Draft
Remedial Investigation Report

Red Devil Mine, Alaska

March 2012

Prepared for:

U.S. DEPARTMENT OF INTERIOR
BUREAU OF LAND MANAGEMENT
Anchorage Field Office
4700 BLM Road
Anchorage, Alaska 99507

Prepared by:

ecology and environment, inc.
Global Environmental Specialists

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Executive Summary

The executive summary will be provided following agency review.

Table of Contents

Section **Page**

List of Tables

List of Figures

Figure **Page**

List of Abbreviations and Acronyms

AAC	Alaska Administrative Code
ADEC	Alaska Department of Environmental Conservation
As_2S_3	arsenic sulfide (orpiment)
As_4S_4	arsenic sulfide(realgar)
AST	aboveground storage tanks
bgs	below ground surface
BLM	Bureau of Land Management
BOM	United States Bureau of Mines
BTEX	benzene toluene, ethylbenzene, xylenes
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
Cfs	cubic feet per seconds
CIS	Community Information Summaries
Cm	centimeters
COPC	contaminant of potential concern
DOI	Department of the Interior
DQO	Data Quality Objective
DRO	diesel range organics
E & E	Ecology and Environment, Inc.,
EPA	U.S. Environmental Protection Agency
ERA	ecological risk assessment
ERS	Alaska Energy Recovery Services, Inc.
FS	Feasibility Study
FSP	Field Sampling Plan
GPS	global positioning system
GRO	gasoline range organics
Hg3S2Cl2	corderoite
HgS	mercury sulfide(cinnabar)
HgSO4-H20	schuetteite
HHRA	health risk assessment
HLA	Harding Lawson Associates
IDW	Investigation-Derived Waste
L/min	liters per minute
LSE	Limited Sampling Event
m	meters
MACTEC	MACTEC Engineering and Consulting
MCL	Maximum Contaminant Level
mg/kg	milligrams per kilogram
m-HgS	metacinnabar
mm	millimeters
NAD	North American Datum
ND	nondetected values

ng/g	nanograms per gram
PCB	polychlorinated biphenyl
ppm	parts per million
QA	Quality Assurance
QC	Quality Control
RCRA	Resource Conservation and Recovery Act
RDM	Red Devil Mine
redox	reduction/oxidation
RI	Remedial Investigation
ROS	regression on order statistics
RRO	residual range organics
Sb_2S_3	antimony sulfide (stibnite)
Sb_2S_3	antimonysulfide
SI	site inspection
SPLP	synthetic precipitation leaching procedure
SSE	selective sequential extraction
SVOC	semi-volatile organic compounds
TAL	target analyte list
TCLP	toxicity characteristic leaching procedure
TDS	total dissolved solids
TOC	total organic carbon
TSS	total suspended solids
UPL	upper prediction limit
USGS	U.S. Geological Survey
UST	underground storage tank
Wilder	Wilder Construction Company
Work Plan	Red Devil Mine Remedial Investigation/Feasibility Study Work Plan
XRF	x-ray fluorescence
µg/kg	micrograms per kilogram
µg/L	micrograms per liter

1 Introduction

This Remedial Investigation Report addresses contamination at the Red Devil Mine (RDM) site. This report represents one of the major deliverables produced for the Remedial Investigation (RI)/Feasibility Study (FS) of the RDM site.

The RDM consists of an abandoned mercury mine and ore processing facility located on public lands managed by the Department of the Interior (DOI) Bureau of Land Management (BLM) in the state of Alaska (see Figure 1-1). Historical mining activities at the site included underground and surface mining. Ore processing included crushing, retorting/furnacing, milling, and flotation. Ecology and Environment, Inc., (E & E) has prepared this RI Report on behalf of the BLM under Delivery Order Number L09PD02160 and General Services Administration Contract Number GS-10F-0160J.

The BLM is performing this work pursuant to its delegated Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) lead-agency authority. Therefore, the RI/FS follows applicable CERCLA guidance. In addition, the regulations for contaminated site cleanup promulgated by the State of Alaska provide a framework for the RDM RI/FS process.

1.1 Purpose and Objectives

The purpose of the RI is to present the RI/FS activities, procedures, and results of field investigations to characterize areas of known environmental contamination and additional areas of potential contamination at the site. The objectives of the RI/FS are to:

- Characterize the nature and extent of environmental contamination released from the site.
- Assess the magnitude of potential human health and ecological risks from site-related contaminants.
- Evaluate potential remedial alternatives to reduce or eliminate human health and ecological risks posed by site contamination. This evaluation will be presented in the FS Report under separate cover.

1.2 Definition of the Site

For this RI/FS, the RDM site is defined as the area where mining operations were conducted, where mine-related waste sources exist, and where mine-related contamination of media (soil, surface water, sediment, groundwater) is known to exist or potentially exist. Accordingly, the site includes the following general areas:

- The Main Processing Area.
- Red Devil Creek, extending from a reservoir south of the site to the creek's delta at its confluence with the Kuskokwim River.
- The underground mine workings.
- The area west of the main mine processing area where historical surface exploration and mining occurred, including the "Dolly Sluice" area and its related delta on the bank of the Kuskokwim River, and the Rice Series area and associated areas of trenching.

Figure 1-2 illustrates the site area and the major features identified above based on an aerial photograph taken in 2001 (Aero-Metric, Inc. 2001).

The Main Processing Area contains most of the former site structures and is where ore beneficiation and mineral processing were conducted. The area is split by Red Devil Creek. Underground mine openings (shafts and adits) and ore processing and mine support facilities (housing, warehousing, and so forth) were located on the west side of Red Devil Creek until 1955. After 1955, all ore processing was conducted at structures and facilities on the east side of Red Devil Creek. The Main Processing Area includes three monofills. The monofills are essentially landfills that contain demolished mine structure debris and other material. Two monofills are unlined (Monofills #1 and #3). Monofill #2, on the east side of Red Devil Creek, is an engineered and lined containment structure for building debris and materials from the demolished Post-1955 Retort structure. The east side of Red Devil Creek is also the former location of petroleum aboveground storage tanks (ASTs), which were used to store fuel for site operations; however, the AST area itself is not included in the RI (see Section 1.4.2.4). The AST area is the subject of a separate investigation (Marsh Creek 2010).

Figure 1-3 illustrates the main historical and current features in the Main Processing Area. Underground and surface mining operations and ore beneficiation and mineral processing are discussed further in Section 1.4.2.

1.3 Document Organization

The RI Report is organized into the following chapters:

- **Chapter 1, Introduction –** Describes the purpose and objectives of the RI/FS; defines the site; describes the project location and regional setting, the operational history of the RDM, the site's environmental setting, previous investigations of the RDM, and previous removal and cleanup actions at the site; and provides a summary of the Data Quality Objectives (DQOs) presented in the Final RI/FS Work Plan.
- **Chapter 2, Study Area Investigations –** Describes the timing, methods, and locations of the RI field investigations and includes summaries of environmental samples collected and their analytical requirements.

- **Chapter 3, Physical Characteristics of the Study Area –** Summarizes the results of field investigations intended to characterize physical components of the media of interest at the site.
- **Chapter 4, Nature and Extent of Contamination –** Summarizes the results of field investigations intended to characterize the presence, nature, and extent of chemical contamination in media of interest at the site.
- **Chapter 5, Contaminant Fate and Transport –** Describes the routes and mechanisms of contaminant migration at and from the site, the environmental fate of site contaminants based on data and information obtained during the RI field investigations, and summarizes the major contaminant transport pathways.
- **Chapter 6, Baseline Risk Assessment –** Presents quantitative cancer and non-cancer human health risks, and ecological risks posed by the site based on data collected during the RI field investigations and other investigations at the site.
- **Chapter 7, Summary and Conclusions –** Summarizes the results of the RI field investigations and risk assessment and provides preliminary recommendations for remedial action objectives for the site.
- **Chapter 8, References –** Lists the guidance documents and literature resources cited in this document.
- **Appendices**
  - **A** Soil Types
  - **B** Data Validation Reports
  - **C** Summary of Surface Soil, Subsurface Soil, and Groundwater Data

1.4 Site Background

1.4.1 Project Location and Regional Setting

The RDM site is approximately 250 air miles west and 1,500 marine/river barge miles from Anchorage, Alaska (see Figure 1-1). Located on the southwest bank of the Kuskokwim River approximately 2 miles southeast of the village of Red Devil, the site is 75 air miles northeast of Aniak.

The legal description for the RDM site is Township 19 North, Range 44 West, Southeast Quarter of Section 6, Sleetmute D-4 Quadrangle, Seward Meridian. The RDM site's approximate coordinates are 61° 45' 38.1" north latitude and 157° 18' 42.7" west longitude (North American Datum [NAD] 27).

The RDM site is in a remote location with no road or rail connection to any community. The site is accessed by boat or barge on the Kuskokwim River or by means of an airstrip at the nearby village of Red Devil.

1.4.2 Operational History

This section summarizes available information on the history of the RDM. Existing historical documents do not provide complete clarity on ownership and other topics related to the mine's history. The ore minerals at the RDM consisted of cinnabar (mercury sulfide [HgS])—the primary mercury ore mineral—and stibnite (antimony sulfide [Sb_2S_3]). Some realgar (arsenic sulfide [As_4S_4]), orpiment (arsenic sulfide [As_2S_3]), and secondary antimony minerals were locally associated with these ore minerals.

1.4.2.1 Mining Operations


Cinnabar from Red Devil Mine

In 1933, Hans Halverson discovered mercury ore in Red Devil Creek and staked the original claim for the RDM. By 1939, there were four claims, Red Devil numbers 1 through 4 (Roehm 1939). Ore was obtained from creek float (sediment) and overburden (Webber et al. 1947).

In 1941 and 1942, the operators sluiced the overburden from the southeast extremity of the ore zone, as then delineated, leaving a considerable depth of bedrock rubble. Ore from this loose material yielded much of the early production. Surface exploration by the United States Bureau of Mines (BOM) in 1942 consisted of more than 2,000 feet of bulldozer and hand trenching (Wright and Rutledge 1947).

In 1941, underground mine workings consisted of two adits and a shaft. The first adit, reported to be at an elevation of 311 feet above sea level, is referred to in this document as the 311 Adit. A second adit was started approximately 70 feet north of the portal of the 311 Adit and at a reported elevation of 325 feet. This second adit is referred to as the 325 Adit in this document. The main shaft, located approximately 55 feet southeast of the 311 Adit portal, was sunk to a depth of 30 feet on a 59-degree incline (Wright and Rutledge 1947).

In 1941, Harold Schmidt and L.J. Stampe secured a lease on the claims. The New Idria Quicksilver Mining Company entered into a sublease agreement with Schmidt and Stampe. The New Idria-Alaska Quicksilver Mining Company was formed and installed new thermal processing equipment for mercury, including a 40-ton rotary kiln (Wright and Rutledge 1947). Production as of June 30, 1944, amounted to 1,096 flasks of mercury recovered from 2,652 tons of ore. Most of the ore was recovered from stopes above the 325 Adit and the 276-foot level (Wright and Rutledge 1947). Ore processing during this time and subsequent operations is discussed in Section 1.4.2.2.

The price of mercury fell in 1944 and the New Idria Quicksilver Mining Company shut down mining operations and subsequently subleased its interest in the mine to the Kuskokwim Mining Company. The Kuskokwim Mining Company operated the mine for two seasons in 1945 and 1946 (Webber et al. 1947). In 1946, the price of mercury fell again and the Kuskokwim Mining Company shut down its operation. Harold Schmidt and C. J. Stampe bought out the New Idria Quicksilver Mining Company lease, including all the mining equipment. Robert Lyman also held a lease on the mine in 1946 and produced 491 flasks of mercury, although Mr. Lyman’s relationship to the other owners at this time is unclear (MACTEC 2005).

As of 1947, the ore recovered was reported to be soft and friable and to break free from the walls. The country rock was reported to be weak and to require close spacing of stulls for support of stope walls and drifts. All ore was mined from stulled stopes. Broken ore was trammed to the shaft on the 276-foot and 236-foot levels and to the storage bin on the 375-foot level. As of 1947, power for the reduction plant and mine was generated by two Caterpillar 46-30 diesel-electric units. Water was pumped from the mine at the rate of 100 gallons per minute with a 2-inch centrifugal pump (Wright and Rutledge 1947).

Between 1947 and 1951 the mine was not in operation (MACTEC 2005). In 1952, the DeCoursey Mountain Mining Company leased the mine. Various organizational changes in the operating companies occurred subsequently. As of 1962, the operating unit was called Alaska Mines and Minerals, Inc.

In 1952, DeCoursey Mountain Mining Company dewatered the mine workings and resumed production. In October 1954, a fire destroyed a large portion of the mine surface structures and equipment. The Pre-1955 Retort and the Pre-1955 Rotary Furnace facilities were rendered unusable by the fire. Some of the mine camp buildings were also damaged by the fire, but it is unknown if they were destroyed or repaired (Malone 1962).

Following the 1954 fire, DeCoursey Mountain Mining Company rebuilt a modern plant, including an airfield, a camp with bunkhouses, a commissary, a mess hall, offices, shops, warehouses, a diesel electric power station, and a modern furnace (Malone 1962). Extensive surface exploration and mining took place at the mine some time after 1956. The reservoir was created after 1956 by constructing an earthen dam across Red Devil Creek. Aerial images indicate that soils from the hillsides adjacent to the reservoir dam were scraped and used for dam material. The reservoir may have been constructed to provide a source of water for the hydraulic sluicing operations such as those conducted at the Dolly Sluice Area, where loose overburden was washed through a sluice to recover ore. The waste material from the sluice operation was washed down a gully toward the Kuskokwim River. This resulted in the formation of the Dolly Sluice delta on the Kuskokwim River at the base of the gully (MacKevett and Berg 1963).

As of 1963, the underground workings consisted of approximately 9,600 feet of shafts, adits, crosscuts, drifts, raises, and winzes, with workings on five levels. As indicated above, the underground mine workings began with the 311 Adit and 325 Adit. Later, the Red Devil inclined shaft (referred to in this document as the main shaft) was sunk with stations at the 33, 73, 150, 300, and 450 levels. The Dolly shaft was connected with the main shaft on the 300 level (Malone 1962). Other mine openings documented as of 1963 are the “F” Zone shaft and a caved shaft located northwest of the main shaft.

In a description of mine operations as of 1962, ore shoots were characterized as extremely short in strike length but locally persisting along the plunge for several hundred feet. Strike lengths ranged from 6 to 30 feet and vein widths from 3 to 10 inches. The ore shoots plunge at an average of 39 degrees. The combination of short strike length, narrow width, and low-angle plunge resulted in high mining costs. After a level had been opened for mining, raises were driven on the ore shoots. Stoping proceeded from the top down; the stope width was controlled by the closest convenient hanging wall that would stand until it could be supported. Stope widths ranged from 3 to 6 feet. Stulls and headboards were used for support. Muck from the stopes would not run by gravity, and the relatively small tonnage from a stope did not warrant installing slusher setups. Hence, mucking to the level was accomplished by hand, assisted with water run in from above. Where ore could not be moved economically by raises, slusher crosscuts were used to transfer muck to shafts, winzes, or ore passes. The scraper dumped directly into skips or into ore passes to the haulage level. Drifts and crosscuts were 5 by 7 feet in the clear (Malone 1962).

A large part of the 200 level and most of the shallower workings were driven during the early period of mining, and the rest of the workings present as of 1962 were excavated after 1953. The most extensive workings were near the main shaft, the portal and main shaft headworks of which were located in the vicinity of what have been referred to in previous investigations as Shop Pad A and Shop Pad B, respectively. Five main levels connect with the main shaft. The Dolly series of ore bodies was discovered in 1957. By 1963, underground workings in the vicinity of the Dolly shaft had been extensively developed and the surface had been mined by sluicing.

As of 1962, the Rice series of ore bodies had been explored by shallow trenches and pits (MacKevett and Berg 1963) and was being explored by a shaft sunk along the plunge of the strongest surface showing of ore revealed by the surface exploration, with a shaft sunk to 84 feet deep on the plunge of the shoot (Malone 1962).

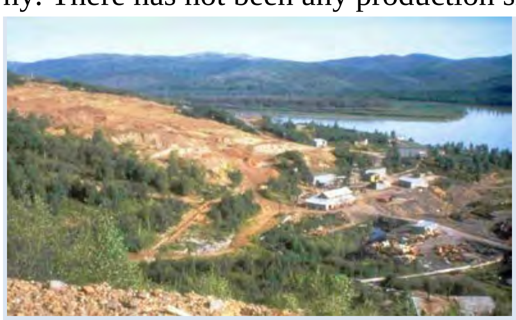
The approximate locations of underground workings and associated mine openings as of 1962 are illustrated in Figure 1-4. As of 1963, many of the older shallow workings were caved and inaccessible (MacKevett and Berg 1963). It should be noted that nomenclature of the underground workings varies depending upon the report, potentially resulting in confusion as to the identification and depth of several mine levels. For example, Wright and Rutledge (1947) and Webber et al. (1947) refer to adits driven at the 311-foot level and 325-foot levels and report that these adits were driven at 311 and 325 feet above sea level, respectively. These two adits are referred to in one subsequent report as the 311 Adit and 325 Adit (MacKevett and Berg 1963) and in another report as the 1311 Adit and 1325 Adit (Malone 1962). Furthermore, several levels referred to in earlier reports, such as the 236-foot level and 276-foot level, are not reported in subsequent reports (e.g., MacKevett and Berg 1963 and Malone 1962), likely because the levels were assigned different identifiers at later stages of mine development. The underground mine workings as presented in Figure 1-4 represent a combination of information presented in Malone (1962) and MacKevett and Berg (1963). Mine openings documented as of 1962 are:

- 311 Adit.
- 325 Adit.
- Main Shaft.
- “F” Zone Shaft.
- Caved shaft located southeast of the “F” Zone Shaft.
- Dolly Shaft.
- Rice Shaft.
- Two stopes that reached the surface from the 325 Adit level approximately 300 feet northwest of the 325 Adit portal.
- Two stopes that reached the surface from the 503 Crosscut (“D-3” and “D-4” Stopes) and one stope that reached the surface from the 507 Crosscut southeast of the Dolly Shaft.

In 1963, a new adit was reportedly driven on the “left limit of Red Devil Creek gulch an estimated 100 feet to mine a faulted ore-body segment in the vicinity of the mine shaft,” and 40 tons of high-grade ore were stockpiled from that effort (Jasper 1964). The specific location of this adit is not known. Production in 1963 and 1964 was minimal. The mine was subsequently shut down and allowed to flood, and equipment was removed from the site. The mine remained inactive until 1969.

In 1969, Alaska Mines and Minerals, Inc., resumed operations at the mine. Mining operations included open pit and underground mining (Buntzen and Miller 2004). Information on the location of the underground workings from this period is not available. Surface mining was conducted over a large area on the hillside west of the Main Processing Area by trenching, bulldozing, pit excavation, and, possibly, sluicing. The surface expression of these features is visible in aerial images dated 1974 and illustrated in Figure 1-5. Based on aerial photos dated 1953 and 1955 and a surficial geologic map (MacKevett and Berg 1963), most of the surface exploration and mining that had been conducted prior to 1974 lies within the footprint of the post-1969 surface mining activities.

Cinnabar and stibnite concentrates were produced after 1969 using flotation and were reportedly shipped to Japan. In addition, some mercury was also reported to be retorted at the mine. The flotation mill operated for most of 1970, and the mine closed in June 1971 due to a sharp drop in the price of both mercury and antimony. There has not been any production since that time (Buntzen and Miller 2004).



Red Devil Mine in 1971, including the area of surface mining and exploration on upper left.

On June 1, 1971, the mine owner, Alaska Mine and Minerals, Inc., ceased operations at the mine. Dewatering of the underground mine workings continued, with the intent that the disruption in mine operations would be temporary. In 1982, the mine was permanently closed and dewatering operations ceased (MACTEC 2005).

1.4.2.2 Ore Processing

Early production from the mine used a Johnson-McKay retort to process the ore (Webber et al. 1947). The location of early retorting operations is unknown.

Two “D” retorts were used to process ore beginning in 1940 (Webber et al. 1947); these retorts are assumed to have been constructed within the Pre-1955 Retort Building.

In 1941, the New Idria Quicksilver Mining Company installed a 40-ton rotary kiln (Wright and Rutledge 1947). In 1943, the New Idria-Alaska Quicksilver Mining Co. installed modern equipment for furnacing and retorting the Red Devil ore. The reduction plant was equipped with a 50-ton fine ore bin, a 12-ton burned ore bin, a 36-inch by 40-foot rotary kiln, Sirocco dust collectors, a fan, condensers, and redwood tanks. A jaw crusher reduced the ore to less than 2 inches (Webber et.al. 1947). Wood was used for furnace fuel from 1943 to 1946. In 1947, the furnace was equipped with a burner, and diesel oil was used thereafter (Wright and Rutledge 1947). It is assumed that this rotary kiln was installed in the structures labeled “Pre-1955 Rotary Furnace building” in Figure 1-3. The term “Pre-1955 Rotary Furnace” is retained for the purpose of this report to maintain consistency with previous reports.

The Pre-1955 Main Processing Area, showing headworks and support buildings. The post-1955 mill is in the background.

The 1954 fire destroyed several mine structures and processing facilities, including the Pre-1955 Retort and the Pre-1955 Rotary Furnace facilities. In 1956 a new processing facility and other plant facilities were built on the east side of Red Devil Creek. A modified Herreshoff furnace was installed (Malone 1962); the location of this newly installed furnace was the Post-1955 Retort building (MACTEC 2005). The thermal ore processing equipment installed in the Post-1955 Retort building is believed to consist of the Herreshoff furnace rather than a retort. The term “Post-1955 Retort” is retained for the purpose of this report to maintain consistency with previous reports. In 1955, five diesel ASTs were installed on a road northeast of the Post-1955 Retort building.

Some time after production resumed in 1969, a flotation mill was installed within an addition to the northern end of the Post-1955 Retort building to produce cinnabar and stibnite concentrates. A ball mill was used to mill the ore, and various chemicals, including “pine oil,” lead acetate, and Dowfroth 250, were used as flotation agents. Tailings from the flotation unit were sluiced from the flotation mill into the three settling ponds via a wooden chute (TNH 1987).

The Main Processing Area in 1969, showing the flotation mill added to the post-1955 mill building, and the settling ponds.

Processing of mercury ores at the RDM by thermal methods (in retorts, kilns, and furnaces) was greatly complicated by the close association of stibnite (antimony sulfide) with the cinnabar within the ore. The antimony content of RDM ores was many times that of the mercury content and averaged more than double the mercury content. Various remedies, most of them aimed at eliminating the stibnite before thermally processing the cinnabar, had been proposed over the course of mine operations (e.g., Webber et al. 1947, Wright and Rutledge 1947), but none had been considered sufficiently promising to justify installing special equipment as of 1962. The installation of the flotation mill in 1969 was likely intended to eliminate the problems encountered over the previous decades of thermal ore processing (Webber et al. 1947, Wright and Rutledge 1947, Malone 1962).

The operational difficulties encountered as a result of furnacing mixed stibnite and cinnabar ores are summarized below based on a description by Malone (1962).

Like cinnabar, stibnite breaks down at a relatively low temperature. Its rate of reaction is similar to that of cinnabar within the operational temperature range of furnacing practices. There are, however, two differences in the way stibnite and cinnabar react during thermal treatment. First, unlike cinnabar, which transitions directly from solid to gaseous phase, stibnite passes through a liquid state. Second, the newly liberated antimony combines with oxygen to form oxides of antimony, particularly antimony trioxide, within the temperature range of mercury furnacing. These differences allowed some separation of the mercury from stibnite ore during the furnacing operations. However, in practice at the RDM, such separation was limited (Malone 1962).

Burning of stibnite in the furnaces caused problems throughout the process. Antimony oxides would be transported by the furnace gas flow and rabble arms, "slagging" with the dust and adhering to the inside of the furnace. The burner blocks and drop holes required frequent cleaning to keep them from plugging with antimony glass, and periodic shutdowns were required to clean the entire inside of the furnace. A portion of the antimony oxide passed into the condensing system with the mercury-laden gases through a cyclone dust collector. A cyclone was ineffective at separating most of the antimony oxide materials due to the small particle size. For the same reason, a cyclone also was ineffective at separating arsenic trioxide, which resulted from furnacing of the arsenic sulfides that also were associated with the cinnabar ore. Within the furnace, the arsenic fumes were mostly vapor. The antimony and arsenic oxides in the cyclone and associated ducts resulted in coating of the surfaces, requiring daily blowing with compressed air and hammering with a rubber mallet to keep these components clean (Malone 1962).

When the furnace gases bearing antimony oxide and arsenic oxide reached the condensers, some of the oxides fell out as a result of the reduced gas flow velocity. Much of the oxide was so finely divided that it never settled, and it passed through the condenser and out the stack. Some of the oxides, however, settled into the launders, where the recovered mercury also accumulated, thus diluting the condenser mud, also commonly referred to as soot. This made the process of removing the mercury from the soot much more difficult than at most other mercury mines at that time. At most mines, up to 80 percent free mercury was recovered from the soot by simply settling and pouring off the mercury from under the soot, with the remainder dumped on an inclined metal hoe table and worked over by hand. At the RDM, the soot showed no visible mercury, and free metal did not separate from the mud without treatment. At the RDM, the soot was worked both wet and dry by hoeing, paddling, pushing, agitating, stirring, scraping, vibrating, rolling, pressing, raking, and jigging, with or without various additives (Malone 1962).

At times during the mine's operations, the impoverished soot from the hoeing table was returned to the furnace. This resulted in considerable recycling of the antimony and arsenic oxides and the coating issues discussed above. Retorting the worked-over soot was found to be not only unsatisfactory but expensive and hazardous because, unless a large amount of lime was added to the soot before retorting, the charge fused into an antimonial-arsenical glass, which boiled and frothed in the retort, resulting in molten oxide glass sticking to the retort charging pans as well as condensing of the oxides in the head of the retort and in the condenser pipes, thus sealing them (Malone 1962).

The practice of hoeing the mud/soot in a mechanical hoeing machine with quicklime was used at the RDM until late 1959. In November 1959, equipment was installed to treat the condenser mud by a wet method, in which mercury was separated from the mud by (1) agitating and aerating the heated mud and (2) centrifuging with a wet cyclone. This process resulted in a residual mercury content of less than 2 percent, and treatment time was reduced to about 5 percent of that formerly needed with the hoeing machine. As of 1962, the tailings were dried and fluxed with lime for refurnacing (Malone 1962).

The processes and operational difficulties summarized above based on Malone (1962) pertain to the Herreshoff furnace. Similar operational difficulties were described for the rotary kiln (Webber et al. 1947; Wright and Rutledge 1947).

1.4.2.3 Mining and Ore Processing Wastes

Wastes generated during the mine operations consisted primarily of waste rock and tailings. These and other mining and mineral processing wastes at the RDM are discussed further below.

Dozed and Sluiced Overburden

Surface mining operations entailed dozing and sluicing of overburden soils, trenching, and open pit mining. Much of the early exploration at the mine was performed by trenching, resulting in trenches and associated spoils piles. During early mine operations, overburden on the southeast-facing slope above Red Devil Creek was sluiced downhill, with some of the sluiced overburden likely washing into Red Devil Creek and downstream to the Kuskokwim River. During the later surface mining activities, overburden was locally bulldozed into overburden dumps northwest of the Main Processing Area. Overburden also was sluiced from the Dolly and Rice ore zone areas via bermed and naturally developed gullies down to the Kuskokwim River. Sluiced overburden was deposited in fans, or deltas, along the Kuskokwim River shoreline, referred to herein as the Dolly Sluice delta and Rice Sluice delta. These features are illustrated in Figure 1-5.

Waste Rock

Waste rock included sub-ore grade material generated during underground and surface mining activities. The disposal of the all of the waste rock generated during underground mining activities is not documented, but can be inferred from historical reports and photographs. Based on a 1941 photograph (Cady 1941a), at least some waste rock generated was disposed of in dumps near the 311 Adit and 325 Adit portals. At least some of the waste rock was likely deposited in the Red Devil Creek drainage. Based on a 1941 photograph (Cady 1941b), at least some waste rock generated at that time was disposed of in a dump northeast of the 311 Adit portal. By 1943, the Main Shaft had been installed. A 1943 photograph shows a waste rock dump immediately east of the Main Shaft headworks (Cady 1943). That dump sloped down to the Red Devil Creek drainage. A 1963 geologic map (MacKevett and Berg 1963) shows a large dump, labeled “Saw dust dump” between the Main Shaft and Red Devil Creek.

As of 1962, ore processing was conducted on the Post-1955 Main Processing Area. Segregation of ore and waste rock was likely conducted at the Post-1955 furnace area prior to thermally processing the ore. Coarse ore material was reportedly passed over a 1.5-inch screen. The ore material that passed through the screen was conveyed to the furnace. The material retained by the screen was passed over a sorting table to segregate the material to be furnaced from waste. The waste rock was conveyed via a 24-inch by 20-foot conveyor to a dump (Malone 1962). The location of the dump is not specified, but was likely in the vicinity of the Post-1955 furnace area.

Tailings

Tailings consisted of thermally processed ore, also variously referred to as calcines, burnt ore, and retorted ore. Such tailings resulted from the thermal treatment processes (retorting and furnacing) that were employed over the history of the site. Historical aerial images and historical documents indicate that over much of the history of mining and ore processing at the site, tailings were sluiced or bulldozed into the channel of Red Devil Creek from the ore processing areas and dozed into dumps. Tailings also were used for road ballast or surfacing material (Malone 1962).

A 1941 photograph illustrates the Pre-1955 Retort building and apparent tailings and/or waste rock deposited east of the retort building (Cady 1941c). This tailings/waste rock pile is evident in subsequent photographs and maps (Cady et al. 1955; MacKevett and Berg 1963).

A geologic map illustrating underground mine workings and surface features, including ore processing buildings, indicates the presence of a "Burnt Ore Disposal Tunnel" that apparently discharged calcines from the Pre-1955 Furnace building to the Red Devil Creek drainage (Cady et al. 1955).

As of 1962, disposal of calcines generated at furnace at the Post-1955 Retort building was accomplished by sluicing and bulldozing. A 7-inch by 10-inch sluicebox, at a slope of 2 inches per foot, extended from under the burned-ore bin to a waste dump 100 feet away. From there, the calcines were reportedly bulldozed away every second day. A 1963 geologic map (MacKevett and Berg 1963) shows an area labeled "Tailings" between the Post-1955 furnace and Red Devil Creek. When road surfacing material was needed, it was sometimes loaded directly into a truck spotted under the sluiceway (Malone 1962). Information on the location of placement of the calcines for road-surfacing is not available.

The tailings are likely mixed with waste rock locally in both the Pre-1955 and Post-1955 Processing Areas.

Flotation Tailings

From 1969 through 1971, a flotation mill was operated at the site to process ore into cinnabar and stibnite concentrates for shipment to Japan. The resulting flotation tailings consist of the fraction of milled ore remaining after selected ore minerals are separated from the bulk ore slurry using water and flotation agents. These flotation tailings were discharged into the settling ponds north of the Post-1955 Retort building area. Various flotation agents, including pine oil and Dowfroth 250 (frothers and flotation agents), lead acetate (activator for stibnite), and other chemicals may have been used as part of the flotation process (BLM 2009). Although these materials were likely recycled to some extent, some quantities of the flotation agents potentially were discharged to the settling ponds.


Overview of the Main Processing Area in 1969 or 1970 from the southeast.

Other Mine Wastes

Other wastes generated during mining operations include the dust and oxide glasses generated during the furnacing operations, as discussed in Section 1.4.2.2. Dust generated from the cyclone-dust bin was reportedly discharged with the aid of several water jets and discharged to the tailing sluicebox (Malone 1962).

Based on review of historical and recent aerial photographs, land-based photographs, and records of mine operations summarized above, the general locations where mining and ore processing wastes were disposed of at the site during mine operations have been approximated, as illustrated in Figure 1-6.

1.4.2.4 Petroleum-Related Wastes
As noted previously, thermal ore processing equipment, generators, and the on-site powerhouse were fueled with diesel stored in five ASTs located northeast of the Main Processing Area (see Figure 1-2).

The five ASTs had the following storage volumes:

- AST 1: 84,000 gallons
- AST 2: 52,000 gallons
- AST 3: 125,000 gallons
- AST 4: 52,000 gallons
- AST 5: 52,000 gallons

Petroleum contamination in subsurface soil was present at the AST area and was partially remediated in 2006, and further remediated in 2010 (March Creek 2010). The ASTs provided fuel for the Post-1955 Retort and the powerhouse, which was conveyed by a buried fuel line running along the AST access road. Petroleum contamination was encountered in subsurface soil along the pipeline route in 2006 (Wilder/URS 2007).

1.4.3 Environmental Setting

1.4.3.1 Climate
The RDM is located in the upper Kuskokwim River Basin and lies in a climatic transition between the continental zone of Alaska's interior and the maritime zone of the coastal regions. Average temperatures can vary from 7 to 65 degrees Fahrenheit. Annual snowfall averages 56 inches, with a total mean annual precipitation of 18.8 inches.

1.4.3.2 Geology
The RDM site is located within the central Kuskokwim region, which contains a mobile belt of mountain building and volcanic activity. The regional geology is dominated by a thick sequence of folded sedimentary rocks of Cretaceous age known as the Kuskokwim group (MacKevett and Berg 1963).

Lithologic Units
This Kuskokwim group generally contains a very thick sequence of interbedded sedimentary rocks consisting of graywacke and argillaceous rock. The graywacke beds, which commonly are 2 or 3 feet thick, range in thickness from half a foot to about 20 feet. The graywacke is a medium- or dark-gray rock that weathers brown and is fine grained and well indurated. Its fine-grained character makes macroscopic identification of its minerals and textures difficult. Descriptions of similar graywackes from throughout the central Kuskokwim region indicate that many of them contain a variety of detrital rock fragments. Microscopic examination reveals that the graywacke is poorly sorted and composed of subrounded to angular

lithic fragments and mineral grains ranging from less than 0.001 to 0.5 millimeters (mm) in average diameter. The larger and more abundant minerals consist of quartz, muscovite, pyrite, plagioclase, and calcite. These minerals and the lithic fragments, which were principally derived from slate, schist, and volcanic rocks, are surrounded by very fine-grained assemblages of quartz, calcite, plagioclase, muscovite, clay minerals, epidote, and chlorite. Calcite is the dominant cementing mineral, and it also forms veinlets (MacKevett and Berg 1963).


Kuskokwim group bedrock exposure.

The very fine-grained argillaceous rocks of the Kuskokwim group are dark gray or black and weather brown. Most of these rocks that are *exposed underground are argillites*, but some of their surface and near-surface counterparts are shales. Discrete argillaceous beds are commonly a few inches thick, but locally they have a cumulative thickness of 20 or 30 feet. Commonly, the argillaceous rocks are well indurated. Some of them are fissile, and many tend to fracture subconchoidally. The argillites are flecked with fine crystals of muscovite, the only megascopically visible mineral. The argillaceous rocks are similar to the graywackes in composition. A typical argillite from the RDM consists of subangular grains of quartz, epidote, muscovite, and pyrite that are less than 0.03 mm in average diameter, associated with clots and lamellar aggregates of very fine-grained clay minerals and mica (MacKevett and Berg 1963).

The Kuskokwim group sedimentary rocks are tightly folded and intruded by hydrothermally altered dikes composed of quartz basalt (MacKevett and Berg 1963). The dikes range from 1 foot to about 14 feet in thickness. The main dike at the RDM has a few plug-like and sill-like offshoots and a few small discontinuous branching dikes. In underground exposures, the dikes are light gray. At the surface the dikes are masked by pervasive hydrous iron oxides and are difficult to distinguish from similarly weathered graywacke. The dikes consist entirely of fine-grained and very fine-grained masses of calcite, chalcedony, limonite, and sericite, and subordinate amounts of quartz, hematite, and clay minerals. Small relict phenocrysts are largely replaced by calcite in a very fine-grained groundmass. A few veinlets composed of calcite and minor amounts of quartz cut the dikes. As of 1963, surface exposures of bedrock at the RDM were largely confined to road cuts, stripped areas, and trenches (MacKevett and Berg 1963).

The Kuskokwim group and dikes are locally overlain by surficial deposits of loess and alluvium that consist of fluvial deposits associated with the Kuskokwim River, Red Devil Creek, and slope wash (MacKevett and Berg 1963). The loess deposits are buff colored and friable, range from a few inches to about 30 feet in thickness, and commonly lack bedding. The fluvial deposits include gravel, sand, and silt that have been deposited on the flood plains of the Kuskokwim River. The oldest of these deposits is locally overlain by the loess, but most of the fluvial deposits postdate the loess. In some places, as much as 20 feet of the fluvial deposits are exposed. The loess commonly overlies rocky soil derived from weathering of the Kuskokwim group bedrock. Minor quantities of recently deposited alluvium, including slope wash, are exposed on the lower slopes of some of the hills, in the valley of Red Devil Creek and along the Kuskokwim River (MacKevett and Berg 1963).

Surficial geology as mapped by MacKevett and Berg (1963) is illustrated in Figure 1-7. It should be noted that much of the area shown in the geologic map overlay in Figure 1-7 west of the Main Processing Area has been modified by surface mining operations subsequent to the geologic mapping.

Structure

The RDM is located on the southwest limb of the Sleetmute anticline and contains multiple northeastward-trending faults that are cut by northwestward-trending faults that are exposed in some areas of the underground workings. The chronological sequence of structural events is as follows (MacKevett and Berg 1963):

a. Folding of the sedimentary rocks forming the Sleetmute anticline and the probable concurrent development of steep, northeastward-striking tensional joints.
b. Intrusion of dikes into a few of these joints.
c. Development of steep, northwestward-trending faults that offset the dikes right laterally.
d. Minor strike-slip movement of some of the northwestward-trending faults, caused by gravitational adjustments.

Ore and Mineralization

The RDM ore consists of discrete ore bodies localized along and near intersections between the northeastward-trending altered dikes and the many northwestward-trending faults. The ore bodies are crudely prismatic and range from a few inches to about 2 feet in thickness and from 1 foot to 30 feet in length along strike. Although some of the ore bodies diminish in size or pinch out with increasing depth, most of them continue to depths beyond the limits of exploration (as of 1962). The longest known ore bodies, of the Dolly series, extend from the surface at least to the 450 level (MacKevett and Berg 1963).

Some of the RDM ore is exceptionally high grade and contains as much as 30 percent mercury, but most of the ore contains between 2 and 5 percent mercury. Cinnabar, the primary mercury ore mineral, is associated with abundant stibnite; some realgar, orpiment, and secondary antimony minerals; and minor amounts of iron minerals, in a quartz, carbonate, and clay gangue. The stibnite is commonly more abundant than cinnabar (MacKevett and Berg 1963). The only sulfides found throughout the deposit at the RDM are stibnite and cinnabar; small amounts of orpiment and realgar are present locally. Rare, local pyrite films on joints are probably due to migration and redeposition of authigenic pyrite during ore deposition (Malone 1962).

The dominant process of ore formation was open-space filling, although some of the rich ore bodies were probably formed partly by replacement. Cinnabar and stibnite have locally replaced parts of the altered dikes. The high-grade ore typically consists of masses of intimately associated cinnabar and stibnite. Much of the ore consists of closely spaced intricate networks of veinlets, breccia cemented by vein minerals, and cinnabar-bearing incrustations. Some of the veinlets contain numerous vugs (MacKevett and Berg 1963).

1.4.3.3 Hydrogeology

Limited existing information is available about the hydrogeology within the RDM site. The information below is augmented with site-specific data and observations collected during the RI field investigations (see Section 3.2).

A bedrock aquifer is likely hydraulically connected to a shallow aquifer within surficial deposits at the site. Seven soil borings were drilled with the intent of installing monitoring wells during the August 2000 field work for the Red Devil Mine Retort Building Demolition and Limited Site Investigation. Groundwater was encountered in five of these soil borings at depths ranging from approximately 16 to 25 feet below ground surface (bgs); monitoring wells (MW-1, MW-3, MW-4, MW-6, and MW-7) were constructed in these boreholes. The groundwater in these wells was encountered within unconsolidated materials described as tailings and mixtures of gravel, sand, and silt (Wilder/HLA 2001). Available information on groundwater levels in the existing monitoring wells at the site includes water depth measurements on the following dates: August 14, 2000 (Wilder/HLA 2001); September 5, 2007; September 18, 2008; June 19, 2009; October 6 and 7, 2009; and September 20 and 21, 2010. For those monitoring events, measured depths to groundwater in these wells ranged from approximately 18 to 28 feet below ground surface. Seasonally, depth to groundwater varied by as much as 3.5 feet, with the highest recorded groundwater elevations occurring in June 2009 and the lowest recorded elevations occurring in October 2009 or August 2000.

Based on the groundwater elevation from the existing monitoring wells and an assumption that Red Devil Creek is a gaining stream in the vicinity of the site, it appears that the general direction of groundwater flow is toward Red Devil Creek locally, and the Kuskokwim River on a more regional scale, generally mimicking topography. Annual groundwater monitoring was conducted in September 2008. Groundwater elevations measured during this field event were similar to those observed during the August 2000 field event and appear to indicate groundwater flow in a generally north-northeast direction (Shannon and Wilson 2008).

A spring is located along the western bank of Red Devil Creek at the base of a bench comprising tailings/waste rock in the Main Processing Area. The underlying bank and stream bed is coated with “yellowboy,” an iron oxide flocculant associated with excess iron content. Yellowboy is commonly associated with acid mine drainage or acid rock drainage.

Groundwater may migrate through the mine workings. It is possible that groundwater within the mine workings may discharge from former mine openings and/or interconnected bedrock fractures through overlying surface soils, alluvium, or tailings. Such groundwater could discharge to surface waters. The spring along Red Devil Creek could represent localized preferential flow of groundwater originating from underground mine workings.

There is one private drinking water well within a 1-mile radius of the site; it is located at a cabin near the mouth of McCally Creek, approximately 0.6 miles from the mouth of Red Devil Creek. Construction details of this well are unknown. Nineteen private drinking water wells were installed in Red Devil Village in 2004 by the Alaska Village Safe Water Program. These wells range in depth from 28 feet to 172 feet bgs. Some of the wells have been sampled for class A drinking water analyses; however, the results of the samples are reportedly unavailable (Wilson, personal communication, 2010).

Permafrost does not appear to be present in the area of the mine (MacKevett and Berg 1963).

1.4.3.4 Surface Water Hydrology

Red Devil Creek is a tributary of the Kuskokwim River and has a basin of about 687 acres (Wilder/HLA 2001). Red Devil Creek feeds into the Kuskokwim River less than 1,000 feet from the main portion of the mine site. During the 1999 investigation, Red Devil Creek was reported to have a flow of 0.5 cubic feet per second (cfs); however, the flow rate varies significantly seasonally (Wilder/HLA 1999). The Kuskokwim River is generally ice-free from mid-June through October.

A spring is located along the western bank of Red Devil Creek in the Main Processing Area. This spring is discussed in Section 1.4.3.3.

The Kuskokwim River drains an area of approximately 130,000 square kilometers, and flows approximately 1,130 kilometers (700 miles) from interior Alaska to the Bering Sea. At the RDM site, the Kuskokwim River is more channelized than in up-river locations as it bisects the Kuskokwim Mountains. Flow in the river near the RDM site has been reported at 1,102 cubic meters per second (38,916 cfs). Sediment samples collected from the Kuskokwim River near the RDM site contained percent fines (<62 micrometers) ranging from 15 to 22 percent (USGS 1999).

1.4.3.5 Ecology

The vegetation around the RDM is characterized by spruce-poplar forests and upland spruce-hardwood forests. There are no known rare plants in the area of the mine site, but there is a lack of survey data for a complete evaluation. *Aphragrnus eschscholtzianus, Thlaspi arcticum,* and *Arnica lessingii ssp. norbergi,* all rare or sensitive plant species, are found in the region (Wilder/HLA 1999).

Fish found in the Kuskokwim River in the vicinity of the RDM include whitefish, grayling, sheefish, dolly varden, and Northern pike, as well as chinook, sockeye, coho, and chum salmon (Wilder/HLA 1999). Red Devil Creek was nominated for the Alaska anadromous waters catalogue by the BLM based on the observed presence of juvenile chinook and coho salmon in the creek in 2010. Moose, wolves, black bears, brown bears, lynx, martens, foxes, beavers, minks, muskrats, otters, and various small rodents are known to inhabit in the area.

The bird species that migrate through the area are olive-sided flycatcher, gray-cheeked thrush, Townsend's warbler, blackpoll warbler, and Hudsonian godwit (Wilder/HLA 1999). A raptor survey conducted on the Kuskokwim River in July 2000 found an active peregrine falcon nest 7 miles downstream of the RDM site (BLM 2001). Both the arctic peregrine falcon and American peregrine falcon are listed as Alaska species of special concern. However, no data could be found to indicate what kind of peregrine falcon was observed in 2000.

1.4.3.6 Demographics

The community of Red Devil is approximately 2 miles northwest of the RDM, and the community of Sleetmute is approximately 8 miles southeast of the RDM. Subsistence activities are practiced by many members of both communities. During their respective seasons, salmon, bear, moose, caribou, rabbit, and waterfowl are caught and wild berries are harvested (ADC 2010). The Kuskokwim River is used for transportation for both communities; boats are used in the summer and snow machines in the winter. The river is generally ice-free from mid-June through October. Both communities have gravel airstrips that planes can use out of year-round.

According to the Alaska Community Database Community Information Summaries (CIS), the population of Red Devil in 2008 was 48, and 52.1 percent of the population is either full or part Native Alaskan. The Native Alaskans identify either as Yup'ik Eskimos or as Tanaina Athabascans. The 2000 census shows that seven people in the village were employed and that the median household income was $10,938. In the village, 40.9 percent of individuals and 33.3 percent of families had incomes below the poverty level. One school serves six students in the community as of the 2010–2011 school year.

Sleetmute is a larger community than Red Devil and was founded by Ingalik Indians. Sleetmute remains an Ingalik Indian village, with 89 percent of the population identifying as Alaskan Native. According to the Alaska Community Database CIS, the population in 2008 was 70 people. The 2000 census found that 29 people in the community were employed and that 57.7 percent of the individuals in the community had incomes below the poverty level. One school serves all students in the community.

1.4.4 Previous Investigations

Regional studies, contaminant investigations, and sampling programs associated with cleanup activities have been conducted at and near the RDM over the past 40 years. The history of environmental sampling and monitoring at the RDM is described below. Table 1-1 provides a chronological summary. Refer to Figure 1-3 for the locations of features discussed in this section.

1971 EPA Study. While the flotation mill was operating, the U.S. Environmental Protection Agency (EPA) collected surface water samples for mercury and arsenic analyses. One background water sample from Red Devil Creek was collected above the mine and mill. It contained 0.3 micrograms per liter (µg/L) mercury. Arsenic and mercury concentrations in Settling Pond #1 contained 12,850 µg/L mercury and 85,000 µg/L arsenic. A water sample collected from Red Devil Creek below Settling Pond #1 contained 265 µg/L mercury and 39,000 µg/L arsenic. Two water samples were collected from the Kuskokwim River, one upstream of Red Devil Creek and one downstream, near the Red Devil Airstrip. The upstream sample contained 1.7 µg/L mercury and 56 µg/L arsenic, and the downstream sample contained 1.0 µg/L mercury and 32 µg/L arsenic (EPA 1971).

1979 EPA Study. The EPA collected five surface water samples and one sediment sample at the site. Two background sites were sampled; one water sample in Red Devil Creek from above the mine workings contained 0.21 µg/L mercury. Two water samples collected from Red Devil Creek below the settling ponds both reportedly contained 0.14 µg/L mercury. Two water samples were collected from the Kuskokwim River, one upstream of Red Devil Creek and one downstream. Mercury was detected in the upstream sample at 0.28 µg/L, and the downstream sample contained 0.14 µg/L mercury (EPA 1979).

1985 Alaska Department of Environmental Conservation Well Sampling. In October 1985, the Alaska Department of Environmental Conservation (ADEC) sampled two residential wells in Red Devil Village. The identity of the well owners was confidential, so the exact locations are unknown. Neither well sample contained detectable levels of mercury or arsenic; however, one of the two wells tested “extremely high” for zinc (ADEC 1987).

1988 BLM Sampling Event. The BLM collected six surface water and 10 sediment and soil samples from Red Devil Creek, the settling ponds, and other areas around the RDM site (Weston 1989). The results of the sampling indicated the presence of mercury in Red Devil Creek water from 0.2 to 5.5 µg/L and in Red Devil Creek sediments from 41 to 967 milligrams per kilogram (mg/kg). A tailings pile near Settling Pond #1 contained 649 mg/kg mercury. Four background soil samples were collected, which contained 0.2 to 8.0 mg/kg mercury.

Table 1-1 Summary of Previous Investigations

Year	Organization and Report Reference	Major Findings
1971	EPA Study	Mercury and arsenic were detected in surface water samples collected at and near the RDM.
1979	EPA Study	Mercury and arsenic were detected in surface water samples collected at and near the RDM.
1985	ADEC Well Sampling	Two residential use wells in Red Devil Village were sampled; neither well had detectable concentrations of mercury or arsenic.
1988	BLM Sampling Event (unpublished)	Mercury was detected in Red Devil Creek surface water and sediment and in a sample of tailings.
1989	Weston Site Inspection	Antimony, arsenic, and mercury were detected in Red Devil Creek surface water and sediment, in the settling ponds, and in tailings samples.
1997	Bailey and Gray Study	Elevated levels of total mercury and methylmercury in soil and vegetation samples were found at the RDM compared with background locations.
1997	USGS Kuskokwim River Study	Water sample in Red Devil Creek contained arsenic, antimony, copper, chromium, and zinc.
1999	Wilder/HLA Limited Waste Removal Action	Antimony, arsenic, lead, and mercury were detected in soil samples collected near site sources in the Main Processing Area. Benzene was detected in soil at the Gravel Pad.
2001	Wilder/HLA Source Area Removal and Investigation	Monitoring wells were installed at the site. Visible elemental mercury was observed in subsurface soils adjacent to the Post-1955 Retort slab. Groundwater samples contained antimony, arsenic, lead, and zinc at concentrations above federal MCLs.
2002	Wilder Debris Consolidation and Disposal	Construction of Monofill #1 and Monofill #2. No environmental sampling was performed.
2002	Bailey et al. Study	Elevated levels of total mercury and methylmercury in soil and vegetation samples were found at the RDM compared with background locations.
2004	MACTEC ASTs/Ore Hopper Demolition and Petroleum Release Investigation	Construction of Monofill #3. Petroleum Release Investigation detected hydrocarbons (DRO) in subsurface soil at the AST area. Samples from existing monitoring wells contained antimony, arsenic, and mercury above ADEC groundwater cleanup levels.
2005	MACTEC Historic Source Area Investigation	Pre-1955 ore processing structures were located through research and subsurface exploration. Mercury and arsenic were detected in surface and subsurface soil samples within and around the historical structure footprints.
2005, 2006	Wilder Contaminated Soil Stockpiling and Debris Removal	Petroleum-contaminated soil from the former AST area was excavated and stockpiled. Existing monitoring wells were sampled and contained antimony, arsenic, and mercury above ADEC groundwater cleanup standards.
2007, 2008, 2009	Shannon & Wilson and BLM, 2007 and 2008 Monitoring Events	Groundwater monitoring events of the existing monitoring wells showed continued presence of antimony, arsenic, and mercury in groundwater.
2009	E & E October 2009 Monitoring Event	Groundwater monitoring event of the existing monitoring wells showed continued presence of antimony, arsenic, and mercury in groundwater. Groundwater samples collected in October 2009 showed lower concentrations of metals, likely due to the use of low-flow groundwater sampling methods.

Table 1-1 Summary of Previous Investigations

Year	Organization and Report Reference	Major Findings
2010	USGS August 2010 Geophysical Investigation	A geophysical survey was conducted at the site using direct-current resistivity and electromagnetic induction surface methods. Based on the geophysical data and existing soil borings, there was not sufficient electrical or electromagnetic contrast to confidently distinguish between tailings, waste rock, and weathered bedrock. However, a water table was interpreted based on a correlation with the existing monitoring wells.
2010	E & E September 2010 Limited Sampling Event	Data was collected to characterize the nature and extent as well as the fate and transport of COPCs at and near the site; to provide data for human health and ecological risk assessments; and to provide data and information for use in the analysis of remedial alternatives.

Key:

ADEC = Alaska Department of Environmental Conservation
AST = aboveground storage tank
BLM = Bureau of Land Management
COPC = contaminant of potential concern
DRO = Diesel range organics
E & E = Ecology and Environment, Inc.
EPA = Environmental Protection Agency
HLA = Harding Lawson Associates
MACTEC = MACTEC Engineering and Consulting
MCL = Maximum Contaminant Level
TCLP = toxicity characteristic leaching procedure
USGS = U.S. Geological Survey
Wilder = Wilder Construction Company

1989 Site Inspection. Weston, Inc. performed a CERCLA site inspection (SI) at the RDM site on behalf of the BLM during the 1988 field season. The objective of the SI was to characterize conditions for the completion of a Hazard Ranking System score for the site. The SI involved collection of samples from tailings, surface water, and sediment in Red Devil Creek and sediment in the settling ponds. Soil, sediment, and surface water samples were analyzed for a combination of analytes, including arsenic, barium, cadmium, chromium, mercury, lead, antimony, selenium, and silver. Dielectric fluid in the transformers and oil stained soil was sampled for polychlorinated biphenyls (PCBs) using field test kits. Table 1-2 presents the results of the 1989 SI samples for the applicable RI/FS contaminants of potential concern (COPCs).

Table 1-2 Summary of 1989 Site Inspection Sample Results

Matrix	Location	Antimony	Mercury	Arsenic	Chromium	Lead	Units
Sediment	Settling Pond #1	1,872	395	8,474	N/A	418.7	mg/kg
Surface Water	Above Settling Pond #1	200 U	0.4	200 U	10 U	200 U	µg/L
Surface Water	Southern border	200 U	0.3	200 U	10 U	200 U	µg/L
Surface Water	Mouth of creek	278	0.4	244	10 U	200 U	µg/L
Sediment	Above Settling Pond #1	3,450	29	2,449	25.9	480.7	mg/kg
Sediment	Southern border	0.243 U	0.6	165	17.7	261.7	mg/kg
Sediment	Below settling ponds	4,015	4,120	3,185	N/A	N/A	mg/kg
Sediment	Mouth of creek	3,113	33.3	2,194	N/A	N/A	mg/kg
Soil	Settling Pond #2	872	550	8,053	N/A	N/A	mg/kg
Soil	Settling Pond #3	664	83	6,498	N/A	N/A	mg/kg
Soil	Pile above Settling Pond #1	7,074	787	8,024	N/A	N/A	mg/kg
Soil	Pile above Settling Pond #1	22,737	498	5,851	N/A	1391.1	mg/kg

Key:
mg/kg = milligrams per kilogram.
N/A = not analyzed
U = non-detect, value listed is the method detection limit
µg/L = micrograms per liter.

Weston estimated approximately 51,600 cubic yards of tailings are located at the mine and mill area and an unknown quantity of tailings have been deposited in Red Devil Creek (Weston 1989).

Bailey and Gray 1997. The U.S. Geological Survey (USGS) analyzed samples from the RDM, Cinnabar Creek Mine, and regional background sites as part of a study to characterize the geochemistry of southwestern Alaska, and to evaluate environmental conditions at abandoned mercury mines in the region. The study was conducted for research purposes and was not intended to define the full extent of heavy metals contamination from specific sites. The samples included vegetation, surface water, and soil. Results of samples collected in the RDM area are summarized in Table 1-3.

Table 1-3 Summary of Bailey and Gray 1997 Mercury and Methylmercury Data for Vegetation at Red Devil Mine Site

Matrix	Location	Total Hg Range (ppb)		MeHg Range (ppb)	
Alder	Retort area (unmined)	30	310	0.45	90
Willow	Retort area (unmined)	30	330	—	—
Black spruce	Retort area (unmined)	40	370	—	—
Blueberry	Retort area (unmined)	30	330	2.60	2.76
Paper birch	Retort area (unmined)	30	180	—	—
Alder	Mined area	<20	900	0.54	0.87
Willow	Mined area	<20	560	2.73	
White spruce	Mined area	20	140	—	—
Cottonwood	Mined area	20	280	—	—
Black spruce	Mined area	20	200	—	—
Blueberry	Mined area	<20	150	—	—
Paper birch	Mined area	<20	130	—	—
Soil	Retort area (unmined)	0.14	120	8.21	
Soil	Mined area	0.15	1,200	2.73	4.19
Water	Red Devil Creek	<0.10	0.28	—	—

Source: Bailey and Gray 1997
Key:
Hg = mercury.
MeHg = methylmercury.
ppb = parts per billion.

The study concluded that vegetation and soil samples at the mine sites contained significantly higher concentrations of total mercury and methylmercury than background locations.

1997 USGS Kuskokwim River Study. As part of a regional study to assess water quality in the Kuskokwim River, suspended sediment and bed sediment samples were collected from stations located on the river between the villages of McGrath and Akiak. Three tributaries were sampled during the study, including Red Devil Creek. A dissolved surface water sample was collected in Red Devil Creek at its confluence with the Kuskokwim River. Mercury was not analyzed in the sample. Table 1-4 summarizes the results of selected inorganic elements from this sample (USGS 1999).

Table 1-4 Summary of 1997 USGS Red Devil Creek Sample Results

Analyte (Dissolved)	Concentration (µg/L)
Arsenic	180
Antimony	281
Copper	1.4
Chromium	1.6
Zinc	<1

Source: USGS 1999
Key:
µg/L = micrograms per liter
USGS = United States Geological Survey

1999 Limited Waste Removal Action. Wilder Construction Company (Wilder)/Harding Lawson Associates (HLA) conducted an offsite waste removal and a pre-remediation sampling investigation. This project included collection of background soil samples and sampling of known contaminant source areas in the Main Processing Area, Red Devil Creek, and the Kuskokwim River.

Contaminants were detected above Alaska soil cleanup standards (Method 2, Table B1) in samples from multiple locations around sources in the Main Processing Area (see Table 1-5). Surface water and sediment samples collected from Red Devil Creek contained concentrations of metals including arsenic, antimony, and mercury above background concentrations. Sediment samples collected from the Kuskokwim River contained concentrations of arsenic, antimony, and mercury above background concentrations (Wilder/HLA 1999).

Table 1-5 Summary of 1999 Limited Waste Removal Action Selected Soil Sample Results at Source Locations

Source/Location	Contaminants Detected Above Cleanup Levels	Detected Concentrations (mg/kg except where otherwise noted)
Battery Pile Near Shop Pad A	Lead	10,700–13,500
West Side of Post-1955 Retort Building	Antimony	529–1,520
	Arsenic	1,380–3,130
	Mercury	445–1,090
East Side of Post-1955 Retort Building	Mercury	3,330–23,800
Tailings South of Settling Pond 1	Antimony	1,780
	Arsenic	2,280
	Mercury	269
Gravel Storage Pad	Benzene	98.8 µg/kg
	Antimony	8.53
	Arsenic	1,160
	Mercury	88
Chemical Storage Sheds (near south end of Post-1955 Retort building)	Antimony	503–720
	Arsenic	183
	Chromium	255
	Mercury	185–35,300
Settling Ponds	Antimony	162 (J)–892
	Arsenic	2,450–3,680
	Chromium	27.1
	Mercury	191 (J)–982

Key:
J = Estimated concentration.
mg/kg = milligrams per kilogram.
µg/kg = micrograms per kilogram.

2001 Source Area Removal and Investigation. This project involved asbestos abatement, demolition of structures, plugging of mine shafts, offsite waste removal, and environmental sampling in the Main Processing Area and the AST area. Soil borings and monitoring wells were installed in the Main Processing Area. Nine subsurface borings were drilled and sampled; five were completed as monitoring wells. In addition, an extensive subsurface soil investigation was conducted around the slab of the Post-1955 Retort Building.

Surface and near-surface soil samples collected from soil borings contained antimony, arsenic, and mercury at concentrations exceeding background concentrations, consistent with result of previous investigations. Concentrations of these metals decrease significantly with depth.

The soils investigation around the Post-1955 Retort Building slab indicated the presence of relatively high concentrations of arsenic and mercury in surface and subsurface soils using x-ray fluorescence (XRF) field screening and fixed laboratory methods. Elemental mercury was observed in samples from five soil borings on the west side of the slab at depths between 2 and 6 feet bgs.

Groundwater samples collected after well installation contained concentrations of antimony, arsenic, lead, and zinc above federal Maximum Contaminant Levels MCLs (Wilder/HLA 2001).

2002 Debris Consolidation and Disposal Project. Wilder/URS was contracted by the BLM to perform further building demolition, debris segregation, and debris burial. This project involved construction of Monofill #1 and Monofill #2. No environmental sampling was performed during this project (Wilder/URS 2003).

Bailey et al. 2002. This study conducted vegetation and soil sampling at three abandoned mercury mines and at regional background sites in southwestern Alaska. Total mercury and methylmercury concentrations were found to be higher in the vegetation and soil samples from the mine sites compared to the samples collected from the regional background sites. No correlation was found between total mercury in soil and total mercury in vegetation or between total mercury and methylmercury. Results of samples collected in the RDM area are summarized in Table 1-6.

Table 1-6 Summary of Bailey et al. 2002 Mercury and Methylmercury Data for Vegetation at Red Devil Mine Site

Sample Matrix	Location	Units	Total Mercury			Methylmercury		
			Mean	Range	n	Mean	Range	n
Alder leaves and stems[a]	Tailings	ng/g	226	149-374	3	0.5	0.4–0.6	3
	Retort	ng/g	310	--	1	--	--	0
	Mined Area	ng/g	211	24-900	10	0.3	0.1–0.7	7
Willow leaves and stems[a]	Tailings	ng/g	350	346-353	2	1.6	1.4–1.8	2
	Retort	ng/g	166	74-330	19	1.8	0.4–3.4	6
	Mined Area	ng/g	136	11-560	7	5	0.3–11	6
Soil	Tailings	µg/g	970	12-1578	5	0.4	0.1–0.7	5
	Retort	µg/g	8.5	0.05-120	21	3.3	0.7–8.2	8
	Mined Area	µg/g	210	6-1200	12	2.2	0.3–7.2	10

Notes:
[a] Current year's growth.
[b] Different units are used for vegetation (ng/g) and soil (µg/g).

Key:
-- = Not available or not relevant.
n = Number of samples.
ng/g = Nanograms per gram (parts per billion).
µg/g = Micrograms per gram (part per million).

2003 Historic Source Area Investigation. For the BLM, MACTEC Engineering and Consulting (MACTEC) conducted a literature review, interviews of local persons knowledgeable about the mine history, and a sampling investigation of the Pre-1955 Retort Building, the Pre-1955 Rotary Furnace, the Pre-1955 Rotary Furnace Stack, and a “burnt ore” (tailings) disposal pile located southeast of the Pre-1955 Retort Building (MACTEC 2005).

Pre-1955 Retort Building. Nine surface soil samples were collected from within and around the historical structure footprint. Samples were analyzed for mercury and arsenic. Mercury speciation analysis was also performed. Arsenic was detected at concentrations from 89 to 1,250 mg/kg. Mercury was detected at concentrations from 2.9 to 32.0 mg/kg. Mercury speciation indicated methylmercury concentrations from 0.357 to 1.688 micrograms per kilogram (µg/kg).

Pre-1955 Rotary Furnace. Eleven soil samples were collected around the historical footprint of the structure. The samples were collected from the surface to 2.7 feet bgs. Samples were analyzed for mercury and arsenic. Mercury speciation analysis was also performed. Arsenic was detected at concentrations from 38 to 2,000 mg/kg. Mercury was detected at concentrations from 2.5 to 140 mg/kg. Mercury speciation indicated methylmercury concentrations from 0.186 to 0.563 µg/kg.

Pre-1955 Rotary Furnace Stack. One surface soil sample was collected and analyzed for mercury, arsenic, and mercury speciation at the site of the historical rotary furnace stack. Arsenic was detected at a concentration of 118 mg/kg. Mercury was detected at a concentration of 3.4 mg/kg. Mercury speciation indicated a methylmercury concentration of 0.050 μg/kg.

Pre-1955 Retort "Burnt Ore" Stockpile. One surface soil sample was collected and analyzed for mercury, arsenic, and mercury speciation at the site of the "burnt ore" (tailings) disposal pile southeast of the Pre-1955 Retort Building. Arsenic was detected at 1,390 mg/kg. Mercury was detected at 940 mg/kg. Mercury speciation indicated a methylmercury concentration of 0.445 μg/kg.

2004 AST/Ore Hopper Demolition and Petroleum Release Investigation. MACTEC was contracted by the BLM to demolish and dispose of the ASTs and ore hopper. This project involved construction of Monofill #3. Environmental sampling, including 12 soil borings, was conducted to characterize the AST area, and the existing monitoring wells were sampled.

Soils investigations at the AST area detected petroleum hydrocarbons (diesel range organics [DRO]) above ADEC cleanup levels in excavations and soil borings. Groundwater samples collected from the existing monitoring wells contained antimony, arsenic, and mercury at concentrations above ADEC cleanup levels; DRO and residual range organics (RRO) were detected in groundwater samples below ADEC cleanup levels (MACTEC 2004).

2005/2006 AST Soil Stockpiling and Debris Removal. Wilder and URS Corporation excavated petroleum-contaminated soil in the AST area and sampled the excavated soil prior to placing the material in covered stockpiles. Environmental sampling was not conducted except for the annual sampling of the five monitoring wells. Antimony, arsenic, and mercury were detected in the groundwater samples above ADEC cleanup levels.

2007, 2008, and 2009 Monitoring Events. The monitoring wells were sampled in 2000, 2003, 2005, 2006, 2007, 2008, and 2009. The 2007 and 2008 sampling events were done by Shannon & Wilson, Inc., and are summarized in groundwater sampling reports for each year. The 2008 monitoring event also included one sample taken from a hillside seep.

2009 Monitoring Event. The October 2009 sampling event was conducted by E & E and included five surface water samples in addition to the monitoring well samples (E & E 2010a). The October 2009 data are presented in Chapter 4 of this report.

2010 USGS Geophysical Investigation. In August 2010, in cooperation with the BLM and in conjunction with the RI/FS, the USGS conducted a geophysical investigation at the RDM site using surface-based direct-current resistivity and electromagnetic induction methods (Burton and Ball 2011). Eight two-dimensional cross-sections and one three-dimensional grid of direct-current resistivity data, and 5.7 kilometers of electromagnetic induction data, were obtained along Red Devil Creek valley, from the Main Processing Area to Red Devil Creek's confluence with the Kuskokwim River. Results of the geophysical investigation indicate no significant contrast in resistivity between the tailings, waste rock, and bedrock at the site. However, based on correlation with existing monitoring wells, a water table was interpreted on the direct-current resistivity cross-sections. Several anomalies were also identified in the direct-current resistivity profiles and the three-dimensional grid. Down-hole geophysical logs and analysis of soil and rock samples to determine how water content affects the bulk resistivity values were recommended.

1.4.4 Previous Removal and Cleanup Actions

Five major removal/cleanup actions were performed at the RDM between 1999 and 2006. These actions have included offsite disposal of hazardous waste and materials and onsite consolidation of mine structure debris. To date, all mine structures have been demolished, and three debris burial areas (monofills) have been constructed.

1.4.5.1 Limited Waste Removal Action (1999)

In 1999, Wilder and HLA conducted limited waste removal and site characterization activities to address the most hazardous conditions observed at the site during the 1988 SI. The following subsections summarize the waste removal activities conducted, by waste type; the information source through Section 3.1.2 is Wilder/HLA 1999. Site features referred to within this section are depicted in Figure 1-3.

Battery Storage Areas

Five EP-2 boxes of batteries (approximately 100 batteries) were removed from the vicinity of the “Shop Building,” Shop Pads A and B, the Gravel Pad, and three vehicles. The batteries were taken to Excide in Anchorage, Alaska, for recycling. Following removal, two soil samples were collected from the battery storage areas, and lead was detected at concentrations above the ADEC soil cleanup level established in 18 Alaska Administrative Code (AAC) 75, Method 2, Table B1, Under 40-Inch Zone, Most Conservative Pathway. Lead-contaminated material was addressed in 2002, but it is unknown whether contaminated soil was addressed in these areas.

Transformer Areas

Four 55-gallon drums were identified at the site. One 55-gallon drum containing used oil was recovered from the Power Plant and transported to Alaska Energy Recovery Services, Inc. (ERS), in Anchorage for recycling. Philip Services Corporation tested the oil onsite and determined that it contained less than 50 parts per million (ppm) PCBs. One soil sample was collected near the Power Plant, and no contaminants were detected at concentrations above the ADEC soil cleanup levels.

After onsite testing indicated PCBs greater than 50 ppm, two 55-gallon drums containing PCB-contaminated transformer oil were recovered from the Gravel Storage Pad and transported to the Philips Burlington Environmental, Inc. (BEI), disposal facility in Georgetown, Washington. One 55-gallon drum containing non-PCB-contaminated transformer oil (onsite testing indicated PCBs less than 50 ppm) was transported to ERS for recycling. One soil sample was collected from the Gravel Storage Pad, and benzene was detected at a concentration above the ADEC soil cleanup level. The emptied transformers were addressed in 2002.

Drum Areas

There were three main drum storage areas: an area north of the Post-1955 Retort Building containing 89 drums, an area north of the Power Plant containing 92 drums, and an area near the Former Shop Pad containing 25 drums. Drums were also found near the housing area and on the Gravel Storage Pad. Most of the drums were empty. The contents of the drums were characterized by Philip Services Corporation and bulked into a total of 23 drums for recycling or disposal:

- Seventeen 55-gallon drums of used oil were transported to ERS for recycling.
- Three 55-gallon drums of Stoddard solvent were transported to BEI for disposal.
- Three 55-gallon drums of grease were transported to BEI for disposal.

Four soil samples were collected from the drum areas. Mercury, antimony, and arsenic were detected at concentrations above the ADEC soil cleanup levels. The emptied drums were addressed in 2002, but it is unknown whether contaminated soil was addressed in these areas.

Post-1955 Retort

Wilder/HLA removed mercury-contaminated material from the Post-1955 Retort Building, including the exhaust port concrete base and ash. In addition, approximately 5 pounds of free mercury was collected from the periphery of the Post-1955 Retort Building and placed in one of the drums of mercury-contaminated material. The mercury-contaminated material transported to BEI for disposal consisted of:

- Two 55-gallon drums of mercury-contaminated ash.
- Two 55-gallon drums of mercury-contaminated concrete (broken into small pieces).
- Two SupersacksTM of mercury-contaminated ash.
- Two SupersacksTM of mercury-contaminated personal protective equipment and debris.

Seven soil samples were collected around the Post-1955 Retort Building. Mercury, antimony, and arsenic were detected at concentrations above the ADEC soil cleanup level. This soil was addressed in 2002.

Chemical Storage Areas

Wilder/HLA bulked chemicals from the two dilapidated chemical storage sheds located south of the Post-1955 Retort Building. The East Chemical Storage Shed contained potassium carbonate, and the West Chemical Storage Shed contained copper sulfate, sodium hydroxide, and sodium dichromate dihydrate. The bulked chemicals transported to BEI for disposal were:

- Two 55-gallon drums of sodium dichromate dihydrate.
- Seven SupersacksTM of potassium carbonate.
- Five SupersacksTM of chemical-contaminated soil and debris.
- Two SupersacksTM of sodium hydroxide.
- Two 55-gallon drums of copper sulfate.

One soil sample was collected from each of the chemical storage sheds. Mercury, antimony, arsenic, and chromium were detected at concentrations above the ADEC soil cleanup levels. This soil was further characterized in 2001 and addressed in 2002.

1.4.5.2 Post-1955 Retort Demolition (2000)

Wilder/HLA demolished the Post-1955 Retort Building and West Chemical Storage Shed in 2000. Mercury-impacted asbestos, soil, and “slag” wastes generated during the demolition were transported offsite for disposal. Demolition debris, including wood, steel, tin sheeting, bricks, retort chamber, process piping, and miscellaneous equipment, was pressure-washed in a low area of the retort building foundation. Wash water was collected with sump pumps and discharged into a high-density polyethylene-lined holding pond. Approximately 1,067 cubic yards of washed demolition debris was staged in a pile on the concrete retort building foundation. In addition, approximately 8 cubic yards of furnace “slag” was stockpiled on a bottom liner adjacent to the concrete foundation. The “slag” stockpiled adjacent to the Post-1955 Retort Building concrete foundation was addressed in 2002.

The headworks was also demolished, resulting in a debris pile of wood and steel with a volume of approximately 175 cubic yards. The debris pile remained at the headworks location and the debris was not sampled for contaminants.

Wilder/HLA recovered approximately 55 gallons of fuel from the fuel storage and distribution system. The recovered fuel was transported to ERS in Anchorage for recycling.

Wilder/HLA also collapsed and backfilled the entrances to five mine shafts and one adit. Large rock debris was placed in each entrance, the entrance walls were collapsed, and the material was compacted in place.

Wilder/HLA conducted source area investigations at the Post-1955 Retort Building and fuel storage and distribution system, including collection of surface soil, subsurface soil, and groundwater samples (see Section 1.4.4).

1.4.5.3 Debris Consolidation and Disposal (2002)

In 2002, Wilder demolished several onsite structures, most of which were cleared of hazardous substances in 1999 (see Section 3.2.2). Wilder also segregated and chemically treated debris and constructed Monofill #1 and Monofill #2 (Figure 1-3). In addition, some lead-contaminated material was removed from the vicinity of the houses and mess hall/bunkhouse. This material included drainpipe, sewer pipe, and lead heat trace. No sampling for lead was conducted in soils surrounding this removed debris; however, building materials tested for lead did not exceed the toxicity characteristic levels established by the Resource Conservation and Recovery Act (RCRA). One 55-gallon drum of hydraulic fluid was recovered from the drum storage areas and transported offsite for disposal. The debris consolidation and disposal work was intended to reduce arsenic and mercury mobility (Wilder/URS 2003).

Monofill #1

Approximately 4,400 cubic yards of "inert debris" (as defined by ADEC, 18 AAC 60) was placed within Monofill #1. The debris placed in Monofill #1 consisted of building debris, wood, concrete, scrap metal, 23 transformers (confirmed dry), and Category I and II non-friable asbestos-containing material (Wilder/URS 2003).

Monofill #1 was constructed below grade, ranging in depth from 8 to 15 feet bgs. Following placement of compacted inert debris, the debris was capped with at least 2 feet of soil and contoured so that it blended with the existing grade. Soil stockpiled during excavation of the monofill was used as void-filling and cap material. The cap slope was less than or equal to 3 feet horizontal to 1 foot vertical (3H:1V) (Wilder/URS 2003).

Monofill #2

Monofill #2 contains approximately 938 cubic yards of chemically treated mercury- and arsenic-contaminated debris from the Post-1955 Retort Building. A treatability study of the retort debris demonstrated that mercury and arsenic could be stabilized to RCRA toxicity characteristic leaching procedure (TCLP) criteria using chemical encapsulants. Reportedly, treatment of the debris with the chemical encapsulants rendered the debris "inert"; however, there was no confirmation sampling to determine that the treated material met the definition of "inert" as defined by ADEC (18 AAC 60). In addition to the chemical encapsulation treatments, an impermeable geomembrane liner was used in the construction of Monofill #2 as a second precautionary measure (Wilder/URS 2003). Monofill #2 was constructed above the Post-1955 Retort Building foundation where elemental mercury was previously found in the subsurface (see Section 3.1, 2001 Source Area Removal and Investigation). This mercury was not removed or otherwise remediated prior to construction of the monofill.

The debris placed within Monofill #2 consisted of retort building debris, bricks, and "slag"; tailings; and some arsenic-containing soil excavated from the vicinity of the chemical storage sheds and mess hall/bunkhouse (arsenic was detected in these areas at concentrations above RCRA TCLP criteria during sampling conducted in 2001). The Gravel Storage Pad was used as a temporary staging area for debris segregation and chemical encapsulation treatment. Prior to construction of Monofill #2 above the concrete foundation, the mercury chemical encapsulant was placed over the concrete foundation and inside the cracks, and mercury- and arsenic-contaminated soil surrounding the foundation was also treated with mercury and arsenic chemical encapsulants (Wilder/URS 2003).

Monofill #2 was constructed above-grade on top of the concrete foundation of the Post-1955 Retort Building. All debris placed within Monofill #2 was first treated with chemical encapsulants, as recommended in the treatability study. Monofill #2 was lined with an impermeable geomembrane layered with geotextile on each side for abrasion protection. The geotextile/geomembrane liner was installed above and below the monofill debris and welded to seal the liner. Liner installation and welding were supervised by qualified technicians, and Quality Assurance (QA)/Quality Control (QC) reports were provided (Wilder/URS 2003). Tailings treated with the arsenic chemical encapsulant were used as backfill material above, below, and all around the geomembrane-lined portion of Monofill #2. Treated tailings were also placed within the geomembrane-lined portion of Monofill #2 in a 1-foot layer separating the liner from the compacted retort debris to prevent protrusions from damaging the liner. Treated tailings were also used as void-filling material within the geomembrane-lined portion of Monofill #2 (Wilder/URS 2003). The report is inconsistent in stating whether or not all tailings used in the monofill construction were treated with the chemical encapsulant.

Monofill #2 is approximately 9 feet high at the center. The depth of waste in Monofill #2 is approximately 3 feet, and the treated tailings cap on top of the debris is at least 3 feet thick. The cap slope is less than or equal to 20H:1V. The sidewall on the western side is approximately 2H:1V. A crown was constructed at the top to promote surface water drainage (Wilder/URS 2003).

1.4.5.4 Aboveground Storage Tanks/Ore Hopper Demolition (2003–2004)

In 2003 and 2004, MACTEC conducted demolition and onsite consolidation of the five fuel ASTs and the Ore Hopper and conducted an assessment of petroleum contamination at the former AST sites. The debris was consolidated in the “AST Metal Disposal Area” (MACTEC 2004). This feature is Monofill #3 (Figure 1-3).

Approximately 12,700 square feet of tank metal was placed in the onsite disposal area, which measured approximately 55 feet long, 15 feet wide, and 12 feet deep. The ASTs were reportedly inspected and emptied during previous site activities. Approximately 1,400 square feet of Ore Hopper metal, and less than 10 cubic yards of broken concrete, was also placed in the disposal area. Most of the Ore Hopper concrete structure was left in place and buried with tailings from the bench above the Ore Hopper. The disposal area was capped with more than 3 feet of soil that originated from the original excavation of the monofill pit and graded to facilitate drainage (MACTEC 2004).

1.4.5.5 Contaminated Soil Stockpiling and Debris Removal (2005–2006)

In 2005 and 2006, Wilder performed petroleum-contaminated soil excavation and stockpiling, debris removal, and inspection/repair of monofill erosion/settling problems. Wilder excavated approximately 3,306 cubic yards of petroleum-contaminated soil from four of the 2003 AST excavation sites, the pipeline area, and the former fuel barge area and stockpiled the petroleum-contaminated soil in two lined stockpiles. Prior to its placement in the stockpiles, the contaminated soil was screened, and material larger than 2 inches in diameter (large cobbles and boulders) were segregated and used as cap material for Monofill #3. Wilder burned some AST wooden base debris and added the following debris to Monofill #3 (Wilder/URS 2007):

- A 300-foot, 6-inch-diameter steel fuel delivery pipeline that connected the AST farm to the fuel barge landing area (cut into pieces).
- Approximately 10 cubic yards of debris consisting mainly of empty drums, cans, and boxes collected from a location near the former location of AST 3.
- A collapsed mine portal iron gate.

Following placement of this miscellaneous debris in Monofill #3, the monofill was capped with the material screened from the petroleum-contaminated soil stockpiles (Wilder/URS 2007).

Wilder also performed monofill repair activities in 2005, including (Wilder/URS 2007):

- Monofill #1 – Minor settling/erosion was noted at this monofill site. In particular, the areas of concern were small surficial depressions, which were regraded to prevent pooling of rain and runoff waters.
- Monofill #2 – Precipitation runoff was observed cutting into the southwest corner of Monofill #2. This corner was regraded to stabilize erosion. A runoff ditch was also re-worked to allow runoff to leave the monofill cap in a direction that would prevent future erosion in that area.

1.4 Summary of RI/FS Data Quality Objectives

The Red Devil Mine RI/FS Work Plan (Work Plan) includes a chapter dedicated to specifying DQOs (E & E 2011). The DQO process specifies project decisions, the data quality required to support those decisions, data types needed, and data collection requirements and ensures that analytical techniques are used that will generate the specified data quality (EPA 2000). The data types that pertain to this RI report should be analyzed using the following key study questions:

Nature and Extent of Contamination

1. What COPCs, in addition to those identified in previous investigations, exist at and near the site?
2. Do COPC concentrations differ in areas where different ore processing operations were conducted?
3. Are COPC reporting limits sufficient to characterize human health and ecological risks?
4. Is mercury present in organic forms at the site?
5. What is the areal and vertical extent of tailings, flotation tailings, and waste rock?

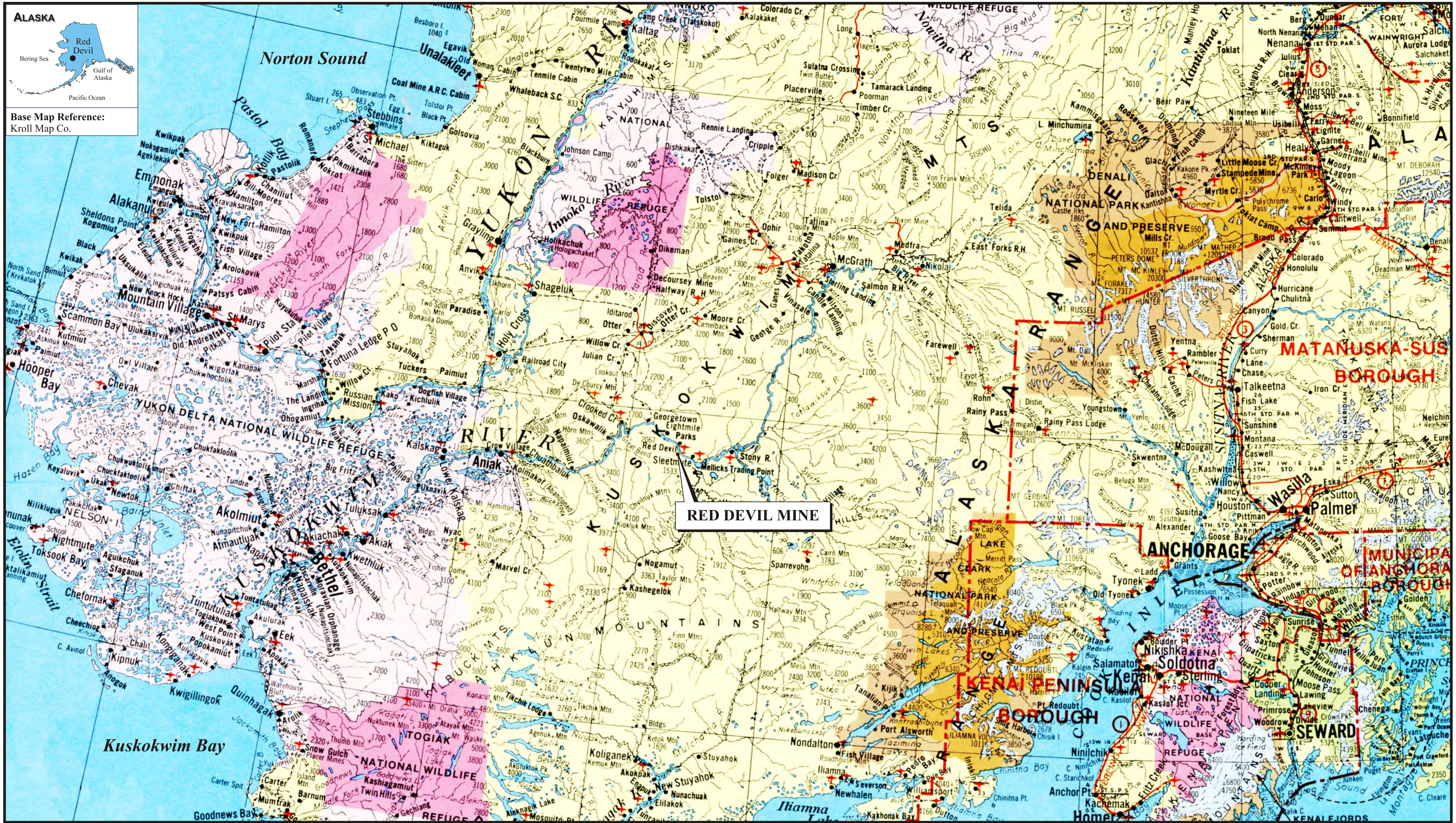
6. Are soils in the area of former surface exploration and mining a source of COPCs, and are metals in a mobile or bioavailable form?
7. Are roads at and to the site a source of COPCs?
8. Are the Dolly Sluice and possible Rice Sluice areas sources of COPCs?
9. What is the nature and extent of contamination in native subsurface soil?
10. What is the nature and extent of contamination in groundwater?
11. What is the nature and extent of contamination in aquatic biota?
12. What are the background concentrations of COPCs in native soils and in groundwater, surface water, sediment, and biota in areas undisturbed by mining activities?
13. Are the previous locations of transformers a source of COPCs?
14. What physical and chemical characteristics can be used to define a difference between tailings, waste rock, and native soils at the site?

Fate and Transport of Contamination

15. Is contaminated groundwater impacting Red Devil Creek or the Kuskokwim River?
16. Have tailings, flotation tailings, waste rock, and/or other site sources impacted sediments, surface water, or aquatic biota in Red Devil Creek?
17. Have tailings, flotation tailings, waste rock, and/or other site sources impacted sediments in the Kuskokwim River downriver of the mouth of Red Devil Creek?
18. Have tailings, flotation tailings, waste rock, and/or other site sources impacted native subsurface soils at the site?
19. Has elemental mercury, previously documented in subsurface soil near Monofill #2, mobilized and/or entered groundwater?
20. What is the leaching potential of COPCs in tailings and flotation tailings at the site?
21. What is the fraction of mercury in tailings, flotation tailings, waste rock, and contaminated soil that is available to chemically mobilize?
22. Are COPCs in waste rock and impacted soils leachable?
23. What is the fraction of arsenic in soil, sediment, surface water, and groundwater that is bioavailable to humans?
24. Are the underground mine workings influencing the nature, extent, and migration of COPCs in groundwater and surface water?

Human Health and Ecological Risk

25. What risks to human health under future residential, subsistence user, and industrial land use scenarios are posed by COPCs at and near the site?
26. What risks to ecological receptors at various trophic levels are posed by COPCs at and near the site?



ecology and environment, inc.
International Specialists in the Environment
Seattle, Washington

N

0 40 80
Approximate Scale in Miles

RED DEVIL MINE
Red Devil, Alaska

Figure 1-1
SITE LOCATION MAP

Date:	Drawn by:	
10/1/09	AES	10:001096OX70.01\fig 1

Ecology & Environment, Inc. GIS Department Project:
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RED DEVIL MINE

Red Devil, Alaska

Figure 1-2
Site Area

0 50 100 200 300 400 500 Feet
0 25 50 100 150 Meters
Scale 1:2,900

Image Source: Aero-Metric, Inc 5/29/2001

Debris Boundary
Settling Pond
Monofill
Historical Structure

RED DEVIL MINE

Red Devil, Alaska

Figure 1-3
Main Processing Area

0 25 50 100 150 Feet
0 5 10 20 30 40 50 Meters
Scale 1:1,000

Image Source: Aero-Metric, Inc 5/29/2001

Ecology & Environment, Inc. GIS Department Project:
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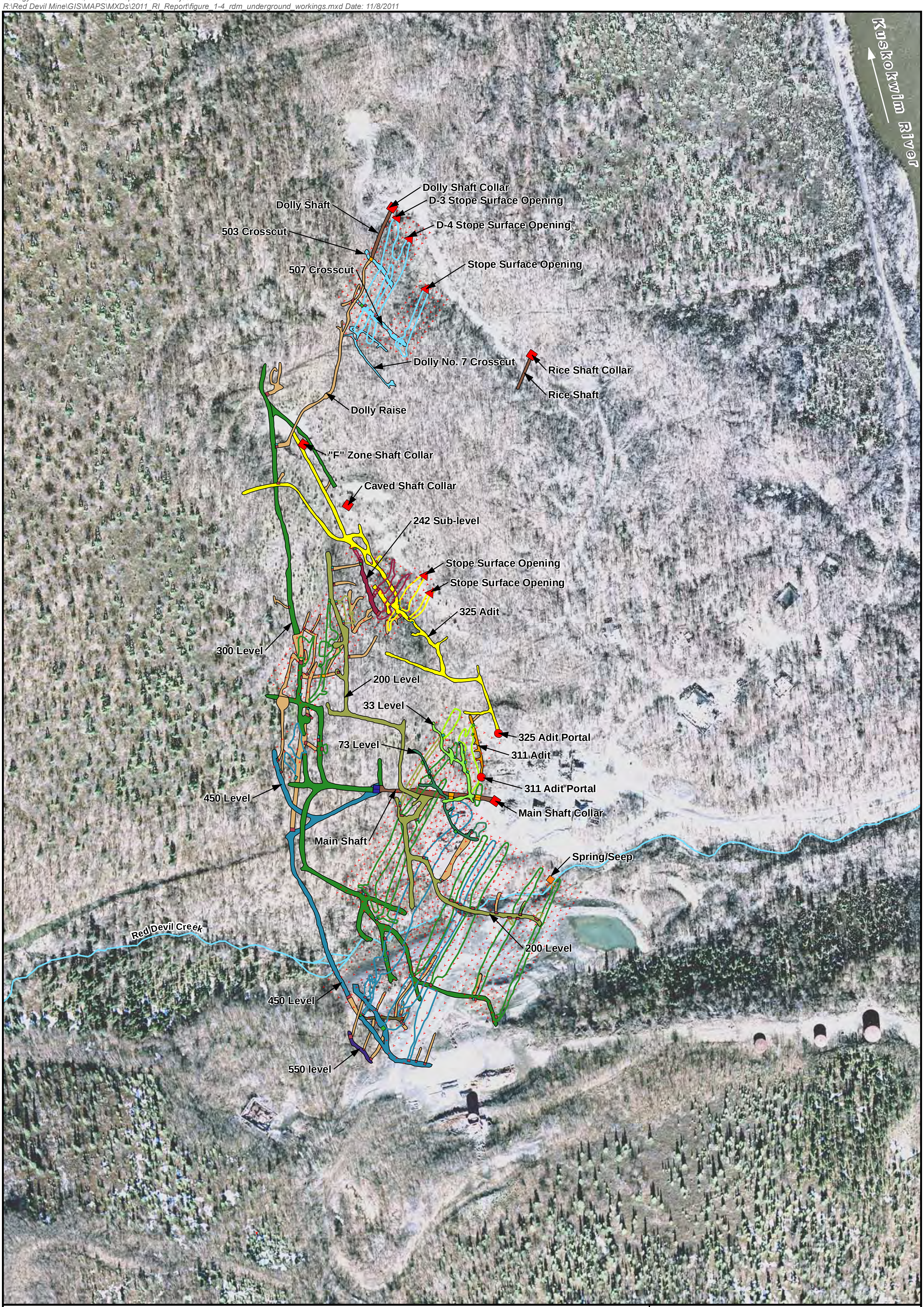

Levels, Adits, and Assoiciated Crosscuts and Drifts
- Dolly Area Crosscuts
- 325 Adit
- 311 Adit
- 242 Sub-level
- 33 Level
- 73 Level
- 200 Level
- 300 Level
- 450 Level
- 550 Level

Shafts, Raises, and Winzes
- Shaft
- Raise or Winze
- Shaft going above and below level
- Ore shaft

Stopes
- Stope ("ˇ" points downward)

Other Workings
- Bottom of Shaft
- Foot of raise or winze
- Head of raise or winze

- Spring/Seep Location

Former Mine Openings
- Adit Portal
- Shaft Collar
- Stope Surface Opening

RED DEVIL MINE

Red Devil, Alaska

Figure 1-4
Underground Workings

0 50 100 200 300 400
Feet
0 12.5 25 50 75 100
Meters
Scale 1:2,000

Source: Malone 1962 and MacKevett and Berg 1963, Image Source: Aero-Metric, Inc 5/29/2001

Ecology & Environment, Inc. GIS Department Project:
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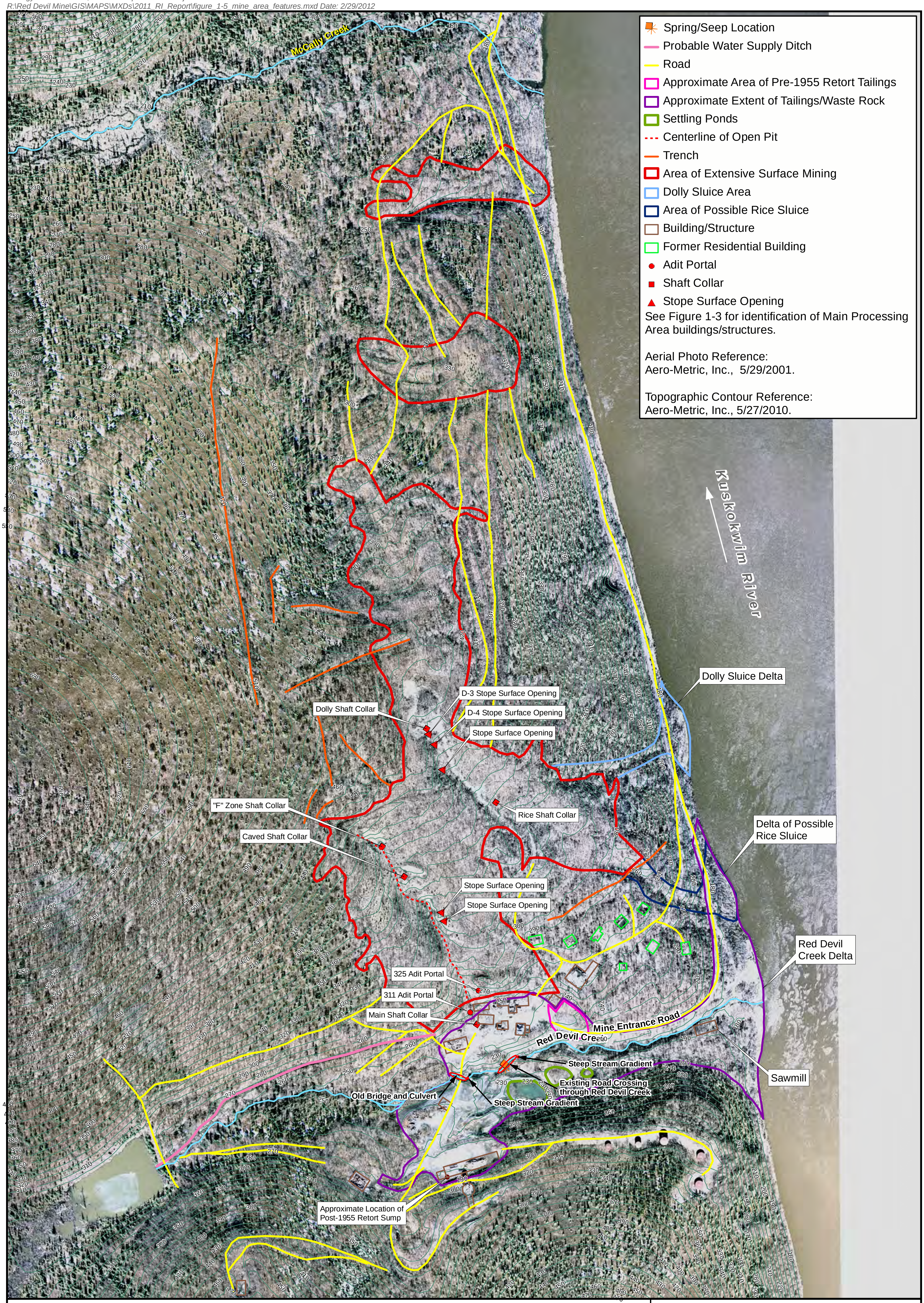

RED DEVIL MINE

Red Devil, Alaska

Figure 1-5
Mine Area Surface Features

0 100 200 400 600 800
Feet
0 25 50 100 150 200
Meters
Scale: 4,000

Ecology & Environment, Inc. GIS Department Project: R:\Red Devil Mine\GIS\MAPS\MXDs\2011_RI_Report\figure_1-6_mining_ore_processing_wastes.mxd Date: 11/8/2011

Ore processing waste source locations
Potential areas containing tailings/waste rock
Areas where disturbed soil is present

RED DEVIL MINE

Red Devil, Alaska

Figure 1-6
Mining and Ore Processing Wastes

0 100 200 400 600 Feet
0 25 50 100 150 200 Meters
Scale 1:3,600

Image Source: Aero-Metric, Inc 5/29/2001

Ecology & Environment, Inc. GIS Department Project:
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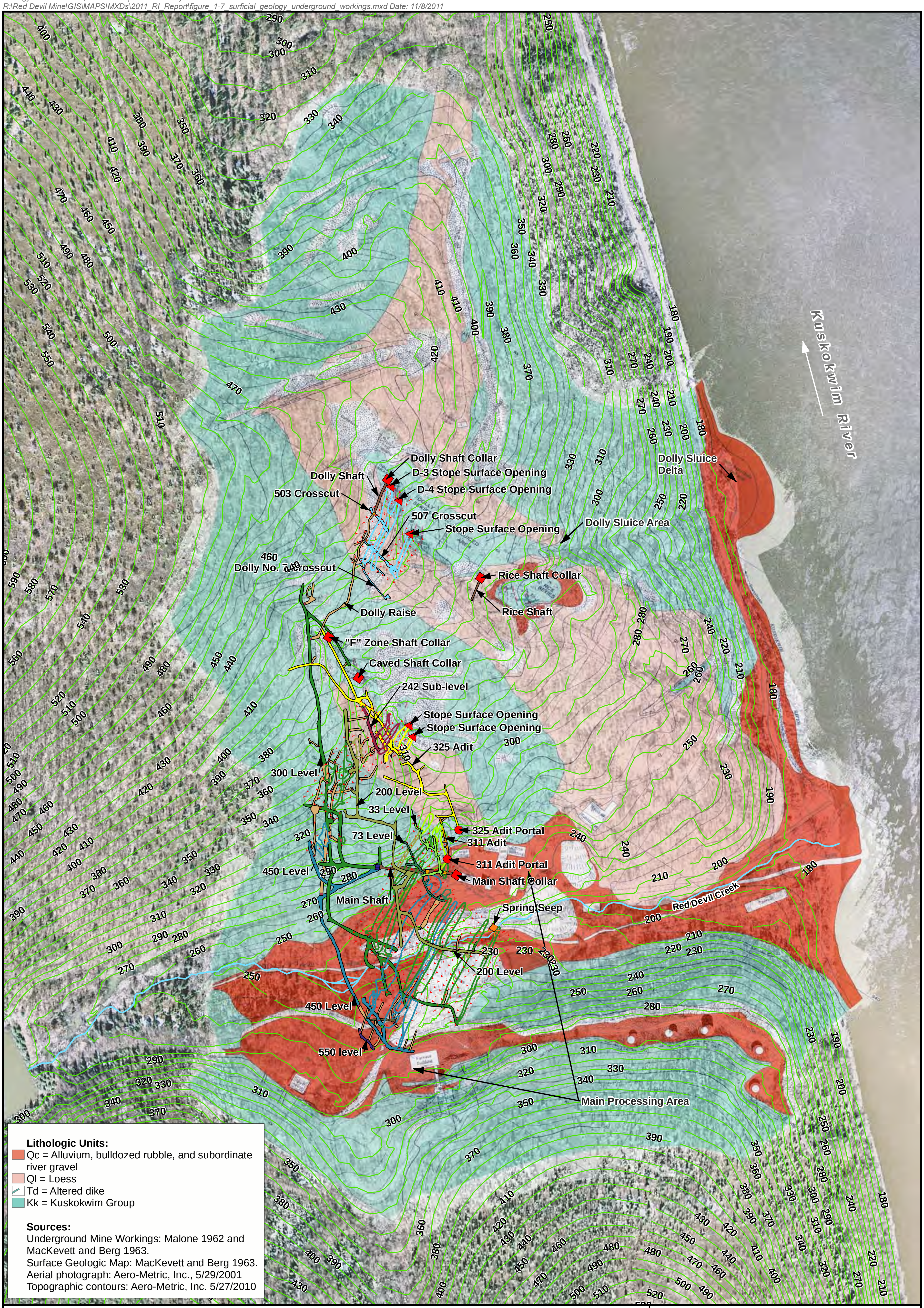

Levels, Adits, and Assoiciated Crosscuts and Drifts
- Dolly Area Crosscuts
- 325 Adit
- 311 Adit
- 242 Sub-level
- 33 Level
- 73 Level
- 200 Level
- 300 Level
- 450 Level
- 550 Level

Shafts, Raises, and Winzes
- Shaft
- Raise or Winze
- Shaft going above and below level
- Ore shaft

Stopes
- Stope ("v" points downward)

Other Workings
- Bottom of Shaft
- Foot of raise or winze
- Head of raise or winze

- Spring/Seep Location

Former Mine Openings
- Adit Portal
- Shaft Collar
- Stope Surface Opening
- Topographic Contour (10 ft. interval)

RED DEVIL MINE

Red Devil, Alaska

Figure 1-7
Surficial Geology and Underground Workings

0 50 100 200 300 400 500 Feet
0 25 50 100 150 Meters
Scale 1:3,000