Cyanide. in *The Environmental Geochemistry of Mineral deposits, Part A: Processes, Techniques, and Health Issues*., Chapter 11. Plumlee, G.S. and Logsden, M.J., editors, *Reviews in Economic Geology Volume 6A*, Society of Economic Geologists, Littleton Colorado.

Smith, K.S., Huyuk, H.L.O. 1999. *An Overview of the Abundance, Relative Mobility, Bioavailability, and Human Toxicity of Metals, 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, Colorado, p. 29-64.

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.

Sobek. 1978. *Field and Laboratory Methods Applicable to Overburdens and Minesoil*. EPA600/2-78-054.

Suave, S.,Dumestre, A., McBride, M., Hendershot, W. 2000. *Derivation of Soil Quality Criteria Using Predicted Chemical Speciation of Pb2+ and Cu2+. Environ. Tox. Chem* 17(8):1481-1489.

Stone W.J. 1999. *Hydrology in Practice, A Guide to Characterizing Ground-Water Systems*. Prentice Hall, Upper Saddle River, New Jersey, p. 96.

Stumm, W. and Morgan, J.J. 1996. *Aquatic Chemistry, Chemical Equilibria and Rates in Natural Waters, Third Edition*. John Wiley & Sons, Inc., p. 273.

Towill, L., Drury, J., Whitfield, B., Lewis, E., Galyan, E., Hammons, A. 1978. *Review of Environmental Effects of Pollutants: V. Cyanides, EPA-600/1-78-027*. United States Environmental Protection Agency, Cincinnati, Ohio.

UOS. 1999. *Analytical Results Report for Site Inspection for Gilt Edge Mine, Lead, South Dakota*. Prepared for the USEPA by UOS. November.

BOR. 2000a. *Closure Plan for the Gilt Edge Mine, Lawrence County South Dakota*. Denver, Colorado: U.S. Bureau of Reclamation, Technical Services Center. February.

_____. 2000b. *Surface and Underground Mapping Geologic Investigations, Gilt Edge Mine Superfund Site, Lawrence County, South Dakota*. Denver, Colorado: U.S. Bureau of Reclamation, Technical Services Center.

_____. 2003. *Geological Reconnaissance Mapping Investigations and Analysis, Gilt Edge Mine Superfund Site, Lawrence County, South Dakota*. Denver, Colorado: U.S. Bureau of Reclamation, Technical Services Center. January.

USDA. 1993. *Soil Survey Manual, U.S. Natural Resources Conservation Service.*

EPA. 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 (RAGS). Volume I. Human Health Evaluation Manual (Part A).*

_____. 1992. *Framework for Ecological Risk Assessment.* U.S. Environmental Protection Agency. EPA/630/R-92/001.

_____. 1994a. *USEPA Contract Laboratory Program National Functional Guidelines for Inorganic Data Review*.

_____. 1994b. *Guidance Manual for the Integrated Exposure Uptake Biokinetic Model for Lead in Children*. U.S. Environmental Protection Agency, Office of Emergency and Remedial Response. Publication Number 9285.7-15-1. EPA/540/R-93/081.

_____. 1997. *Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessments*. Interim Final. U.S. Environmental Protection Agency, Environmental Response Team, Edison, NJ.

_____. 1998. *Guidelines for Ecological Risk Assessment. U.S. Environmental Protection Agency*. EPA/630/R-95/002F.

_____. 2000a. *Hazard Ranking System Package*. May.

_____. 2000b. *Guidance for the Data Quality Objectives Process, Final*. EPA QA/G-4. August.

_____. 2001a. *Interim Record of Decision, Operable Unit 2 Interim Water Treatment Plant Operations, Gilt Edge Mine NPL Site, Lawrence County, South Dakota*. November.

_____. 2001b. *Draft Screening Ecological Risk Assessment (SERA) for the Gilt Edge Mine, Lead, South Dakota*. Prepared for the USEPA by Syracuse Research Corporation, Denver, Colorado. November.

_____. 2003. *Final Baseline Ecological Risk Assessment (SERA) for the Gilt Edge Mine Site*. Prepared for the USEPA by Syracuse Research Corporation, Denver, Colorado. November.

_____. 2005a. USEPA Region III Risk-Based Concentration Table (last updated April 2005). Electronic data downloaded from http://www.epa.gov/reg3hwmd/risk/human/index.htm.

_____. 2005b. *Draft Estimation of Relative Bioavailability of Arsenic in Soil and Soil-Like Materials by In Vivo and In Vitro Methods*. USEPA Review Draft. March.

_____. 2006a. *Draft Final Baseline Human Health Risk Assessment for the Gilt Edge Mine Site, Lawrence County, South Dakota.* Prepared for the USEPA by Syracuse Research Corporation, Denver, Colorado. July.

_____. 2006b. *Memorandum*, *Human Health Preliminary Remediation Goals and Remedial Action Levels for Recreational Visitors and Residents at the Gilt Edge Mine Site*. Prepared for the USEPA by Syracuse Research Corporation, Denver, Colorado. December.

_____. 2007a. *Final First Five-Year Review Report for Gilt Edge Mine Superfund Site, Operable Units 2 and 3, Lawrence County, South Dakota*. April.

_____. 2007b. *Biological Monitoring Report for the Gilt Edge Mine, Lead, South Dakota*. Prepared for the USEPA by Syracuse Research Corporation, Denver, Colorado. January.

United States Geological Survey (USGS). 2006. *Quantification of Mass Loading to Strawberry Creek near the Gilt Edge Mine, Lawrence County, South Dakota, June 2003*. Scientific Investigations Report 2006-5006.

Waterland, J. 1991. The Mines Around and Beyond. Rapid City, South Dakota: Grelind Printing Center. p. 94-128.

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.

Younger P.L., Banwart, S.A., Hedin, R.S. 2002. *Mine Water Hydrology, Pollution, Remediation*. Kluwer Academic Publishers, Dordrecht. p. 65-117.

Appendix A

First Five-Year Review Report

First Five-Year Review Report

for

Gilt Edge Mine Superfund Site
Operable Units 2 and 3

Lawrence County
South Dakota

April 2007

PREPARED BY:

U.S. Environmental Protection Agency, Region 8
Denver, Colorado

Approved by: Date:

4/10/07

Carol Rushin
Assistant Regional Administrator
U.S. Environmental Protection Agency, Region 8

The following staff and managers have read and recommend approval of this report:

Mark Lawrensen for SD Dept of Environment & Natural Resources, 7 Dec 06

Rebecca Thomas, 25 January 07

Peggy Churchill, 29 January 07

Karen Kellen, 16 March 07

Ken Wangerud, 21 March 07

Russell Leclerc, 21 March 07

James Hanley, 23 March 07

Bill Murray, 26 March 07

Five-Year Review Report

Table of Contents

Executive Summary 1

I. Introduction 7

Purpose of the Review 7

Authority for Conducting the Five-Year Review 7

Who Conducted the Five-Year Review 7

Other Review Characteristics 7

II. Site Chronology 8

III. Background 8

Location and Setting: 8

Site History and Extent of Contamination: 9

Baseline Risk Assessment: 10

IV. Response Actions 10

V. Progress since the Last Review 11

VI. Five-Year Review Process 11

Administrative Components: 11

Community Involvement: 12

Data Review: 13

Site Inspection: 15

VII. Technical Assessment 16

Question A: Is the remedy functioning as intended by the decision documents? 16

Question B: Are the exposure assumptions, toxicity data, cleanup levels and remedial action objectives used at the time of the remedy selection still valid? 18

Question C: Has other information come to light that could call into question the protectiveness of the remedy? 18

Technical Assessment Summary 19

VIII. Issues 20

IX. Recommendations and Follow-up Actions 21

X. Protectiveness Statement(s) 21

XI. Next Review 22

Tables

Table 1 Chronology of Site Events 8
Table 2 Issues 20
Table 3 Recommendations and Follow-up Actions 21

Appendices

Appendix A - Figures
Appendix B – Photo Log
Appendix C – Treatment Facility Effluent Quality Data and Performance Standards

List of Acronyms

aml	above mean sea level
ARD	Acid Rock Drainage
ARARs	Applicable or Relevant and Appropriate Requirements
BMC	Brohm Mining Company
BRA	Baseline Risk Assessment
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
HDPE	High-Density Polyethylene
MCL	Maximum Contaminant Levels
MDL	Method Detection Limit
NCP	National Contingency Plan
NPL	National Priority List
O&M	Operation and Maintenance
OU1	Operable Unit 1
OU2	Operable Unit 2
OU3	Operable Unit 3
PRP	Potentially Responsible Party
RAO	Remedial Action Objective
RCRA	Resource Conservation and Recovery Act
RD/RA	Remedial Design/Remedial Action
RI/FS	Remedial Investigation/Feasibility Study
ROD	Record of Decision
SDDENR	South Dakota Department of Environment and Natural Resources
SDWDS	South Dakota Water Discharge System
TSS	Total Suspended Solids
ug/L	Microgram per Liter
USBOR	United States Bureau of Reclamation
EPA	United States Environmental Protection Agency

Executive Summary

The U.S. Environmental Protection Agency (EPA) Region 8 conducted the first five-year review of the remedial actions implemented at Operable Units (OU) Nos. 2 and 3 of the Gilt Edge Mine Site (the Site) near Lead, in Lawrence County, South Dakota. The purpose of the five-year review is to determine whether the Site remedy is protective of human health and the environment. The trigger action for this review is the August 2001 OU3 Record of Decision. Because hazardous substances, pollutants or contaminants remain at the Site above levels that allow for unrestricted use and unlimited exposure, a five-year review is required by statute.

The Site is located in Lawrence County, approximately two miles southeast of Lead, South Dakota in the Black Hills. The Site boundaries have not yet been formally established, however the overall study area encompasses the area disturbed by mining as well as a buffer area. The overall study area is bounded by largely undeveloped land. The Site is the location of a former heap leach gold mining operation and is divided into three OUs including:

- OU1 – Site-Wide Conditions
- OU2 – Water Treatment
- OU3 – Ruby Dump and Gulch

This five-year review addresses only OU2 and OU3.

Mining activities began at the Site in 1876 when the Gilt Edge and Dakota Maid claims were located. Historical underground mining extracted sulfide-bearing gold ores from irregular deposits in veins and fracture zones in the igneous rocks. The area was mined intermittently until 1941 and continuously from 1986 through 1998 when the operator, Brohm Mining Company (BMC), announced it would abandon the Site. BMC's parent company, Dakota Mining Corp., filed for bankruptcy in 1999 and the State of South Dakota (the State) assumed responsibility for water treatment at the Site. In 2000, the State also sought National Priority List (NPL) listing from EPA with the listing announced in December. In August 2000, the EPA Region 8 Emergency Response Program assumed responsibility for water treatment.

Wastes associated with mining included waste rock, tailing and spent ores contaminated with a wide array of metals. Some of the original contamination sources were removed from the Site prior to EPA's involvement.

Contamination of primary concern under OU2 and OU3 is Acid Rock Drainage (ARD). The potential impact of the metal content of the mine waste through direct exposure to human and environmental receptors is being assessed under OU1 and currently is incomplete.

The remedy for OU2 requires that ARD be collected from the toe of the Ruby Repository and from seeps in two drainages (Hoodoo Creek and the Upper Strawberry Creek watershed above Pond C) and conveyed to a water treatment facility prior to discharge to Strawberry Creek. The remedy also calls for the conversion of an existing treatment facility employing a sodium hydroxide process to a lime-based neutralization/precipitation process. Treatment facility effluent quality must comply with South Dakota surface water quality standards except for total dissolved solids and selenium. The standards for these two parameters are subject to an interim waiver requiring resolution under OU1. The resolution may take the form of improvements to the water treatment facility such that the effluent meets the standard(s) or the standard(s) will be permanently waived.

The remedy for OU3 included regrading the waste rock dump in the Ruby Gulch drainage, construction of a synthetic cap and vegetative cover, clean water diversion ditches, and an ARD collection gallery. The majority of remedial construction for OU2 and OU3 was completed in March 2003 and April 2006, respectively.

Several issues were identified in connection with OU2 and OU3 during the five year review that should be addressed. State surface water quality limits for the water treatment facility (OU2) have largely been met, however, several parameters for which there are water quality standards have not been analyzed for during most or all of the monitoring period. These include; alkalinity, weak acid dissociable cyanide, total cyanide, chromium VI and dissolved mercury. In addition, when cyanide analyses were performed, the detection limit employed was twice the water quality standard.

In OU3, all of the remedial action objectives (RAOs) are being met and remedy elements are performing as designed with one exception. Sections of the clean water diversion ditches were constructed with a geomembrane liner to minimize infiltration of storm water into the adjacent repository. Portions of the liner system are suspected to be leaking thereby allowing clean water to enter the repository leading to an increase in ARD reporting to the collection system at the repository toe. Other concerns related to the diversion ditches include unlined sections in fractured bedrock and the presence of sediment dams in the ditches. RAOs for OU3 call for control of mine waste erosion and a reduction in the formation of ARD. These RAOs are being met despite the suspected leaking clean water diversion ditches.

An approximately 10-acre area of the Ruby Dump was not capped as part of the Interim Remedy for OU3. This exposed waste rock allows precipitation to infiltrate into the Ruby Repository resulting in ARD generation. The disposition of this portion of the Site will be addressed under OU1.

Several remedy elements are not performing at optimum efficiency. These include clean water diversion ditches (discussed above) and the ability of the water treatment facility to operate at 250 gallons per minute when the influent stream consists exclusively of the highest sulfate waters present at the Site. Although these remedy inefficiencies do not affect protectiveness, EPA is considering improvements to remedy efficiency through modification to the diversion ditches and treatment facility.

RAOs are being met at the Site under the Interim RODs for OU2 and OU3. Therefore, the remedy as implemented is currently protective of human health and the environment. Residual risks associated with remaining contaminated environmental media will be addressed under OU1.

Five-Year Review Summary Form

SITE IDENTIFICATION		
Site name: Gilt Edge Mine Superfund Site, Operable Units 2 and 3.		
EPA ID: SDD987673985		
Region: 8	**State:** SD	**City/County:** Lead/Lawrence
SITE STATUS		
NPL status: Listed 12/00		
Remediation status: Operating		
Multiple OUs: Yes	**Construction completion date:** OU2 — 10/03 OU3 — 4/06	
Has site been put into reuse? No		
REVIEW STATUS		
Lead agency: EPA		
Author name: Rebecca Thomas		
Author title: Project Manager	**Author affiliation:** U.S.EPA, Region 8	
Review period: 8/30/01 to 9/30/06		
Date(s) of site inspection: 08/30/06		
Type of review: Statutory		
Review number: 1 (first)		
Triggering action: OU3 ROD Signature Date		
Triggering action date: 8/30/01		
Due date: 9/06		

* [“OU” refers to operable unit.]

Five-Year Review Summary Form, cont'd.

Issues:

Item No.	Issues	Affects Current Protectiveness (Y/N)	Affects Future Protectiveness (Y/N)
1	Occasional exceedence of applicable State surface water quality standards (OU2) including temperature, total suspended solids and nitrate.	N	potentially
2	Alkalinity, weak acid dissociable cyanide, total cyanide, chromium VI and dissolved mercury not measured in water treatment facility effluent during most or all of the monitoring period.	potentially	potentially
3	Detection limit for weak acid dissociable (WAD) cyanide is twice the water quality standard	potentially	potentially
4	New effluent standard for ammonia. The standard is calculated using equations in Appendix A referenced in § 74:51:01:49.	potentially	potentially
5	Clean water diversion ditches may discharge to waste rock mass due to suspected leaky channel liner, unlined ditches in fractured bedrock and sediment dams in the ditches.	N	N
6	ROD required site-specific toxicology study of sulfate TDS has not been performed	potentially	potentially

Five-Year Review Summary Form, cont'd.

Recommendations and Follow-up Actions:

Item No	Issues	Recommendations and Follow-up Actions	Party Responsible	Due Date
1	Occasional exceedence of applicable State Surface Water Quality Standards (OU2) including temperature, total suspended solids and nitrate.	Continue monitoring	EPA	NA
2	Alkalinity, weak acid dissociable cyanide, total cyanide, chromium VI and dissolved mercury not measured in water treatment facility effluent during most or all of the monitoring period.	Improve monitoring program	EPA	September 2007
3	Detection limit for weak acid dissociable (WAD) cyanide is twice the water quality standard	Revise analytical detection limits	EPA	September 2007
4	New effluent standard for ammonia. The standard is calculated using equations in Appendix A referenced in § 74:51:01:49.	Revise performance standards	EPA	September 2007
5	Clean water diversion ditches may discharge to waste rock mass due to suspected leaky channel liner, unlined fractured bedrock ditches and sediment dams in the ditches.	Consider repair to suspected leaking channels	EPA	September 2008
6	ROD required site-specific toxicology study of sulfate TDS has not been performed	Conduct study	EPA	September 2008

Five-Year Review Summary Form, cont'd.

Protectiveness Statement(s):

The remedy as implemented is currently protective of human health and the environment. All contaminated water reporting to the toe of the Ruby Repository, in the Hoodoo Gulch main channel and emanating from seeps above Pond C is collected and treated prior to discharge to surface water.

Other Comments:

Several remedy elements are not performing at optimum efficiency. These include clean water diversion ditches and the ability of the water treatment facility to operate at 250 gallons per minute when the influent stream consists exclusively of the highest sulfate waters present at the Site. Although these remedy inefficiencies do not affect protectiveness, EPA will consider options to improve remedy efficiency.

EPA recognizes that the interim waiver of State surface water quality standards for total dissolved solids (TDS) and selenium will require resolution under OU1. The resolution may take the form of improvements to the water treatment facility such that the effluent meets the standard(s) or the standard(s) will be permanently waived.

An approximately 10-acre area of the Ruby Dump was not capped as part of the Interim Remedy for OU3. EPA recognizes that this exposed waste rock allows precipitation to infiltrate into the Ruby Repository resulting in ARD generation. The disposition of this portion of the Site will be addressed under OU1.

Formal monitoring reports providing treatment facility effluent quality and flow data have not been prepared.

EPA acknowledges such documentation is necessary to complete the Site files and will take steps to resolve this deficiency in the Site files.

Five-Year Review Report

I. Introduction

Purpose of the Review

The purpose of five-year reviews is to determine whether the remedy at the Gilt Edge Mine NPL Site (the Site) is protective of human health and the environment. The methods, findings and conclusions of reviews are documented in Five-Year Review reports. In addition, five-year review reports identify issues found during the review, if any, and recommendations to address them.

Authority for Conducting the Five-Year Review

The U.S. Environmental Protection Agency (EPA) is preparing this five-year review pursuant to CERCLA §121 and the National Contingency Plan (NCP). CERCLA §121 states:

> *If the President selects a remedial action that results in any hazardous substances, pollutants, or contaminants remaining at the site, the President shall review such remedial action no less often than each five years after the initiation of such remedial action to assure that human health and the environment are being protected by the remedial action being implemented. In addition, if upon such review it is the judgment of the President that action is appropriate at such site in accordance with section [104] or [106], the President shall take or require such action. The President shall report to the Congress a list of facilities for which such review is required, the results of all such reviews, and any actions taken as a result of such reviews.*

The EPA interpreted this requirement further in the National Contingency Plan (NCP); 40 CFR §300.430(f) (4) (ii) states:

> *If a remedial action is selected that results in hazardous substances, pollutants, or contaminants remaining at the site above levels that allow for unlimited use and unrestricted exposure, the lead agency shall review such action no less often than every five years after the initiation of the selected remedial action.*

Who Conducted the Five-Year Review

The EPA Region 8 conducted the five-year review of remedial actions implemented at Gilt Edge Mine NPL Site Operable Units (OU) 2 and 3 near Lead, South Dakota. This review was conducted from August 2006 through September 2006. This report documents the results of the review. HDR Engineering, Inc. (HDR) of Denver, Colorado was retained under a subcontract to Project Resources Inc. (PRI) to prepare this Five-Year Review Report for EPA. PRI was retained by the US Army Corps of Engineers, Omaha District under a Rapid Response Program contract.

Other Review Characteristics

This is the first five-year review for the Site. The triggering action for this review is the release of the Record of Decision for OU3 on August 30, 2001. Because hazardous substances, pollutants or contaminants remain at the Site above levels that allow for unlimited use and unrestricted exposure, a Statutory Five-Year Review is required.

II. Site Chronology

Table 1
Chronology of Site Events

Event	Date
Mining activity begins	1876
Intermittent gold, silver, copper, lead and zinc mining	1876-1941
Permit issued to Brohm Mining Corp. (BMC) for cyanide heap leach operation	1986
Preliminary Assessment (PA) of the Site prepared by South Dakota Department of Environment and Natural Resources (SDDENR)	1991
Cyanide solution released into local drainages	1991
Unpermitted discharge of acid waters and metals.	1992
NPDES permit issued to BMC to address cyanide and metal releases	1993
150,000 tons of tailings removed from Strawberry Creek drainage by BMC as a requirement of the 1986 mining permit.	1993 – 1994
BMC reports it will abandon the Site by May 29, 1998	1998
State of South Dakota obtained a restraining order issued to BMC against Site abandonment	May 29, 1998
BMC's parent, Dakota Mining Corp. files for bankruptcy	July 1999
SDDENR assumes water treatment operation	1999
SDDENR seeks National Priority Site (NPL) listing	February 2000
Site is placed on the NPL	December 2000
Early Action Interim Record of Decision for OU2 (water treatment) transferring interim water treatment operations from SDDENR to EPA Region 8 Emergency Response Program	April 2001
Interim Record of Decision for OU3 (Ruby Ridge Waste Rock Dump)	August 2001
Interim Record of Decision for OU2 requiring conversion of the existing sodium hydroxide treatment plant to a lime-based treatment process.	November 2001
OU3 90% remedial design complete (design/build project)	March 2002
OU2 remedial design complete	March 2003
OU2 remedial construction complete	October 2003
OU3 remedial construction of the Ruby Gulch Waste Rock Dump complete	April 2006

III. Background

Location and Setting:

The Site is located in Lawrence County, approximately two miles southeast of Lead, South Dakota in the Black Hills. An aerial photograph of the Gilt Edge Mine is provided as Figure 1 in Appendix A. Site boundaries have not yet been formally established (to be established as part of OU1) however, the overall study area encompasses the area disturbed by mining as well as a

buffer area. The study area is bounded by largely undeveloped land. Land surface elevation within the study area ranges from 5,680 feet above mean sea level (aml) to 4,880 aml.

The Site is divided into three OUs including:

- OU1 – Site-Wide Conditions
- OU2 – Water Treatment
- OU3 – Ruby Dump and Gulch

This five-year review addresses OU2 and OU3. The remedy for OU1 has not been selected.

The Site has been mined intermittently by several owners from the late 1800s to late 1990s. Cyanide leaching, mercury amalgamation and zinc precipitation among other methods were used to recover gold. The Site currently consists of a heap leach pad in addition to several ore extraction pits (Figure 1 – Appendix A). The heap leach pad covers 37 acres with approximately 3.2 million tons of spent ore. An expansion to this pad was begun before BMC declared bankruptcy; however no ore was processed on the expansion. There are also surge, neutralization and diatomaceous earth ponds with high density polyethylene (HDPE) primary liners and HDPE and soil composite secondary liners.

Ore for the leach pad was obtained from the Dakota Maid/Sunday Pits (29.5 and 17 acres, respectively), the SE Langley Pit (8.1 acres) and the Anchor Hill Pit (23.6 acres). Waste rock from the mining activities and spent ore from the leach pad were transported to the Ruby Waste Dump, a tiered storage area in the Ruby Gulch Drainage. The Ruby Waste Dump was recognized as the main source for acid rock drainage (ARD) at the Site.

During BMCs operations at the Site, ARD discharging from the Ruby Waste Dump was collected in an HDPE-lined containment pond. The ARD was then pumped to the Dakota Maid/Sunday Pit and from there, pumped to a water treatment facility using sodium hydroxide neutralization/precipitation as the treatment process. Treated water was discharged to Strawberry Creek drainage.

Additional sources for ARD include historical deposits of mill tailings in Strawberry and Bear Butte Creek drainages. These wastes were discharged to these drainages prior to 1941, well before BMCs operations at the Site.

Two water-bearing zones were identified; a thin zone of saturated alluvium perched on top of bedrock and a regional deep bedrock aquifer. The direction of flow in the alluvial and bedrock aquifers is to the south and southeast, respectively. Depth to water in the bedrock aquifer ranged from more than 100-feet at the north end of the Site to less than 10-feet at the south end. Flows are influenced by the underground mine workings, exploration boreholes, faults, bedding plains, joints and fracture zones within the bedrock.

The surface water at the Site drains through three sub-basins into Bear Butte Creek. The sub-basins are Strawberry Creek, Hoodoo Gulch and Ruby Creek (Figure 1 - Appendix A).

Site History and Extent of Contamination:

Mining activities began at the Site in 1876 when the Gilt Edge and Dakota Maid claims were located. Historical underground mining extracted sulfide-bearing gold ores from irregular deposits in veins and fracture zones in the igneous rocks. The area was mined intermittently until 1941. In 1984, Gilt Edge, Inc. applied for a permit to begin a heap leach operation. Gilt Edge,

Inc. was acquired by BMC before the permit was issued in 1986. In response to permit requirements, BMC removed over 150,000 tons of tailings from upper Strawberry Creek drainage and constructed a water treatment facility designed to prevent ARD from entering Strawberry or Bear Butte Creeks.

Construction of the open-pit mine and cyanide heap leaching facilities began in 1987. Mining of the Dakota Maid and Sunday open pits was completed in 1992. Subsequent operations by BMC developed the Langley and Anchor Pits.

In 1998, BMC announced it would abandon the Site by May 29th. During that month, the State of South Dakota (the State) filed for and was granted a Temporary Restraining Order to prevent BMC's abandonment of the Site. A Preliminary Injunction followed in June. BMC's parent company, Dakota Mining Corp., filed for bankruptcy in 1999 and the State assumed responsibility for water treatment at the Site. In 2000, the State also sought National Priority List (NPL) listing from EPA with the listing announced in December. In August 2000, the EPA Region 8 Emergency Response Program assumed responsibility for water treatment.

Wastes associated with mining included waste rock, tailing and spent ores contaminated with a wide array of metals. Some of the original contamination sources were removed from the Site prior to EPA's involvement.

Contamination of primary concern under OU2 and OU3 is ARD. A geochemical field reconnaissance in 2000 classified mine waste materials for ability to generate ARD in four categories:

- Non acid generating
- Highly acid generating
- Moderately acid generating
- Initially acid consuming but ultimately acid generating

Different areas of the original heap leach pad and its extension were ranked across the full range of categories. The former Ruby Waste Dump was comprised of highly acid generating material overlain by moderately acid generating materials.

Baseline Risk Assessment:

Estimated risks to humans and the environment from contamination associated with mine wastes are being quantified under OU1 in a Baseline Risk Assessment (BRA) for the overall Site. Risks to humans and the environment above a level of concern as estimated in the BRA will be addressed under OU1. Therefore, review of exposure assumptions, toxicity factors etc., is not appropriate under this five year review.

IV. Response Actions

A series of response actions were conducted beginning in 2000 to address ARD contamination at the Site. Considerable reclamation activities were conducted by BMC under the requirements of their mining permit. However, these actions were not performed under a ROD; therefore they are not discussed herein.

All response actions in OU2 and OU3 were performed as interim remedial actions and focused on minimization, collection and treatment of ARD generated in the Ruby Waste Rock

Repository. Additional ARD was collected from seeps in Hoodoo Gulch in the upper Strawberry Creek watershed and treated prior to discharge.

A summary of the various response actions is provided below by OU.

OU2 – Water Treatment

1. Early Action Interim ROD (4/01) - Remedial action to use an existing ARD collection system at the toe of the Ruby Waste Rock Dump and an existing water treatment facility to treat ARD. The ARD collection system and treatment facility was constructed by BMC during active mining. The ROD required the addition of ferric iron to the treatment system to enhance precipitation of metals from ARD. Modification of sludge management operations to include storage basins was also required.
2. Interim ROD (11/01) – Remedial action requiring the continued collection of ARD from the toe of the Ruby Repository as well as from seeps in Hoodoo Gulch and conveyance to the water treatment facility. Collection of ARD seep flows west of the Heap Leach Pad (upper Strawberry Creek watershed above Pond C) and conveyance to the water treatment facility. Conversion of the existing sodium hydroxide-based water treatment process to a 250-gallon per minute net treatment capacity consisting of a lime-based neutralization/precipitation process with lime slaking and slurry chemical feed equipment upgrades. A high-density sludge process was selected after pilot test evaluations.

OU3 – Ruby Gulch Waste Rock Dump

1. Interim ROD (11/01) - Remedial action to regrade waste rock in the upper Ruby Gulch drainage, construction of a synthetic cap and vegetative cover, clean water diversion ditches and an ARD collection gallery.

V. Progress since the Last Review

This is the first five-year review.

VI. Five-Year Review Process

Administrative Components:

This is the first five-year review for the Site. The five-year review was led by Rebecca Thomas, EPA Project Manager. The following Team Members participated in the review:

- Rebecca Thomas, EPA Project Manager
- Ken Wangerud, EPA Site Remedial Project Manager
- Peggy Churchill, EPA Site Remedial Project Manager
- Nancy Mueller, Community Involvement Coordinator
- Karen Kellen, EPA Attorney
- Mark Kennihan, SDDENR Representative

EPA Contractors:

- Kenneth Napp, HDR Engineering, Inc.

This five-year review consisted of the following activities: a review of relevant documents; a meeting with representatives of EPA and SDDENR during a Site visit; and data review. The schedule for the review extended through September 2006.

Community Involvement:

A display ad was published Thursday, August 24, 2006, in the Rapid City, SD Journal to announce the Five-Year Review and to invite public input. No one contacted EPA as a result of the ad.

Nancy Mueller, Community Involvement Coordinator for the Site, conducted limited community interviews of local stakeholders in September 2006. Interviewees included private citizens, local officials and local business persons. Each person was asked the following questions:

1. What is your overall impression of the project?
2. What effects have Site operations had on the surrounding community?
3. Are you aware of any events, incidents or activities at the Site such as vandalism, trespassing, or emergency responses from local authorities? If so, please give details.
4. Are you aware of any community concerns regarding the site or its operation and administration? If so, please give details.
5. Do you feel well-informed about the Site's activities and progress?
6. Do you have any comments, suggestions or recommendations regarding the Site's management or operation?

The following is a summary of responses, organized by the number of each question:

1. The overall sentiment is that cleanup of the Site needs to occur. Opinions regarding successful reclamation of the Site vary from "impossible" to "looking forward to being able to reuse the land." There is some frustration regarding the slow speed at which things are moving, particularly in the area of resolving issues surrounding land ownership.
2. The persons interviewed indicated there weren't many physical effects in the area (dust, increased traffic, etc.), but that the economic effects have been substantial and quite appreciated. One respondent indicated that she felt that people owning property in the immediate vicinity of the Site are somewhat in limbo due to property ownership issues (unable to get utilities due to easement issues).
3. All of the respondents indicated they were not aware of ANY "emergency" incidents at the Site, and all attributed it to the fact that the Site is so isolated.
4. One respondent indicated that, because abandoned open-pit, heap leach operations are nearly impossible to completely clean up, the area will likely be left with some sort of "mess" forever. Another concern has to due with taxpayer costs (and the fact that it's unlikely EPA will be able to recover much, if any of those costs due to bankruptcy). Other concerns have to do with future land use possibilities (private, public, Tribal), or whether the land will be able to put back into productive use AT ALL.
5. All respondents indicated they felt adequately informed of Site activities. Hands-on attention from EPA staff and management has gone a long way in building positive relationships in the area.
6. One person indicated that he felt that more sampling of the sediments in the creeks on and around the Site needs to occur. Another person is very grateful that, in the process of dealing with the entire Site, "smaller" problems have been taken care of. Resolving

property ownership issues and determining future land use is very important, as is potential beneficial reuse of the area.

In general, community involvement at the Site has been fairly low-key. A number of meetings and availability sessions have been held, and attendance is usually quite good. The general public does not seem overly concerned about the contaminated status of the Site; rather, they are more concerned about what the future might hold for the entire area.

Document Review:

In preparing this Five-Year Review Report, the following documents were reviewed:

- Final Feasibility Study for Gilt Edge Mine Ruby Dump and Gulch Operable Unit 3, March 2001
- Early Action Interim Record of Decision for OU2, April 2001
- Interim Record of Decision for OU3, August 2001
- Interim Record of Decision for OU2, November 2001
- Ruby Gulch Waste Rock Repository and Cap Design Summary for Phases 1, 2, and 3, Gilt Edge Mine Superfund Site OU-3, Draft Report, February 6, 2003.
- Preliminary Feasibility Study Report for Gilt Edge Mine Site, Operable Unit 1, November 2004
- Monitoring data and data plots provided by CDM via email, September 2006
- Monitoring data plots provided by EPA via email, September 2006

Interviews were conducted with the following individuals to provide supplemental technical information:

- Steve Fundingsland – CDM (Consultant to EPA)
- Mike Gobla – US Bureau of Reclamation
- Dave Paul - US Bureau of Reclamation

Data Review:

The remedy includes a treatment facility effluent monitoring program as well as a flow monitoring program designed to track the volume of ARD discharging from OU3. However, monitoring reports presenting and interpreting the monitoring data have not been prepared and so in performing this five-year review, data from the following sources were reviewed and evaluated:

- Water Treatment Facility 30-day average effluent quality data for July 2004 through July 2006 provided by CDM via email.
- Plots of total monthly discharge from the Ruby Waste Rock Dump/Repository for January 1996 through August 2006 (several months of data are missing from late 2005) provided by EPA via email.
- Plots of monthly precipitation vs. monthly discharge from Ruby Waste Rock Dump from January 1997 through November 2002 provided by CDM via email.
- Plots of monthly precipitation vs. monthly discharge from Ruby Repository from December 2002 to February 2005 provided by CDM via email.

A summary of these data and their interpretation for demonstrating remedy performance is provided below.

OU2 – Water Treatment

Performance standards for OU2 are limited to effluent quality standards set according to the requirements of the South Dakota Surface Water Discharge System. Effluent quality standards are monitored at the point of discharge to Strawberry Creek. State surface water quality standards for total dissolved solids (TDS) and selenium were waived with the understanding that they will be part of the final Site remedy objectives under OU1. It is assumed that the waiver of TDS also includes a waiver of the conductivity standard as the two are related.

Monitoring data and corresponding standards are summarized on a table provided in Appendix C. Monitoring data indicate infrequent exceedences of several parameters between August 2004 and August 2006. These exceedences include:

- One exceedence of the monthly average temperature standard.
- Two exceedences of the monthly average total suspended solids (TSS) standard.
- One exceedence of the monthly average nitrate standard.

Many chemicals/parameters for which performance standards exist were not analyzed for during most or all of the monitoring period. These chemicals/parameters include:

- Alkalinity
- Weak acid dissociable (WAD) cyanide
- Total cyanide
- Chromium (VI)
- Dissolved mercury

In addition, the analytical detection limit for WAD cyanide is twice the water quality standard of 0.005 milligrams per liter (mg/L).

OU3 – Ruby Repository

Numerical performance standards were not established for OU3. Instead, qualitative performance standards (Remedial Action Objectives (RAOs)) were established for the Ruby Repository as described in the OU3 ROD and subsequent Design Summary Report and includes the following:

1. Control erosion of mine waste contaminants into Ruby Gulch and Bear Butte Creek.
2. Reduce formation and volume of ARD
3. Reduce leaching and migration of contaminants from mine waste into surface water.
4. Reduce leaching and migration of contaminants from mine waste that may enter groundwater.

The construction of the Ruby Repository cap constitutes “control” of mine waste erosion thereby meeting RAO No. 1.

Monitoring data provided by EPA and CDM support the conclusion that the OU3 remedy is meeting RAOs 2 through 4. RAOs 2 through 4 require a reduction in the generation of ARD and subsequent discharge to either surface water or groundwater.

ARD potentially reporting to surface water is measured as ARD collected at the toe of the Ruby Repository prior to treatment. Monthly ARD volumes collected at the toe of the Ruby Repository (Ruby Waste Rock Dump prior to 2003) is illustrated on Figure 2 (Appendix A) for the period 1996 through 2006. A review of this figure suggests that greater quantities of ARD were collected prior to construction of the Ruby Repository cap (largely completed by January 2003) than afterwards. This conclusion may be considered overly simplistic for two reasons:

1. Variability in the quantity of precipitation over the monitoring period can greatly influence the generation of ARD.
2. Clean water leaked into the repository in 2005 and 2006 during the testing of clean water diversion channel integrity, thereby artificially increasing the amount of ARD reported during those years.

In order to compensate for these two variables, plots of precipitation versus volume of ARD reporting to the collection system were prepared for the period prior to and after construction of the cap. The plot for the period after cap construction does not include the time over which the clean water diversion channel integrity testing was conducted. These plots are presented as Figures 3 and 4, respectively (Appendix A). A review of these plots shows the slope of the best fit line is flatter for the period after the cap was installed. This supports the conclusion that for each unit of incident precipitation, the quantity of ARD generated is much less after cap construction than before. This conclusion speaks to RAO's Nos. 2 and 3. It is also reasonable to assume that the overall reduction in the generation of ARD also speaks to RAO No. 4.

Site Inspection:

The Site Inspection was performed on August 30, 2006 by the EPA Remedial Project Manager for the Site, Ken Wangerud; Mark Keenihan of SDDENR; and Kenneth Napp, the HDR Project Manager. The purpose of the Site Inspection was to observe the current Site condition and remedy elements. At the time of the inspection it appeared that all physical remediation elements had been constructed. No construction completion reports were available for review.

In OU2, the water treatment plant was observed to be operational and in good condition. A photograph of the facility exterior is provided in Appendix B (photo No. 4). The ARD seep collection system in Hoodoo Gulch consists of a french drain constructed across the drainage with an adjacent lift station ultimately delivering water to the treatment facility. The french drain itself was not observed, as it is subsurface. The lift station was not operating at the time of the inspection but reportedly is in working order (Photo No. 5, Appendix B).

The ARD seep collection system upstream of Pond C reportedly was constructed in accordance with the design documents and consists of the following:

- A concrete head structure constructed in an unlined channel directing flow into a 12-inch diameter flexible pipe.
- Conveyance of ARD to Pond C via the 12-inch pipe.
- Discharge of ARD from Pond C to a smaller diameter pipe (Photo No. 7, Appendix B) delivering ARD to Pond E (water in Pond E is pumped to the treatment facility).

In OU3, the Ruby Repository reportedly was constructed as designed with the exception of clean water diversion ditches which reportedly are leaky due to a damaged liner system, unlined ditches constructed in fractured bedrock, and sediment dams redirecting water under liners.

However, visual evidence of such damage was not apparent, nor is it expected to be. A photograph of a typical section of clean water diversion channel is shown on Photo No. 3 (Appendix B). The vegetative cover was observed to be in good condition (Photo Nos. 1 and 2, Appendix B). The ARD storage pond at the toe of the repository appeared to be in good condition with no obvious damage to the portion of the liner above the water level. The lift station below the collection pond was not operating at the time of the inspection but reportedly is in working order.

VII. Technical Assessment

Question A: Is the remedy functioning as intended by the decision documents?

<u>The remedy for OU2 consists of the following elements:</u>

1. Continued collection of ARD from the toe of the Ruby Waste Rock Dump and conveyance to the Sunday Pit for water treatment.
2. Collection of ARD seeps in Hoodoo Gulch and conveyance to the Sunday Pit for water treatment.
3. Collection of ARD seep flows upstream of Pond C and conveyance to Pond D for water treatment.
4. Conversion of the existing sodium hydroxide-based water treatment process to a 250-gallon per minute (gpm) net treatment capacity system consisting of a lime-based neutralization/precipitation high density sludge process with lime slaking and slurry chemical feed equipment upgrades. Effluent quality performance standards (based on South Dakota surface water quality standards) are summarized on a table provided in Appendix C.

The remedy would be considered to be protective if Hoodoo Gulch ARD seeps and seeps above Pond C are collected and delivered to the water treatment facility (along with ARD generated in OU3) and treated to the effluent quality standards.

The performance of each remedy element is discussed below:

1. ARD is collected from the toe of the former Ruby Waste Rock Dump (present Ruby Repository- OU3) and conveyed to the Sunday Pit prior to being pumped to the treatment facility.
2. The Hoodoo Gulch seep collection system is constructed and operating. No flows were observed in the channel at the time of the Site Inspection. In addition, the collection system is below-ground. Therefore, a favorable performance assessment is based on personal communications with the EPA Project Manager.
3. An ARD collection system for seeps above Pond C was observed during the Site Inspection. No flows were observed in the channel at the time of the Site Inspection. However, most system components are above-ground and were observed to be in working order.
4. Water treatment facilities were constructed in accordance with the ROD requirements. Effluent quality conforms to numerical performance standards during the monitoring period (July 2004 to July 2006) with the following exceptions:

- One exceedence of the monthly average temperature standard.
- Two exceedences of the monthly average total suspended solids (TSS) standard.
- One exceedence of the monthly average nitrate standard.

Additional exceedences of performance standards may have occurred prior to the monitoring period examined for this 5-Year Review (July 2004 through July 2006).

Remedial action objectives for OU2 include the following statement:

"Achieve compliance, to the extent possible and practicable for the interim, with currently applicable water quality standards"

Based on this RAO, it appears the few exceedences of water quality standards described above are not inconsistent with ROD requirements (and the TDS and Selenium interim waiver). However, many chemicals/parameters for which performance standards exist were not analyzed for during most or all of the monitoring period. These chemicals/parameters include:

- Alkalinity
- Weak acid dissociable (WAD) cyanide
- Total cyanide
- Chromium (VI)
- Dissolved mercury

According to a representative of CDM (EPA's contractor), these parameters were dropped from the analyte list after multiple sample results showed consistent concentrations below the corresponding standard. The analytical data presented in Appendix C supports this explanation with one exception. The analytical detection limit for WAD cyanide is twice the water quality standard of 0.005 mg/L. Therefore, it is not possible to determine whether sample results showed consistent concentrations below the corresponding standard

An additional concern involves the reported inability of the water treatment facility to operate at 250 gpm when the influent stream consists exclusively of the highest sulfate waters present at the Site. EPA is considering improvements to remedy efficiency through modification of the treatment facility.

<u>The remedy for OU3 consists of the following elements:</u>

1. Regrading of waste rock, including placement in the upper Ruby Gulch drainage.
2. Construction of a composite cap using a geomembrane liner.
3. Installation of lateral drainage structures to limit erosion and convey runoff
4. Construction of a protective layer for the synthetic cap, and benches to carry clean water off of the repository.
5. Construction of clean-water diversion ditches.
6. Seeding the repository.
7. Construction of vault collection system, overflow pond and upgraded pumping facility at the repository toe.

8. Although not required by the ROD, a resistivity geophysics monitoring system to supplement a limited number of wells, was part of the remedial design.

All of these remedy elements (i.e. the cap-cover, lateral bench drains, and perimeter diversion conveyance ditches) were constructed as designed (personal communication with EPA Project Manager). Based on conversations with the EPA Project Manager, bedding material was not placed (because of high cost) beneath a geocomposite-membrane liner that was installed in the sections of clean water diversion ditches where native materials were known to have unacceptably high vertical permeability. As a result, some degree of damage to and/or displacement of the geocomposite-membrane liner is suspected to have occurred during placement of overlying rip-rap. Other concerns related to the diversion ditches include unlined sections that were constructed in more tightly-fractured bedrock and the post-construction influx of a sediment dam in one of the ditches. Several design and construction factors are suspected to be the cause of losses during storm water conveyance in the diversion channels. These water losses enter the waste rock mass and report to the collection system at the toe of the repository. However, the relative proportion of these losses to total annual runoff, ditch conveyance volumes, and repository discharge is not yet well known.

An approximately 10-acre area of Ruby Gulch waste rock remains outside of the capped area (Figure 1 – Appendix A). This area was deliberately excluded from the design (personal communication, USBOR) and would be addressed under OU1 during closure of the Heap Leach Pad, if appropriate.

The RAOs for OU3 called for control of mine waste erosion into Ruby Gulch and a reduction in the formation of ARD. As previously discussed, these RAOs are being met in spite of the leaking clean water diversion ditches.

Question B: Are the exposure assumptions, toxicity data, cleanup levels and remedial action objectives used at the time of the remedy selection still valid?

Numerical performance standards are restricted to water treatment facility effluent quality. All other performance standards are qualitative. Therefore, assessment of exposure assumptions and toxicity data related to risk-based remediation goals is not appropriate, as risk-based remediation goals have not be set for OU2 or OU3. A baseline risk assessment is in preparation under OU1.

Clean-up levels, as they apply to treatment facility effluent remain valid with one exception. The EPA approved South Dakota water quality standards now contains pertinent equations to determine the total ammonia concentrations that cannot be exceeded (Appendix A referenced in § 74:51:01:49). In addition, the 30-day average is now seasonal.

RAO's used at the time of the remedy selection remain valid. Final RAO's for the Site are being addressed under OU1.

Question C: Has other information come to light that could call into question the protectiveness of the remedy?

There is no other information that calls into question the protectiveness of the remedy.

Technical Assessment Summary

According to the data reviewed and the Site inspection, the remedy is largely operating as intended by the ROD. The physical remedy elements are in place and functioning. The occasional exceedences of water quality standards in treatment facility effluent do not appear to be inconsistent with the intent of the ROD. However, inconsistencies between the required monitoring of treatment system effluent and the actual monitoring program implemented during the review period for OU2 require resolution.

Protectiveness currently is achieved through collection of ARD and its treatment before leaving the Site. Although leaking clean water diversion ditches may be contributing waters to the waste rock mass inside the repository and ultimately increasing the volume of collected ARD, the issue is one of remedy efficiency rather than protectiveness.

VIII. Issues

Based on the information collected during the first five-year review, the following issues were identified:

Table 2
Issues

Item No.	Issues	Affects Current Protectiveness (Y/N)	Affects Future Protectiveness (Y/N)
1	Occasional exceedence of applicable State Surface Water Quality Standards (OU2) including temperature, total suspended solids and nitrate.	N	potentially
2	Alkalinity, weak acid dissociable cyanide, total cyanide, chromium VI and dissolved mercury not measured in water treatment facility effluent during most or all the monitoring period.	potentially	potentially
3	Detection limit for weak acid dissociable (WAD) cyanide is twice the water quality standard	potentially	potentially
4	New effluent standard for ammonia. The standard is calculated using equations in Appendix A referenced in § 74:51:01:49.	potentially	potentially
5	Clean water diversion ditches may discharge to waste rock mass due to suspected leaky channel liner, unlined fractured bedrock ditches and sediment dams in the ditches.	N	N
6	ROD required site-specific toxicology study of sulfate TDS has not been performed	potentially	potentially

IX. Recommendations and Follow-up Actions

Table 3
Recommendations and Follow-up Actions

Item No	Issues	Recommendations and Follow-up Actions	Party Responsible	Due Date
1	Occasional exceedence of applicable State Surface Water Quality Standards (OU2) including temperature, total suspended solids and nitrate.	Continue monitoring	EPA	NA
2	Alkalinity, weak acid dissociable cyanide, total cyanide, chromium VI and dissolved mercury not measured in water treatment facility effluent during most or all the monitoring period.	Improve monitoring program	EPA	September 2007
3	Detection limit for weak acid dissociable (WAD) cyanide is twice the water quality standard	Revise analytical detection limits	EPA	September 2007
4	New effluent standard for ammonia. The standard is calculated using equations in Appendix A referenced in § 74:51:01:49.	Revise performance standards	EPA	September 2007
5	Clean water diversion ditches may discharge to waste rock mass due to suspected leaky channel liner, unlined fractured bedrock ditches and sediment dams in the ditches.	Consider repair to suspected leaking channels.	EPA	September 2008
6	ROD required site-specific toxicology study of sulfate TDS has not been performed.	Conduct study	EPA	September 2008

X. Protectiveness Statement(s)

RAOs are being met under the Interim RODs for OU2 and OU3. Therefore, the remedy as implemented is currently protective of human health and the environment. Residual risks associated with remaining contaminated environmental media will be addressed under OU1.

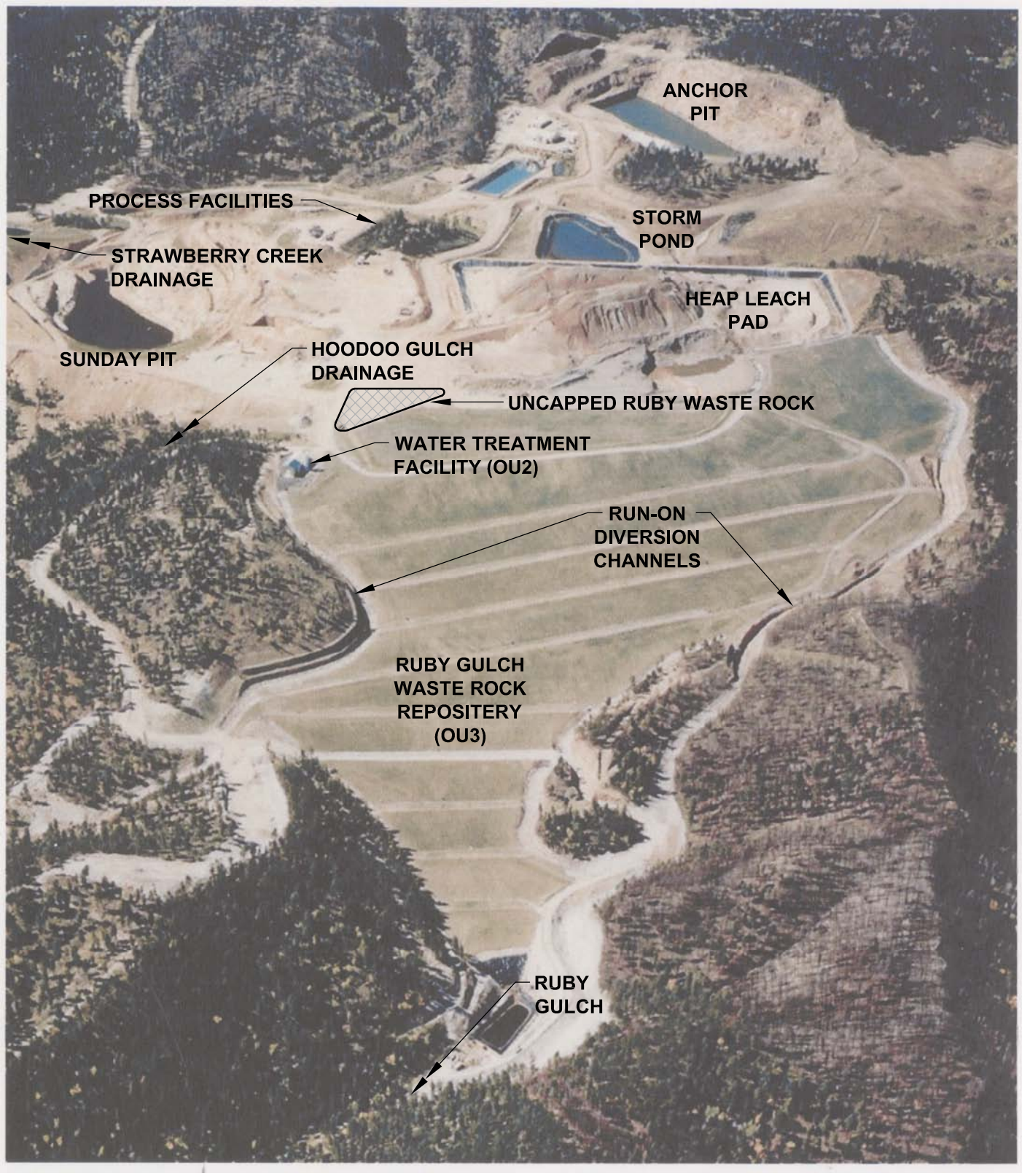
XI. Next Review

The Site requires ongoing five-year reviews in accordance with CERCLA § 121 (c). The next five year review for the Site will be performed by September 2011, five years from the date of this review.

APPENDICES

APPENDIX A

FIGURES



HDR

Gilt Edge Mine
Lawrence County, South Dakota

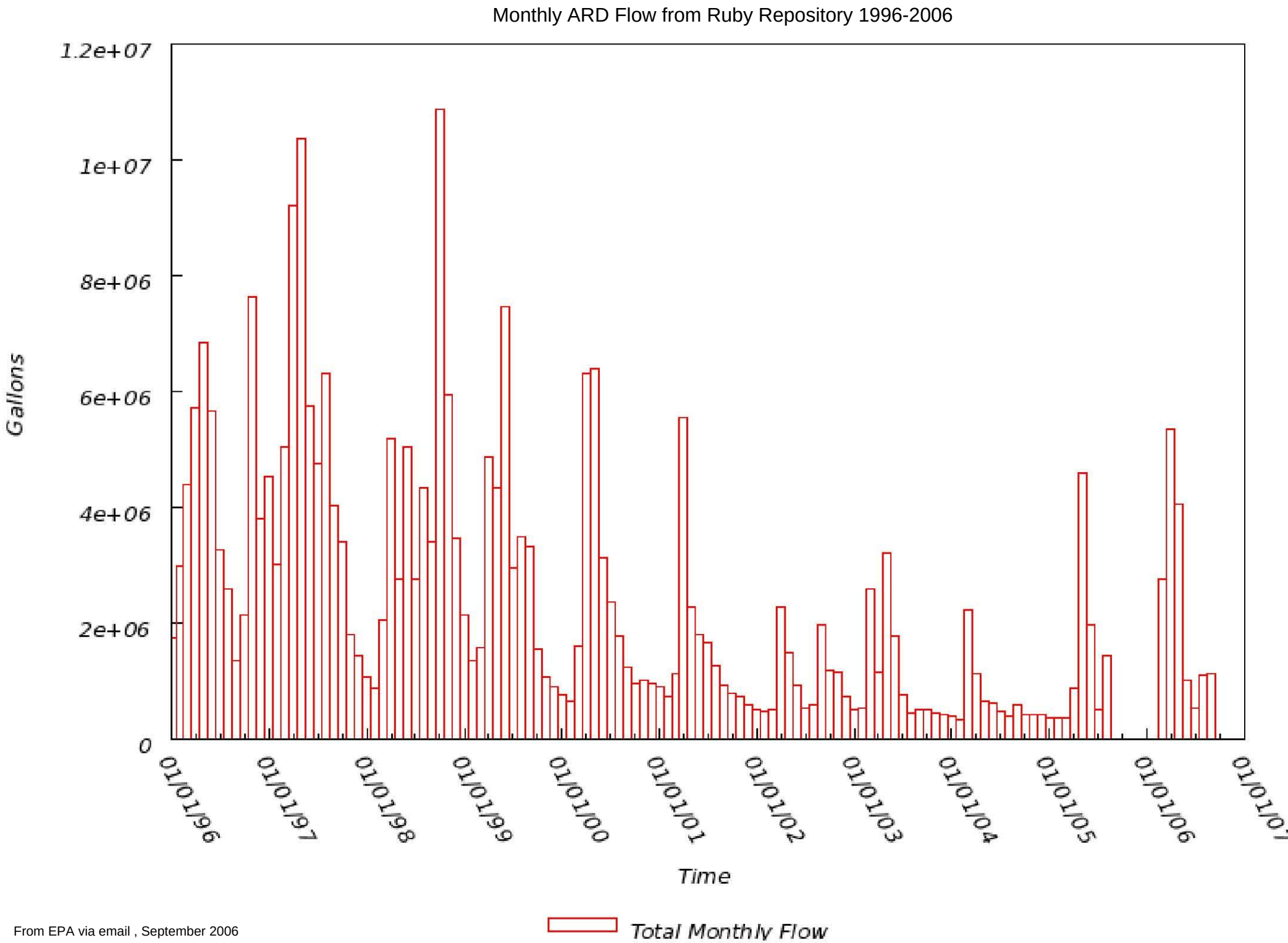
PRIMARY SITE FEATURES

DATE
SEPT. 2006

FIGURE
1

9/21/2006 3:28:14 PM, RNelson

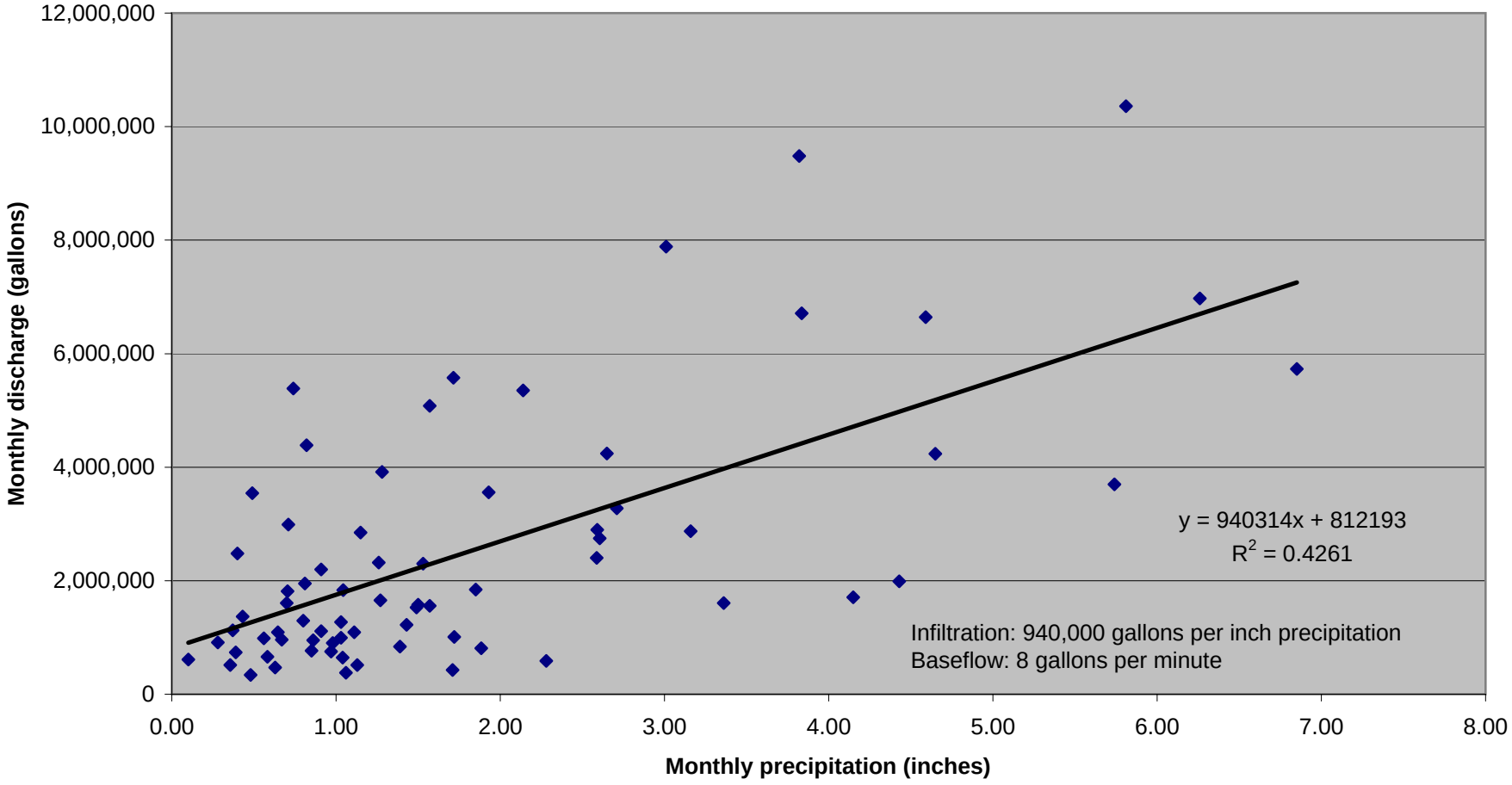
Figure 2



From EPA via email , September 2006

Figure 3
Monthly ARD Flow versus Precipitation

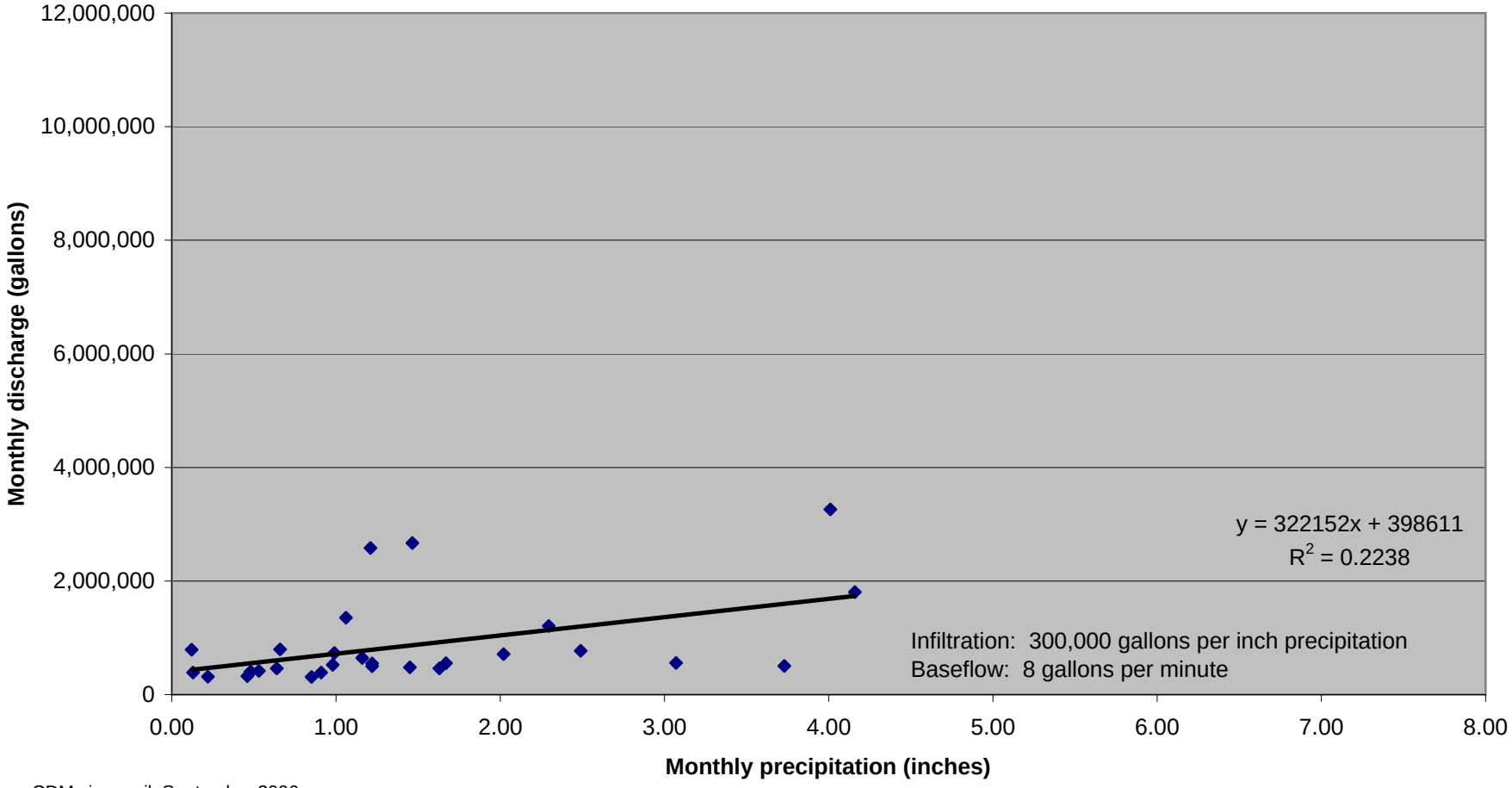
Ruby Waste Dump: Prior to Cap
January 1997 to November 2002



From CDM via email, September 2006

Figure 4
Monthly ARD Flow versus Precipitation

Ruby Waste Dump: After Cap Installed
December 2002 to February 2005



From CDM via email, September 2006

APPENDIX B

PHOTO LOG

Photo Log

Photo No. 1
Top of Ruby Repository, Seen from Heap Leach Pad
View to East

Photo No. 2
Ruby Repository
View to North

Photo No. 3
North Surface Water Run-on Diversion Channel
View to East

Photo No. 4
Water Treatment Plant
View to West

Photo No. 5
Hoodoo Gulch Lift Station
View to South

Photo No. 6
Pipeline Conveying ARD Seep Discharge above Pond C
View to North

Photo No. 7
Pond C w/ ARD Intake (90° elbow) and Clean Water Diversion (Pipe Right of Ladder)
View to South

Photo No. 8
36-inch Clean Water Diversion Pipe Staged for Installation
View to South

APPENDIX C

TREATMENT FACILITY EFFLUENT QUALITY DATA AND PERFORMANCE STANDARDS

Table 1

SUMMARY OF SURFACE WATER COMPLIANCE POINT SAMPLING
Analytical Results From Midcontinent Testing Laboratory.

Units are mg/l unless otherwise noted

Water Treatment Plant End-Of-Pipe

Date	Time	Sampler	Temperature	Conductivity	Hardness	pH	TDS	TSS	Turbidity	Alkalinity	CN	CN	Nitrate	As	As	Cd	Cd	Ca	Cr (III)	Cr (VI)	Cu	Cu	Pb	Pb	Mg	Hg	Hg	Ni	Ni	Se	Se	Ag	Ag	Zn	Zn
			(deg C)	umhos/cm					(NTU)		WAD	total		(trec)	(diss)	(trec)	(diss)	(diss)	(diss)	(diss)	(trec)	(diss)	(trec)	(diss)	(diss)	(trec)	(diss)	(trec)	(diss)	(trec)	(diss)	(trec)	(diss)	(trec)	(diss)
				30-day			30-day	24-hour		30-day	chronic		30-day		chronic		chronic		chronic	chronic		chronic		chronic			chronic		chronic		chronic		acute		chronic
SD AWQC Limits			24.0	2500		6.5-8.8	2500	10		750	0.005		50		0.190		0.003		0.554	0.010		0.037		0.011			0.00001		0.508		0.005		0.037		0.338
9/29/2003	14:40	CDM	13.3	2850	2000	7.51	2934	<10	1.4					<0.005	<0.005	<0.001	<0.001	774	0.005	<0.010	0.012	0.007	0.001	0.001	16.4	<0.0002	<0.0002	<0.005	<0.005	0.006	0.006	<0.001	<0.001	<0.050	<0.050
August 2004 Avg's		CDM	n/a	3490	2173	7.77	3307	12	0.5	27.6	<0.010	<0.010	32.4	<0.005	<0.005	<0.001	<0.001	860	0.009		0.038	0.032	<0.001	<0.001	6.3	<0.0002	<0.0002	0.025	0.020	0.013	0.013	<0.001	<0.001	<0.050	0.069
September 2004 Avg's		CDM	n/a	3420	2420	7.61	4280	23	8.5	29.6	<0.010	<0.010	31.3	<0.005	<0.005	<0.001	<0.001	960	0.009		0.015	0.015	<0.001	<0.001	6.7	<0.0002	<0.0002	0.019	0.019	0.012	0.011	<0.001	<0.001	<0.050	<0.050
October 2005 Avg's		CDM	12.8	2930	1695	7.77	2890	<5		30.0	<0.010		17.9	<0.005	<0.005	<0.001	<0.001	666	0.005		0.012	0.01	<0.001	<0.001	13.0	<0.0002	<0.0002	0.021	0.019	0.011	0.008		<0.001	<0.050	<0.050
November 2005 Avg's			7.3	3008	1685	7.31		<5.5					20.2	<0.005	<0.005	0.001	0.001	650	0.002		0.017	0.016	0.004	<0.001	15.2	<0.0002		0.020	0.018	0.009	0.009		<0.001	<0.050	<0.050
December 2005 Avg's		CDM	4.9	3028	1695	7.3		<5.5					21.7	<0.005	<0.005	<0.001	<0.001	655	0.002		0.019	0.011	0.001	<0.001	14.8	<0.0002		0.020	0.019	0.010	0.009		<0.001	<0.050	<0.050
January 2006 Avg's		CDM	5.5	2964	1634	7.26		<5.2					22.2	<0.005	<0.005	<0.001	<0.001	627	0.001		0.012	0.011	<0.001	<0.001	16.0	<0.0002		0.020	0.015	0.009	0.009		<0.001	<0.050	<0.050
February 2006 Avg's		CDM	3.8	3158	1688	7.31		<5.5					23.4	<0.005	<0.005	<0.001	<0.001	616	0.002		0.014	0.010	<0.001	<0.001	36.0	<0.0002		0.022	0.018	0.011	0.010		<0.001	<0.050	<0.050
March 2006																																			
3/6/2006	12:55	CDM	5.2	2640	1400	7.46		<4					23.2	<0.005	<0.005	<0.001	<0.001	541	0.001		0.009	0.009	<0.001	<0.001	11.5	<0.0002		0.014	0.014	0.010	0.008		<0.001	<0.050	<0.050
3/13/2006	9:30	CDM	5.8	2440	1170	7.23		<4					26.9	<0.005	<0.005	<0.001	<0.001	448	0.001		0.011	0.011	<0.001	<0.001	11.9	<0.0002		0.013	0.013	0.009	0.007		<0.001	<0.050	<0.050
3/20/2006	n/a	CDM	4.0	2510	1280	7.40		<4					24.3	<0.005	<0.005	0.001	0.001	496	0.001		0.020	0.020	<0.001	<0.001	10.8	<0.0002		0.010	0.010	0.007	0.006		<0.001	<0.050	<0.050
3/27/2006	10:25	CDM	5.0	2350	1220	7.38		<4					22.4	<0.005	<0.005	<0.001	<0.001	473	<0.001		0.011	0.010	<0.001	<0.001	9.2	<0.0002		0.008	0.007	0.006	0.005		<0.001	<0.050	<0.050
March 2006 Avg's		CDM	5.0	2485	1268	7.37		<4					24.2	<0.005	<0.005	<0.001	0.001	490	0.001		0.013	0.013	<0.001	<0.001	10.9	<0.0002		0.011	0.011	0.008	0.007		<0.001	<0.050	<0.050
April 2006																																			
4/4/2006	13:00	CDM	8.8	1870	921	7.53		<4					19.6	<0.005	<0.005	<0.001	<0.001	351	<0.001		0.024	0.010	<0.001	<0.001	10.9	<0.0002		0.007	0.006	0.006	0.006		<0.001	<0.050	<0.050
4/10/2006	tba	CDM	10.5	1660	769	7.68		<4					12.9	<0.005	<0.005	<0.001	<0.001	286	<0.001		0.009	0.008	<0.001	<0.001	13.4	<0.0002		<0.005	<0.005	<0.005	<0.005		<0.001	<0.050	<0.050
4/17/2006	11:28	CDM	11.9	1740	1020	7.66		<4					12.3	<0.005	<0.005	<0.001	<0.001	329	<0.001		0.006	0.007	<0.001	<0.001	48.5	<0.0002		0.005	0.006	<0.005	<0.005		<0.001	<0.050	<0.050
4/24/2006	9:40	CDM	6.5	1360	628	7.61		<4					7.98	<0.005	<0.005	<0.001	<0.001	241	<0.001		0.006	0.006	<0.001	<0.001	6.5	<0.0002		0.007	0.006	<0.005	<0.005		<0.001	<0.050	<0.050
April 2006 Avg's		CDM	9.4	1658	835	7.62		<4					13.2	<0.005	<0.005	<0.001	<0.001	302	<0.001		0.011	0.008	<0.001	<0.001	19.8	<0.0002		0.006	0.006	0.006	0.006		<0.001	<0.050	<0.050
May 2006																																			
5/1/2006	12:00	CDM	10.0	1650	803	7.82		<4					6.78	<0.005	<0.005	<0.001	<0.001	312	<0.001		0.006	0.005	<0.001	<0.001	5.9	<0.0002		0.007	0.007	<0.005	<0.005		<0.001	<0.050	<0.050
5/8/2006	9:21	CDM	10.9	1930	989	7.41		5.2					12.1	<0.005	<0.005	<0.001	<0.001	379	<0.001		0.007	0.006	<0.001	<0.001	10.3	<0.0002		0.010	0.010	0.006	0.006		<0.001	<0.050	<0.050
5/15/2006	9:45	CDM	11.9	1900	971	7.50		<4					11.6	<0.005	<0.005	<0.001	<0.001	372	<0.001		0.005	0.005	<0.001	<0.001	10.2	<0.0002		0.013	0.012	0.006	0.005		<0.001	<0.050	<0.050
5/22/2006	9:10	CDM	19.0	2050	1150	7.56		<4					11.9	<0.005	<0.005	<0.001	<0.001	445	<0.001		0.007	0.006	<0.001	<0.001	8.3	<0.0002		0.015	0.014	0.006	0.005		<0.001	<0.050	<0.050
5/30/2006	9:45	CDM	18.5	2200	1230	7.57		<4					11.8	<0.005	<0.005	<0.001	<0.001	476	<0.001		0.005	0.005	<0.001	<0.001	9.9	<0.0002		0.013	0.013	0.007	0.006		<0.001	<0.050	<0.050
May 2006 Avg's		CDM	14.1	1946	1029	7.57		<5					10.8	<0.005	<0.005	<0.001	<0.001	397	<0.001		0.006	0.005	<0.001	<0.001	8.9	<0.0002		0.012	0.011	0.006	0.006		<0.001	<0.050	<0.050
June 2006																																			
6/5/2006	11:10	CDM	22.0	2220	1230	7.50		<10					11.5	<0.005	<0.005	0.001	0.001	478	<0.001		0.008	0.007	<0.001	<0.001	9.8	<0.0002		0.015	0.015	0.007	0.006		<0.001	<0.050	<0.050
6/12/2006	8:45	CDM	21.0	2470	1310	7.63		<4					11.0	<0.005	<0.005	<0.001	<0.001	510	0.002		0.006	0.005	<0.001	<0.001	9.4	<0.0002		0.016	0.015	0.007	0.007		<0.001	<0.050	<0.050
6/19/2006	9:05	CDM	24.0	2330	1190	7.93		13.6 *	not offsite discharge				9.1	<0.005	<0.005	<0.001	<0.001	461	0.002		0.009	0.008	<0.001	<0.001	8.9	<0.0002		0.015	0.016	0.005	0.005		<0.001	<0.050	<0.050
6/26/2006	9:15	CDM	25.0	2360	1270	7.95		9.2					9.4	<0.005	<0.005	0.001	<0.001	497	0.003		0.132	0.012	<0.001	<0.001	7.7	<0.0002		0.013	0.013	0.005	0.005		<0.001	<0.050	<0.050
June 2006 Avg's		CDM	23.0	2345	1250	7.75		<10					10.3	<0.005	<0.005	<0.001	<0.001	487	0.002		0.039	0.008	<0.001	<0.001	8.9	<0.0002		0.015	0.015	0.006	0.006		<0.001	<0.050	<0.050
July 2006																																			
7/5/2006	9:15	CDM	20.0	2500	1340	7.86		<4					9.6	<0.005	<0.005	<0.001	<0.001	527	0.003		0.007	0.006	<0.001	<0.001	5.2	<0.0002		0.006	0.012	0.005	0.006		<0.001	<0.050	<0.050
7/10/2006	9:25	CDM	25.0	2450	1300	7.90		<4					9.3	<0.005	<0.005	<0.001	<0.001	510	0.001		0.006	0.006	<0.001	<0.001	5.9	<0.0002		0.014	0.014	0.006	0.006		<0.001	<0.050	<0.050
7/17/2006	9:55	CDM	22.2	2430	1330	7.78		<4					9.6	<0.005	<0.005	<0.001	<0.001	525	0.001		0.007	0.007	<0.001	<0.001	5.6	<0.0002		0.012	0.012	0.005	0.005		<0.001	<0.050	<0.050
7/24/2006	7:55	CDM	22.3	2440	1350	7.95		<4					10.2	<0.005	<0.005	<0.001	<0.001	529	0.002		0.006	0.006	<0.001	<0.001	7.1	<0.0002		0.016	0.016	0.007	0.005		<0.001	<0.050	<0.050
July 2006 Avg's		CDM	22.4	2455	1330	7.87		<4					9.7	<0.005	<0.005	<0.001	<0.001	523	0.002		0.007	0.006	<0.001	<0.001	6.0	<0.0002		0.012	0.014	0.006	0.006		<0.001	<0.050	<0.050
August 2006																																			
8/1/2006	9:00	CDM	20.7	2450	1400	7.70		<4					9.5	<0.005	<0.005	<0.001	<0.001	553	0.001		0.006	0.005	<0.001	<0.001	5.4	<0.0002		0.013	0.013	0.005	0.005		<0.001	<0.050	<0.050
8/7/2006	8:50	CDM	22.0	2530	1250	8.32		<4					9.8	<0.005	<0.005	<0.001	<0.001	483	0.001		0.007	0.006	<0.001	<0.001	9.6	<0.0002		0.013	0.013	0.005	0.005		<0.001	<0.050	<0.050

From CDM via email, 9/06

Appendix B

DVD of Gilt Edge Database