3 Physical Characteristics of the Study Area

This chapter presents information on the physical characteristics of the media of interest at the RDM based on field observations, measurements, and selected chemical analyses, as well as topography, historical aerial and land based photographs, and other historical information. The information provided in this section augments the background information presented in Section 1.4.3.

3.1 Soil

Native soils at the site consist of loess, soils derived from Kuskokwim group bedrock and alluvial deposits associated with the Kuskokwim River and Red Devil Creek. Non-native materials at the site comprise various types of mining and ore processing wastes and fill. Mining waste at the site comprises waste rock and dozed and sluiced overburden. Ore processing waste primarily consists of tailings (here defined as thermally processed ore, also known as calcines, burnt ore, and retorted ore) and flotation tailings. Native materials have been removed, disturbed, relocated, covered, and/or mixed with other native soils and/or mine waste and tailings and fill locally across the site. These native soils, mine and ore processing wastes, and their distribution at the RDM are discussed further below.

3.1.1 Native Soils

Soils derived from the weathering of Kuskokwim group bedrock contain silt, sand, and gravel derived from the underlying greywacke and argillite bedrock. Soil derived from the Kuskokwim group is found in both disturbed and undisturbed areas of the site. Undisturbed occurrences of Kuskokwim group–derived soils are present throughout much of the upland areas west of the Main Processing Area.

Kuskokwim Group–derived soil.

Loess commonly overlies soil derived from the Kuskokwim group bedrock. The loess deposits are buff, light brown, or gray colored and friable. Undisturbed deposits were reported to range from a few inches to about 30 feet in thickness and commonly lack bedding.


Loess near the Main Processing Area

Kuskokwim River alluvial 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. Kuskokwim River alluvium was also encountered in RI soil borings beneath the Red Devil Creek delta and the Dolly and Rice Sluice deltas, as discussed further below. Those soils are described in Section 3.1.3. Physical characteristics of Kuskokwim River sediment from shoreline and offshore locations are described in Section 3.3.2.

Red Devil Creek alluvium occurs within the present Red Devil Creek channel and floodplain upstream of the Main Processing Area, and locally beneath other soil types. Sediment in Red Devil Creek within the Main Processing Area includes Red Devil Creek alluvium locally mixed with mine and ore processing waste materials. Red Devil Creek alluvium is composed of mixtures of silt, sand, and predominantly sub-angular to sub-rounded gravel. Fine materials in the alluvium within the present Red Devil Creek channel contain organic matter and display a medium to dark brown color. Soils interpreted as Red Devil Creek alluvium were encountered in several RI soil borings within the Main Processing Area. These soils consist of mixtures of silt, sand, and gravels with olive to brown color.

3.1.2 Mining and Ore Processing Wastes

Historical information on mine and ore processing waste types at the RDM is presented in Section 1.4.2.3. Additional information gathered on these materials is presented below.

Waste Rock

Waste rock has not undergone thermal processing and, as such, the common sulfide minerals at the RDM—cinnabar, stibnite, realgar, and orpiment—are commonly observed in waste rock material. Waste rock at the RDM typically consists predominantly of large angular gravel and sand composed of Kuskokwim group argillite and greywacke with lesser dike material.

Dozed and Sluiced Overburden

Overburden 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. Material observed in the deltas consists of mixtures of silt, sand, and gravel. Gravel consists of clasts of greywacke and argillite of the Kuskokwim Group.

Tailings

Thermally processed mercury ore is often a rusty red color due to oxidation of iron within the rock. Review of historical photographs also suggests that not all tailings at the RDM may possess the rusty red color. Historical photographs of the Post-1955 furnace area show small piles of rusty red materials that are believed to be tailings. A remnant pile of rusty red rock in the Post-1955 Main Processing Area was examined during the RI. In addition to the distinctive rusty red color, some of the fragments of the material exhibit visible porosity. Presence of similar rusty red porous rock (hereafter referred to as red porous rock) and/or rock fragments with a distinctive red oxidation rind elsewhere at the RDM is interpreted to indicate the likely presence of tailings.

Flotation Tailings

Flotation tailings at the RDM were observed in Settling Ponds #1, #2, and #3, and consist predominantly of light to dark gray or brown silt and very fine to fine sand.

Other Mine Wastes

Other wastes generated during mining operations include the dust and generated during the furnacing operations, as discussed Sections 1.4.2.2 and 1.4.2.3. Brown vitreous material fused to red porous rock (tailings) and other rock materials were identified during the RI. No dust materials were observed during the RI. Mercury vapor and particulates that did not accumulate in the furnaces, condensing system, or other components of the processing system may have discharged from the stack and precipitated in the vicinity of the mine. According to the 1999 Limited Waste Removal Action Report, the highest mercury concentrations were identified in the vicinity of the retort exhaust port (Wilder/HLA 1999).

3.1.3 Identification and Present Distribution of Soil Types

The distribution and arrangement of soils and mine and ore processing wastes at the site plays a significant role in determining the nature and extent of contamination, and the fate and transport of contaminants in the environment at the RDM. The identification and extent of soils and mine and ore processing waste types at the RDM are confounded by the mixing of mine and ore processing waste, and removal, disturbance, redistribution, and covering of materials of various types across much of the site. Tailings and waste rock were deposited at various locations at the site during mining and mineral processing operations and subsequently redistributed for disposal or use as construction fill and road base. For much of the mine's operational history, it appears that waste rock and tailings were generated and disposed of in close proximity at the ore processing facilities. As a result, with few exceptions, tailings and waste rock appear commonly to be mixed within the disposal areas on both the Pre-1955 and Post-1955 Main Processing Areas.

Native soils have been removed by mining; disturbed, redistributed, and mixed by dozing, trenching, and road and building construction; covered by other native soils or mine waste; and sluiced. Both native soils and mine wastes are also subject to redistribution by erosion and transport downslope and by alluvial processes in Red Devil Creek and the Kuskokwim River. In addition to the complexities introduced by the reworking of soils and mine wastes, waste rock and portions of tailings, which ultimately derive from Kuskokwim group bedrock, share characteristics of native soils and sediments that are also derived from Kuskokwim group bedrock.

Given the complexities outlined above, multiple lines of evidence were required to identify soil types and define their extent. These lines of evidence consist primarily of:

- Analysis of historical and recent aerial and land-based photographs.
- Analysis of historical and recent (2001) topography.
- Review of historical geologic and other maps.
- Review of reports of historical mining and ore processing activities.
- Lithological analysis of soil samples.
- XRF and laboratory analysis of metals concentrations.
- Results of a geophysical survey completed by USGS (Burton and Ball 2011).

Detailed lithological analysis was performed for laboratory samples and at XRF field screening locations. In addition to typical lithological description characteristics, the presence or absence of key minerals or materials was noted. These key components include red porous rock (tailings indicator); cinnabar, stibnite, realgar, and orpiment (indicative of waste rock where it occurs in mine waste and where red porous rock is absent); and vitreous material (associated with tailings).

Each surface and subsurface soil sample collected as part of the RI was assigned a site-specific soil type (hereafter, soil type). The assigned soil types for each sample are summarized in Tables A-2 through A-9 (Appendix A). The generalized distribution of soil types on the surface is illustrated in Figure 3-1. Geologic cross-sections illustrating soil type and other geologic features in the subsurface are presented in Figures 3-3 through 3-8. A cross-section reference map is presented in Figure 3-2. The soil types identified in Tables A-2 though A-9 and presented in Figure 3-1 and the geologic cross sections are described in Table A-1.

Key observations regarding the distribution of mining and ore processing wastes at the RDM are presented below:

- Accumulations of tailings/waste rock materials are present in dumps in the vicinity of both the Pre-1955 and Post-1955 Processing Areas (Figures 3-3, 3-4, 3-5, and 3-6), consistent with historical information regarding the locations of such dumps.
- Tailings and waste rock are largely mixed in the dumps at both the Pre-1955 and Post-1955 Processing Areas. Dump material in a portion of the Pre-1955 Processing Area appears to be waste rock with no discernible tailings (Figures 3-5 and 3-6).

- Tailings/waste rock material was identified in soil borings 11MP35SB and 11SB39SB (north of Settling Pond #2) and 11MP40SB (north of Settling Pond #3. Tailings/waste rock in these areas is likely reworked material originally deposited in the “Saw dust dump” identified in the 1963 geologic map (Figure1-7) associated with the Pre-1955 Processing Area (Figures 3-3 and 3-7.
- Material used to construct the berm of Settling Pond #1 appears to be tailings/waste rock material, flotation tailings, and fill/debris (Figure 3-3).
- Flotation tailings are largely limited to the basins of Settling Ponds #1, #2, and #3 (Figures 3-3 and 3-7). Flotation tailings were tentatively identified in a single subsurface soil interval in boring 11MP38 SB, located north of Settling Pond #1.
- Tailings/waste rock materials, mixed to varying degrees with Red Devil Creek alluvium and/or soil, is locally present in the Red Devil Creek channel within and downstream of the Main Processing Area (Figures 3-4, 3-5, 3-7, and 3-8). Such materials are present in the Red Devil Creek delta (Figures 3-3 and 3-8).
- Sluiced overburden is present in fans or deltas in the Kuskokwim River at the Rice Sluice Delta and Dolly Sluice Delta (Figure 3-8).
- Dozed overburden consisting of soil derived from Kuskokwim Group bedrock and/or loess is present in the Surface Mined Area (Figures 3-4 and 3-7).

3.2 Hydrogeology

Monitoring wells were installed during the RI to assess groundwater conditions at the RDM. Monitoring wells were installed to depths ranging from 15 to 70 feet below the top of well casings. Well construction information is summarized in Table 3-1. Groundwater was observed during drilling in unconsolidated materials and bedrock at the depths indicated in Table 3-1. Following well completion and development, static water levels were measured in RI and existing monitoring wells. Static water levels were measured on two occasions for each well during the 2011 field event: once on the day of groundwater sampling immediately before sample collection, and again during a site-wide water level measurement event on September 1, 2011. With the exception of the pre-RI monitoring wells, the wells were sampled between August 29 and September 1, 2011. The pre-RI wells were sampled between August 22 and 26, 2011. Static water levels were measured in existing monitoring wells during the 2010 LSE. Measured static water levels and elevations are summarized in Table 3-1. Static water levels range from approximately 4 to 63 bgs across the site.

Based on static water elevations, stream elevations, and discharge measurements along Red Devil Creek, a potentiometric surface map was developed, presented in Figure 3-9. As the groundwater elevation contours indicate, groundwater at the site generally flows toward Red Devil Creek and the Kuskokwim River, with groundwater elevations generally mimicking topography.

Table 3-1 Well Construction and Groundwater Depth Information

Monitoring Well ID	Soil Boring ID	Total Well Depth (feet below TOC)	Screened Interval (feet bgs)	Ground Elevation (feet AMSL)	Top of Casing Elevation (feet AMSL)	GW Encountered During Drilling	Ground Water Measurements			Ground Water Elevation (feet AMSL)
							Depth (feet from TOC)	Date	Time	
MW01	N/A	29.70	19.0 - 29.0	254.51	257.51	17.8 - TD	19.55	9/1/2011	16:03	237.96
							19.46	8/24/2011	16:38	238.05
							20.04	9/20/2010	18:18	237.47
							22.27	10/6/2009	17:30	235.24
							19.62	6/19/2009	NR	237.89
							22.16	9/18/2008	13:28	235.35
							19.87	9/5/2007	13:15	237.64
							21.72	8/14/2000	NR	235.79
MW03	N/A	27.73	14.5 - 25.5	228.37	230.77	19.0 - TD	19.96	9/1/2011	15:41	210.81
							19.44	8/26/2011	10:18	211.33
							20.95	9/20/2010	19:50	209.82
							23.01	10/7/2009	13:20	207.76
							19.51	6/19/2009	NR	211.26
							22.57	9/18/2008	14:11	208.20
							20.68	9/5/2007	14:40	210.09
							22.28	8/14/2000	NR	208.49

Table 3-1 Well Construction and Groundwater Depth Information

Monitoring Well ID	Soil Boring ID	Total Well Depth (feet below TOC)	Screened Interval (feet bgs)	Ground Elevation (feet AMSL)	Top of Casing Elevation (feet AMSL)	GW Encountered During Drilling	Ground Water Measurements			Ground Water Elevation (feet AMSL)
							Depth (feet from TOC)	Date	Time	
MW04	N/A	32.9	20.0 - 30.0	239.92	242.12	25.3 - TD	25.99	9/1/2011	15:00	216.13
							25.24	8/22/2011	16:02	216.88
							26.79	9/20/2010	16:09	215.33
							27.77	10/6/2009	18:55	214.35
							25.43	6/19/2009	NR	216.69
							26.82	9/18/2008	12:32	215.30
							26.78	9/5/2007	12:25	215.34
							27.77	8/14/2000	NR	214.35
MW06	N/A	26.14	13.0 - 23.0	214.99	217.49	20.0 - TD	18.70	9/1/2011	15:09	198.79
							18.78	8/24/2011	14:56	198.71
							19.03	9/20/2010	13:22	198.46
							19.29	10/7/2009	17:25	198.20
							17.90	6/19/2009	NR	199.59
							19.08	9/18/2008	11:35	198.41
							18.63	9/5/2007	15:30	198.86
							19.29	8/14/2000	NR	198.20

Table 3-1 Well Construction and Groundwater Depth Information

Monitoring Well ID	Soil Boring ID	Total Well Depth (feet below TOC)	Screened Interval (feet bgs)	Ground Elevation (feet AMSL)	Top of Casing Elevation (feet AMSL)	GW Encountered During Drilling	Ground Water Measurements			Ground Water Elevation (feet AMSL)
							Depth (feet from TOC)	Date	Time	
MW07	N/A	23.70	11.0 - 21.0	278.39	280.89	14.8 - TD	19.97	9/1/2011	16:14	260.92
							19.51	8/26/2011	9:12	261.38
							20.40	9/21/2010	10:20	260.49
							DRY	10/7/2009	NR	DRY
							20.10	6/19/2009	NR	260.79
							DRY	9/18/2008	NR	DRY
							20.42	9/5/2007	14:00	260.47
							DRY	8/14/2000	NR	DRY
MW08	11MP01SB	16.0	5.0 - 15.0	328.92	331.32	2.5 - 4.0	13.65	9/1/2011	16:28	317.67
						10.5 - TD	13.70	8/30/2011	9:21	317.62
MW09	11MP17SB	31.0	20.0 - 30.0	274.88	277.28	14.0 - 16.0	28.11	9/1/2011	16:43	249.17
						31.0 - TD	>31.56	8/29/2011	18:21	DRY
MW10	11MP14SB	61.0	50.0 - 60.0	274.31	276.21	48.0 - TD	29.17	9/1/2011	16:38	246.37
							30.60	8/29/2011	16:15	245.61
MW11	11MP12SB	23.0	12.0 - 22.0	268.70	271.30	dry	DRY	9/1/2011	16:34	DRY
							DRY	8/29/2011	> 12:00	DRY
MW12	11RD13SB	15.0	4.0 - 14.0	263.22	265.62	1.0 - TD	3.70	9/1/2011	16:20	261.92
							3.72	8/31/2011	13:34	261.90
MW13	11MP20SB	32.0	21.0 - 31.0	274.30	276.70	27.0 - TD	29.70	9/1/2011	16:09	247.00
							30.05	8/30/2011	18:04	246.65
MW14	11MP25SB	36.0	25.0 - 35.0	246.71	249.01	25.7 - TD	30.01	9/1/2011	16:00	219.00

Table 3-1 Well Construction and Groundwater Depth Information

Monitoring Well ID	Soil Boring ID	Total Well Depth (feet below TOC)	Screened Interval (feet bgs)	Ground Elevation (feet AMSL)	Top of Casing Elevation (feet AMSL)	GW Encountered During Drilling	Ground Water Measurements			Ground Water Elevation (feet AMSL)
							Depth (feet from TOC)	Date	Time	
							30.51	8/31/2011	10:05	218.50
MW15	11MP29SB	26.0	15.0 - 25.0	242.63	244.93	16.2 - TD	19.59	9/1/2011	15:56	225.34
							19.64	8/30/2011	10:35	225.29
MW16	11MP30SB	22.0	11.0 - 21.0	226.09	228.09	16.0 - TD	14.90	9/1/2011	15:50	213.19
							13.84	8/30/2011	11:35	214.25
MW17	11MP91SB	52.5	41.5 - 51.5	226.36	228.66	25.0 - 33.0	13.78	9/1/2011	15:52	214.88
						33.0 - TD	15.00	8/30/2011	9:20	213.66
MW18	11MP31SB	40.0	29.0 - 39.0	241.33	243.83	38.0 - TD	29.87	9/1/2011	15:37	213.96
							29.66	8/31/2011	15:47	214.17
MW19	11MP33SB	43.0	32.0 - 42.0	237.70	240.00	39.0 - TD	19.47	9/1/2011	15:32	220.53
							19.38	9/1/2011	9:34	220.62
MW20	11MP38SB	15.5	4.5 - 14.5	212.90	215.20	6.5 - TD	6.97	9/1/2011	15:43	208.23
							6.89	8/31/2011	8:53	208.31
MW21	11MP39SB	17.5	6.5 - 16.5	208.23	210.13	7.0 - TD	8.82	9/1/2011	17:10	201.31
							8.80	8/31/2011	10:16	201.33
MW22	11MP40SB	15.5	4.5 - 14.5	203.10	205.10	7.8 - TD	8.48	9/1/2011	17:04	196.62
							8.20	8/31/2011	11:08	196.90
MW23	11MP66SB	29.0	18.0 - 28.0	201.96	204.16	20.0 - TD	16.01	9/1/2011	15:14	188.15
							16.02	8/30/2011	16:31	188.14
MW24	11MP62SB	30.0	19.0 - 29.0	221.41	223.51	20.0 TD	17.61	9/1/2011	15:06	205.90
							17.70	8/30/2011	14:51	205.81

Table 3-1 Well Construction and Groundwater Depth Information

Monitoring Well ID	Soil Boring ID	Total Well Depth (feet below TOC)	Screened Interval (feet bgs)	Ground Elevation (feet AMSL)	Top of Casing Elevation (feet AMSL)	GW Encountered During Drilling	Ground Water Measurements			Ground Water Elevation (feet AMSL)
							Depth (feet from TOC)	Date	Time	
MW25	11MP89SB	42.0	31.0 - 41.0	237.56	239.76	32.0 - TD	31.88	9/1/2011	14:50	207.88
							31.85	8/30/2011	18:02	207.91
MW26	11MP52SB	43.0	32.0 - 42.0	244.03	245.93	34.0 - TD	36.30	9/1/2011	14:47	209.63
							36.25	8/30/2011	11:35	209.68
MW27	11MP60SB	34.0	23.0 - 33.0	241.04	242.94	29.0 - TD	30.37	9/1/2011	14:58	212.57
							30.30	8/30/2011	16:50	212.64
MW28	11MP88SB	64.0	53.0 - 63.0	239.94	241.94	49.0 - TD	28.61	9/1/2011	14:53	213.33
							25.50	8/30/2011	14:57	216.44
MW29	11MP41SB	70.0	59.0 - 69.0	280.35	282.25	61.0 - TD	63.21	9/1/2011	13:20	219.04
							63.21	9/1/2011	13:28	219.04
MW30	11SM31SB	53.0	42.0 - 52.0	275.71	277.41	45.0 - TD	53.53	9/1/2011	14:35	223.88
							53.44	9/1/2011	15:41	223.97
MW31	11UP11SB	44.8	33.8 - 43.8	495.79	497.99	34.0 - TD	37.51	9/1/2011	14:05	460.48
							37.75	8/29/2011	13:51	460.24
MW32	11RD05SB	25.0	14.0 - 24.0	194.38	196.58	16.5 - TD	18.86	9/1/2011	15:26	177.72
							18.90	8/31/2011	15:55	177.68
MW33	11RD20SB	23.0	12.0 - 22.0	176.62	178.92	10.5 - TD	8.19	9/1/2011	15:20	170.73
							8.14	8/31/2011	17:57	170.78
MW34	AST5 MW1	NR	NR	290.95	294.25		15.57	9/1/2011	16:49	278.68
MW35	AST5 MW2	NR	NR	285.76	289.26		41.97	9/1/2011	16:55	247.29
MW36	AST5 MW3	NR	NR	286.33	290.03		35.81	9/1/2011	16:57	254.22

Table 3-1 Well Construction and Groundwater Depth Information

Monitoring Well ID	Soil Boring ID	Total Well Depth (feet below TOC)	Screened Interval (feet bgs)	Ground Elevation (feet AMSL)	Top of Casing Elevation (feet AMSL)	GW Encoun-tered During Drilling	Ground Water Measurements			Ground Water Elevation (feet AMSL)
							Depth (feet from TOC)	Date	Time	

Notes

Elevations are NAVD88 computed using GEOID09.

Key

AMSL	Above Mean Sea Level
bgs	Below ground surface
ID	identifier
NR	Not Recorded
TD	Soil Boring Total Depth
TOC	Top of Casing

3.2.1 Groundwater Flow

Groundwater flow at the RDM is complicated due primarily to complex modification of the natural hydrogeologic environment at the site, including extensive surface and underground mining and disposal of mine waste. In order to evaluate groundwater flow at the site, the following were evaluated:

- Historical and recent aerial and land-based photographs
- Historical and recent (2001) topography
- Historical geologic maps
- Historical maps and sections of underground mine workings.
- Reports of historical mining and ore processing activities
- XRF and laboratory analysis of metals concentrations of soil materials.
- Data obtained during soil boring installation, including lithology and moisture content.
- Major ion chemistry of groundwater and surface water samples.
- Trace element chemistry of groundwater and surface water samples.
- Static water level measurements in monitoring wells.
- Red Devil Creek stream elevations.
- Red Devil Creek stream discharge measurements.
- Results of a geophysical survey completed by USGS (Burton and Ball 2011).

Specific aspects of the groundwater flow regime at the RDM are discussed below.

3.2.2 Stream Gain and Loss

Based on the groundwater elevations in monitoring wells, elevations of Red Devil Creek, and stream flow gauging (see Section 3.3), groundwater generally flows toward Red Devil Creek locally and toward the Kuskokwim River on a more regional scale, generally mimicking topography. Red Devil Creek is a generally gaining stream over most of its length below the reservoir dam.

Exceptions consist of two areas where Red Devil Creek exhibited losing conditions. Static water level measurements taken in monitoring wells, stream elevation, and stream flow measurements (see Section 3.3) in late August and again on September 1, 2011, indicate that Red Devil Creek was a losing stream at those times in the area of a former culvert and road crossing that provided access between the Pre-1955 and Post-1955 portions of the Main Processing Area during mining operations. The lowermost section of Red Devil Creek at the delta is likely a losing reach under most conditions, particularly at low Kuskokwim River levels. Stream gain/loss is discussed further in Section 3.3 below.

3.2.3 Hydraulic Segregation

Unconsolidated overburden and bedrock saturated zones appear to be in communication on the scale of the site, although some hydrologic hydraulic compartmentalization exists locally.

Thin perched groundwater zones above apparently low permeability unconsolidated zones were identified during drilling at the following soil boring locations:

- MP01 / MW08
- MP17 / MW09
- MP29 / MW15
- MP32
- MP56

Monitoring well MW15 was screened within the perched saturated zone. For this reason, the static water level in this well is disregarded in the potentiometric surface map (Figure 3-9). Wells installed in the other borings listed above were screened within deeper saturated zones that are expected to be continuous.

Weathered bedrock locally exhibits clay and silt filling fractures. Where this occurs, the top of weathered bedrock may comprise a low permeability zone locally. A thin saturated zone was observed during drilling at the contact between unconsolidated materials and underlying weathered bedrock with such fracture filling at MP14 / MW10. The well installed in boring MP14 was screened within a deeper saturated interval in bedrock.

In several cases, groundwater was observed in saturated zones overlying the bedrock, but drilling was not advanced deeper than these zones. As such, it is not known whether the saturated zones encountered are perched or in hydraulic communication with bedrock. The following soil borings were installed at such locations:

- MP25 / MW14
- MP34
- MP35

3.2.4 Bedrock Fracture Flow

Groundwater within the Kuskokwim Group bedrock unit appears to occur primarily within fractured bedrock. During drilling of RI soil borings in Kuskokwim Group bedrock, commonly little or no groundwater was observed until a transmissive fracture was penetrated at some depth below the static water level that was eventually established in the completed monitoring well. In the following soil borings (and wells) that were screened within bedrock, the static water level on September 1, 2011 was at a higher elevation than the groundwater encountered during drilling:

- MP14 / MW40
- MP17 / MW09
- MP31 / MW18
- MP33 / MW19

- MP62 / MW24
- MP66 / MW23
- MP88 / MW28
- MP89 / MW25
- MP91 / MW17
- RD20 / MW33

Static water levels in the following bedrock wells were at approximately the same elevation as the first occurrence of groundwater observed during drilling:

- MP20 / MW13
- MP41 / MW29
- MP52 / MW26
- RD05 / MW32
- UP11 / MW31

3.2.5 Vertical Gradient

Based on static water levels measured in the following paired shallow and deep wells, there is an upward vertical gradient from bedrock at those locations:

- MW16 (shallow) / MW17 (deep)
- MW27 (shallow) / MW28 (deep)

3.2.6 Underground Mine Workings

The presence of an extensive network of underground mine workings at the site likely exerts a significant influence over groundwater flow at the RDM. The mine workings appear to provide a highly transmissive groundwater flow network that connects a large area west of and underlying the Main Processing Area.

As indicated in Figure 3-9, static water elevations are somewhat depressed in the area of underground mine workings. This is likely attributable to a “French drain” effect of the mine workings. Groundwater within the mine workings likely readily drains from the mine to the highest nearby base level, which is the level of Red Devil Creek. Such groundwater migration would occur via the mine workings network and bedrock fractures. A map illustrating the configuration of the underground mine workings as of 1962 (Malone 1962 and MacKevett and Berg 1963) is presented in Figure 1-7. Information from a 1962 mine workings cross section is projected onto geologic cross section B-B’ (Figure 3-4). These historical mine documents indicate that overhand stopes were driven from the 200 level (see Figure 1-7), also referred to as the 150 level (see Figure 3-4), to near the surface in the vicinity of Red Devil Creek. Stoping followed the ore shoots, which are associated with fracture systems. As such, bedrock fractures associated with the stopes likely extend to the top of bedrock in the vicinity. Groundwater from the mine workings may be expected to migrate from the stopes up the fractures to the top of bedrock. The 1962 mine workings map and cross section also indicate stoping upward from the 73 level (Figure 1-7), also referred to as the 70 level (Figure

3-4), to near the surface in the Pre-1955 Main Processing Area. These mine workings may also represent preferential groundwater flow pathways.

Results of a geophysical survey conducted by the USGS (Burton and Ball 2011) at the RDM site using surface-based, direct-current resistivity and electromagnetic induction methods, support the presence of stopes near the surface. The resistivity results indicated the presence of several anomalies in the subsurface along Red Devil Creek in the Main Processing Area, including two anomalies that appear likely to be associated with underground mine workings. Anomaly D is interpreted to be an elongate conductive anomaly that underlies Red Devil Creek for a distance of at least 60 meters (m). Anomaly E is interpreted to be a "discrete, nearly vertical, conductive anomaly that extends to within 2 m of the surface (anomaly E) that is closer to the creek level and has a character more indicative of a point source." Anomaly E is in close proximity to the seep on the left bank of Red Devil Creek. The approximate locations of these resistivity anomalies are shown in geologic cross sections (Figures 3-4 and 3-5).

During both the 2010 and 2011 field seasons, yellowboy was present at the seep location. During the 2011 field season, yellowboy was also observed on the stream's northern bank between the seep and approximately 20 feet upstream of the seep, suggesting a relationship between baseflow in this area and the focused flow at the seep. The source(s) of groundwater that emanates from the seep is not clear, but may include groundwater flowing from the mine workings via fractures.

Further discussion of groundwater conditions in the Main Processing Area, including the area of the seep, is provided in Chapters 4 and 5.

3.3 Surface Water Hydrology and Sediment

3.3.1 Red Devil Creek

As described in Section 1.4.3.4, Red Devil Creek drains an area of approximately 687 acres and is one of the smaller tributaries of the Kuskokwim River in the region. The reach of the creek extending from the reservoir dam to the Kuskokwim River is approximately 2,500 linear feet and varies with the stage of the Kuskokwim River. Red Devil Creek forms a relatively broad delta at its confluence with the Kuskokwim River. The delta extends into the channel of the Kuskokwim River. The creek flows through the Main Processing Area. The creek channel has evidently migrated over time due emplacement of mine waste materials into the stream bed in the Main Processing Area. The channel has likely also migrated as a result of heavy sediment loading downstream. Figure 1-7 illustrated the positions of the stream channel as of 1963 and 2001.

Red Devil Creek at sample station RD06.

Stream Gradient

Red Devil Creek has an average gradient of approximately 5 percent between the reservoir dam and the Kuskokwim River. The elevation profile of Red Devil Creek is illustrated in Figure 3-10. Key features of Red Devil Creek are illustrated on Figures 1-3 and 1-5. The creek's gradient is relatively consistent along this reach, except for two noteworthy sections within the Main Processing Area where gradient the stream gradient flattens and then abruptly steepens to approximately 10 percent. These sections are discussed further below.

The upper of these two sections is located between approximately 1,250 and 1,400 linear feet downstream of the reservoir dam (Figure 3-10). This section is centered at the former culvert and road across Red Devil Creek. During mine operations, a culvert and road provided access between the Pre-1955 and Post-1955 portions of the Main Processing Area. The former road and culvert have since been destroyed. The remnants of the fill around the culvert presently comprise a small impoundment that marks the lower end of the low gradient portion of Red Devil Creek between approximately 1,250 and 1,300 feet downstream of the reservoir. The high gradient portion of Red Devil Creek downstream (between approximately 1,300 and 1,400 feet downstream of the reservoir) is likely underlain by a wedge of material consisting of tailings and waste rock that has slumped into the creek and the fill material that formerly covered the culvert, and which is gradually being eroded and transported downstream (Figure 3-5).

The second of the two sections of coupled lower and higher gradient is located between approximately 1,600 and 1,750 linear feet downstream of the reservoir dam(Figure 3-10). The low gradient portion comprises the present road crossing through the stream. The short high gradient portion is located immediately downstream of the road crossing.


The Red Devil Creek delta on the Kuskokwim River.

Stream Discharge

Discharge was measured on August 18, 2011, at locations along Red Devil Creek that are collocated with sediment and surface sampling stations. Table 3-2 summarizes the discharge data for Red Devil Creek.

Table 3-2 2011 Red Devil Creek Discharge

Measurement Location	Discharge (cubic feet/second)	Linear Distance Below Reservoir Dam (feet)
RD03SW	4.09	830
RD10SW	5.52	1,005
RD04SW	5.95	1,230
RD05SW (seep)	0.18	1,488
RD12SW	8.24	1,495
RD09SW	5.98	1,678
RD06SW	6.81	1,899
RD07SW	7.61	2,132
RD08SW	7.19	2,507

The calculated discharge rate at station RD12SW is believed to be inaccurate. Station RD12SW is located at the road stream crossing, where the stream is broad and shallow, making water velocity measurements difficult and subject to error.

The mouth of Red Devil Creek at the Kuskokwim River, September 2010.

Discharge conditions in Red Devil Creek were relatively high during the 2011 field investigation, due mainly to high precipitation levels prior to and during the collection of discharge data. This may account for the discrepancy in measurements collected in 2011 compared to the historical reported discharge of 0.5 cfs measured in 1999 (see Section 1.4.3.4). Discharge in Red Devil Creek is expected to be highly variable according to season and is expected to range from near zero discharge during the winter months when the watershed is frozen, to the levels measured during the RI in 2011, and possibly greater levels during peak spring runoff periods (i.e., breakup).

Stream Gain and Loss

The section of Red Devil Creek in the vicinity of the former culvert discussed above appears to be subject to losing conditions. The stream elevation profile, in conjunction with static water level measurements taken in monitoring wells, and the stream flow measurements collectively indicate that Red Devil Creek was a losing stream at the times the measurements were taken in late August/early September 2011. Below this losing reach, the stream again exhibited gaining conditions in late August/early September 2011. By surface water station RD09SW, the stream appeared to regain the flow lost in the section below the former culvert.

The flow in this section appears to be regained primarily through baseflow. Some of the flow in this section could potentially be regained at a seep located on the northern bank of the creek in the central portion of the Main Processing Area, at sample station RD05. The seep is approximately 3 feet above the creek level and discharges from coarse gravelly material. The measured discharge at the seep was 0.18 cfs, comprising only a small fraction of flow in this section of Red Devil Creek. Alternatively, the seep may not be associated with

The lowermost section of Red Devil Creek at the delta is likely a losing reach under most conditions, particularly at low Kuskokwim River levels. The decrease in discharge between stations RD07SW and RD08SW suggests that that section was losing at the time of the stream gauging event.

Stream Substrate

The substrate of Red Devil Creek upstream of the Main Processing Area is composed primarily of natural alluvium. From the Main Processing Area downstream to the Kuskokwim River, the creek substrate is dominated by the tailings and waste rock. Table 3-3 presents the grain size distribution of sediment samples collected from Red Devil Creek. Results are presented starting with upstream samples and moving downstream.

Seep

As discussed above, during both the 2010 and 2011 field seasons, yellowboy was present at the seep location RD05. During the 2011 field season, yellowboy was also observed on the stream's northern bank between the seep and approximately 20 feet upstream of the seep, suggesting a relationship between baseflow in this area and the focused flow at the seep. The source of groundwater that emanates from the seep is unclear

.

Table 3-3 Red Devil Creek Grain Size Data

Sample Identification	Percent[1] Gravel (4.75–75 mm)	Percent Coarse Sand (2–4.75 mm)	Percent Medium Sand (0.425–2 mm)	Percent Fine Sand (0.075–0.425 mm)	Percent Fines (silt and clay >0.075 mm)	Description
10RD01SD	32.7	19.3	11.8	12	24.1	Gravelly Sand
10RD02SD	0.2	1.6	3.4	12.8	82	Sandy Silt
10RD03SD	34.7	16.1	20.4	10	18.8	Gravelly Sand
11RD11SD	0.3	0.1	3.5	63.9	30.3	Silty Sand
11RD10SD	71.6	10.9	9.83	5.68	2.12	Sandy Gravel
10RD04SD	14.8	40.8	35	2.5	6.8	Gravelly Sand
10RD05SD	4.3	2	5.4	3.8	84.8	Sandy Silt
11RD12SD	83.7	10.79	3.2	0.33	1.95	Sandy Gravel
10RD09SD	15.2	34.1	39.8	2.6	8.4	Gravelly Sand
10RD06SD	22.7	28.2	29.6	4.2	15.3	Gravelly Sand
10RD07SD	14.6	20.2	38	6.5	20.7	Silty Sand
10RD08SD	20.6	26.2	34.6	5.6	13	Gravelly Sand

Notes:
1 – Rocks and cobbles were removed from collected sample material which biases these results toward finer grain size distributions.
Key:
mm = millimeters

3.3.2 Kuskokwim River

Kuskokwim River shoreline sediment.

Discharge in the Kuskokwim River at the RDM site was not measured during the RI field investigations. However, the USGS maintains a river gauging station at Crooked Creek, located approximately 35 river miles downstream of the RDM. The discharge maximum during the 2011 summer season occurred on August 16, 2011, and was recorded at 99,200 cfs. River discharge during the Kuskokwim River off-shore sediment sampling event, conducted between September 21 and 25, 2011, ranged from 47,300 to 51,600 cfs, with river discharge levels decreasing during the sampling period (Burton and Ball 2011).

During the 2011 Kuskokwim River off-shore sediment sampling event, river depth soundings were collected to generate a bottom profile of the river in the near shore zone adjacent to the RDM. Figure 3-11 presents the near shore bathymetry of the Kuskokwim River based on these data.

Table 3-4 presents the grain size distribution of sediment samples collected from the Kuskokwim River. Results are presented starting with upstream samples moving downstream.

Table 3-4 Kuskokwim River Grain Size Data

Sample Identification	Percent[1] Gravel (4.75–75 mm)	Percent Coarse Sand (2–4.75 mm)	Percent Medium Sand (0.425–2 mm)	Percent Fine Sand (0.075–0.425 mm)	Percent Fines (silt and clay >0.075mm)	Description
Shoreline Sediment Samples						
11KR01SD	73.2	11.96	6.62	6.06	1.66	Sandy Gravel
11KR12SD	63.55	8.37	6.85	5.66	17.93	Sandy Gravel
10KR13SD	17.2	6.6	4.9	28.5	42.8	Sandy Silt
11KR14SD	20.65	2.57	5.29	35.05	43.92	Sandy Silt
11KR15SD	59.77	10.61	8.34	9.32	13.29	Sandy Gravel
10KR02SD	11.2	19.7	41.7	9.3	18	Silty Sand
11KR16SD	0.01	0.08	1.06	15.9	98.32	Sandy Silt
10KR03SD	0.4	0.2	0.3	6.8	92	Sandy Silt
10KR04SD	2.6	1.4	1.2	28.1	66.6	Sandy Silt
11KR05SD	13.6	12.91	11.55	36.16	26.63	Silty Sand
11KR06SD	0	0.33	0.92	39.06	70.13	Sandy Silt
10KR07SD	6.3	21.6	32.8	17.9	21.5	Silty Sand
11KR08SD	0.07	1.58	5.96	46.19	50.71	Silty Sand
11KR09SD	2.97	4.27	4.93	44.26	52.92	Sandy Silt
10KR10SD	23.1	15.9	13.9	23.9	23.2	Silty Sand
10KR11SD	6.9	4.7	2.2	44.4	41.7	Silty Sand
11KR17SD	6.24	7.84	12.93	31.16	49.41	Sandy Silt
Off-Shore Sediment Samples						
11KR48SD	61.37	4.52	4.13	19.06	12.36	Sandy Gravel
11KR49SD	77.58	5.97	3.05	12.99	1.26	Sandy Gravel
11KR50SD	59.73	7.87	5.68	20.04	7.31	Sandy Gravel
11KR51SD	60.66	11.28	8.73	13.45	6.37	Sandy Gravel
11KR53SD	0.12	3.86	12.70	41.25	45.53	Silty Sand
11KR18SD	42.46	3.68	2.43	13.74	41.56	Silty Gravel

Table 3-4 Kuskokwim River Grain Size Data

Sample Identification	Percent[1] Gravel (4.75–75 mm)	Percent Coarse Sand (2–4.75 mm)	Percent Medium Sand (0.425–2 mm)	Percent Fine Sand (0.075–0.425 mm)	Percent Fines (silt and clay >0.075mm)	Description
11KR19SD	78.8	6.2	3.1	6.04	6.04	Sandy Gravel
11KR20SD	73.0	6.1	7.8	11.87	0.97	Sandy Gravel
11KR21SD	59.9	13.9	13.8	12.4	0	Sandy Gravel
11KR22SD	74.8	2.8	3.9	11.96	6.33	Sandy Gravel
11KR23SD	59.97	10.82	5.01	11.59	14.52	Sandy Gravel
11KR24SD	72.07	9.26	3.43	11.23	7.2	Sandy Gravel
11KR25SD	32.35	5.51	8.19	28.23	25.46	Gravelly Sand
11KR26SD	2.5	2.4	7.9	48.0	45.96	Silty Sand
11KR27SD	69.2	5.5	3.3	21.7	0.19	Sandy Gravel
11KR28SD	77.3	6.2	3.9	5.58	7.39	Sandy Gravel
11KR29SD	73.2	8.10	4.2	5.52	8.8	Sandy Gravel
11KR30SD	93.84	1.97	2.38	1.18	0.63	Sandy Gravel
11KR34SD	92.37	1.71	1.92	2.81	1.97	Sandy Gravel
11KR35SD	93.26	2.59	2.21	1.43	0.42	Sandy Gravel
11KR36SD	0	0	1.1	50.2	58.1	Sandy Silt
11KR37SD	0	0	1.0	46.4	56.94	Sandy Silt
11KR38SD	58.21	11.75	12.2	15.74	1.41	Sandy Gravel
11KR39SD	62.81	8.97	4.61	2.61	20.72	Silty Gravel
11KR40SD	60.9	3.9	2.1	15.2	21.34	Silty Gravel
11KR41SD	67.8	7.1	6.6	17.12	3.09	Sandy Gravel

Table 3-4 Kuskokwim River Grain Size Data

Sample Identification	Percent[1] Gravel (4.75–75 mm)	Percent Coarse Sand (2–4.75 mm)	Percent Medium Sand (0.425–2 mm)	Percent Fine Sand (0.075–0.425 mm)	Percent Fines (silt and clay >0.075mm)	Description
11KR42SD	88.4	3.8	2.0	3.87	2.47	Sandy Gravel
11KR43SD	59.06	10.35	5.24	4.25	25.82	Silty Gravel
11KR44SD	65.8	12.4	4.9	13.06	4.77	Sandy Gravel
11KR45SD	12.7	2.6	13.0	35.8	41.3	Silty Sand
11KR46SD	77.86	7.9	3.8	4.66	5.77	Sandy Gravel
11KR47SD	67.49	10.26	6.54	5.68	11.47	Sandy Gravel

Notes:
1 – Grain size percentages may not total to 100% due to rounding error and different measurement methodology used to determine percent fines.
Key:
mm = millimeters

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- Road
- Red Devil Creek alluvial deposits
- Kuskokwim River alluvial deposits
- Loess and/or disturbed loess mixed with soil derived from the Kuskokwim Group
- Disturbed soils in surface mined area (includes areas of undisturbed native soils)
- Mixed loess, Kuskokwim Group bedrock, and Kuskokwim Group derived soils found in the Dolly and Rice Sluices
- Disturbed native soils
- Sluiced overburden
- Tailings and/or waste rock
- Flotation tailings
- Disturbed native soil with local tailings and/or waste rock and fill along road alignments and other areas of operations
- Mixed Red Devil Creek alluvium, native soil, and tailings and/or waste rock

RED DEVIL MINE

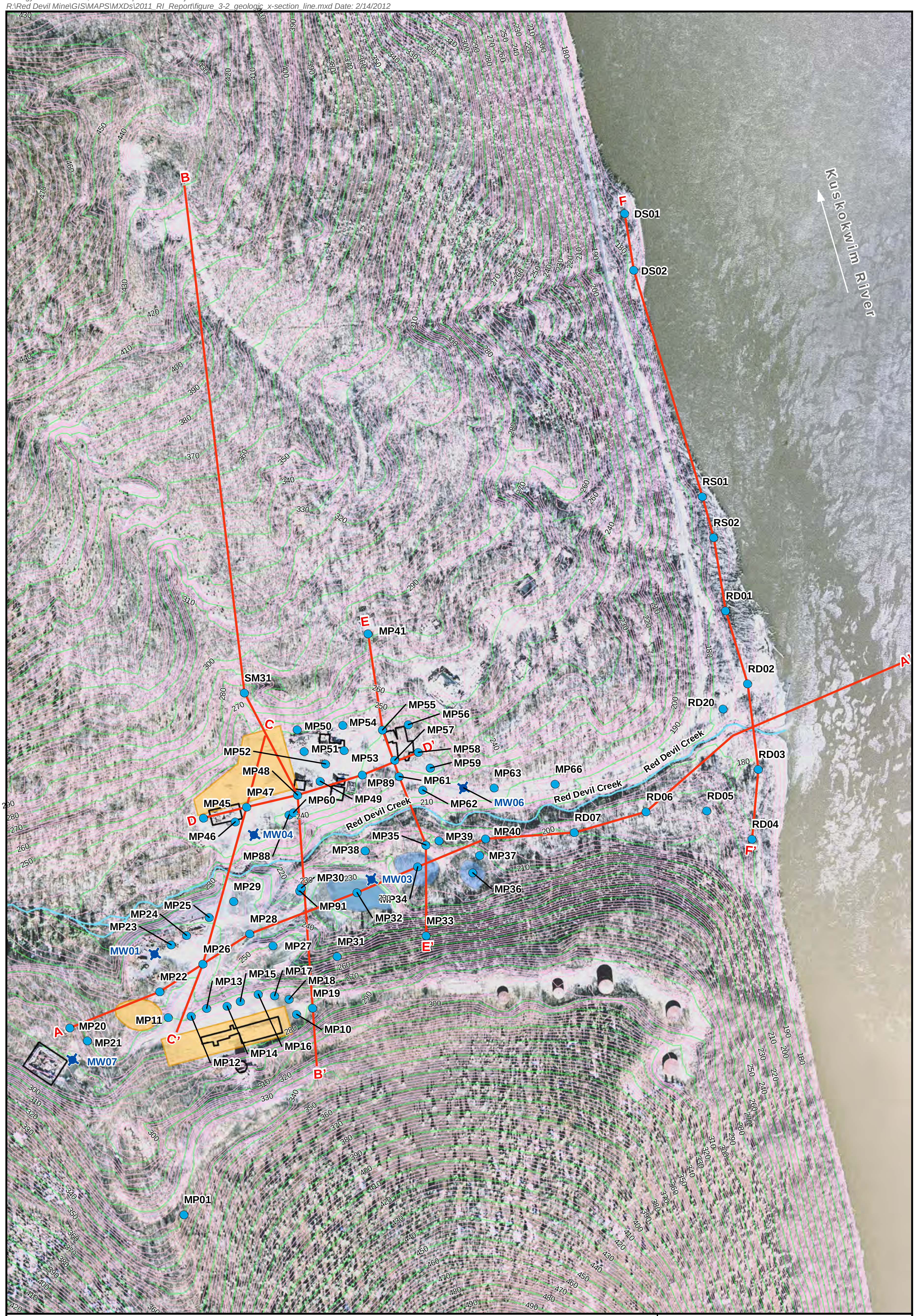
Red Devil, Alaska

- Refer to Table 3-1 for description of soil types
- Refer to Tables 3-2 through 3-9 for detailed soil types at surface soil sample locations

Figure 3-1
Simplified Surface Soil Type Map

0 50 100 200 300 400 500 600
Feet
0 25 50 100 150
Meters
Scale 1:3,800

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



Pre-RI Monitoring Wells
Soil Boring Location
Cross-Section
Topographic Contour (2 ft. interval)
Topographic Contour (10 ft. interval)
Settling Pond
Monofill
Historical Structure

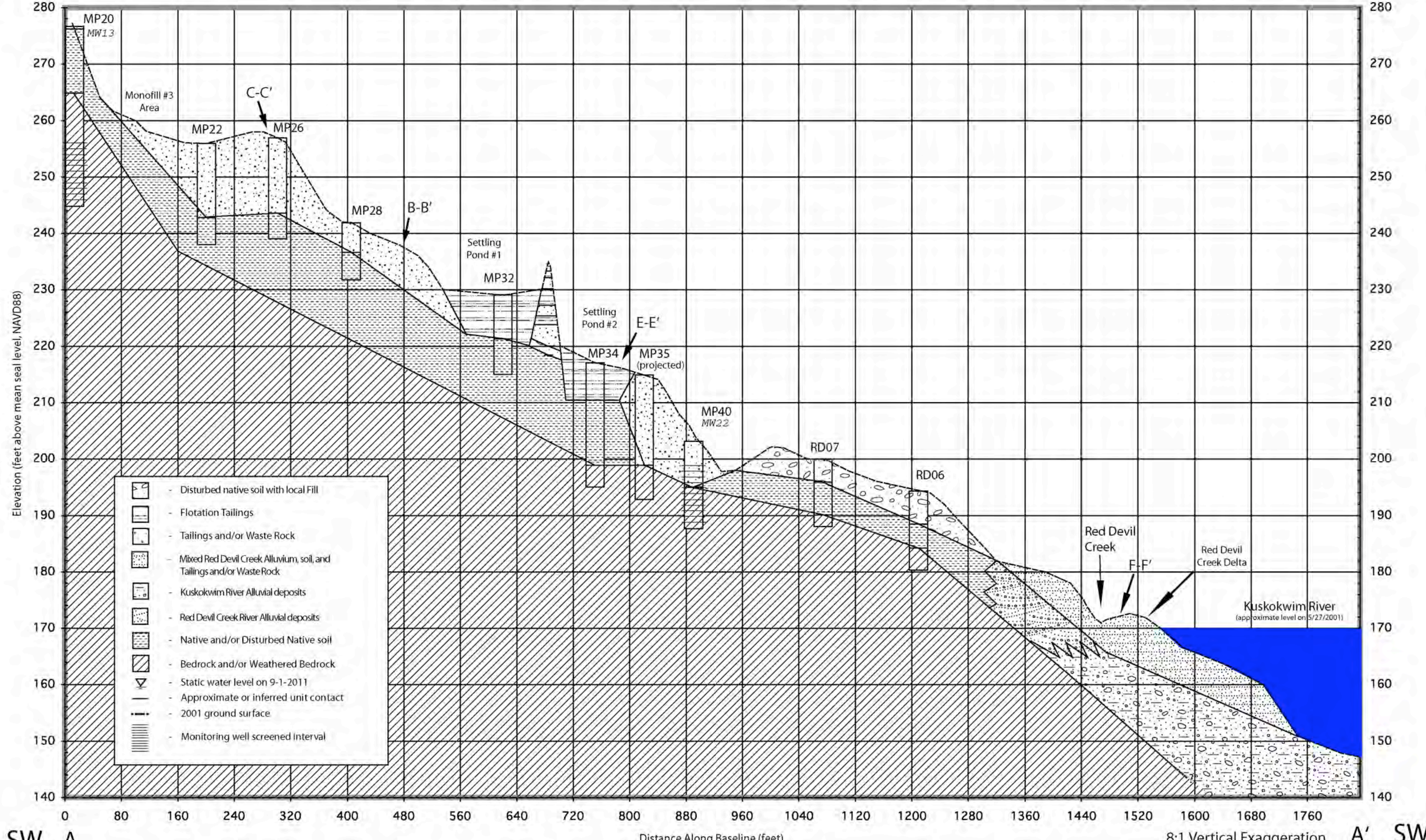
Source: Topographic Contours: Aero-Metric, Inc. (5/27/2010)
Image: Aero-Metric, Inc. (5/29/2001)

RED DEVIL MINE

Red Devil, Alaska

Figure 3-2
Geologic Cross Section Line Map

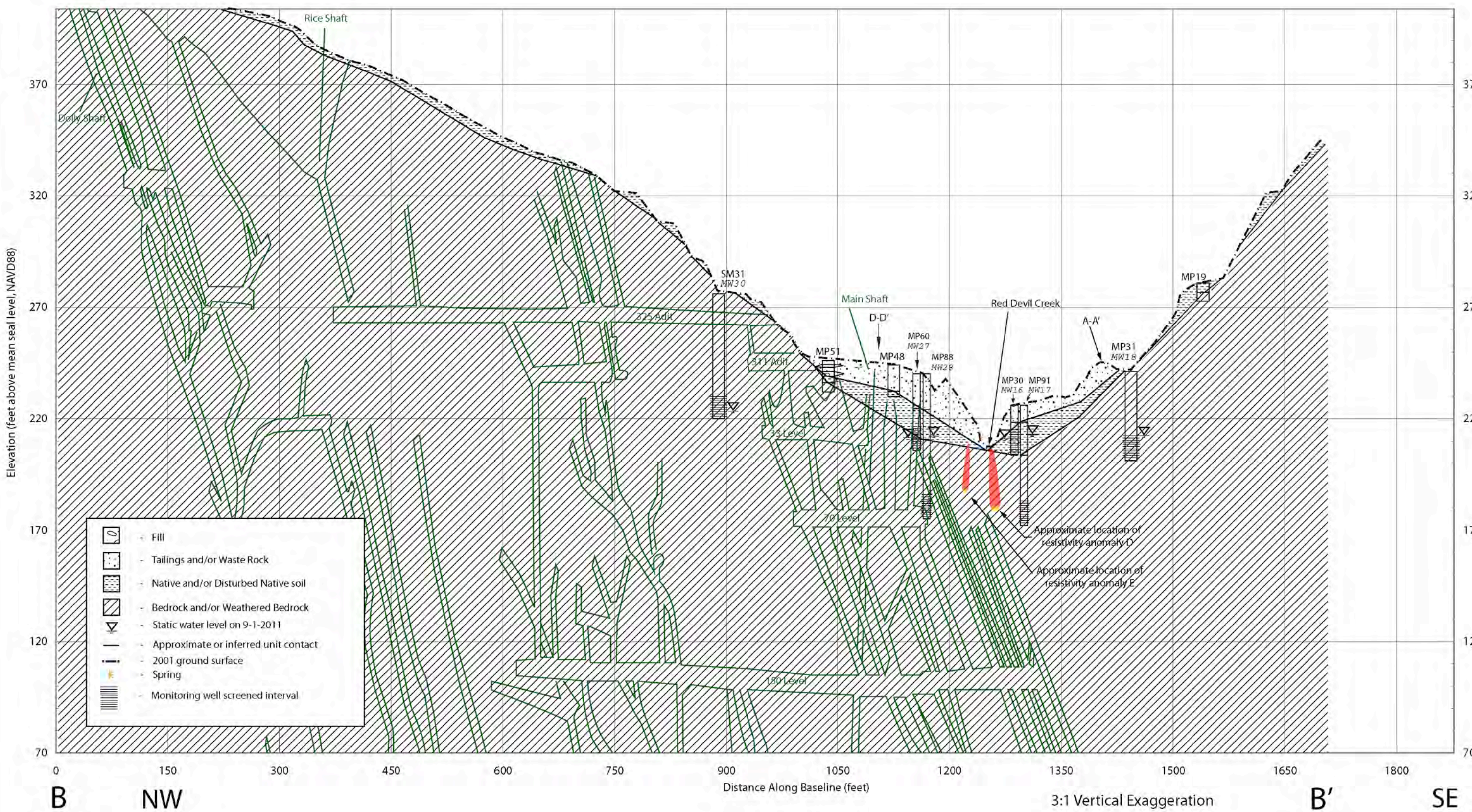
0 50 100 200 300 400
Feet
0 12.5 25 50 75 100
Meters



Note: Surface topography and Kuskokwim River Level based on 5/27/2001 aerial photograph and topographic map (Aero-Metric, Inc. 2010)

RED DEVIL MINE
Red Devil, Alaska

Figure 3-3
Geologic Cross Section
A-A′

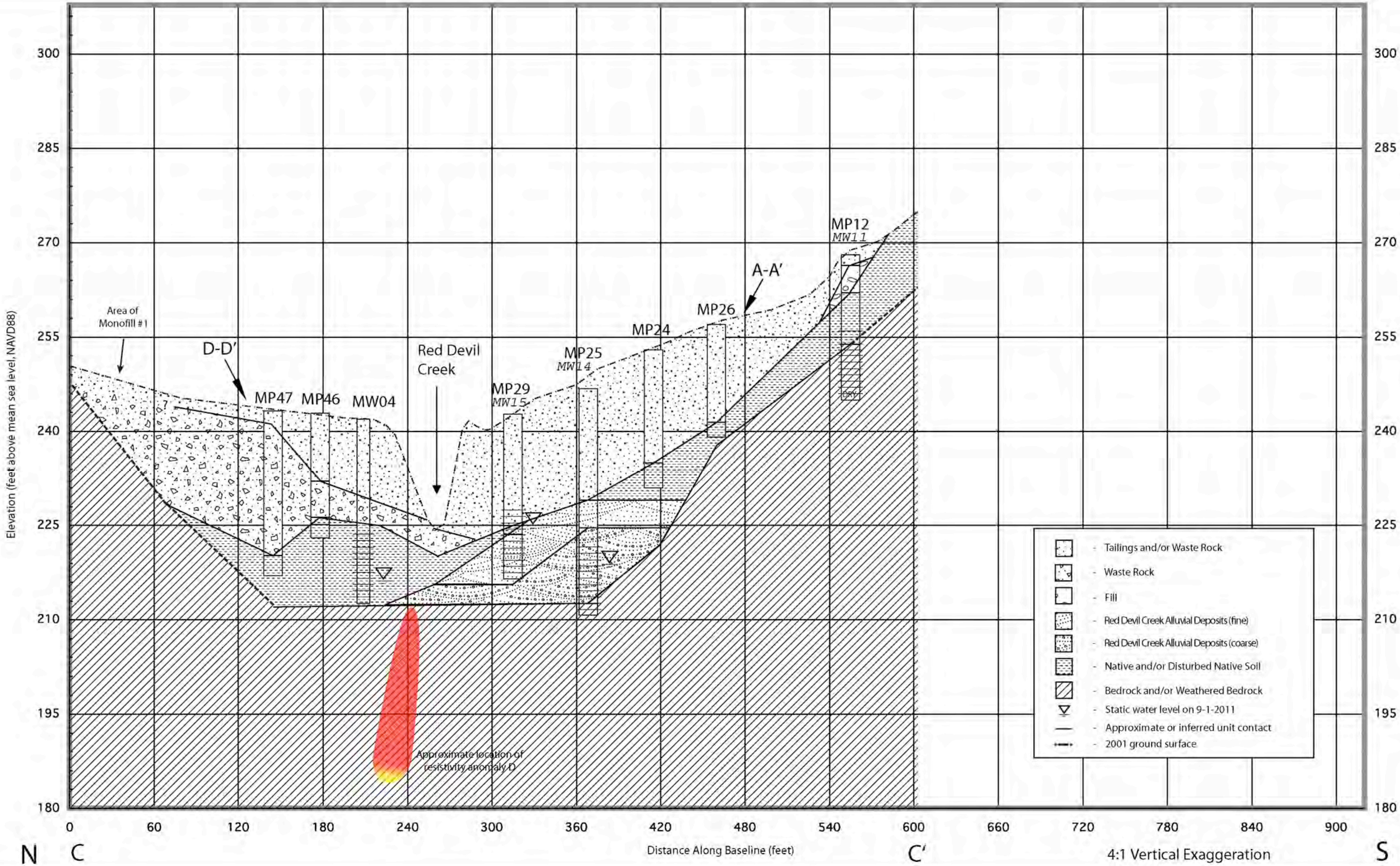


Notes: 1) Surface topography based on 5/27/2001 aerial photograph and topographic map (Aero-Metric, Inc. 2010)
2) Mine workings projected onto geological cross section based on March 1962 longitudinal projection (Alaska Mines and Minerals, Inc. and Decoursey Mountain Mining Co., Inc., 1962)
3) Approximate resistivity anomaly locations based on USGS (2011)

RED DEVIL MINE

Red Devil, Alaska

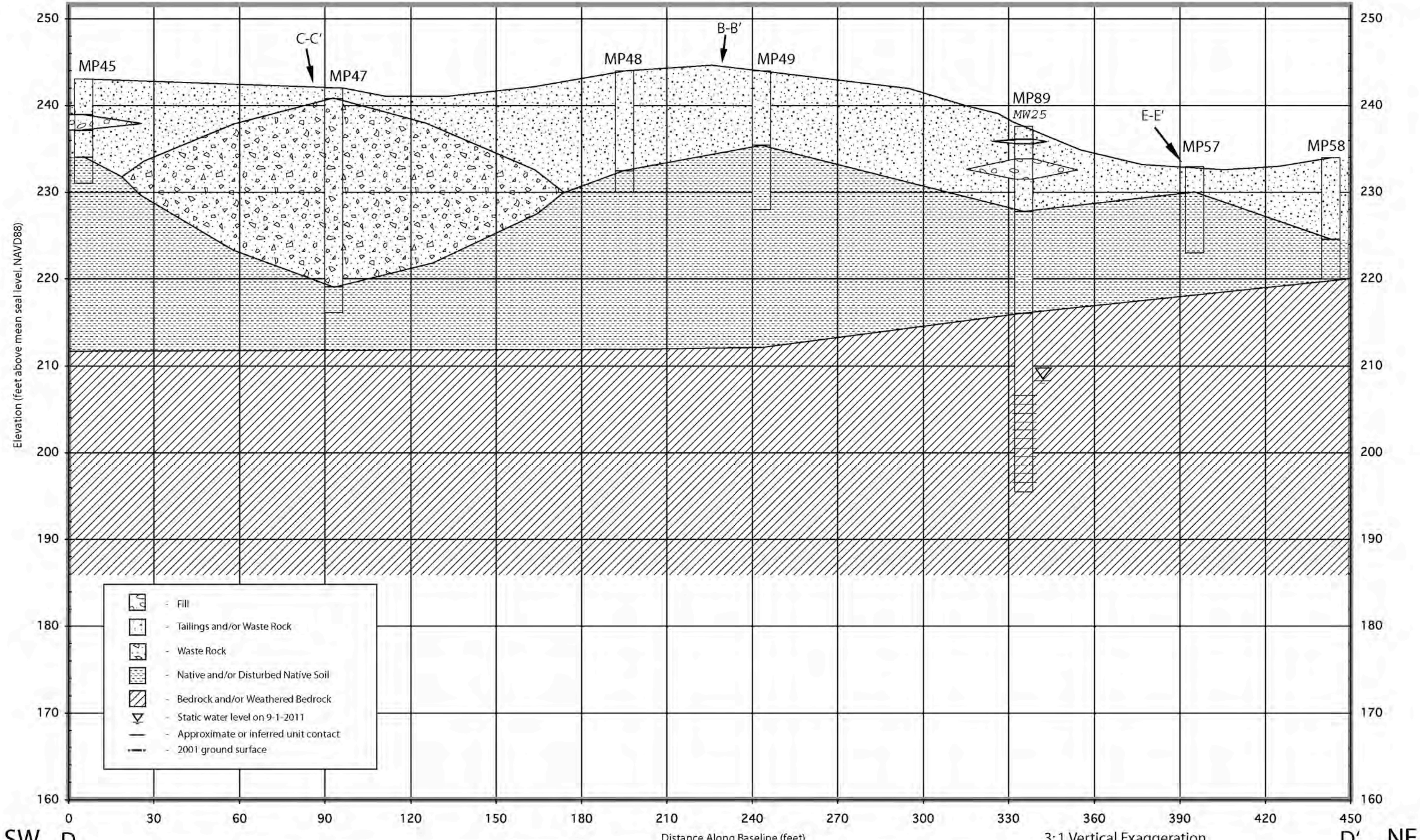
Figure 3-4
Geologic Cross Section
B-B′



Notes: 1) Surface topography based on 5/27/2001 aerial photograph and topographic map (Aero-Metric, Inc. 2010)
2) Approximate resistivity anomaly locations based on USGS (2011)

RED DEVIL MINE
Red Devil, Alaska

Figure 3-5
Geologic Cross Section
C-C′

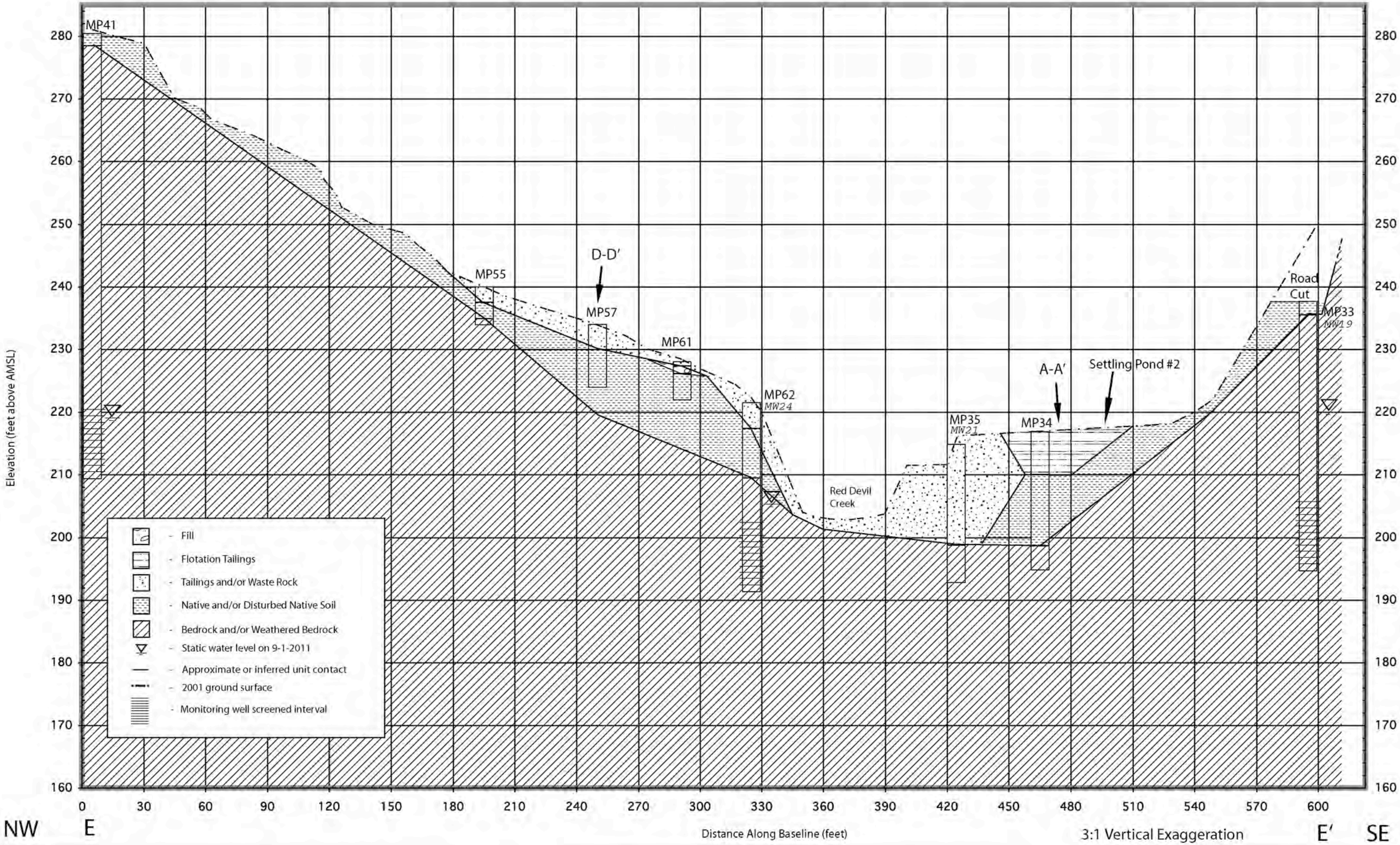


Notes: Surface topography based on 5/27/2001 aerial photograph and topographic map (Aero-Metric, Inc. 2010)

RED DEVIL MINE

Red Devil, Alaska

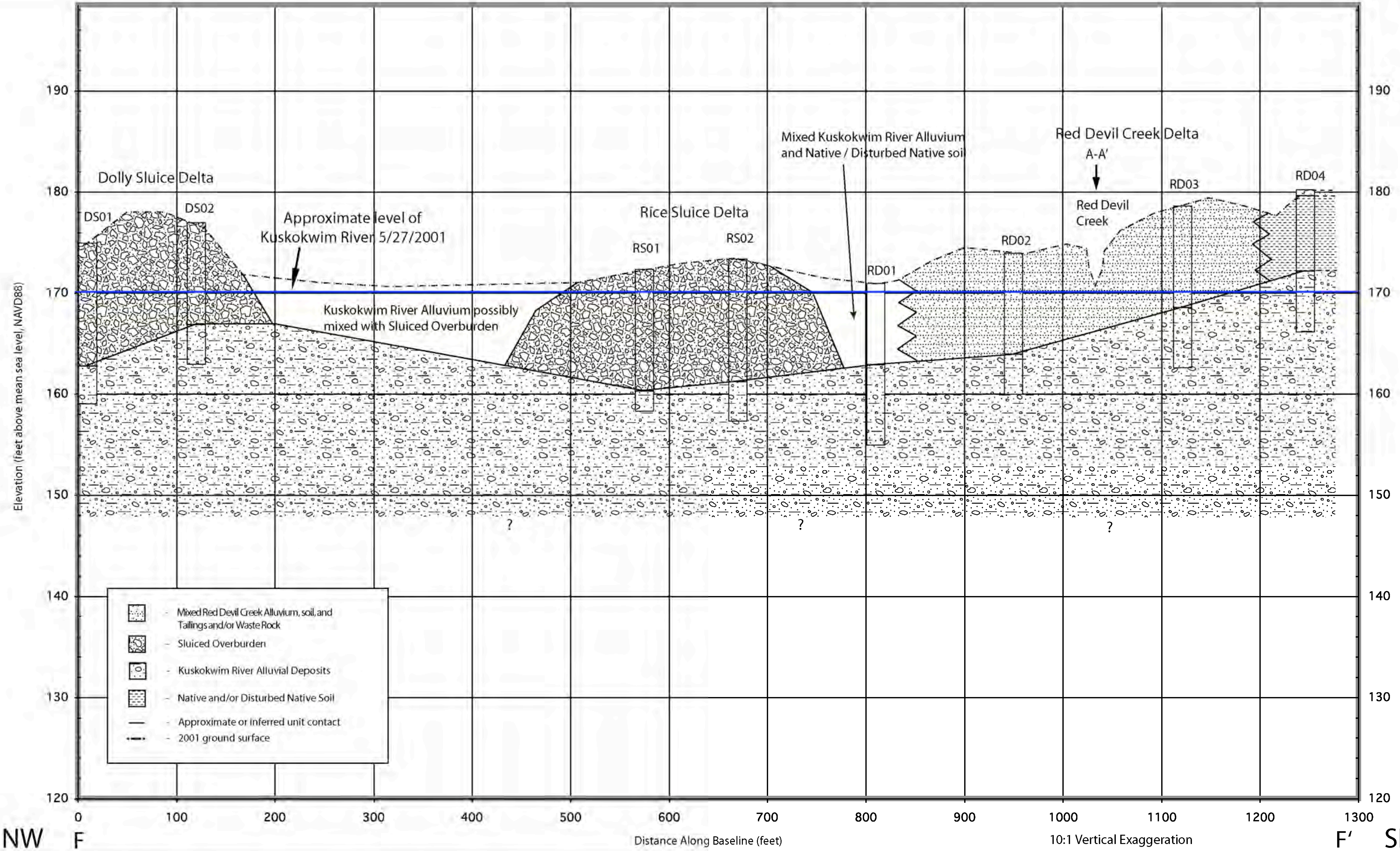
Figure 3-6
Geologic Cross Section
D-D′



Notes: 1) Surface topography based on 5/27/2001 aerial photograph and topographic map (Aero-Metric, Inc. 2010)

RED DEVIL MINE
Red Devil, Alaska

Figure 3-7
Geologic Cross Section
E-E′



Notes: Surface topography and Kuskokwim River level based on 5/27/2001 aerial photograph and topographic map (Aero-Metric, Inc. 2010)

RED DEVIL MINE
Red Devil, Alaska

Figure 3-8
Geologic Cross Section
F-F'

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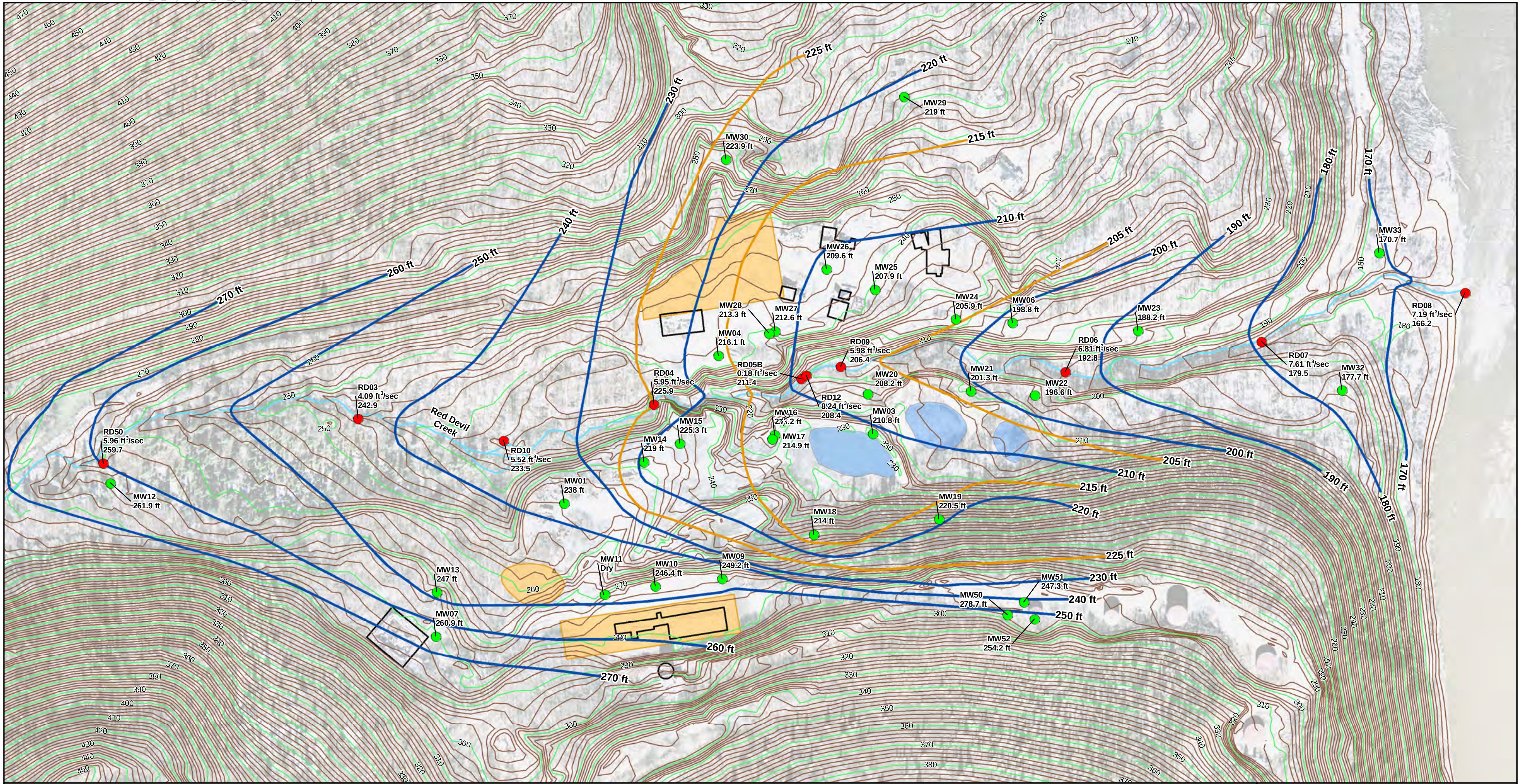

- Red Devil Creek Estimated Flow and Elevation
- Monitoring Well Groundwater Elevation
- Groundwater Contour (10 ft. interval)
- Groundwater Contour (5 ft. interval)
- Topographic Contour (2 ft. interval)
- Topographic Contour (10 ft. interval)
- Settling Pond
- Monofill
- Historical Structure

RED DEVIL MINE

Red Devil, Alaska

Figure 3-9
Groundwater Potentiometric
Surface Map

0 50 100 200 300
Feet
0 12.5 25 50 75
Meters

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

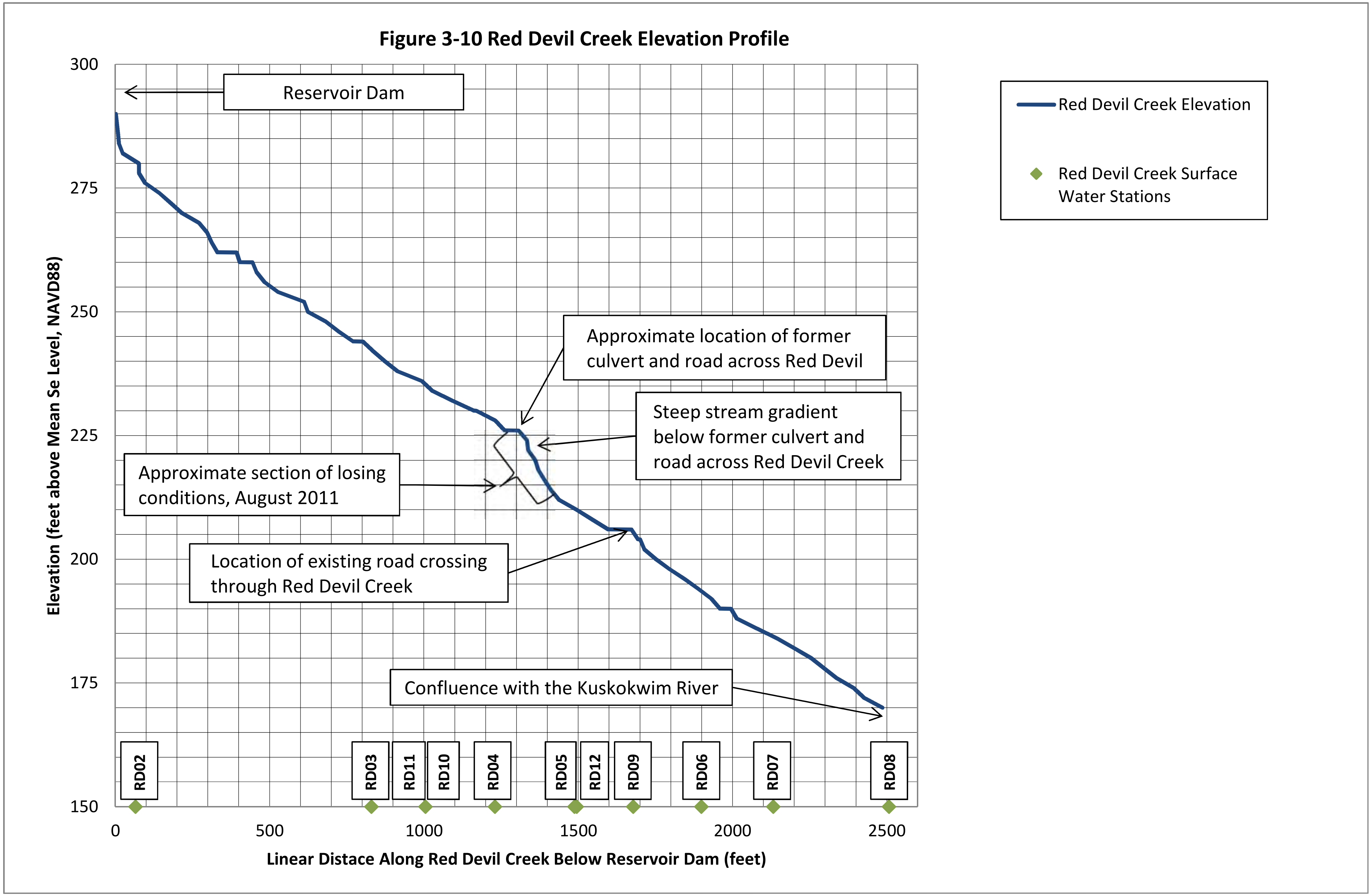

Figure 3-10 Red Devil Creek Elevation Profile
Reservoir Dam
Approximate location of former culvert and road across Red Devil
Steep stream gradient below former culvert and road across Red Devil Creek
Approximate section of losing conditions, August 2011
Location of existing road crossing through Red Devil Creek
Confluence with the Kuskokwim River
RD02
RD03
RD11
RD10
RD04
RD05
RD12
RD09
RD06
RD07
RD08
300
275
250
225
200
175
150
0
500
1000
1500
2000
2500
Elevation (feet above Mean Se Level, NAVD88)
Linear Distace Along Red Devil Creek Below Reservoir Dam (feet)
Red Devil Creek Elevation
Red Devil Creek Surface Water Stations

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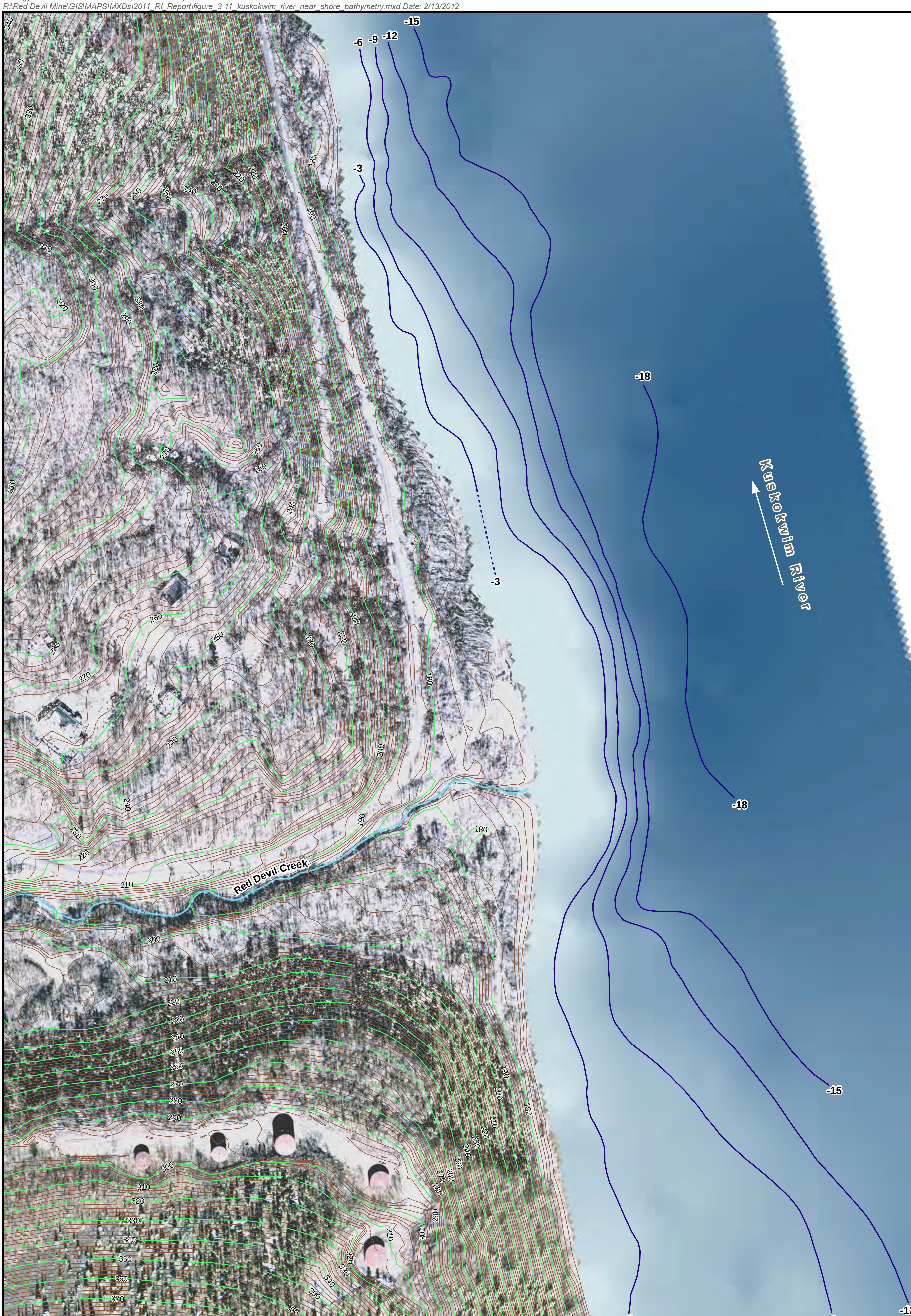

Bathymetric Contour (in feet)
Topographic Contour (2 ft. interval)
Topographic Contour (10 ft. interval)

Notes
Contours represent depths below river surface on September 25, 2011

Sources
Topographic contours: Aero-Metric, Inc. 5/27/2010
Image: Aero-Metric, Inc. 5/29/2001

RED DEVIL MINE

Red Devil, Alaska

Figure 3-11
Kuskokwim River
Near Shore Bathymetry

0 25 50 100 150 200 250
Feet
0 12.5 25 50 75
Meters
Scale 1:6,800