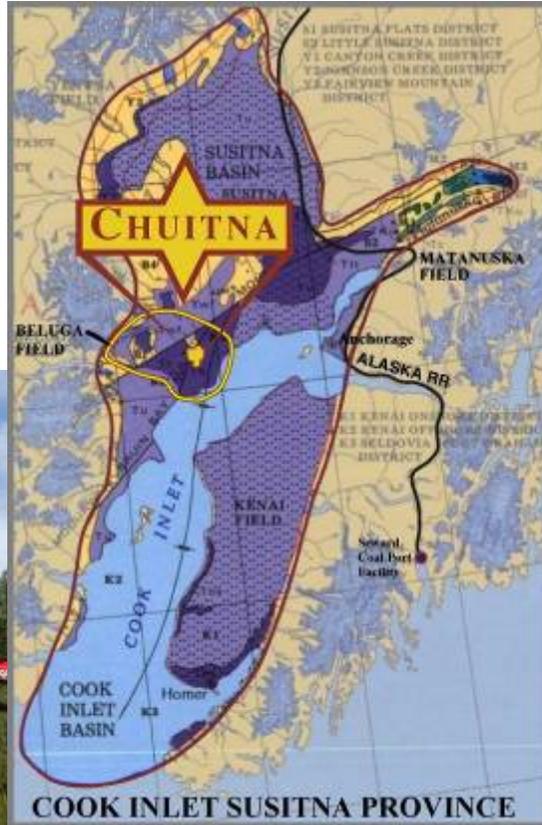




Chuitna Coal Project Groundwater Baseline Report - Draft 1982 through January 2010



RIVERSIDE

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1.0 Introduction

1.1 Project Description

The Chuitna Coal Project is a proposed coal export development located in South Central Alaska on the west side of the Cook Inlet approximately 50 miles west of Anchorage and 11 miles northwest of the village of Tyonek. The Chuitna Coal Project is composed of three major components: the Chuitna Coal Mine, Chuitna Project Infrastructure, and Ladd Landing Development.

The Chuitna Coal Mine is based on a +1 billion metric ton ultra low sulfur sub-bituminous coal resource located within a 20,571-acre lease tract. The first area to be mined (LMU-1) in the lease tract will yield approximately 300 million metric tons of coal under the current proposed plan. The design installed production capacity for the LMU-1 is 12 million metric tons per year.

The Chuitna Project Infrastructure is composed of three subcomponents:

- **Housing and Airstrip facility:** Single status housing for the Project operating workforce and an airstrip for transport of personnel and small equipment to and from the Project Area. This facility will be located in close proximity to the Chuitna Coal Mine.
- **Mine Access Road:** An all weather road, approximately 12 miles, connecting the Mine with Ladd Landing on the coast of the Cook Inlet. The road will be used during development/construction of the Mine and Housing and Airstrip facility and during operations to transport equipment and operating supplies to and from Ladd Landing.
- **Coal Transport Conveyor:** an overland coal transport conveyor with an annual throughput capacity in excess of 18 million metric tons per year.

The Ladd Landing Development is composed of two subcomponents:

- **Ladd Coal Export Terminal:** A facility capable of an annual throughput in excess of 18 million metric tons with upland storage for a minimum of 250,000 tons; an offshore vessel berth with an +/- 65 ft minimum draft and installed capacity to load ocean going vessels at approximately 6000 metric tons per hour.
- **Ladd Logistics Center:** The central receiving, storage, warehouse, and logistics support facility for the Chuitna Coal Project. The Ladd Logistics Center will include a bulkhead structure with a +/- 10 ft minimum draft.

1.2 Baseline Studies

The purpose of this baseline studies report is to present qualitative and quantitative information that can be used to characterize the groundwater resources in the Chuitna Coal Project area. The baseline data collection efforts began in 1982 and continue through present time. This report represents a comprehensive collection of all groundwater hydrology and water quality data collection efforts performed in the project area between 1982 and December 2008. Previous baseline studies reports that included information on both ground and surface water resources include (ERT 1984, Riverside 2007). The current surface water baseline studies report includes data through September 2008 (Riverside 2009).

2.0 Geographic Setting

2.1 Physiographic Setting

The Chuitna Coal Project is situated within the Beluga coalfield located in south-central Alaska. The Beluga coalfield is located on the west side of the Cook Inlet approximately 40 miles west of Anchorage (*Figure 2-1*). The project site is approximately 11 miles northwest from the village of Tyonek and 11 miles west from the Beluga area and occurs within the Cook Inlet-Susitna Lowlands physiographic subprovince (Wahrhaftig, 1965), a broad lowland that generally lies below an elevation of 1,000 feet bounded by the Alaska Range to the west, and the Talkeetna Mountains to the east.

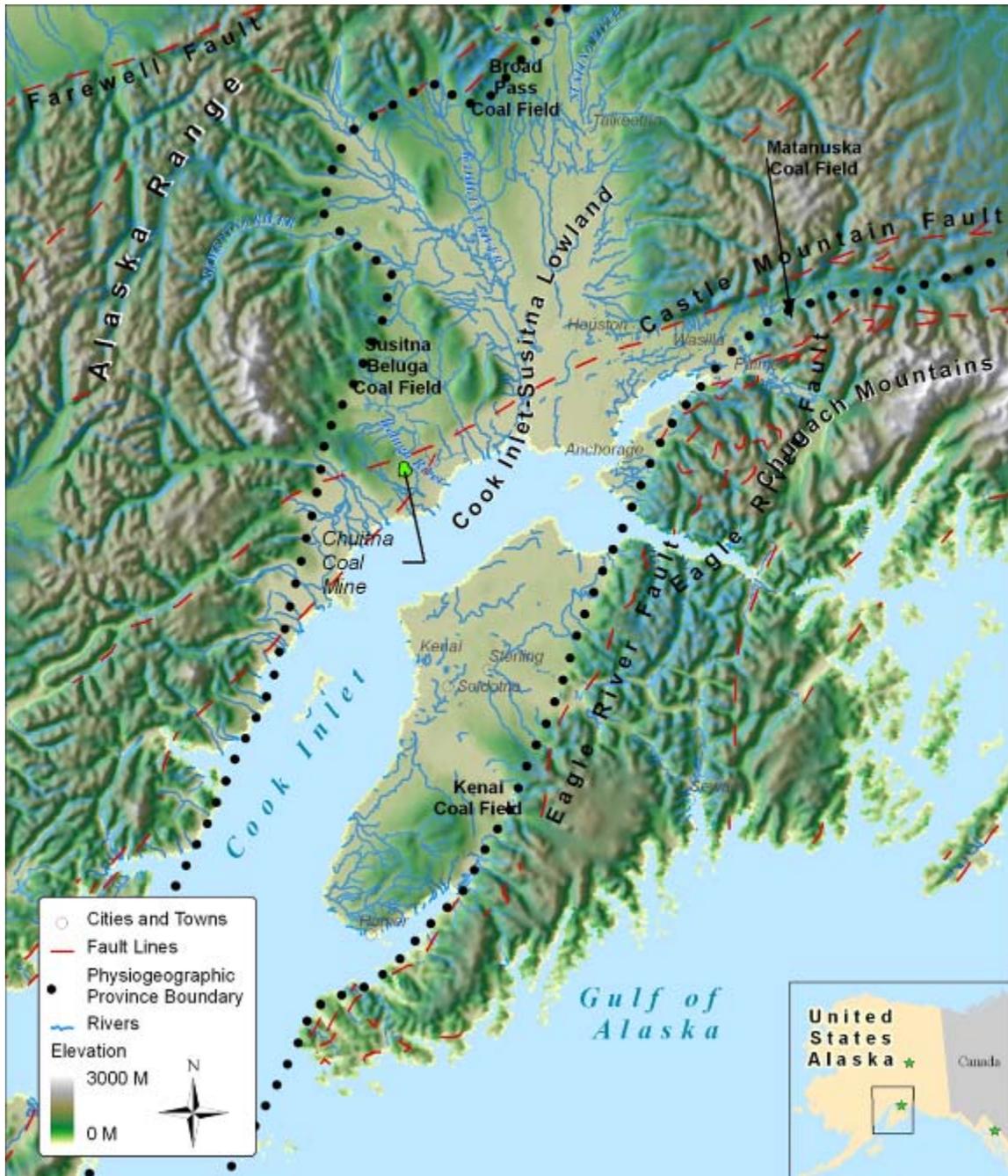


Figure 2-1. Project Physiographic Setting

The project area occurs within a region characterized as a broad plateau (known as the Beluga Plateau, Schmoll et al, 2004) of generally low relief flanked on the north and west by higher surfaces of the plateau and adjoining foothills which rise toward the Alaska Range, and on the south and east by the estuaries and embayments of the Cook Inlet. Principal drainages in the region include the glacial fed Beluga and Chakachat Rivers, and the nonglacial Chuit River. In addition, several local streams such as Tyonek Creek, Old Tyonek Creek, and Nikolai Creek drain directly into Cook Inlet.

The region is mantled by deposits of glacial origin overlying Tertiary-aged sedimentary rocks described in *Section 3.0*. Stream courses are incised into these materials, creating valleys with local relief ranging from 50 to 250 feet. The topography of the plateau is characterized by relatively gentle but irregular topography with discontinuous hills and numerous depressions typical of highly glaciated terrains. The plateau areas between drainages are poorly drained and typically contain extensive bogs and marshes with numerous ponds and lakes. However, the alluvial corridors along the incised stream courses are free draining. Elevations ranges from approximately 925 feet (amsl) along the northwestern perimeter of the proposed mine area to sea level at the proposed port facility at Ladd Landing Development. The shores of Cook Inlet in the project vicinity are predominantly gently curving steep bluffs 50-150 feet high.

2.2 Hydrologic Setting

The Chuit River (also referred to as 20 for this study) flows southeast and drains an area of approximately 150 square miles (*Figure 2-2*). The Chuit River flows into Cook Inlet. Major tributaries to the Chuit River include Wolverine Fork, Chuit Creek, Lone Creek (also referred to as 2002 for this study), Middle Creek (referred to as 2003 Creek in this study), and unnamed 2004 Creek as referred to for this study. All the streams within the Chuit River Basin drain glacier-free areas. Elevations range from sea level to 2,800 feet. Above 1,500 feet elevation, the streams are incised in a broad piedmont lowland that is covered with a thin mantle of poorly drained tundra vegetation. An increase in vegetation and local relief is evident at lower elevations (USGS, 1981).

The Chuitna Coal Project, including the associated facilities, lies within the Chuit River and Threemile Creek basins. The mine area is entirely drained by Chuit River tributaries. The headwaters of the 2003 Creek tributary contain the proposed mine, and tributaries possibly affected by the mine development include Lone Creek and 2004 Creek.

2003 Creek and Lone Creek slope about 1.25% and 1.04%, respectively. Both streams meander in their middle reaches, carry little suspended sediment except during high flows, and have an iron-colored stain in the water column and on substrates during periods of low flow. The slope of the Chuit River is about 1.23%. Slab-shaped coal boulders and cobbles make up part of the stream's substrate. The river carries very little suspended sediment except during high-flow conditions (Maurer and Toland, 1984). This area is well vegetated and areas of muskeg are common.

Threemile Creek drains directly to Cook Inlet and has a drainage basin area of about 25 square miles. There is also an area of about 3.8 square miles between the Chuit River and Threemile Creek that appears to have no defined drainages and apparently drains directly to Cook Inlet. This area contains the proposed Ladd Landing Development area. Much of this area is marshy and very flat. There are no known ground or surface water uses (discharges or diversions) in the lease area.

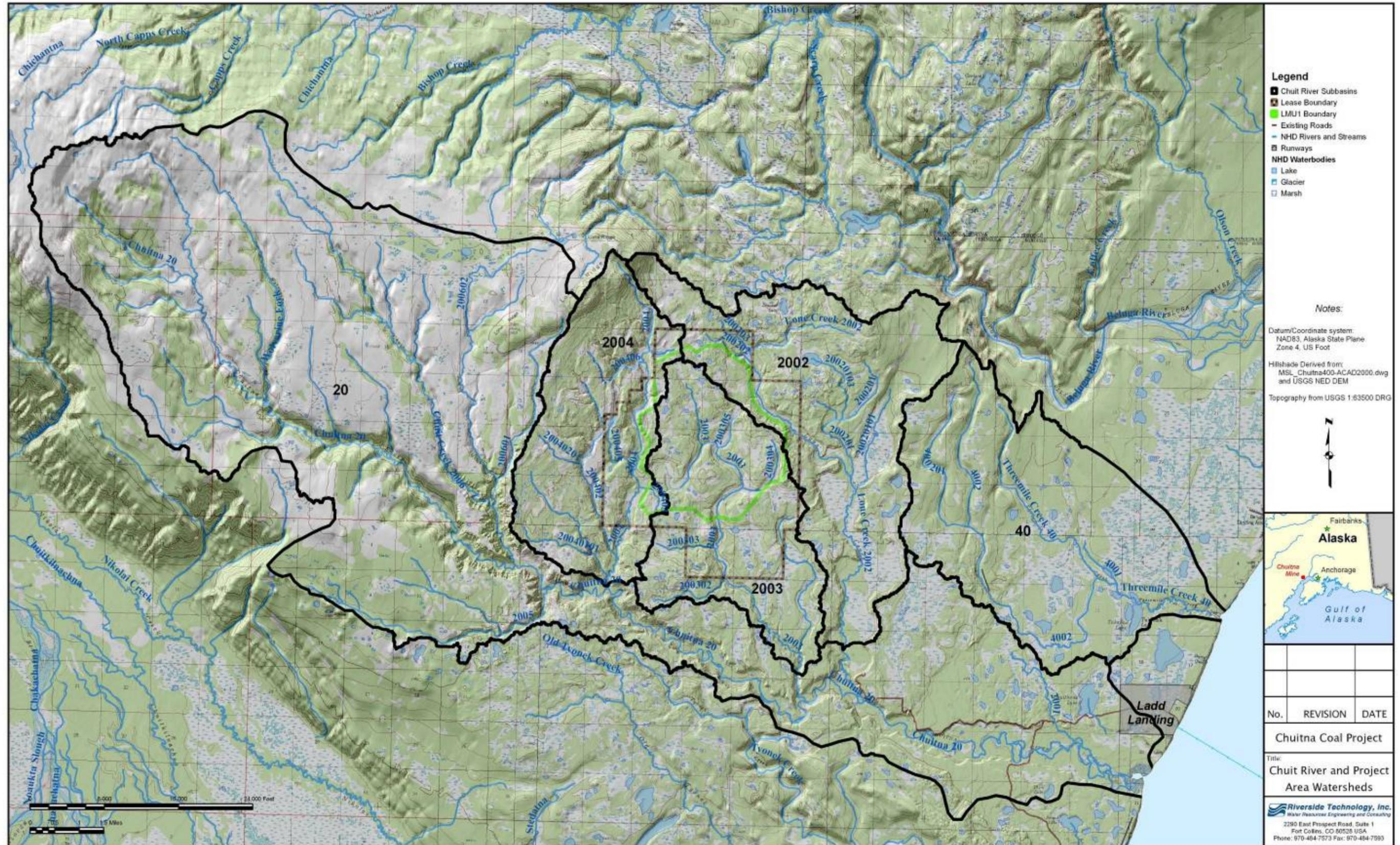


Figure 2-2. Chuitna River and Project Area Watersheds

2.3 Climate

The climate of the area is transitional between maritime and continental. Typically, the area experiences heavy snowfall and below-freezing temperatures from November through March. The most significant rainfall occurs in September and October, with a dry period typically occurring in the spring and early summer months (USGS, 1981). Average daily air temperatures generally range from a minimum of 1.5° F in January to a mean maximum of 64° F in July (Lamke, 1979). For additional information, refer to Section C-VII of the Project Permit Application.

2.3.1 Precipitation

Past reports have estimated that the average annual precipitation in the vicinity of the Chuitna Coal Project exceeds 40 inches per year (USGS, 1981). There is a strong gradient of increasing precipitation in the vicinity of the proposed project with increasing elevation. The previous project baseline study reported precipitation of about 38 inches at the coast (Beluga, Shirleyville) (*Appendix A-1*), about 50 inches on the mine area, and about 65 inches on Capps Plateau (ERT, 1984). Subsequent analysis has estimated the mine site average annual precipitation to be similar at approximately 47 inches (Tetra Tech, 2010). For additional information, refer to Section C-VII of the Project Permit Application.

2.3.2 Evapotranspiration

The previous baseline study reported evapotranspiration to be about 9 inches per year (ERT, 1984). However, there is no citation for this value and no evapotranspiration data were collected as a part of the original study. A literature search was performed for the project area and no evapotranspiration data were found. However, there are several pan evaporation stations in Alaska (*Figure 2-3*).

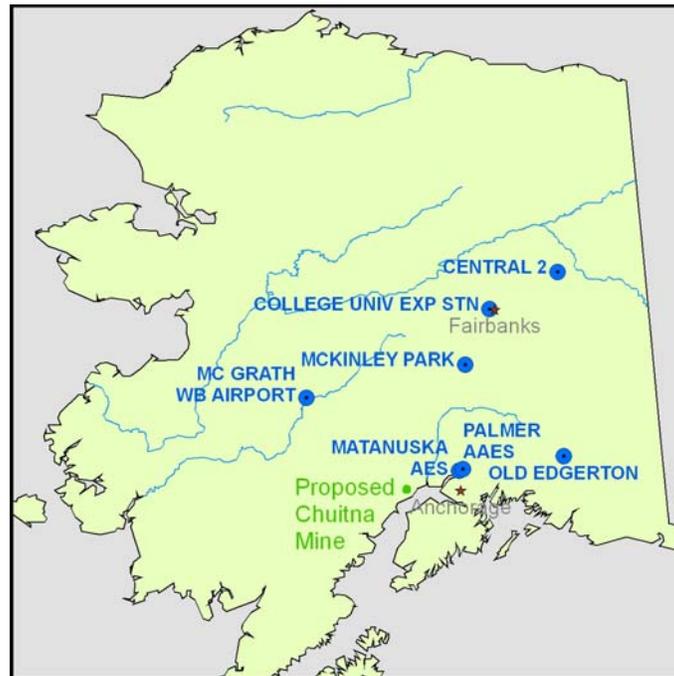


Figure 2-3. Pan Evaporation Locations

The station that is most similar to the project site in terms of elevation and coastal influence is the station at the Matanuska Agricultural Experiment Station (*Table 2-1*). Average annual pan evaporation from this site is about 17.4 inches per year. Pan evaporation can be used to estimate evapotranspiration if adjustments for the pan environment are made (ASCE, 1990). A reasonable estimate for evapotranspiration at this site is about 70% of the pan evaporation or about 12.2 inches per year.

Table 2-1. Alaska Pan Evaporation and Temperature Data¹

	PERIOD OF RECORD	ELEVATION (FT)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
MONTHLY AVERAGE PAN EVAPORATION (INCHES)															
CENTRAL 2	1962-2002	920	0	0	0	0	0	3.97	4.00	2.43	2.19	0	0	0	12.59
MATANUSKA AES	1917-2002	172	0	0	0	0	4.26	4.43	3.92	3.02	1.80	0	0	0	17.43
MC GRATH WB AIRPORT	1939-2002	333	0	0	0	0	4.20	4.42	3.64	2.29	1.40	0	0	0	15.95
MCKINLEY PARK	1949-2002	2070	0	0	0	0	0	3.00	2.55	1.74	0.53	0	0	0	7.82
OLD EDGERTON	1970-1996	1320	0	0	0	0	3.31	4.56	4.16	3.04	1.65	0	0	0	16.72
PALMER AAES	1949-1998	220	0	0	0	0	4.44	4.71	4.12	2.96	1.75	0	0	0	17.98
COLLEGE UNIV EXP STN	1931-2002	475	0	0	0	0	4.25	5.04	4.56	2.82	1.38	0	0	0	18.05
MONTHLY AVERAGE MAXIMUM TEMPERATURE (F)															
CENTRAL 2	1962-2005	920	-10.8	-0.7	15.9	38.0	57.2	70.3	72.2	66.4	52.4	27.4	6.1	-4.9	32.5
MATANUSKA AES	1917-2005	172	21.8	27.5	34.6	46.1	58.1	65.8	67.6	65.1	56.6	43.0	28.9	22.3	44.8
MC GRATH WB AIRPORT	1939-2005	333	1.5	11.0	23.3	38.7	55.5	66.8	68.6	63.1	52.6	32.1	13.0	1.9	35.7
MCKINLEY PARK	1949-2005	2070	9.9	15.9	25.3	38.7	53.4	64.3	66.4	61.5	50.3	32.2	17.9	11.0	37.2
OLD EDGERTON	1970-1996	1320	6.5	15.2	30.4	44.5	57.8	66.6	69.8	66.0	54.8	36.8	16.1	8.7	39.4
PALMER AAES	1949-2005	220	20.5	26.7	34.6	46.0	57.6	64.9	67.0	64.6	56.3	41.5	27.5	22.3	44.1
COLLEGE UNIV EXP STN	1931-2005	475	1.9	11.5	26.5	43.9	60.6	71.8	73.1	67.1	55.5	34.4	13.1	3.4	38.6
MONTHLY AVERAGE MINIMUM TEMPERATURE (F)															
CENTRAL 2	1962-2005	920	-28.6	-22.5	-13.5	10.2	31.0	43.7	46.8	41.0	29.2	10.6	-12.0	-23.1	9.4
MATANUSKA AES	1917-2005	172	4.7	9.9	16.2	27.3	36.2	44.4	48.1	46.2	38.6	27.1	13.3	6.2	26.5
MC GRATH WB AIRPORT	1939-2005	333	-16.7	-11.6	-3.3	16.4	34.8	45.7	49.4	45.4	35.6	18.6	-2.7	-15.0	16.4
MCKINLEY PARK	1949-2005	2070	-7.4	-4.4	1.2	15.6	29.6	39.5	43.3	39.9	30.4	14.3	1.3	-5.9	16.5
OLD EDGERTON	1970-1996	1320	-11.4	-6.8	5.0	20.6	31.9	40.3	44.4	41.1	32.5	20.1	-1.4	-9.2	17.3
PALMER AAES	1949-2005	220	5.0	9.6	15.9	27.8	37.4	45.3	48.6	46.7	39.2	26.2	12.7	7.5	26.8
COLLEGE UNIV EXP STN	1931-2005	475	-15.1	-9.1	0.4	18.7	34.4	45.3	48.4	43.9	33.7	17.4	-2.9	-13.0	16.8

¹ Data from the Western Regional Climate Center (<http://www.wrcc.dri.edu/>)

3.0 Geologic Setting

3.1 Regional Geologic Setting

The project area is situated within the Cook Inlet Basin of south-central Alaska (Dickinson, 1995). The basin is also known as the Southern Alaska-Cook Inlet Coal Province (Flores et al, 2004). The Aleutian and Alaska Ranges bound the basin on the northwest and the Kenai and Chugach Ranges on the southeast. The axis of the basin trends northeast and generally follows the Cook Inlet topography (*Figure 3-1*). The basin is filled with a thick sequence of nonmarine Tertiary age sedimentary rocks that were deposited in a broad subsiding basin. These Tertiary sedimentary rocks crop out locally or are covered by surficial deposits along the margins of the northern Cook Inlet, including the Susitna lowland and Beluga coalfield on the northwest margin, and on the Kenai Peninsula on the southeast margin of the Cook Inlet. These nonmarine sedimentary rocks also occur at depth beneath the waters of Cook Inlet (*Figure 3-1*).

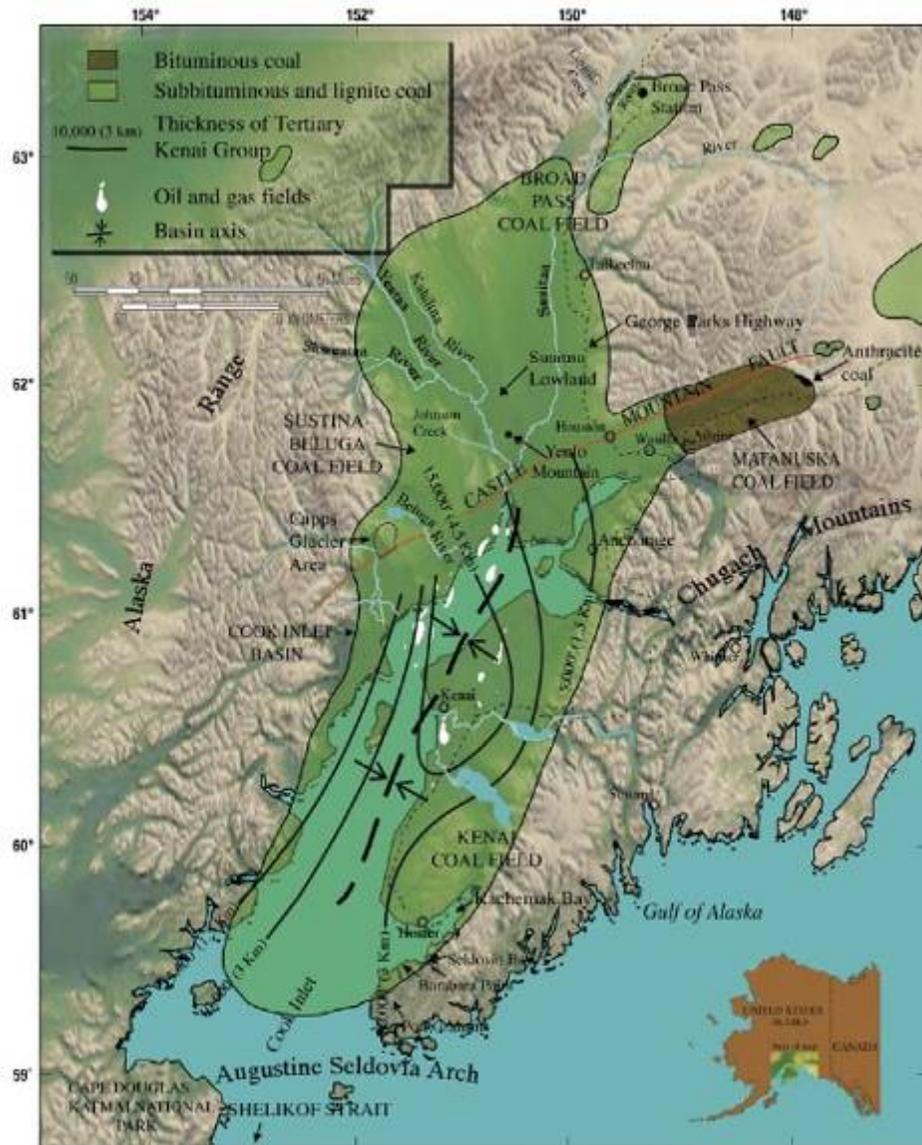


Figure 3-1. Location of the Cook Inlet Basin, Southern Alaska-Cook Inlet coal province, and distribution of the Kenai Group sedimentary rocks (from Flores et al, 2004)

The stratigraphy of the Tertiary age rocks within the Cook Inlet basin is illustrated in *Figure 3-2*. The sedimentary rocks consist of the West Foreland Formation and formations associated with the overlying Kenai Group. The West Foreland Formation is composed of predominantly interbedded sandstone and conglomerate; characterized by marked volcanoclastic deposits; and lacks coal seams (Schmoll and others, 1981a). The Kenai Group consists of interbedded claystone, siltstone, sandstone, and conglomerate. The Kenai Group includes, from bottom to top, the Hemlock Conglomerate, Tyonek, Beluga, and Sterling Formations. All of these formations contain some coal; however, numerous coal seams occur in the Tyonek and Beluga Formations. The combined thickness of the Kenai group is over 25,000 ft and generally thickens towards the central part of the basin (Flores et al, 2004).

The Tertiary coal-bearing rocks in the Cook Inlet basin accumulated in the subsiding Cook Inlet Basin that was presumably drained by a large, fluvial and alluvial fan system that flowed into the Pacific (Kirschner, 1988). Alluvial fans drained the basin margins, and the trunk (axial) stream drained a broad alluvial plain now occupied by the Cook Inlet. Coal is believed to have accumulated in mires related to this large, integrated fluvial drainage system (Flores et al, 2004).

Five major Pleistocene glacial advances have been recognized in the Cook Inlet region. During several major glacial advances, ice lobes originating at the base of the Alaska Range are believed to have coalesced with Kenai Peninsula lobes, filling the Cook Inlet trough as recorded by a lateral moraine deposited along the flanks of the bordering mountains (Karlstrom, 1964). At least three separate glacial advances are recorded by glacial drift that essentially covers the Tertiary bedrock sequence in the Beluga Plateau. The glacial drift consists of a broad sheet of unconsolidated material that includes moraine and glaciofluvial deposits (Schmoll and Yehle, 1987). The primary source of glaciers on the Beluga Plateau is the Tordrillo Mountains in the southern Alaska Range that bounds the plateau to the west. The glacial terrain of the plateau is characterized by hummocky topography left by ground moraines, broken by irregular, arcuate morainal hills inferred to be end moraine lobes (Schmoll et al, 1984).

Two major southwest trending faults occur in the region: the Castle Mountain fault and the Moquawkie fault (*Figure 3-3*). The Castle Mountain fault borders the northwest margin of the Beluga coalfield with rocks downthrown on the southeast side of the fault. The Castle Mountain fault is a major regional structure that is interpreted as a right-lateral strike-slip fault from Mesozoic through Tertiary, and a steep reverse fault from Oligocene to the present (Grantz, 1966). The Moquawkie fault zone, located southeast of the lease area, (*Figure 3-3*) is a secondary fault that splays from the Castle Mountain fault with rocks downthrown on the southeast side of the fault. The Castle Mountain and Moquawkie faults bound a triangular-shaped structural block that contains the Tyonek formation within the project area. Several other northeast-southwest trending faults and folds (that roughly parallel the Castle Mountain and Moquawkie faults) occur within this structural block.

3.2 Project Geology

For the purposes of discussion, the proposed Chuitna Coal Mine area is referred to as the Logical Mining Unit-1 (LMU-1). The stratigraphy and coal geology of the mine area has been defined by extensive exploration drilling completed in 1981, 1982, and 1986. The drill hole data include driller's logs, geologic logs, and downhole geophysical logs. The results of the exploration were used to develop a detailed geologic model for the proposed mine area (Mine Engineers, 1998). The geologic model includes a series of maps and cross-sections that correlate discrete units, estimate thicknesses, and define the structure for the coal beds and interburden units. Information provided in the geologic model was used to characterize the location, depth, and lateral variation of geologic units; and locate faults or other structures in the vicinity of the proposed coal mine.

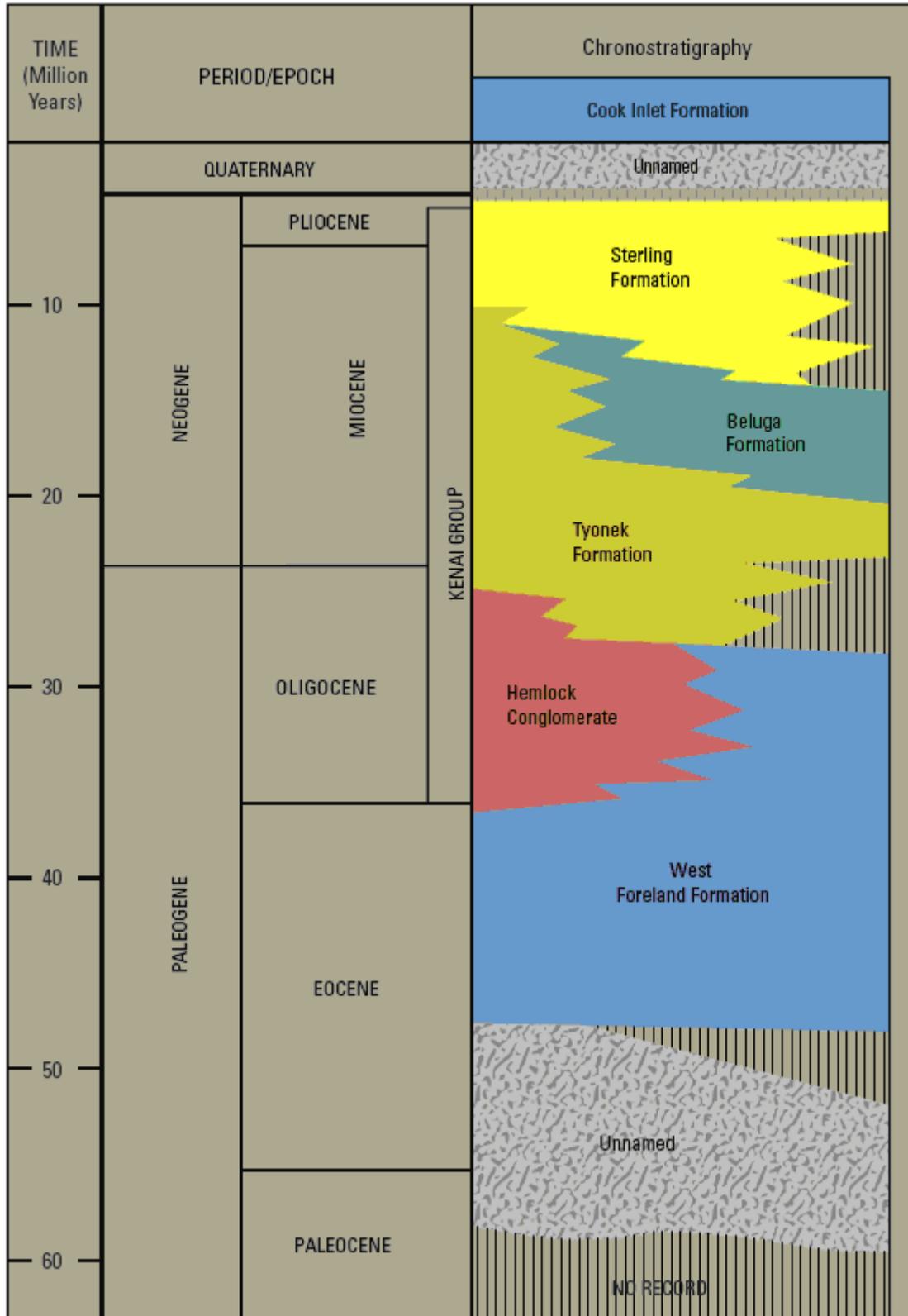


Figure 3-2. Generalized stratigraphy in the Cook Inlet basin (Flores et al, 2004)

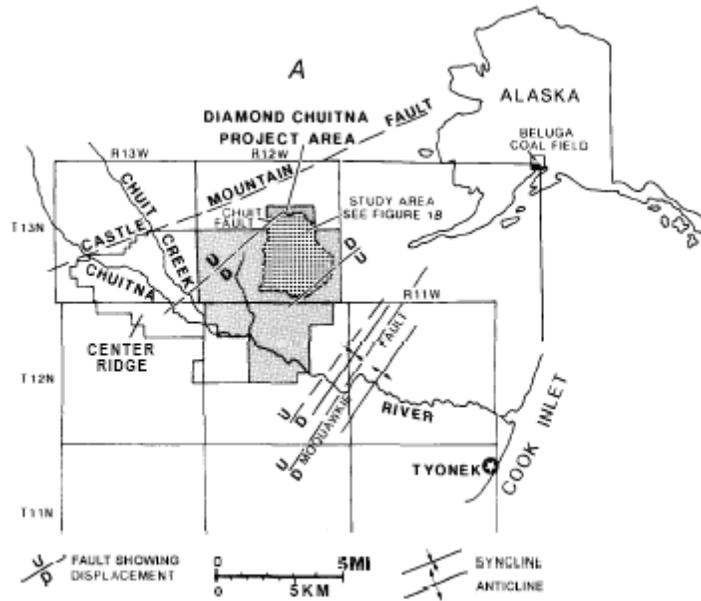


Figure 3-3. Map showing major geologic structures in the project region (From Flores et al, 1995)

The information provided in the geologic model and information from a U.S. Geological Survey report for the area (Flores et al, 1995) were used to describe the general stratigraphy and structure for the project area. The geologic conditions discussed below provide background information for characterizing the hydrogeologic conditions that are discussed in *Section 4.1*. A more detailed geologic description of the project area is provided in the baseline geology report of the project.

As described in *Table 3-1*, the stratigraphy of the proposed mine area can be subdivided into four major units, including (from oldest to youngest): Miocene Tyonek Formation, Pleistocene glacial drift, Holocene alluvium, and Holocene peat deposits.

Table 3-1. Generalized Stratigraphy in the vicinity of the proposed mine area

Age	Depositional Environment	Unit	Description	Est. Thickness (feet)
Holocene	Muskeg	Peat	Peat	0-23
	Active Stream Corridor	Alluvium	Unconsolidated sand and gravel, silt and clay deposited along active streams and floodplains	0-40
Pleistocene	Glacial and Glaciofluvial	Glacial Drift	Undifferentiated mixtures of unconsolidated deposits left after the retreat of glaciers and includes both: (1) unsorted, unstratified material ranging in size from rock flour to large boulders laid down along the margin, or beneath glaciers, or dropped from the surface as ice melted (glacial till); and (2) well sorted, stratified alluvial deposits, including outwash deposits consisting of predominantly sand and gravel. <i>Erosional Surface</i> 	0-200
Miocene	Alluvial Plain (Braided streams, flood plains, with peat forming mires) and intertidal	Tyonek Formation	Complexly interbedded and interfingering sequence of poorly consolidated, weakly cemented, siltstones, mudstones, and sandstone with coal seams	>500

The Tyonek Formation underlies the entire area and is composed of predominantly fine-grained sedimentary rocks (siltstones and mudstones) with coal seams. The Tyonek sequence experienced a period of uplift associated with folding and faulting during the late Tertiary. As a result, the top of the Tyonek Formation was eroded forming an undulating erosional surface that slopes toward the southeast. The elevation of the top of the Tyonek ranges from approximately 900 ft (amsl) along the northwest perimeter to 520 ft (amsl) along the southeast perimeter of the mine area. The stratigraphy of the minable coal sequence within the Tyonek is discussed in more detail in *Section 3.3*.

Extensive glaciation during the Pleistocene deposited a sheet of glacial drift on the erosional surface of the Tyonek formation. The glacial drift consists of both (1) till composed of unsorted mixtures of clay to boulder-sized material deposited by glaciers; with (2) glaciofluvial deposits consisting of lenticular bodies of well-sorted sand and gravel deposited by glacial-fed streams, and as outwash associated with glacial melting and retreat. In the mine area, the glacial drift blankets the plateau and has variable thickness generally ranging from 40-140 ft. Stream erosion has removed the glacial drift along local sections of Lone Creek and streams 2003 and 2004. The surface of the glacial deposits is hummocky and pock marked with numerous shallow closed depressions.

Holocene alluvium deposits are restricted to major stream channels (Lone Creek, and stream 2003 and 2004) and their associated floodplain areas. These alluvial deposits include both well-sorted sand and gravel deposited in channels, and finer-grained sediments deposited as overbank or floodplain deposits.

Peat deposits occur in depressions on the glacial deposits. Drilling indicates that the peat is up to 23 ft thick and covers portions of the proposed mine area (Map 3, Mine Engineers, 1998). The peat is

characterized by accumulations of organic material in various stages of decomposition that typically contain layers of sandy soil.

3.3 Coal Sequence Stratigraphy

A composite stratigraphic section of the Tyonek Formation in Chuit River basin is presented in *Figure 3-4*. The target (or minable) coal sequence in the mine area is the lower section of the stratigraphic section extending up from the Red 1 coal through the Blue coal. This lower section of the Tyonek is described as predominantly mudstone and siltstone with thick coals and occasional sandstone and conglomeratic sandstone (Flores et al, 1995). The purple coal seam is located below the Red 1 coal (below the proposed base of mining). The coal horizons in the upper portion of the stratigraphic column (including the green, yellow, and brown coal seams) herein referred to as the “upper coal sequence”, have mostly been removed by erosion in the mine area. The only exception is a few small isolated areas where remnants of the green coal occur (Map 9, Geologic Model, Mine Engineers, Inc. 1998).

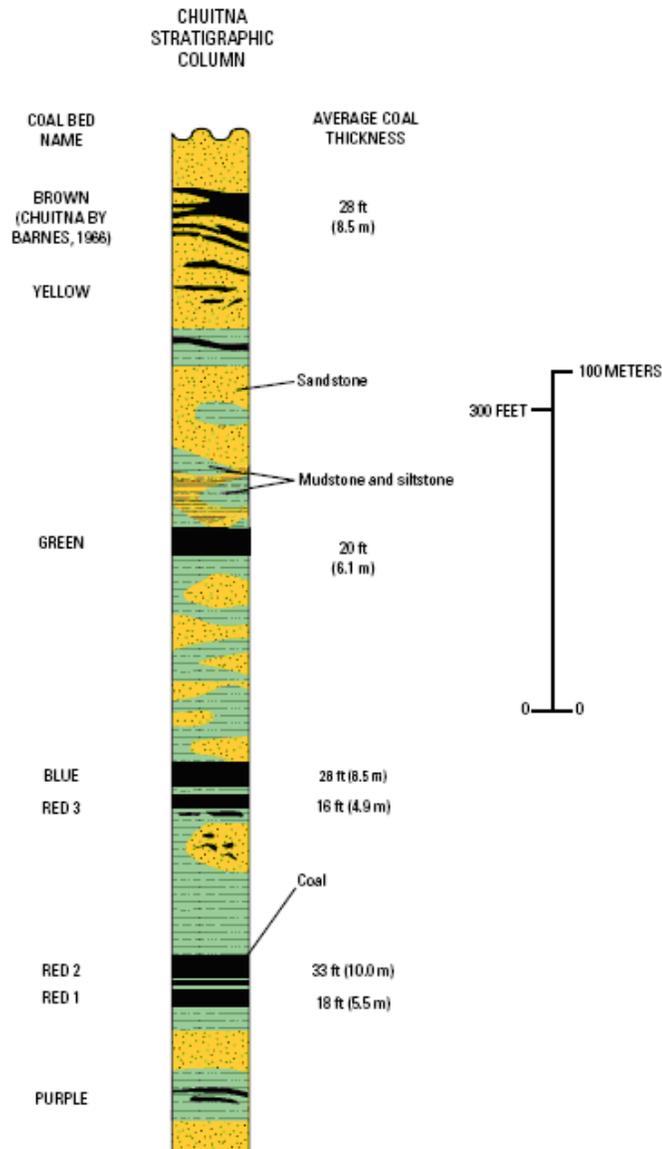


Figure 3-4. Generalized stratigraphic column of minable coal beds in the Tyonek Formation in the Chuitna River drainage basin area (modified from Flores et al, 2004)

Eighteen separate coal seams (and stringers) have been identified within the minable coal sequence (Mine Engineers, 1998). However, most of these coal seams are either localized in small areas or discontinuous across large portions of the mine area. In addition, most of the coal seams exhibit highly variable thickness and complex interfingering with the overburden/interburden sediments. Only three coal seams, the Red 1, Red 2, and Red 3 could be correlated laterally across most of the site. The Red 1 coal is the only coal that has a consistent thickness (10-11 ft) across the entire mine area, but is second to Red 2 in importance from a resource standpoint. The Red 2 coal seam ranges from 0-27.5 ft thick, with an average thickness of 16-18 ft and can be correlated over most of the mine area. Red 3 coal seam ranges from 0-25 ft thick, with a typical thickness of 8-12 ft thick, and does not extend into the northeastern portion of the mine area. The fourth most important coal, the Blue coal seam, ranges from 0-25 ft thick and is typically 8-20 ft thick, occurring only along the western and southern margins of the proposed mine area (see *Map 4.2-2, Movable Coal Sequence Wells for Aquifer Characterization, oversize sheet*).

The sediments within the minable coal sequence are generally clayey and contain abundant carbonaceous material. Sandy horizons occur within the sequence; however, these zones are predominantly isolated and discontinuous. Variations in the stratigraphy across the site are illustrated in *Figure 3-5*. The thicknesses of the sedimentary layers between the coal seams are highly variable and characterized by large variations over relatively short horizontal distances.

The proposed mine would recover coal down to the base of the Red 1 coal. A thick sand bed that is referred to as the Sub Red 1 sand underlies the Red 1 coal. The results of the exploration drilling indicate that the Sub Red 1 sand unit consists of fine-grained sand that is generally on the order of 30 ft thick and extends beneath the entire mine area. In some geologic logs, the sand is noted to grade to medium-grained sand in lower portions of bed. In addition, the geologic logs indicate the sand is typically separated from the base of the Red 1 coal by dark gray clay or silty clay that ranged from a few feet to 25 ft thick. However, in some borings, the intervening clay is potentially missing and the Red 1 coal may be sitting directly on the Sub Red 1 sand bed.

3.4 Structure

The Tyonek Formation within the mine area has experienced a complex structural history that has included folding and faulting. The structural contour maps developed for the geologic model (Mine Engineers, Inc. 1998) indicate that the sequence has been gently folded. A broad, north-south oriented, southward plunging anticline extends across the central portion of the mine area. Dips within the limbs of the anticline are very gentle and range from approximately 1-4 degrees. The Tyonek Formation is also offset by two local faults referred to as the Chuit fault, and South Pit fault (*Figure 3-6*) The Chuit fault is a northeast-southwest trending structure that bounds the northwest margin of the mine area. The Chuit fault is a high-angle normal fault that has downthrown rocks on the southeast side of the fault at approximately 100-300 ft. The South Pit fault is an east-west trending fault that has downthrown rocks on the north side of the fault approximately 100 ft. As a result of the faulting, most of the mine area is situated in a graben-like feature bounded by the Chuit and South Pit faults. In addition, the structural contours suggest that the broad anticline formed first and was later truncated by fault movement. The younger glacial and alluvial sediments overlying the Tyonek Formation do not exhibit evidence of structural deformation.

The locations of the north-south and east-west cross sections through the mine area are shown on *Figure 3-6*; and the cross-sections are presented on *Figure 3-7*. The north-south cross section illustrates southward-dipping coal beds that are cut by the South Pit fault in the southern part of the mine area. This section also shows the undulating erosional surface at the top of the Tyonek formation that gently slopes to the south. The east-west cross-section shows the broad anticlinal fold and offset along the Chuit fault. These cross-sections also illustrate that the coal beds (Red 1, Red 2, Red 3, and Blue) are near the surface in the central part of the study area but are deeper in the subsurface in the western and southern portion of

the mine area. The sections also illustrate the lateral extent and thickness of glacial drift sheet that blankets the plateau and is partially removed by erosion in the stream valleys.

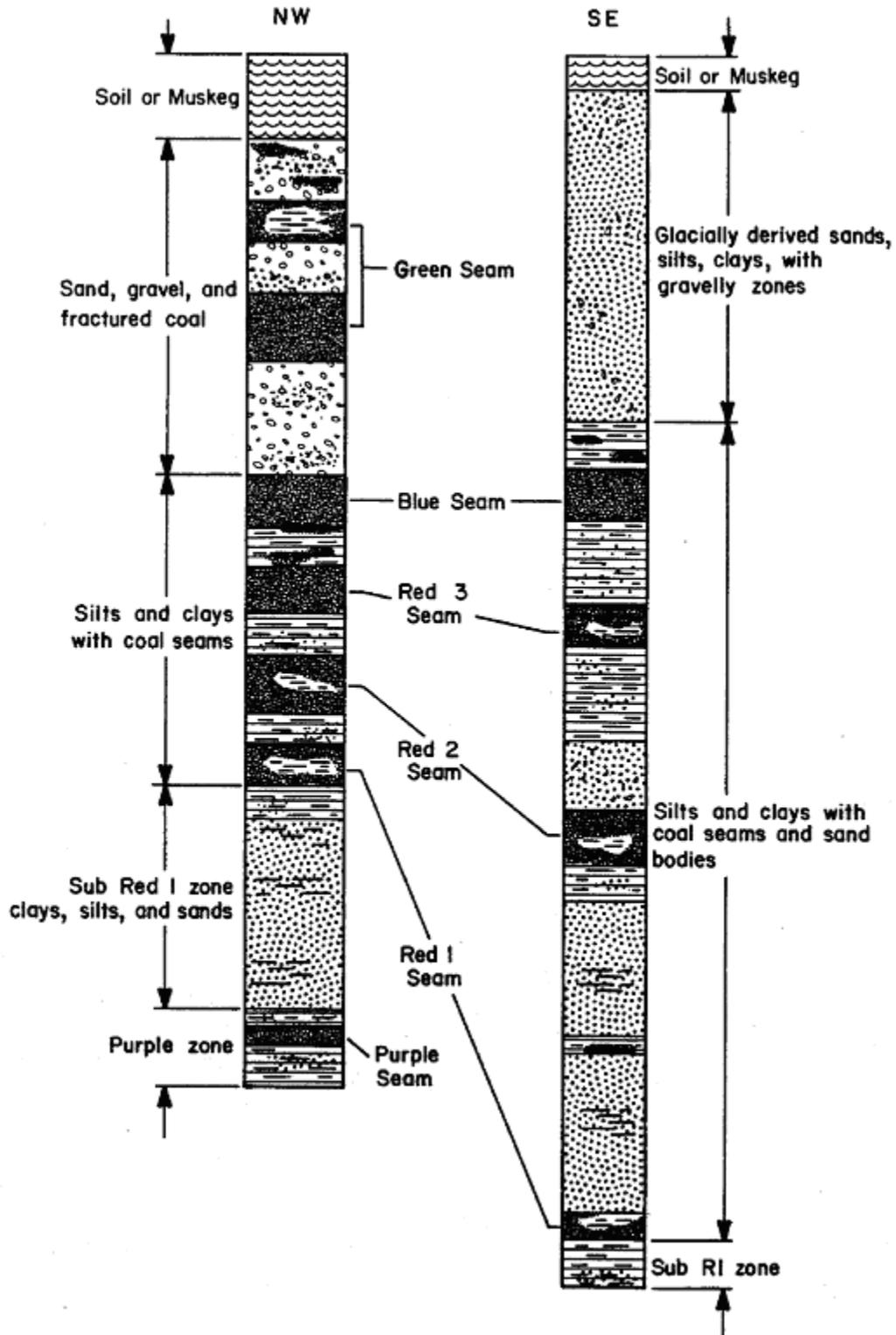


Figure 3-5. Stratigraphic columns showing the general facies changes from northwest to southeast across the mine area

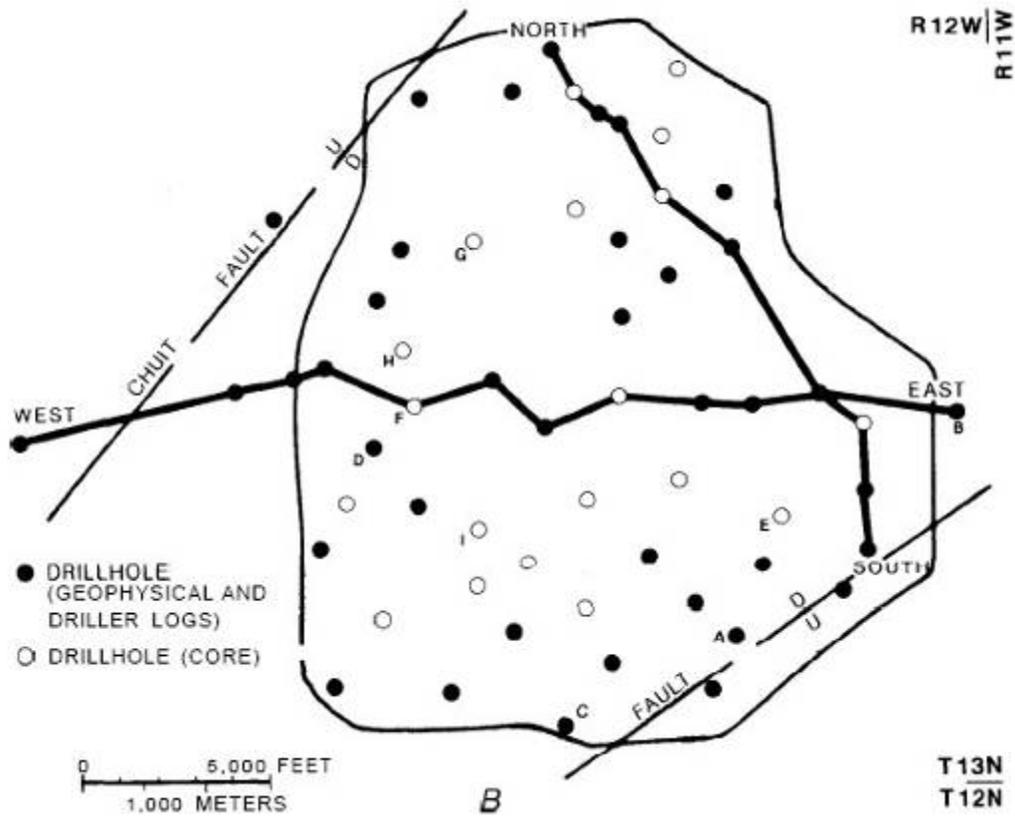


Figure 3-6. Map showing location of representative drill holes and north-south and east-west cross sections displayed in Figure 3-7 (modified from Flores et al, 1995)

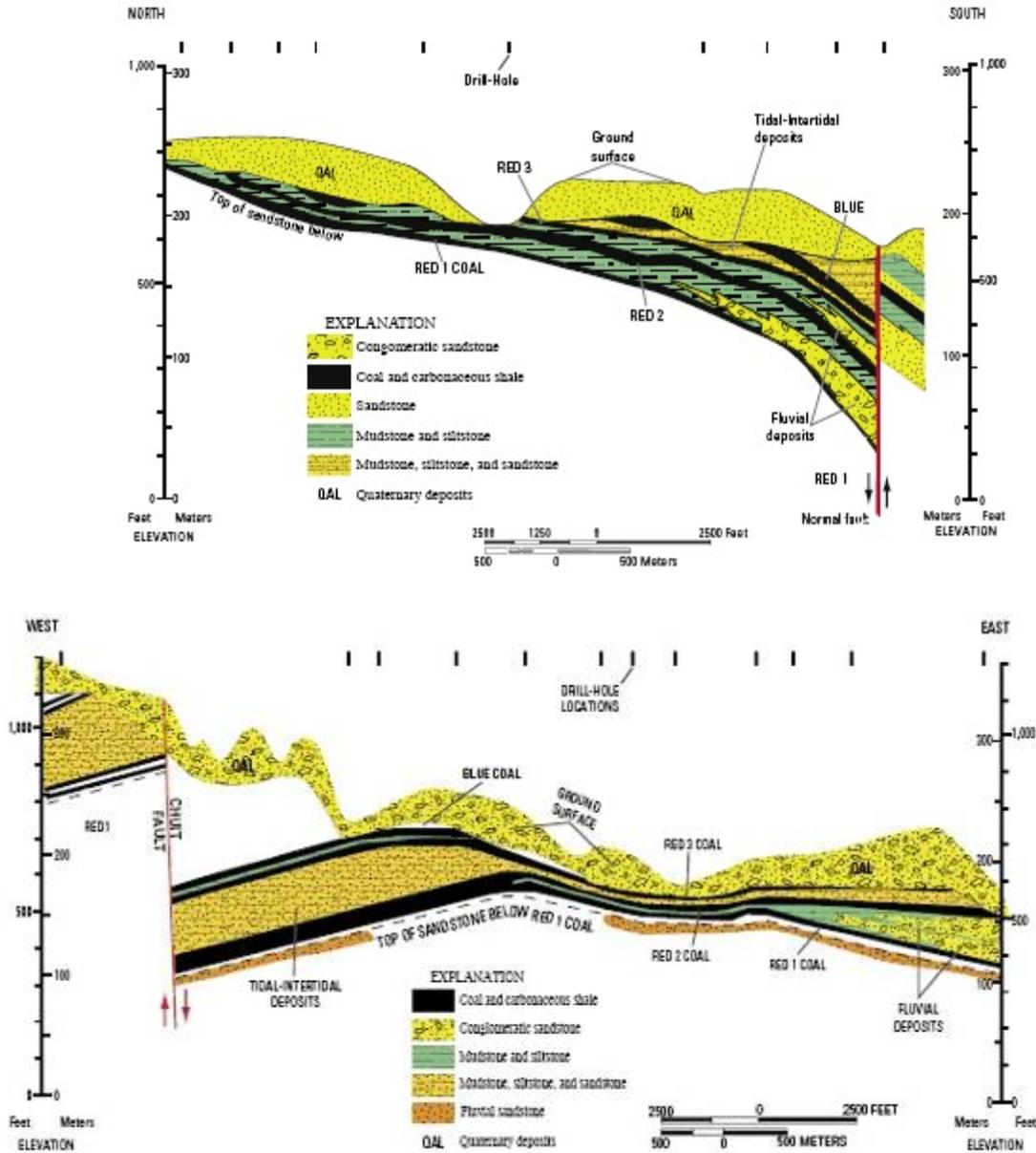


Figure 3-7. North south cross-section and east west cross-section; through the proposed Chuitna Coal Mine (See Figure 3-6 for cross-section locations.) QAL is quaternary glacial drift deposits. Exploration drill holes were generally drilled to the top of the sandstone (referred to in this document as the Sub Red 1 Sand) below the Red 1 coal seam

4.0 Groundwater

4.1 Previous Investigations

Bechtel conducted extensive exploration drilling across the coal lease from 1981-1982. In conjunction with the coal exploration program, Bechtel installed observation wells within exploration holes to monitor groundwater elevations and collect water quality samples; conducted aquifer pumping tests at three locations; and conducted borehole permeability tests in selected core holes. In 1983, Environmental Research & Technology, Inc (ERT) installed supplemental piezometers in alluvium, measured water levels in the well network, and collected additional water quality samples in selected wells. ERT used the Bechtel and ERT-collected data to prepare a baseline groundwater hydrology report for the original Diamond-Chuitna Coal Project (ERT, 1984). Diamond Alaska Coal Company described the baseline hydrogeologic and groundwater conditions in the original permit application for coal mining submitted in January 1985 (Diamond Alaska Coal Company, 1985). In 1986, additional exploration holes were drilled and some of these exploration holes were completed as monitoring wells also (Cloft and Cornachione, 1986). Riverside Technology, inc. (Riverside), collected additional water level measurements in selected wells intermittently between 1986 and 1993. No additional groundwater data was collected between the end of 1993 and 2006. In 2006, efforts were made to supplement the previous data (see *Section 4.2* below). The information provided in *Section 4.0* and *Section 5.0* updates the information from the original mine permit application with the more recent investigations. Relevant information provided in the original permit document has either been reproduced, or revised in accordance with site conditions.

4.2 Recent Investigations

As stated above, no additional groundwater data were collected between the end of 1993 and 2006. A site reconnaissance was completed in early June 2006 to relocate and evaluate the condition of the historic wells in the project. Review of the historic data indicates that there were originally 83 monitoring wells in the project area (see *Section 4.4* for a more detailed discussion). All but 13 of these wells were identified in the field in 2006, although a number of wells were damaged. The most common damage observed was frost damage to the PVC casing at or above the ground surface. The frost damage causes the casing to pinch and restrict the open aperture such that it may not be possible to access the well (for downhole measurements or sampling) without repair.

Downhole surveys were conducted in all accessible wells in June and July 2006. The surveys included a downhole video log, and natural gamma and EM induction logs for each well. A total of 32 monitoring wells and 3 larger diameter wells installed for aquifer pumping tests were logged. The geophysical logging results are presented in the report from COLOG (2006) that is provided in *Appendix B-6*. The results of the survey were used to evaluate the condition of the well for continued use in baseline characterization as discussed in *Section 4.5*.

The location and elevation of the top of the well casing and ground surface at each of the identified wells was surveyed during July and August 2006. The results of the survey were used to update the locations and elevation of the wells and used to convert the depth to water measurements to groundwater elevations.

Between July 2006 and December 2008, water levels were recorded for each well between one and 11 times. Water quality samples were also collected from selected wells during the sampling efforts, which occurred approximately quarterly. Several of the wells with frost-damaged casing were repaired during the September 2006 sampling event. Details regarding the well sampling and repair efforts are provided in the memorandum prepared by Oasis Environmental, Inc. (Oasis 2006A, 2006B) included in *Appendix B-7*. [Note: the studies described in *Appendix B-6* and *Appendix B-7* utilized different well sets; it is a coincidence that both studies included 32 wells.] The recent water level and water quality results were used to update this baseline characterization report.

Three monitoring wells (L-1 {G19A}, L-2 {G19B}, and L-3 {G20A}) were drilled in 2006 in the vicinity of the Ladd Landing Project Component. The locations of the wells are shown in **Figure 4-1**. Boring logs and well completion diagrams for these wells are provided in a separate report prepared by Shannon & Wilson, Inc. The wells range in depth from 21.5 ft. to 35 ft. and all three were completed in unconsolidated sands and gravels. Water quality samples and water level measurements at these wells have been collected since the September 2006 sampling event (Oasis 2006B).

Eighteen shallow piezometers were installed in the vicinity of the proposed mine area between October 24 and November 7, 2006 (Shannon & Wilson, 2006). These piezometers were installed to provide additional information to characterize the shallow (less than 50 feet) water table conditions in the alluvium and glacial drift hydrostratigraphic units. The depth of the piezometers ranges from approximately 17 to 39 feet. The locations of the new piezometers are shown on **Map 4.2-3, Glacial Drift Wells for Aquifer Characterization, oversize sheet** and **Map 4.2-4, Alluvial Wells for Aquifer Characterization, oversize sheet**.

Drilling required for installation of these piezometers was accomplished using a helicopter to transport all equipment and personnel required for the operation. The piezometers were installed by drilling the borehole with hollow stem augers; setting 2-inch diameter schedule 40 PVC casing with a section of slotted casing; and pulling the augers and allowing the native materials to fill the annular space between the borehole wall and the PVC casing (personal communication, Kyle Brennan, 2007). Bentonite chips were used to backfill a section of the annulus near surface and above the screen interval. Although soil samples were not collected during drilling for these borings, observations of the drilling and cuttings brought to the surface by the augers were used to estimate the general lithology encountered. All of the piezometers were completed in unconsolidated sediments with soil-like properties. The general stratigraphy varied between the piezometers locations. The field data indicates that the open interval within the piezometers was completed in one or more of the following materials: peat, silt, sandy silt, sand, sand and gravel, gravel and gravelly clay. The completion and the general stratigraphy inferred for each of the piezometers are summarized in **Table 4-1**.

Table 4-1. Piezometer Summary Table

Well ID ¹	Geologic Drill Log	Well Completion Diagram	Location		Land Surface Elevation ft amsl	Completed By ²	Date Completed	Drill Hole Diameter inch	Drill Hole Depth ft bgs	Casing Type	Casing Diameter inch	Casing Interval ft bgs	Screen Slot Size inch	Screen Interval				Effective Open Interval				Top of Casing (TOC)		Open Interval Lithology ³
			Northing	Easting										Depth	Depth	Elev.	Elev.	Depth	Depth	Elev.	Elev.	ft ags	ft. amsl	
A32A	NA	Yes	2624938	1411636	394.09	SWI	2006	7.5	19.0	PVC sch 40	2.0	18.4	0.02	3.6	18.4	390.49	375.69	2.5	19.0	391.59	375.09	2.7	397.07	silt, sand, gravel
A13A	NA	Yes	2637140	1400777	531.75	SWI	2006	7.5	17.5	PVC sch 40	2.0	17.3	0.02	2.5	17.3	529.25	514.45	1.5	17.5	530.25	514.25	3.0	535.07	Silt, sandy silt to silty sand
A14A	NA	Yes	2641395	1395306	770.30	SWI	2006	7.5	39.0	PVC sch 40	2.0	38.8	0.02	24.0	38.8	746.30	731.50	12.5	39.0	757.80	731.30	3.0	773.59	Silt
A15A	NA	Yes	2639193	1390414	798.09	SWI	2006	7.5	18.5	PVC sch 40	2.0	18.3	0.02	3.5	18.3	794.59	779.79	3.0	18.5	795.09	779.59	3.0	800.99	Peat; gravel (below 17')
A03A	NA	Yes	2619812	1397104	526.28	SWI	2006	7.5	17.5	PVC sch 40	2.0	17.3	0.02	2.0	17.3	524.28	508.98	2.0	17.5	524.28	508.78	2.5	528.99	Peat and clay
G03A	NA	Yes	2619456	1397548	560.60	SWI	2006	7.5	24.0	PVC sch 40	2.0	18.8	0.02	4.0	18.8	556.60	541.80	3.5	24.0	557.10	536.60	3.0	564.28	Gravel, gravelly sand
G35B	NA	Yes	2623461	1399687	693.22	SWI	2006	7.5	23.3	PVC sch 40	2.0	23.1	0.02	8.3	23.1	684.92	670.12	6.0	23.3	687.22	669.92	3.0	696.76	Sandy gravel
G25A	NA	Yes	2627418	1404254	727.81	SWI	2006	7.5	38.0	PVC sch 40	2.0	37.1	0.02	22.3	37.1	705.51	690.71	12.0	38.0	715.81	689.81	3.0	731.69	Silty, sandy Gravel
G26A	NA	Yes	2626367	1395160	739.22	SWI	2006	7.5	18.5	PVC sch 40	2.0	18.3	0.02	3.5	18.5	735.72	720.72	1.0	18.5	738.22	720.72	3.0	742.70	Peat
G14B	NA	Yes	2637211	1400238	583.86	SWI	2006	7.5	39.0	PVC sch 40	2.0	38.0	0.02	23.0	38.0	560.86	545.86	7.0	39.0	576.86	544.86	3.3	587.21	Silty, sandy gravel, silty sand
G14A	NA	Yes	2640802	1395442	776.66	SWI	2006	7.5	19.5	PVC sch 40	2.0	19.1	0.02	4.3	19.1	772.36	757.56	3.0	19.5	773.66	757.16	2.7	779.53	Peat, sandy silt
G15A	NA	Yes	2639375	1391080	800.12	SWI	2006	7.5	18.0	PVC sch 40	2.0	17.3	0.02	2.5	17.3	797.62	782.82	2.0	18.0	798.12	782.12	2.5	802.82	Peat, gravelly sand
G21A	NA	Yes	2635210	1387483	932.20	SWI	2006	7.5	29.0	PVC sch 40	2.0	28.8	0.02	14.0	28.8	918.20	903.40	9.0	29.0	923.20	903.20	2.9	935.36	Sandy silt, silty sand
G22A	NA	Yes	2633618	1389934	888.75	SWI	2006	7.5	18.0	PVC sch 40	2.0	17.8	0.02	3.0	17.8	885.75	870.95	2.0	18.0	886.75	870.75	2.9	891.83	Peat, sandy silt
G28A	NA	Yes	2626582	1386009	855.36	SWI	2006	7.5	19.4	PVC sch 40	2.0	19.2	0.02	4.4	19.2	850.96	836.16	2.0	19.4	853.36	835.96	3.0	858.55	Peat, silt
G33A	NA	Yes	2621874	1384954	811.54	SWI	2006	7.5	29.5	PVC sch 40	2.0	29.1	0.02	4.3	14.3	807.24	797.24	1.5	29.5	810.04	782.04	3.0	814.36	Peat, silt
G34A	NA	Yes	2621729	1391238	761.83	SWI	2006	7.5	25.0	PVC sch 40	2.0	24.8	0.02	10.0	24.8	751.83	737.03	3.0	25.0	758.83	736.83	3.0	765.17	Gravelly clay; cobbles 17-19'
G01B	NA	Yes	2615452	1408311	448.77	SWI	2006	7.5	18.1	PVC sch 40	2.0	19.9	0.02	3.1	17.9	445.67	430.87	3.0	18.1	445.77	430.67	3.0	452.54	Peat

Source: SWI 2006

¹ G = glacial drift; A = alluvium

² SWI = Shannon & Wilson, Inc.

³ Inferred from drilling action and cuttings

4.3 Hydrostratigraphic and Hydrostructural Units

Recharge, storage, and movement of groundwater depends in part on the geologic conditions of the site. The general stratigraphic and structural framework in the proposed mine area and vicinity are described in *Section 3.0*. In summary, the geology of the site consists of semi-consolidated coal-bearing sedimentary rocks of the Tyonek Formation overlain by younger unconsolidated sediments that include glacial drift that blankets the plateau and alluvium along active stream courses. On the basis of general hydrologic properties and groundwater conditions, the lithologic units can be grouped into four hydrostratigraphic units that include (from oldest to youngest): sub red 1 sand, minable coal sequence, glacial drift, and alluvium as described in *Table 4-2*.

Sub Red 1 Sand

The sub red 1 sand is the most laterally consistent aquifer identified in the Tyonek Formation. It is extensive, occurring beneath the entire mine site and adjacent areas. The thickness of this unit is about 30 ft. In most areas, a clay or silty clay bed (that is up to 30 ft. thick) separates the sub red 1 sand from the overlying minable coal sequence. The clay bed is assumed to behave as an aquitard separating it from the overlying hydrostratigraphic units. The sub red 1 sand appears to crop out or subcrop below surficial sediments in the valley walls of Lone Creek, and was removed by erosion along the section of Lone Creek, immediately northeast of the mine area as shown on *Map 4.2-1, Sub Red 1 Sand Monitoring Wells, oversize sheet*.

Bechtel performed aquifer tests in the sand at two locations (ERT, 1984). Transmissivity estimates calculated from these tests were 300 and 1,800 gpd/ft. (*Section 4.6*). These values may be low, however, because the wells at these sites appeared to penetrate the aquifer zone only partially. The areal distribution of transmissivity of the sub red 1 sand was estimated from short-term well recovery tests. Highest values occurred west of the permit area and decreased eastward toward Lone Creek (ERT, 1984; *Appendix B-2*).

Table 4-2. Hydrostratigraphic Units in the Chuitna Coal Mine Area

Hydrostratigraphic Unit	Geologic Unit	Estimated Thickness in LMU (feet)	Lithologic Description	Occurrence	Groundwater Conditions	General Hydrologic Characteristics
Upper Flow System						
Alluvium	Quaternary Alluvium	0-40	Unconsolidated, well-sorted sand and gravel, silt and clay deposited along active streams and their associated floodplains	Along active streams and associated floodplains	Unconfined	High to low permeability depending on material
Glacial Drift	Quaternary Glacial Drift	0-200	Unconsolidated mixture of (a) unsorted, unstratified material ranging in size from rock flour to large boulders (glacial till); and (b) well-sorted, stratified glacial-alluvial deposits consisting predominately of lenses of sand and gravel.	Blankets the plateau area between drainages; partially removed by erosion along sections of Lone Creek, and 2003 and 2004 stream valleys.	Unconfined with local confined zones associated with clay lenses	High to low permeability depending on material
Lower Flow System						
Minable Coal Sequence	Tertiary Tyonek Formation	60-300	Complexly interbedded and interfingering sequence of poorly consolidated, weakly cemented, siltstones, mudstones, and sandstone with coal seams. Includes the Red 1, Red 2, Red 3 and Blue coal seams that would be exploited by the proposed mine. The Red1 coal forms the base of the sequence, and is the lower most unit that would be exploited by the proposed mine.	Sequence underlies the entire LMU. The sequence crops out in the valley walls (and removed by erosion along the creek bottom along Lone Creek adjacent to the northeast boundary of the LMU.	Confined to semi-confined	Predominantly low permeability due to predominance of fine-grained interbeds, discontinuity and presence of clay associated with most of the coal beds
Sub Red 1 Sand	Tertiary Tyonek Formation	30	Well sorted very fine- to medium-grained, fining upward, semi consolidated sandstone	Underlies the entire LMU. Unit outcrops, or subcrops below shallow surficial deposits along the valley walls of upper Lone Creek. Represents the first undisturbed aquifer beneath the base of the proposed strip mine.	Confined Over most of the area, a clay or silty clay bed (aquitar) occurs between the base of the Red 1 Coal (bottom of the minable coal sequence) and the top of the Sub Red 1 Sand	Low to moderate permeability

Minable Coal Sequence

The minable coal sequence as defined herein consists of that portion of the coal bearing Tyonek Formation that contains the coal reserves targeted by the proposed Chuitna Coal Mine. This unit is characterized as a complex interstratified sequence of predominately fine-grained sedimentary rocks with a series of discontinuous coal seams, and four main coal beds: from oldest to youngest, Red 1, Red 2, Red 3, and the Blue coal seams. The variation in thickness and lateral continuity of the coal seams are described in **Section 3.4**. In brief, portions of the upper coal sequence including the Red 3 and Blue coals were removed from portions of LMU-1 by erosion before deposition of the glacial deposits. The thickness of interburden sediments separating the seams is variable, but the Red 1 and Red 2 seams tend to be close together and extend over the greatest area. The Blue Coal and Red 3 Seam tend to occur together but are relatively discontinuous because of removal by erosion. The lower portion of this coal sequence (including the Red 1 and Red 2 coal seams) outcrops or subcrops below surficial sediments in the valley walls of Lone Creek immediately northeast of the mine area. The entire sequence was also removed by erosion along the valley bottom of Lone Creek within this same area (as illustrated by the area shown in **Map 4.2-2, Minable Coal Sequence Wells for Aquifer Characterization, oversize sheet**, where the Red 1 coal seam was removed by erosion).

Groundwater flow and storage in the coal seams are controlled by fractures. As a result, the effective porosity is probably limited with small releases from storage under gravity drainage. Moisture content in the coal is approximately 30 percent. Aquifer tests indicate that there is some flow between the seams through the predominantly fine-grained interbeds but that the coal seams have a higher permeability compared to the interburden sediments (ERT, 1984). Transmissivities for the coal seams vary from about 7-815 gpd/ft; the average coal seam transmissivity is estimated to be 238 gpd/ft (ERT, 1984).

Interburden consists of dense, semi-consolidated silt, clay, and silty sands with some relatively clean sands and gravels of limited extent. The interburden units exhibit highly variable thicknesses. For example, the interburden between the Blue Coal and Red 3 Seam ranges in thickness from about 5 ft to 50 ft. Between the Red 3 and Red 2 Seams, interburden thickness varies from about 10 ft to 180 ft.; and between the Red 2 and Red 1 Seams, interburden ranges from about 10 ft to about 150 ft in thickness (generally thickening from northeast to southwest). As described previously, in most areas, a clay bed separates the minable coal sequence from the underlying sub red 1 sand and acts as an effective confining layer over the sand unit. The interburden beds also generally act as aquitards providing partial confinement for flow within the coal seams.

Glacial Drift

As described in **Section 3.2**, the glacial drift consists of unconsolidated sediment characterized as predominantly unsorted mixtures of clay to boulder-sized material with lenticular bodies of well-sorted sand and gravel. This unit also contains occasional well-bedded lacustrine silts and clays and volcanic ash (Diamond Alaska Coal Company, 1985). In the mine area, the glacial drift blankets the plateau and has variable thickness generally ranging from 40-140 feet. Stream erosion has removed the glacial drift along local sections of Lone Creek and streams 2003 and 2004 at locations shown on **Map 4.2-3, Glacial Drift Wells for Aquifer Characterization, oversize sheet**. The surface of the glacial deposits is hummocky and pock-marked with numerous shallow closed depressions. Muskeg deposits composed of organic silts and peat occur in depressions, abandoned channels, and other poorly drained areas.

Hydraulic properties of the glacial drift unit are heterogeneous and controlled by lithologic characteristics. Mapping and characterization of individual zones within the deposit are not practical. Transmissivities estimated from three aquifer pumping tests range from 4,500 to 250,000 gpd/ft (**Section 4.6**). The highest transmissivities are assumed to correspond to well-sorted sand and gravel zones or lenses within the unit. One highly permeable zone was identified in the east central portion of the mine area; however due to the heterogeneity of the deposits and geologic setting, it seems likely that other highly permeable zones occur within this unit in the mine area. The glacial deposits have intermediate hydraulic conductivities ranging

from about 10-60 ft/day. Vertical hydraulic conductivities were not measured, but are probably one to two orders of magnitude lower than the horizontal values. Overall, the storage capacity of the overburden is large relative to other units. The specific yield of the glacial drift unit is generally on the order of 10 percent or more of the unit's volume. The high transmissivity zones in the east central part of the area generally have an estimated specific yield on the order of 20 to 25 percent.

Alluvium

Alluvium consists of stream channel and associated finer-grained overbank deposits associated with the stream floodplains. Areas inferred to be underlain by alluvium are shown on *Map 4.2-4, Alluvial Wells for Aquifer Characterization, oversize sheet*. These deposits are composed of lenticular bodies of sands and gravels and silts with some clays. These deposits occur only along streams and are estimated to range up to about 40 ft thick. The alluvial deposits are usually covered with muskeg and peat deposits in the flat areas outside the active channels. The peat deposits are often thickest in abandoned channels. The sands and gravels are generally well sorted and highly permeable. Field test data are not available; however, transmissivities are estimated to range from about 3,000 to 50,000 gpd/ft with specific yield ranging up to 20 percent.

4.4 Hydrostructural Units

Groundwater flow pathways are potentially influenced by faults that offset and displace the Tyonek Formation material. Depending on the physical properties of the rock involved, faulting may create either barriers or conduits for groundwater flow. For example, faulting of softer, less competent rocks tends to form zones of crushed and pulverized rock material that behaves as a barrier to groundwater movement. Faulting of hard, competent material often creates conduits along the fault trace, resulting in zones of high groundwater flow and storage capacity compared to the unfaulted surrounding rock.

Major faults or fault zones in the mine area include the Chuit fault and South Pit fault described *Section 3.4*. These faults displace the sub red 1 sand and minable coal sequence hydrostratigraphic units, but apparently do not displace the younger unconsolidated glacial drift and alluvium units. Information on the physical properties or hydraulic properties of these two fault zones is not available. Considering the weak, fine-grained characteristics of the bedrock in the area, and the amount of vertical offset (80-200 ft), both of these faults could behave as impediments to groundwater flow.

4.5 Historic Monitoring Wells Evaluation

Review of available information indicates that 83 monitoring wells were installed in the project area prior to 2006 (see *Appendix B-5*). In 2006, three new wells were drilled in the Ladd Landing area (i.e., G19A, G19B, G20A). Eighteen additional piezometers were installed to measure water levels (see *Table 4-1*).

Available information on the monitoring wells that were installed prior to 2006 was researched, compiled, and evaluated in 2006 to document the well completion details and determine the suitability of the wells for the collection of groundwater elevation data and additional water quality samples for principal hydrostratigraphic zones within the vicinity of the planned mine for baseline characterization. The focus of this evaluation was to:

1. Document how the well was drilled, constructed and developed;
2. Describe the geologic materials encountered within the monitoring well open interval; and
3. Identify the geologic unit / principal hydrostratigraphic unit monitored by each well.

The locations of these historic monitoring wells in relation to the currently proposed project components are shown in *Appendix B-5*. Most of these wells were constructed in coal exploration boreholes as part of the exploration program between 1982 and 1986. A few additional shallow (<10 feet) drive-point-type piezometers were installed in alluvium in 1983. These wells and piezometers were used to monitor water

levels intermittently from 1983 to 1992; and selected wells were used to collect water quality samples between 1982 and 1983.

Table 4-3. Chuitna Coal Project: Completion Details for Historic Monitoring Wells

Well ID	Location					Original Completion Data Summary														2006 Downhole Geophysical Survey			Summary and Suggested Use					Hydrostratigraphic Unit					
	Location UTM, NAD83 (COR 96)		TOC Elev.	Ground Surface Elev.	Casing Stickup	Completed		Drill Hole Diam.	Drill Hole Depth	Casing Type	Casing Diam.	Casing Interval	Screen Slot Size	Screen Interval		Effective Open Interval (1)		Open Interval Based on Geologic Logs and Correlation Sheets		Obs. Depth	Screen Top	Screen Bottom	Use Hist. Data For Baseline Report	Future Monitoring		Allu.	Glacial Drift	Minable Coal Sequence			Sub Red 1 Sand		
	Northing	Easting	ft. amsl	ft. amsl	ft ags	By	Date	inch	ft bgs	inch	ft bgs	inch	ft bgs	ft bgs	ft bgs	ft bgs	ft bgs	Unit	Material	ft. TOC	ft bgs	ft bgs		W.Q	WL			W.Q	WL	Upper Coal (brown, yellow, green)		Blue Coal	Red Coal
05A1	2619816	1386713	644.83	642.14	2.70	Bechtel	3/15/1982	4.75	375	sch 40 pvc	2	63	0.03	55.6	60.6	52	63	Alluvium	Sand & gravel with clay	56.8	53.7	56.6	1	1	1	1	1						
06A2	2617445	1378253	947.51	945.53	1.98	Bechtel	3/20/1982		334.7	sch 40 pvc	2	318	0.04	310	315	300	333.7	Yellow 3, 4 & 5 with sediment	Coal & clayey coal w/ thin carb clay seams, silty clay	312.8	305	310		1				1					
07A2	2615702	1380322	930.35	927.22	3.14	Bechtel	4/11/1982	3 7/8	378	sch 40 pvc	2	92.5	0.04	79.1	89.1	35	92.5	Glacial Drift	Silty fine SAND (sm), yellowish brown					1				1					
14A2	2637680	1395864	799.49	796.43	3.06	Bechtel	Winter-83			sch 40 pvc	2					185	195	NA	No geologic log	181	176.9	181.2		1	1	1				1			
15T	2638351	1393360	834	832.0	2.00	Cloft & Others	3/8/1986	3.88	180	sch 40 pvc	2	91	0.04	79	89	77	93	Glacial Drift	No boring log; obs. Well diagram indicates completion in sand					1				1					
19A1	2634333	1375912	1320.17	1317.43	2.74	Bechtel	4/7/1982	4.75	375	sch 40 pvc	2	96	0.04	87	93	70	96	Blue Coal	70-80 silty clay (cl); 80-96 Coal, gray black w/ trace of clay					1						1			
20B1	2631843	1383320	1036.28	1033.66	2.62	Bechtel	4/14/1982	4 3/4	390	sch 40 pvc	2	370	0.04	360	365	350	390	Red Coal Sequence	350-360, silty clay; 360-390 coal w/ occasional silty clay, carbonaceous clay					1	1	1	1				1		
20C1	2632686	1382556	1078	1076.3	2.20	Bechtel	4/6/1982	4.75	252	sch 40 pvc	2	111	0.04	103	108	97	111	Red 1 Top Coal, Red 2 Coal,	Coal, with some carbonaceous clay					1	1						1		
21J1	2636124	1386428	975.95	973.26	2.69	Bechtel	4/9/1982	4.75	120	sch 40 pvc	2	95	1mm	87.7	91.7	72	120	Red 1 Top, Red 1 Coal, Fine-Grained Interburden	72-78 silt w/ minor clay; 78-98 coal; 98-120 clayey silt						1			1				1	
21K	2635649	1389318	886.90	884.09	2.80	ERT	6/83	1 3/4	8.3	Mild steel Well Point	1.75	8.3	Torch cut slots	5	7.3	0	7.3	Alluvium	No geologic log						1				1				

Well ID	Location					Original Completion Data Summary														2006 Downhole Geophysical Survey			Summary and Suggested Use				Hydrostratigraphic Unit							
																															Location UTM, NAD83 (COR 96)		TOC Elev.	Ground Surface Elev.
	Northing	Easting	ft. amsl	ft. amsl	ft ags	By	Date	inch	ft bgs		inch	ft bgs	inch	ft bgs	Unit	Material	ft. TOC	ft bgs	ft bgs	W.Q	WL	W.Q	WL			Upper Coal (brown, yellow, green)	Blue Coal	Red Coal						
22H	2633334	1393589	786.07	783.14	2.93	Bechtel	1/20/1982	3.875	204.3	sch 80 pvc	2	127.1	0.03	115	122	110	128.5	Red 3 Coal	109.5-124.5 coal; 124.5-128.5 clay	114.4	114	NA		1		1								
22H1-U ¹	2633336	1393599	786.98	783.11	3.86	Bechtel	3/14/1982	6	240	Galvanized Steel	2.5	236	0.04	228	233	189	240	Sub Red 1 Sand	Sand	223.9	NA	NA		1									1	
22H2-G	2633351	1393627	786.20	783.29	2.91	Bechtel	3/15/1982	6	107	Galvanized Steel	2.5	107	0.04	99	104	45	107	Glacial Drift	45-56 clay; 56-75 sand & gravel; 75-93 med sand & silt; 93-105 silt; 105-107 cobbles;	96.7	96'	96.7		1		1		1						
23T	2635499	1397099	756.70	752.51	4.19	Cloft & Others	3/8/1986	3.8	185	sch 40 pvc	2	113	?	100	110	98	117	Glacial Drift		110	96	106		1		1		1						
24K	2634479	1400910	514.2	512.2	2.00	ERT	6/83	1 3/4	7.37	Mild steel	1.75	7.37	Torch cut slots	?	?	0	7.37	Alluvium	No geologic log					1			1							
24D2	2634376	1400158	593.94	592.15	1.79	Bechtel	1/20/1982	3.78	120	sch 40 pvc	2	102.21	0.04	94.2	97.2	85	120	Sub Red 1 Sand	Not provided in geologic log				1	1	1	1							1	
25G	2630606	1401075	712.56	709.68	2.88	Bechtel	2/12/1982	5.125	280.5	sch 40 pvc	2	183	0.4	175	180	170	188	Red 2 Coal	170-188 Coal					1		1								
25H2	2628118	1402284	681.98	679.47	2.52	Bechtel	2/16/1982	3.88	358.3	sch 40 pvc	2	127.5	0.4	120	125	110	136	Blue Coal	109-112.3 Clay; 112.3-136 Coal;					1	1							1		

¹ Recovery Test (Permit Application Part C, Environmental Resources, 1985): C-28

Well ID	Location					Original Completion Data Summary													2006 Downhole Geophysical Survey			Summary and Suggested Use					Hydrostratigraphic Unit						
																																Location UTM, NAD83 (COR 96)	
	Northing	Easting	ft. amsl	ft. amsl	ft ags	By	Date	inch	ft bgs	inch	ft bgs	inch	ft bgs	Unit	Material	ft. TOC	ft bgs	ft bgs	W.Q	WL	W.Q	WL			Upper Coal (brown, yellow, green)	Blue Coal	Red Coal						
35U	2623871	1395327	650.30	646.39	3.91	Cloft & Others	3/6/1986	3.88	359	PVC	2	133	?	120	130	118	138	Glacial Drift	NA	120	111.2	120		1		1							
36C1	2625768	1400060	584.70	581.82	2.89	Bechtel	2/19/1982	4.75	70	sch 40 pvc	2	70	0.04		62	58	70	Glacial Drift	58-70 sand and gravel according to well completion diagram					1									

*Additional detailed information on historic wells is provided in separate tables in Appendix B-5. Completion details for new monitoring wells at Ladd Landing (L-1, L-2, and L-3) provided in Appendix B-8

12 39 5 22 6 13 3 2 11 4

The target monitoring zone for each well was identified by comparing the depth intervals in the well completion diagrams for the open interval within each well with the original borehole correlation sheets completed during the coal exploration program. The borehole correlation sheets were originally developed by interpreting the geologic logs and downhole geophysical logs to correlate coal and interburden and overburden units for use in defining the coal reserves and stripping ratios. These borehole correlations sheets are part of the same dataset used to develop a detailed geologic model for the project area (Mine Engineers, Inc., 1998).

The results of the compilation and review of well completion details for the 83 historic monitoring wells and piezometers are presented in *Table B-5-1, Appendix B-5*. The compilation and review included checking the following information:

- Well ID number,
- Location and elevation,
- Drill hole diameter and depth,
- Monitoring well casing type, diameter, and depth intervals,
- Screen type and depth interval,
- Sand or gravel filter pack type and depth interval,
- Surface seal and isolation seal intervals,
- Effective open interval (defined as the filter pack interval constructed above and below the well screen),
- Geologic materials encountered within the effective open interval,
- Interpreted stratigraphic unit(s) intercepted in borehole within the effective open interval.

There have been discrepancies in some of the wells' identification (ID) numbers reported in prior baseline and permit documents. For this reason, each well was correlated back to the original boring site ID and well completion diagram to verify the original well ID number. Once confirmed, a single well ID number was used for reporting all information associated with the well including map location, water level, water quality and aquifer parameter data.

As stated in *Section 4.2*, most of the historic wells were located and surveyed in 2006. The location and elevation of wells that were not surveyed in 2006 should be considered approximate for the reasons discussed below. Cloft and Cornachione (1986) indicated that the original wells installed in 1982 and 1983 were located on available aerial photographs and topographic maps. Eleven additional monitoring wells were installed in 1986. Cloft and Cornachione (1986) also reported that the additional wells installed in 1986 were surveyed using a "Litton Dash II Inertial System aboard a helicopter" with a reported initial accuracy of plus or minus 2 meters. However, the report notes that vertical elevation may be further affected by the fact that there was 1-5 ft of snow cover during the survey; and a few holes were offset from the actual staked (surveyed) location.

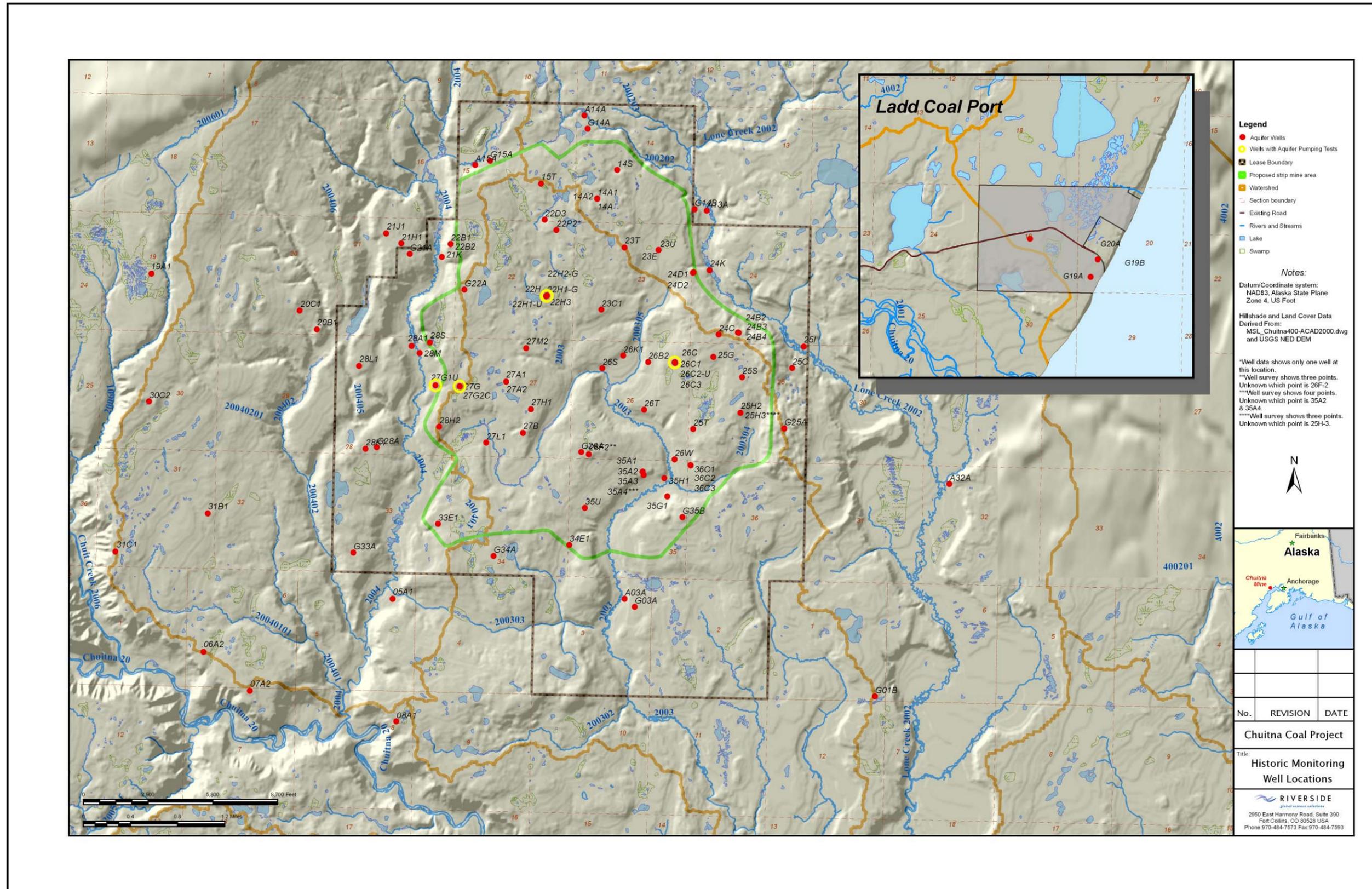


Figure 4-1. Monitoring Well Locations

4.6 Aquifer Hydraulic Properties

Bechtel conducted aquifer pumping tests in 1982 at four of the locations shown on *Figure 4-1*. Each pumping well had two screened zones, an upper zone in the glacial drift unit, and the lower zone in the sub red 1 sand unit. Separate testing of each zone was accomplished by setting a packer seal between the screened zones within the casing. A pump was set above the packer to test the upper zone, and then placed below the packer to test the lower zone. For testing in the glacial drift, observation wells were constructed in the glacial drift and the minable coal sequence. For testing in the sub red 1 sand unit, observation wells were constructed in the sub red 1 sand and the minable coal sequence between the two zones. These wells were monitored to measure the drawdown caused by pumping. Wells were pumped at a constant rate that lowered the water level but maintained a water level above the producing zone. Water levels and pumping rates were measured throughout the test. The results of the pumping test are provided in *Table 4-4* (ERT, 1984).

Bechtel conducted constant head in-situ permeability tests, (referred to as packer tests) in 16 exploratory borings in 1982. The testing procedure used was an open-ended drill stem test. This method allows a calculation of permeability to be made by: drilling through the formation of interest, removing the drill bit and inserting an inflatable packer between joints in the drill string, running the drill string back down the hole and inflating the packer across an impermeable formation just above the permeable formation to be tested, inserting a flow recording meter between the drill string and swivel base at the ground surface, and then pumping water down inside the drill string at a constant pressure from the drilling-mud pump. The rate of water intake was measured when the water was pumped down the hole and the permeability calculated.

Tests were conducted in the overburden and in all coal seams and major interbeds. The test values for the overburden ranged from approximately 2×10^{-5} to 3×10^{-3} cm/sec. The test values for the coal seams ranged from approximately 1×10^{-6} to 5×10^{-3} cm/sec; and interburden materials ranged from 1×10^{-7} to 5×10^{-4} cm/sec. In general, packer tests are more prone to the potential effects of partial plugging within the tested interval by drill cuttings than are aquifer pumping tests, where the wells are developed prior to testing. As a result, the actual hydraulic conductivity may be one-half to one order of magnitude higher than indicated by the packer tests.

Single well pumping tests were conducted by ERT in 1983 by installing a small diameter bladder pump in the 2-inch monitoring wells and withdrawing water at a rate sufficient to lower the water level and maintain a water level above the producing zones. Water levels and pumping rates were measured at intervals using an electric water level sounder and a calibrated bucket (ERT, 1984). The water level drawdown and recovery data from the pumped wells were used for to estimate transmissivity and storativity if a relatively constant water level was achieved during the pumping phase of the test. Theis and Jacobs modification to the Theis equation was used to calculate a value of transmissivity and storativity (ERT, 1984). The estimated hydraulic properties for wells included in the baseline characterization program are provided in *Appendix B-2*.

Table 4-4. Summary of Aquifer Pumping Test Conducted by Bechtel in 1982

Pumping Well	Observation Wells	Distance from Pumping Well	Test Unit	Pumping Rate	Duration	Maximum Drawdown in Obs. Well	Calculated Transmissivity	Comment
Unit		feet		gpm	hrs	feet	gpd/ft	
22H-TW	22H1-G	21.5	Glacial Drift	300	48	45	4500	
26C-TW	26C1	41	Glacial Drift	300	25	2	250,000	
27G-TW	27G	38	Glacial Drift	50 – 75	48	9.8	5000	
22H-TW	22H1-U	10	Sub Red 1 Sand	10	12	5.2	300	
26C-TW	26C2-U	45	Sub Red 1 Sand	5	23	0	-	(1) Open interval included both sub red 1 sediments and Purple Coal; (2) No discernable drawdown in observation well
27G-TW	27G1U	19	Sub Red 1 Sand	8	30	2.8	1800	

4.7 Groundwater Flow Systems

This section describes the existing groundwater elevation data, groundwater gradients, and groundwater recharge and discharge patterns.

4.7.1 Groundwater Elevation Data

The station network for collecting water level data has evolved throughout the course of the project. Water levels were recorded for 77 monitoring wells at intermittent periods between 1983 and 1993. No water levels were collected in any of the monitoring wells between 1993 and 2006. During the June 2006 site reconnaissance, 70 of the original 83 wells were relocated in the field. However, a number of the wells suffered from frost damage to the PVC casing that restricted access to the well for down hole measurements or sampling. A number of wells with water level data were excluded from the 2007 baseline characterization for reasons that included multiple zone completions and a lack of seal between zones. **Table 4-5** presents a comprehensive list of wells that have associated water level data. For the 2007 baseline report, 36 wells were used to assess water levels in the project area. Wells were excluded from the baseline characterization if their associated hydrostratigraphic unit was unknown or if the wells were determined to be inadequate for sampling water levels (see **Table 4-3**). For the wells and piezometers installed in 2006, there was insufficient data to use for baseline characterization in the 2007 report, though the data were included in Appendix B-1 (Riverside 2007).

Table 4-5. Groundwater Wells with Water Level Data

Well ID	Hydrostratigraphic Unit	Period of Record	Number of Measurements ¹	2007 Baseline Report	2010 Baseline Report
05A1	Alluvium	1983-2009	37	X	X
21K	Alluvium	1983-1983	2	X	X
24K	Alluvium	1983-1983	2	X	X
25I	Alluvium	1983-1990	18	X	X
28M	Alluvium	1983-1993	29	X	X
35H1	Alluvium	1983-1993	28	X	X
A03A	Alluvium	2006-2008	8		X
A13A	Alluvium	2006-2009	11		X
A14A	Alluvium	2006-2009	10		X
A15A	Alluvium	2006-2009	10		X
A32A	Alluvium	2006-2009	11		X
07A2	Glacial Drift	1983-2009	37	X	X
15T	Glacial Drift	1986-1993	15	X	X
22H2-G	Glacial Drift	2006-2009	11	X	X
23T	Glacial Drift	1986-2010	30	X	X
26C	Glacial Drift	1983-2006	31		
26C1	Glacial Drift	1983-2009	43	X	X
27B	Glacial Drift	1983-1983	7	X	X
27G	Glacial Drift	1983-2007	35	X	X
27M2	Glacial Drift	1983-1993	29	X	X
28L1	Glacial Drift	1983-1993	25	X	X
28S	Glacial Drift	1986-2009	25	X	X
31C1	Glacial Drift	1983-1983	6	X	X
35U	Glacial Drift	1986-2009	27	X	X
G01B	Glacial Drift	2006-2008	6		X
G03A	Glacial Drift	2006-2009	11		X
G14A	Glacial Drift	2006-2008	8		X

Well ID	Hydrostratigraphic Unit	Period of Record	Number of Measurements ¹	2007 Baseline Report	2010 Baseline Report
G14B	Glacial Drift	2006-2008	9		X
G15A	Glacial Drift	2006-2008	9		X
G19A	Glacial Drift	2007-2009	7		X
G19B	Glacial Drift	2007-2009	8		X
G20A	Glacial Drift	2007-2009	8		X
G21A	Glacial Drift	2006-2009	10		X
G22A	Glacial Drift	2006-2009	9		X
G25A	Glacial Drift	2006-2006	2		X
G26A	Glacial Drift	2006-2009	11		X
G28A	Glacial Drift	2006-2008	8		X
G33A	Glacial Drift	2006-2009	9		X
G34A	Glacial Drift	2006-2009	11		X
G35B	Glacial Drift	2006-2009	11		X
06A2	Minable Coal	1983-2009	34	X	X
14A2	Minable Coal	1984-2009	32	X	X
19A1	Minable Coal	1983-1983	7	X	X
20B1	Minable Coal	1983-2009	43	X	X
20C1	Minable Coal	1983-1983	8	X	X
21J1	Minable Coal	1983-2008	40	X	X
22H	Minable Coal	1983-2008	41	X	X
23E	Minable Coal	1983-1990	27		
24B2	Minable Coal	1984-2006	28		
25G	Minable Coal	1983-2009	42	X	X
25H2	Minable Coal	1983-1992	31	X	X
26F2	Minable Coal	1983-2009	42	X	X
27A1	Minable Coal	1983-2009	16	X	X
27H1	Minable Coal	1983-1983	7		
28A1	Minable Coal	1983-2009	39		X
28K1	Minable Coal	1983-2009	41	X	X
31B1	Minable Coal	1983-1990	31	X	X
35A3	Minable Coal	1984-2008	31	X	X
22H1-U ²	Sub Red 1 Sand	1983-2006	30	X	X
24D2	Sub Red 1 Sand	1983-2009	44	X	X
27G1U	Sub Red 1 Sand	2006-2008	5	X	X
35G1	Sub Red 1 Sand	2006-2010	10	X	X
08A1	Unknown	1983-2006	7		
14A	Unknown	1983-2007	7		
14A1	Unknown	1983-2006	31		
14S	Unknown	1987-1990	16		
22B1	Unknown	1984-2006	25		
22B2	Unknown	1983-1983	6		
22D3	Unknown	1983-2006	33		
22H2	Unknown	1983-1983	3		
22H3	Unknown	1984-1993	25		
22P2	Unknown	2006-2006	3		
23C1	Unknown	1983-2006	33		
23U	Unknown	1986-1993	18		
24B	Unknown	1984-2006	25		
24B3	Unknown	1984-2006	26		

Well ID	Hydrostratigraphic Unit	Period of Record	Number of Measurements ¹	2007 Baseline Report	2010 Baseline Report
24B4	Unknown	2006-2006	1		
24C	Unknown	1983-1990	32		
24D1	Unknown	2006-2006	1		
24L	Unknown	1983-1984	29		
25C	Unknown	1983-2006	28		
25H3	Unknown	1984-1992	25		
25J	Unknown	1983-1984	14		
25S	Unknown	1986-2006	17		
25T	Unknown	1986-2006	17		
25U	Unknown	1987-1990	12		
26B1	Unknown	1984-1993	24		
26B2	Unknown	1983-2006	8		
26C2	Unknown	1983-2006	4		
26C3	Unknown	1984-2006	28		
26K1	Unknown	2006-2006	2		
26S	Unknown	1986-1993	10		
26T	Unknown	1986-2006	20		
26W	Unknown	1986-2006	19		
27A2	Unknown	1983-1983	5		
27G1	Unknown	1983-2006	31		
27G2	Unknown	1983-1993	31		
27G2C	Unknown	2006-2006	2		
28H2	Unknown	1983-1983	7		
30C2	Unknown	1983-1990	29		
33E1	Unknown	1983-2006	32		
34E	Unknown	1984-1993	24		
34E1	Unknown	1983-2006	8		
35A1	Unknown	1986-2009	20		
35A2	Unknown	1984-1993	26		
35A4	Unknown	1984-1992	21		

¹ Value includes number of times well was observed to be flowing.

² Data recorded prior to 2006 are associated with well ID 22H1.

The wells included in the groundwater monitoring program have changed over time. A number of wells could not be relocated (i.e., 20C1, 24K, 25I, 27B, 27M2, 28L1, 28M, 31B1, G25A) or were damaged (i.e., 15T, 19A1, 21K, 22H1-U, 25H2, 31C1, 35H1, 27H1). All suitable water level data continues to be used for baseline characterization, regardless of whether the well is a part of the current monitoring program. Data were excluded from the analysis if:

- The data values were clearly in error (e.g., data recording errors). Only 11 measurements out of approximately 1100 were excluded for this reason.
- The data values were measured at the piezometers damaged by frost heave.

All water level data for the project is provided in *Appendix B-1*.

The water level data were plotted and analyzed by hydrostratigraphic unit to determine the hydraulic gradient and to identify seasonal or temporal variations. The locations of monitoring wells for each of the hydrostratigraphic units and average groundwater elevations are presented in *Map 4.2-1, Map 4.2-2, Map 4.2-3, Map 4.2-4 (oversize sheets)*. In general, the average groundwater elevation combined with the spatial distribution of wells provides a general indication of groundwater flow patterns.

4.7.2 Groundwater Flow System

The existing baseline information suggests that the groundwater flow can conceptually be divided into an upper and lower system. The lower system consists of the sub red 1 sand and minable coal sequence units that are generally confined and connected to regional groundwater flow patterns. The upper flow system consists of the glacial drift and alluvial units that are generally unconfined and exhibit more local recharge and discharge patterns as discussed below.

Lower Flow System

Sub Red 1 Sand. Hydrographs for wells completed within the sub red 1 sand unit are presented in *Figure 4-2*. Although there are four wells completed within the sub red 1 sand unit as shown on the map (*Map 4.2-1 sub red 1 sand Monitoring Wells, oversize sheet*), only two wells (22H1-U and 24D2) have water level measurements prior to 2006. Based on an examination of these wells, water levels have been relatively consistent over the period of record. Both wells show small variations over time, with the highest elevations recorded from 1983-1986, slightly lower elevations recorded in 1987-1993, and intermediate levels recorded from 2006-2009. There is no significant seasonal variation evident from the hydrographs. Monitoring well 35G1, located south of the South Pit fault, was noted to be flowing at the surface when water quality samples were collected in 1982 and 1983; and was flowing when visited in 2006-2010.

The direction of groundwater movement in the central portion of the proposed mine area can be inferred from groundwater elevations from the four monitoring wells completed within this unit. Water level data from these wells indicate that groundwater flow within the central portion of the proposed mine area, between the Chuit fault and South Pit fault, is predominantly west to east. The primary recharge area for this unit is located in higher elevation areas west of the project site. The groundwater gradient between the upgradient well (27G1U) and down gradient well (24D2) is 0.013 or approximately 68 feet per mile. As shown *Map 4.2-1 Sub Red 1 Sand Monitoring Wells, oversize sheet*, the sub red 1 sand unit has been removed by erosion along a segment of Lone Creek adjacent to the northeast boundary of the proposed mine area. Groundwater within the sub red 1 sand unit is inferred to discharge where the unit outcrops or subcrops below surficial sediments in the Lone Creek Valley area.

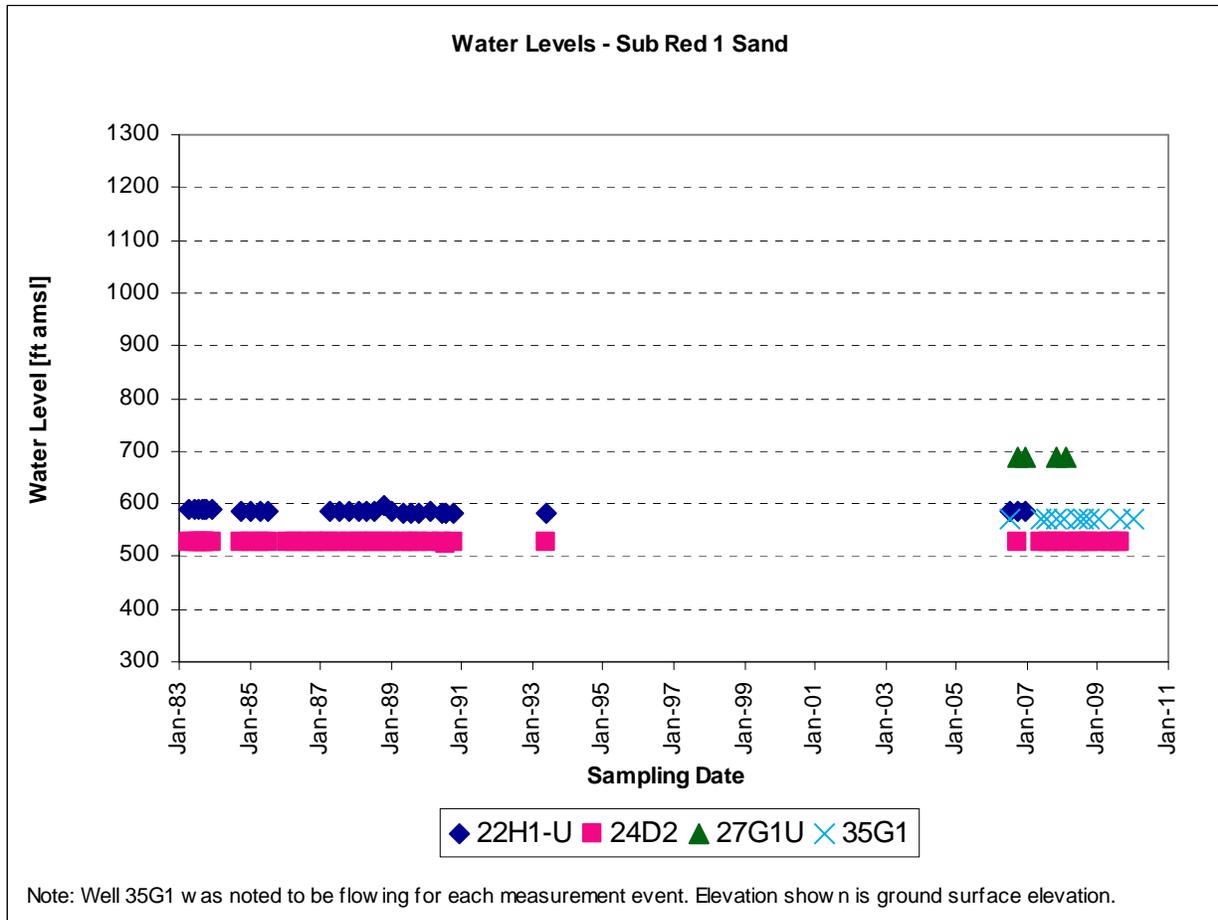


Figure 4-2. Hydrographs for monitoring wells completed within the Sub Red 1 Sand Unit, Chuitna Coal Mine Project Area

The existing water level data from monitoring well 22H1-U in the central portion of the mine area indicate that groundwater within the sand unit at this location is marginally confined or unconfined. A comparison of groundwater elevations between the monitoring wells completed in the minable coal sequence (22H) and the sub red 1 sand (22H1-U) located at the same site suggest that the units are not strongly interconnected. Specifically, the average water level elevation in 22H1-U completed in the sub red 1 sand is 585.9 ft (amsl), whereas, the average groundwater elevation in 22H completed in the minable coal sequence is 768.3 ft (amsl): a head difference of approximately 182.4 ft.

Groundwater flow directions in the sub red 1 sand south of the South pit fault cannot be defined with the existing dataset. The single well (35G) completed in this unit south of the fault is artesian. The difference between apparent unconfined conditions at 22H1-U north of the fault, and strongly confined conditions at 35G south of the fault, suggests that the South Pit fault may behave as a hydraulic barrier that has resulted in compartmentalization of the flow systems on either side of the fault. Although there are limited data, it seems likely considering the regional setting that flow south of the South Pit fault would be towards the east or southeast.

Minable Coal Sequence. Hydrographs for wells completed within the minable coal sequence are presented in *Figure 4-3*. As with the sub red 1 sand, water elevation data indicate that groundwater within the minable coal sequence flows from west to east across the central portion of the site between the Chuit fault and South Pit fault. By comparing the average groundwater elevation measured in the various wells, it appears that the gradient of the potentiometric surface steepens towards the eastern portion of the

proposed mine area. For example, the gradient between monitoring well 20B1 (located about one mile west of the mine boundary) and 22H (located near the center of the mine) is 0.015 or approximately 79 ft per mile. Between 22H and 25G (located near the eastern margin of the mine area), the gradient is approximately 0.19 or 103 ft per mile.

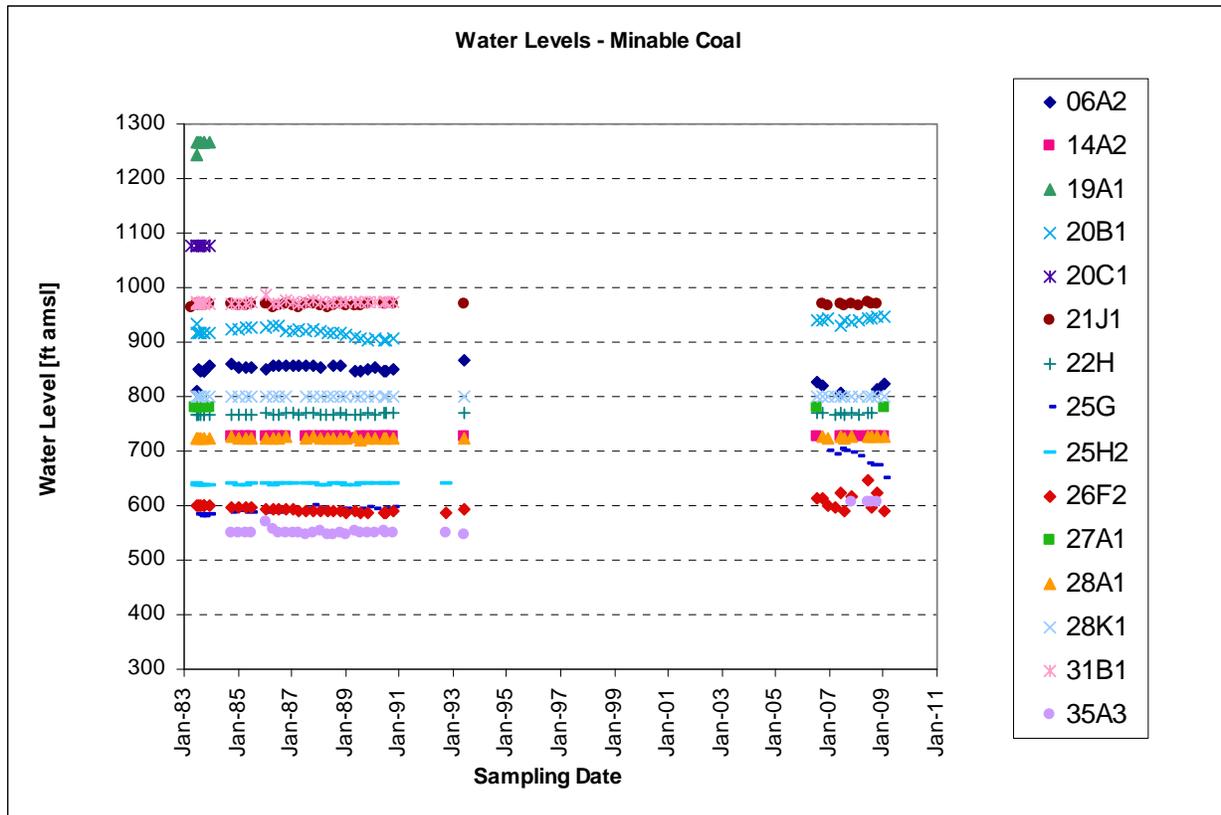


Figure 4-3. Hydrographs for monitoring wells completed within the Minable Coal Sequence, Chuitna Coal Mine Area

A number of the wells completed in the minable coal sequence have periods of record extending back to 1983 (i.e., 06A2, 14A2, 20B1, 21J1, 22H, 25G, 26F2, 28A1, 28K1, 35A3). With the exception of well 06A2, all wells show an increase in water levels for the 2006-2010 period compared to the 1983-1993 period. Seasonality was examined for selected wells (i.e., 06A2, 14A2, 21J1, 22H, 28A1, 28K1) for the period 1983-1993 to eliminate interactions from long-term variability. Consistent seasonal patterns could not be identified, although all wells except 28A1 tended to show slightly lower water levels in April compared to other times of the year.

In the west central portion of the mine area, groundwater is generally confined with wells exhibiting a strong upward flow potential, and three of the monitoring wells (20C1, 27A1, and 27H1) having artesian flow. Along the eastern margin of the mine area (25G), the water levels suggest that groundwater (at least in the red coal sequence) is semi-confined to unconfined. The transition from confined conditions in the central portion of the site to semi-confined to unconfined near the east margin of the mine area appears to be related to geologic conditions along Lone Creek. The minable coal sequence was removed by erosion in the valley bottom along a segment of Lone Creek immediately northeast of the proposed mine boundary (*Map 4.2-2, Minable Coal Sequence Wells for Aquifer Characterization, oversize sheet*). As a result, this sequence essentially daylights or is covered by shallow surficial soils in the valley walls within this same segment of Lone Creek. The semi-confined to unconfined conditions exhibited along the eastern margin of the mine are inferred to reflect local drainage and depressurization of the coal sequence

where it is exposed along this segment of Lone Creek. Due to the fine texture of the sediments within the coal sequence, the contribution to streamflow in this reach is minor.

Groundwater flow patterns across and south of the South Pit fault cannot be defined fully with the existing dataset. There are two monitoring wells (26F2 and 35A3) in the minable coal sequence located south of the fault. The groundwater elevations in these wells are lower than monitoring wells located in the same sequence north of the fault. This limited data suggest that the South Pit fault may act as an impediment to groundwater flow and may possibly act as a partition for the groundwater flow system within the Tyonek Formation bedrock units (herein subdivided into the minable coal sequence and underlying sub red 1 sand hydrostratigraphic units). There is insufficient information to define the potentiometric surface south of the South Pit fault. However, it seems likely considering the regional setting that flow south of the South Pit fault would be towards the southeast. Groundwater flow patterns suggest that both the primary recharge area for the sub red 1 sand and minable coal sequence is higher elevation areas west of the mine area.

Upper Flow System

Glacial Drift. Groundwater elevation data for monitoring wells completed in the glacial drift unit are presented in *Figure 4-4*. The depth to the water table in the glacial drift in the proposed mine area is approximately 8 to 76 ft. (One exception is monitoring well 36C1, completed in the glacial drift in the southeast margin of the mine area, which was reported to be flowing during sampling in 1982.) The water levels in the glacial drift exhibited variations ranging from less than one foot to 22 feet over the monitoring period in individual wells. An examination of the wells with long periods of record (i.e., 07A2, 23T, 26C1, 27G, 28S, 35U) shows that the wells have exhibited small changes in water levels between the 1983-1993 and 2006-2010 time periods, although the changes have not been consistent. Three of the wells show slight increases in water level (i.e., 26C1, 27G, 28S), while three wells show slight decreases (i.e., 07A2, 23T, 35U).

The wells completed in the glacial drift exhibit the most consistent seasonal patterns. These wells typically exhibit lower water levels in spring to early summer, with slightly higher water levels in fall to early winter, suggesting response to seasonal recharge.

Some of the data collected from the piezometers installed in 2006 is questionable. Frost heave has damaged the wells and the data are not considered reliable after December 2006.

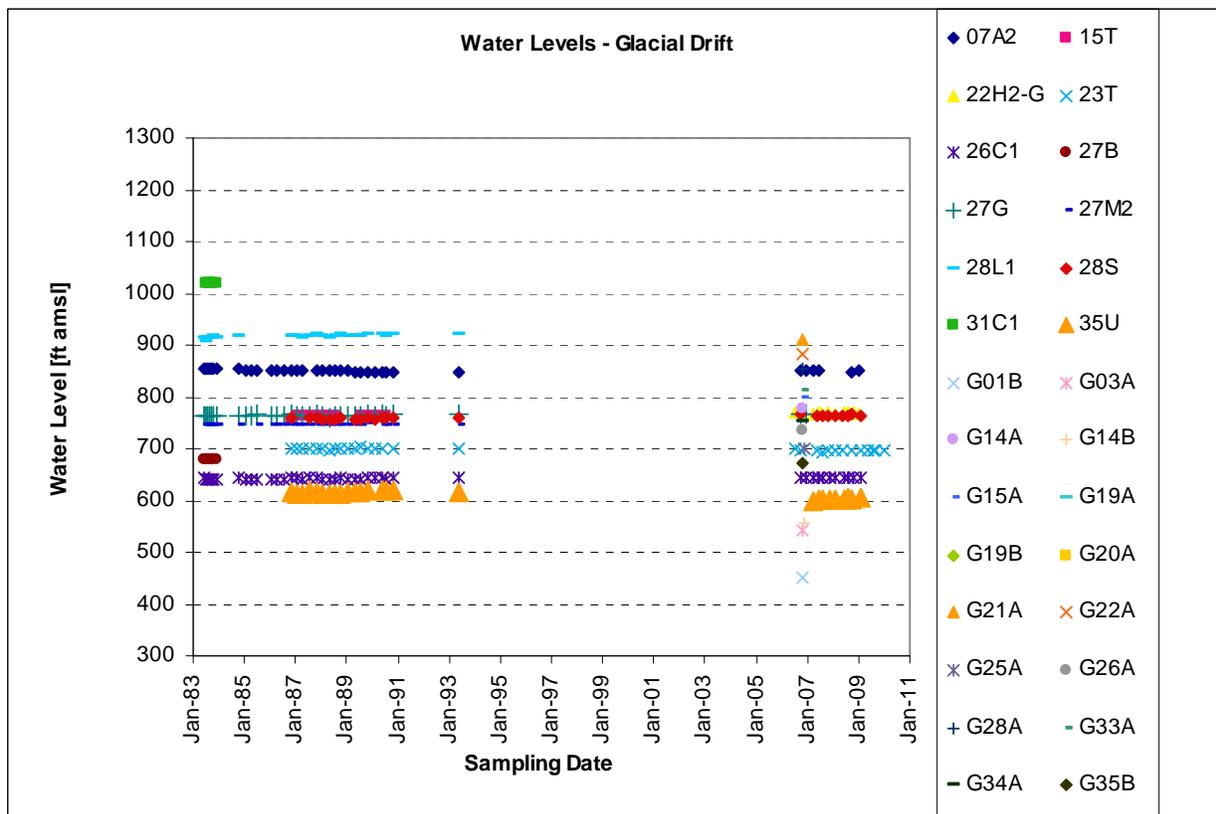


Figure 4-4. Hydrographs for monitoring wells completed within the Glacial Drift, Chuitna Coal Mine Area

The glacial drift unit receives the most recharge, and transmits relatively large volumes of water in comparison to the underlying minable coal sequence and sub red 1 sand hydrostratigraphic units. Groundwater generally occurs under water table conditions except locally where it may be confined by or perched on low-permeability beds (such as lacustrine clays or ash beds).

As described previously, the glacial drift mantles the gentle plateau in the proposed mine area. The surface of the glacial drift in this area is dotted with numerous small ponds, lakes, and bogs that are poorly drained. However, the water level data indicate that the depth to groundwater in the glacial drift ranges from 8 to 76 ft beneath the surface. These data suggest that in general, the surface water features are not directly connected to the water table. The numerous surface water features are presumably perched on low-permeability soils that mantle the surface of the glacial drift over most of the mine area. Most infiltration likely occurs in the better-drained wooded areas where soil conditions are more amenable to percolation.

Water table levels presumably mimic the topography with flow from local topographic highs to stream channels where groundwater is discharged. The existing data also suggest that groundwater flow systems within the glacial drift can be subdivided into several separate areas controlled by local groundwater divides along topographic highs and discharge boundaries along streams.

Stream erosion has removed the glacial drift along local sections of Lone Creek and streams 2003 and 2004 at locations shown on *Map 4.2-3, Glacial Drift Wells for Aquifer Characterization*. Removal of the glacial drift along stream channels immediately west and north of the proposed mine area limits the potential for groundwater inflow via the glacial drift into the mine area from potential upgradient recharge areas. Recharge to the glacial drift is received throughout the proposed mine area except for narrow zones of discharge along stream channels and limited areas of coal seam outcrop. Recharge is by direct

infiltration of precipitation or snowmelt, infiltration from muskeg bogs in depressions, and from small fluvial channels that are perched above the water table.

In addition to the local recharge and discharge patterns controlled by the local topography, there is also an overall decline in water levels in the glacial drift from northwest to southeast across the site.

Alluvium. Groundwater elevation data for monitoring wells completed in the alluvial unit are presented in *Figure 4-5*. Alluvial deposits along perennial stream corridors are saturated under water table conditions. Flow in the alluvium generally occurs as stream underflow. Movement of groundwater in recent alluvial deposits is primarily controlled by the stream gradient. The gradient of the water table in the alluvium is relatively flat compared to the other hydrostratigraphic units. Water levels in monitoring wells located in Lone Creek and Stream 2004 indicate similar gradients around 0.008, or approximately 45 feet per mile.

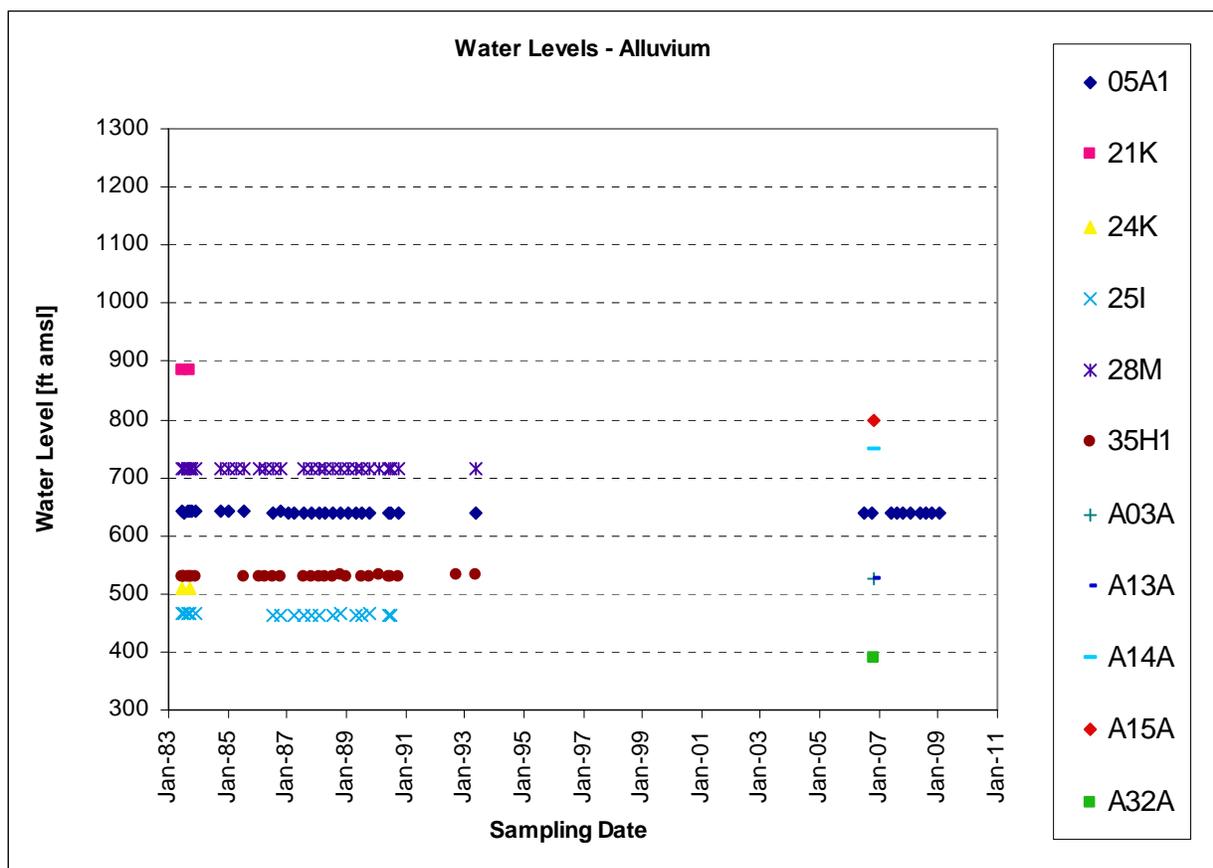


Figure 4-5. Hydrographs for monitoring wells completed within the alluvium, Chuitna Coal Mine Project Area

Recharge to the alluvium is primarily received from streamflow and discharge from the other hydrostratigraphic units, particularly the glacial drift along stream valleys. Minor recharge presumably also occurs associated with discharge from the minable coal sequence and sub red 1 sand units along Lone Creek, as discussed previously. Discharge from the alluvium contributes to stream baseflow (Oasis 2010).

The depth to water surface calculated for A03A was calculated to be negative (*Map 4.2-4, Alluvial Wells for Aquifer Characterization*). Field personnel report that the casings for the piezometers have migrated over time as a result of frost heave, indicating that the calculated values using the 2006 survey elevations are uncertain.

5.0 Chemistry of Groundwater

5.1 Water Quality Criteria

Under 18AAC 70.020(a), the State of Alaska has defined designated uses for which water resources must be protected. By default, all freshwater resources (both ground and surface waters) are protected for seven designated uses, and all marine resources are protected for seven designated uses unless specific exceptions have been approved (see *Table 5-1*; AKDEC 2009).

Table 5-1. Alaska Designated Water Uses

Freshwater Designated Uses	Marine Designated Uses
Drinking water	Seafood processing
Agriculture	Harvesting raw mollusks or other aquatic life
Aquaculture	Aquaculture
Industrial	Industrial
Contact recreation	Contact recreation
Non-contact recreation	Non-contact recreation
Growth and propagation of fish, shellfish, other aquatic life, wildlife	Growth and propagation of fish, shellfish, other aquatic life, wildlife

The Alaska Department of Environmental Conservation has adopted water quality standards for these designated uses. Each designated use is associated with its own set of relevant water quality parameters and pollutant thresholds. The standards are described in “Alaska Water Quality Standards (amended as of September 1, 2009)” and “Alaska Water Quality Criteria Manual for Toxic and Other Deleterious Organic and Inorganic Substances (amended through December 12, 2008)” (AKDEC 2009, AKDEC 2008). The criteria were adopted by the State of Alaska in 18AAC 70.020(b).

Table 5-2 presents a summary of water quality criteria established for inorganic toxics for fresh waters. The drinking water maximum contaminant levels (MCLs) are established to protect human health from exposure via drinking water and during contact recreation. A second set of water quality criteria is established for water used for agricultural water supply (i.e., stock water, irrigation water). A third set of water quality criteria is established to protect aquatic life, aquaculture, and wildlife. Lastly, water quality criteria are established to protect human health when aquatic organisms are consumed.

Table 5-2. Alaska Water Quality Criteria for Inorganic Toxic Pollutants for Fresh Waters (amended through December 12, 2008) (AKDEC 2008)

Alaska Water Quality Criteria -- Fresh Water													
adapted by JVohden from "Alaska Water Quality Criteria Manual for Toxic and Other Deliterious Organic and Inorganic Substances" (as amended through May 15, 2003)													
updated by Riverside from "Alaska Water Quality Criteria Manual for Toxic and Other Deliterious Organic and Inorganic Substances" (as amended through December 12, 2008)													
updated by Riverside to set Human Health Criteria (Water + Aquatic Organisms) for mercury to 0.012 ug/L (March 12, 2009)													
all units in micrograms per liter (ug/L)													
Parameter	Drinking Water	Stockwater	Irrigation Water	Aquatic Life-Fresh Water								Human Health Criteria for NonCarcinogens	
				Acute				Chronic				Water + Aquatic Organisms	Aquatic Organisms Only
				criteria	as	multiply by conversion factor	to convert to	criteria	as	multiply by conversion factor	to convert to		
alkalinity (as CaCO3)										20,000 minimum			
aluminum			5,000	750	TR					87	TR		
antimony	6											14	4,300
arsenic	10	50	100	340	TR	1	D			150	TR	1	D
barium	2,000												
beryllium	4		100										
boron			750										
cadmium	5	10	10	$e^{-1.0166(\ln \text{ hardness})-3.924}$	TR	$1.136672-[(\ln \text{ hardness})/(0.041838)]$	D			$e^{-0.7409(\ln \text{ hardness})-4.719}$	TR	$1.101672-[(\ln \text{ hardness})/(0.041838)]$	D
chloride				860,000	D					230,000	D		
chlorine (total residual)				13						11			
chromium (total)	100		100										
chromium III				$e^{-0.819(\ln \text{ hardness})+3.7256}$	TR	0.316	D			$e^{-0.819(\ln \text{ hardness})+0.6848}$	TR	0.860	D
chromium VI		50		16	D					11	D		
cobalt			50										
copper			200	$e^{-0.3422(\ln \text{ hardness})-1.700}$	TR	0.360	D			$e^{-0.8545(\ln \text{ hardness})-1.702}$	TR	0.360	D
cyanide (as free CN)	200 *			22 **						5.2 **			700
fluoride	4,000		1,000										
iron			5,000							1,000			
lead		50	5,000	$e^{-1.273(\ln \text{ hardness})-1.460}$	TR	$1.46203-[(\ln \text{ hardness})/(0.145712)]$	D			$e^{-1.273(\ln \text{ hardness})-4.705}$	TR	$1.46203-[(\ln \text{ hardness})/(0.145712)]$	D
lithium			2,500										
manganese			200										50
mercury (inorganic)	2			1.4	D					0.77	D		0.051
molybdenum			10										
nickel			200	$e^{-0.846(\ln \text{ hardness})+2.255}$	TR	0.398	D			$e^{-0.846(\ln \text{ hardness})+0.0584}$	TR	0.397	D
nitrate (as N)	10,000												
nitrite (as N)	1,000												
nitrate + nitrite	10,000												
selenium	50	10	20	$1/[(\text{selenite})/185.9]+[(\text{selenate})/112.82]$	TR	0.322	D			5	TR	0.396	D
silver				$e^{-1.72(\ln \text{ hardness})-6.59}$	TR	0.850	D						
thallium	2												1.7
vanadium			100										6.3
zinc			2,000	$e^{-0.8473(\ln \text{ hardness})+0.884}$	TR	0.378	D			$e^{-0.8473(\ln \text{ hardness})+0.884}$	TR	0.386	D

all units in micrograms per liter (ug/L)

* measured as TOTAL CN
 ** measured as WAD CN

TR: total recoverable
 D: dissolved
 H: some of the criteria for this parameter are hardness dependent
 FWA: Fresh Water Acute
 FWC: Fresh Water Chronic

all units in micrograms per liter (ug/L)

Table 5-3 presents a summary of water quality criteria established for conventional pollutants for fresh waters by designated use. The values presented represent a simplification of the true criteria. For example, turbidity and fecal coliform have multiple criteria that govern both the average values and the maximum values observed.

Table 5-3. Alaska Water Quality Criteria for Conventional Pollutants for Fresh Waters

Designated Use	Color (cu)	Fecal coliform bacteria (FC/100mL)	Dissolved Oxygen (mg/L)	Total Dissolved Solids (mg/L)	pH (su)	Temperature (degC)	Turbidity (ntu)
Drinking water	15	20 (SW) 1 (GW)	4	500	6.0-8.5	15	5*
Agriculture	n/a	200	3 (SW)	1000	5-9	30	Qual
Aquaculture	50	200	7 (SW)	1000	6.5-8.5	20 [Migration 15 Spawning 13 Rearing 15 Incubation 13]	25*
Industrial	Qual	200	Qual	Qual	5-9	25	Qual
Contact recreation	15	100	4	n/a	6.5-8.5	30	5*
Non-contact recreation	Qual	200	4	n/a	5-9	n/a	10*
Growth and propagation of fish, shellfish, other aquatic life, wildlife	50	n/a	7-17	1000	6.5-8.5	20 [Migration 15 Spawning 13 Rearing 15 Incubation 13]	25*

n/a = not applicable

Qual = qualitative criteria

* = Turbidity criteria represent maximum increases above natural conditions

For the purposes of the baseline characterization, it is assumed that the most stringent water quality criteria would apply. As some of the water quality criteria for aquatic life depend on hardness, waters with different hardness concentrations will have different water quality criteria. A constant hardness concentration of 25 mg/L was assumed for calculating the criteria values. This is the same value used for calculating the SW criteria (Riverside, 2009) and is consistent with the low hardness values observed in waters in the project area. **Table 5-4** presents the hardness based criteria computed at 25 mg/l hardness.

Table 5-4. Alaska Water Quality Criteria Computed at 25mg/l. Adapted from J. Vohden (2005) and AKDEC (2008a).

Enter the appropriate **Hardness** value for the water you are interested in: 25 mg/L as CaCO₃

color key: orange highlighting: the most stringent criterion
yellow highlighting: the criterion depends on the hardness

all units in micrograms per liter (ug/L)

Parameter	Aquatic Life-Fresh Water												Human Health Criteria for NonCarcinogens		
	Drinking Water	Stockwater	Irrigation Water	Acute				Chronic				Water + Aquatic Organisms	Aquatic Organisms Only		
				the criterion is	as	using the conversion factor	the criterion is	as	the criterion is	as	using the conversion factor			the criterion is	as
alkalinity															
aluminum			5,000	750	TR				20,000 minimum						
antimony	6								87	TR				14	4,300
arsenic	10	50	100	340	TR	/	340	D	150	TR	/	150	D		
barium	2,000														
beryllium	4		100												
boron			750												
cadmium	5	10	10	0.52	TR	1.002	0.52	D	0.10	TR	0.207	0.09	D		
chloride				860000					230000						
chlorine (total residu)				19					11						
chromium (total)	100		100												
chromium III				579.32	TR	0.316	183.07	D	27.69	TR	0.49	23.81	D		
chromium VI		50		16	D				11	D					
cobalt			50												
copper			200	3.79	TR	0.960	3.64	D	2.85	TR	0.949	2.74	D	1,300	
cyanide (as free CN)	200 *			22 **					5.2 **					700	220,000
fluoride	4,000		1,000												
iron			5,000						1,000						
lead		50	5,000	13.88	TR	0.533	13.88	D	0.54	TR	0.539	0.54	D		
lithium			2,500												
manganese			200											50	100
mercury (inorganic)	2			1.4	D				0.77	D				0.012	0.051
molybdenum			10												
nickel			200	145.21	TR	0.399	144.32	D	16.14	TR	0.397	16.10	D	610	4,600
nitrate (as N)	10,000														
nitrite (as N)	1,000														
nitrate + nitrite	10,000														
selenium***	50	10	20	$M\left(\frac{[selenite]}{185.9} + \frac{[selenate]}{12.82}\right)$	TR	0.322	--	D	5	TR	0.336	4.98	D	170	11,000
silver				0.35	TR	0.209	0.30	D							
thallium	2													17	6.3
vanadium			100												
zinc			2,000	37.02	TR	0.376	36.20	D	37.02	TR	0.366	36.50	D	3,100	63,000

all units in micrograms per liter (ug/L)

* measured as free CN
 ** measured as WAD CN
 *** more information is needed to determine most stringent criteria

TR total recoverable
 D dissolved
 H some of the criteria for this parameter are hardness dependent
 F/WA Fresh Water Acute
 F/WC Fresh Water Chronic

5.2 Groundwater Sampling Procedures

Bechtel and ERT collected water quality field measurements and water quality samples between April 1982 and October 1983. Additional water quality samples were collected in selected wells approximately quarterly from June 2006 to January 2010. No water quality data were collected between 1983 and 2006. A brief description of the sampling procedures from each program is provided below

5.2.1 1982-1983 Field Sampling

The following description of sampling procedures is taken from the information provided in *Diamond Alaska Coal Company (1985). Diamond Chuitna Mine, Permit Application to Conduct Surface Coal Mining; Part C, Volume IX: Environmental Resources Information. Appendix C - Groundwater Information.*

Samples were collected using two different types of sampling devices during different sampling periods (Brown et al 1970). A stainless steel, down-hole compressed gas pump with Teflon bladder was used for samples taken in 1982 and June 1983. The intake of the pump was set just above the completed interval of the well. Prior to sample collection the well was pumped to remove a volume of water equal to the standing volume of water in the well. Pumping rates were usually maintained such that the water level did not fall below the top of the completed interval. A PVC bailer was used for samples collected in October 1983. A procedure similar to that used with the bladder pump was used. Samples collected after July 1982 were field filtered. Samples were immediately chilled, removed from sunlight, and sent by airfreight to the laboratory within 12 hours of collection.

Samples were filtered using a 0.45-micron membrane filter under pressure from a peristaltic pump or hydrostatic pressure from an inverted bailer. The first 100 ml of filtrate was routinely discarded to flush the pump and filter apparatus of contaminants.

Selected parameters were measured in the field (ERA, 1979). Water samples were immediately measured for dissolved oxygen, pH, temperature, conductivity, and alkalinity. Water level measurements using an electric water level sounder were made at all wells. Thermometers and YSI model 33 SCT meters were used for temperature measurements and were calibrated against a thermometer traceable to an NBS standard. Hydrogen ion activity (pH) was measured with an Orion model 201 or 211 pH meter. Field alkalinity was measured by titration. A 100-ml sample of water was titrated using standardized sulfuric acid as titrant and bromocresol green methyl red indicator solution (American Public Health Association, 1976). Results of the titrations were reported in milligrams per liter total alkalinity as calcium carbonate. Calibrations were checked with buffer solutions traceable to an NBS standard. Dissolved oxygen was measured with a YSI model 57 dissolved oxygen meter with a membrane polarographic probe. The instrument was calibrated to moist air saturation at the ambient air temperature.

Groundwater samples were analyzed for standard water quality indicators, including pH, alkalinity, major cations and anions, and metals. The samples were not analyzed for barium or thallium. Field data were collected for pH, conductivity, temperature, dissolved oxygen, and total alkalinity. The water quality of the samples was compared to the most stringent water quality criteria. However, for several trace metals, the most stringent water quality criteria were lower than the detection limit used at the time. For cadmium, the detection limit is one order of magnitude higher than the water quality criteria. The same is true for copper, lead, mercury, silver, and cyanide. For beryllium and selenium, the criteria are close to the detection limit. Thus, even if the water quality results show non-detects for the above trace metals, no conclusion on whether the water actually meets the criteria can be drawn. Values reported below detection limits were set to one-half the detection limit value for the purposes of data analysis.

5.2.2 2006-2010 Field Sampling

Groundwater samples were collected from selected monitoring wells approximately quarterly from June 2006 through January 2010 for laboratory analysis. The field procedures and conditions encountered

during sampling are documented in the well sampling summaries prepared by Oasis Environmental (Oasis 2006a, 2006b). Sampling was performed according to the Quality Assurance Project Plan (*Appendix C-1*). Groundwater sampling was performed using pumps to purge and sample the wells following established procedures for low-flow sampling techniques. Artesian wells were sampled by collecting samples of water flowing at the surface. Field parameters were measured prior to collecting samples. Sample collection including pretreatment of sample bottles, preservation, and analysis adhered to EPA methods (U.S. Environmental Protection Agency 1979a; U.S. Environmental Protection Agency, 1979b; American Public Health Association, 1976). Samples that were to be analyzed for dissolved parameters were filtered through a 0.45-micron membrane filter under pressure with a peristaltic pump. Additional details regarding sampling procedures are provided in the Quality Assurance Project Plan (*Appendix C-1*) and summaries of the sampling activities (*Appendix B-7*).

5.3 Water Quality Analyses

Water samples were collected starting in August 1982 to be analyzed by analytical laboratories. *Table 5-5* summarizes physical and chemical parameters that have been measured from the original baseline period to present. However, the parameter list has varied from the original 1982-1983 study to the current study. The original study used an extensive list consistent with the water quality criteria in place at the time. Analysis of these samples used a less extensive parameter list. Samples for the current study include most of the parameters in *Table 5-5* except coliform bacteria, gross alpha, and gross beta. Samples collected in August 1982 were also tested for EPA priority organic pollutants (*Table 5-6*) to establish pre-mining concentrations. *Table 5-7* lists references to methodologies and, where applicable, detection limits used beginning in 2006. *Appendix C-3* contains the methodologies and, where applicable, the detection limits used in the 1982-1983 study. Since the original study was completed, detection limits for metals have moved lower in response to the current hardness-based water quality criteria. In addition, the hardness of waters found in the Chuit River basin is low, resulting in criteria concentrations in the lower part of the possible range. Extensive coordination was done with the laboratory to ensure that the detection limits used for metals analysis in the current study were consistent with current criteria.

Pretreatment of sample bottles, preservation, and analysis adhered to EPA methods (U.S. Environmental Protection Agency 1979a; U.S. Environmental Protection Agency, 1979b; American Public Health Association, 1976).

Samples that were to be analyzed for dissolved parameters were filtered through a 0.45-micron membrane filter under pressure with a peristaltic pump. The first 150-200 milliliters of filtrate was discarded to flush the pump and filter apparatus of contaminants. Filtration was done in the field. All samples were preserved immediately after filtering (U.S. Environmental Protection Agency, 1979b).

Table 5-5. Water Quality Parameters^{4,5}

Parameter	Parameter
Streamflow, Instantaneous (cfs) ⁵	Antimony, Total Recoverable
Temperature (deg C)	Antimony, Dissolved
Oxygen, Dissolved ⁷	Arsenic, Total Recoverable
pH, Field (units)	Arsenic, Dissolved
Conductivity, Field (micromhos/cm) ⁵	Beryllium, Total Recoverable
Conductivity, Field Value Corrected to 25 deg C (micromhos/cm) ⁵	Beryllium, Dissolved
Solids, Total Suspended at 103 Deg C	Boron, Total Recoverable
Solids, Total Dissolved at 180 Deg C	Boron, Dissolved
Alkalinity, Field Total as CaCO ₃	Cadmium, Total Recoverable
Bicarbonate, Field Total as HCO ₃	Cadmium, Dissolved
Carbonate, Field Total as CO ₃	Chromium, Total Recoverable
pH, Lab (units)	Chromium, Dissolved
Conductivity, Lab (micromhos/cm)	Copper, Total Recoverable
Color, Lab (PCU) ⁸	Copper, Dissolved
	Iron, Total Recoverable
	Iron, Dissolved
Turbidity, Lab (NTU)	Lead, Total Recoverable
Coliform, Total (colonies/100 ml) ⁷	Lead, Dissolved
	Lithium, Dissolved
	Lithium, Total Recoverable
Coliform, Fecal (colonies/100 ml) ⁷	Manganese, Total Recoverable
Hardness, Total as CaCO ₃	Manganese, Dissolved
Calcium	Mercury, Total Recoverable
Magnesium	Mercury, Dissolved
	Molybdenum, Total Recoverable
	Molybdenum, Dissolved
Sodium	Nickel, Total Recoverable
Potassium	Nickel, Dissolved
Ammonia, as N	Selenium, Total Recoverable
Alkalinity, Total as CaCO ₃	Selenium, Dissolved
Bicarbonate, as HCO ₃	Silica, Total Recoverable as Si
Carbonate, as CO ₃	Silica, Dissolved as Si
Hydroxide, as OH	Silver, Total Recoverable
Chloride	Silver, Dissolved
	Stontium, Total Recoverable
	Stontium, Dissolved
	Thallium, Total Recoverable
	Thallium, Dissolved
Fluoride	Titanium, Total Recoverable
Nitrate + Nitrite, as N	Titanium, Dissolved
	Vanadium, Total Recoverable
	Vanadium, Dissolved
Sulfate	Zinc, Total Recoverable
Cation Anion Difference (meq/l) / Acceptable Limit (meq/l) ⁹	Zinc, Dissolved
Orthophosphate, as P	Cyanide, WAD
Aluminum, Total Recoverable	Gross Alpha (pCi/l) Dissolved
Aluminum, Dissolved	Gross Beta (pCi/l) Dissolved
Barium, Dissolved	Phenol
Barium, Total Recoverable	Organic Carbon, Total
Cobalt, Dissolved	
Cobalt, Total Recoverable	

Note: Dissolved metals are those metals that will pass through a 0.45-micron membrane filter. Samples for dissolved metals were 0.45 micron filtered in the field immediately prior to preservation.

Note: Total recoverable metals refer to the concentration of metals in an unfiltered sample following treatment with hot diluted mineral acid.

⁴ Units in mg/l unless indicated otherwise

⁵ Analysis in laboratory by Northern Testing Laboratories unless indicated otherwise

⁶ Analysis performed in field

⁷ Analysis performed at field water temperature unless indicated otherwise

⁸ Analysis in laboratory performed by Chemical & Geological Laboratories of Alaska.

⁹ Acceptable limits (meq/l) equals: $\sqrt{(0.1065 + 0.0155 \text{ 3 Anions})}$

Table 5-6. List of Priority Pollutants

Volatile Organics (µg/L)

Acrolein
 Acrylonitrile
 Chloromethane
 Dichlorodifluoromethane
 Bromomethane
 Vinyl chloride
 Chloroethane
 Methylene chloride
 Trichlorofluoromethane
 1,1-dichloroethylene
 1,1-dichloroethane
 trans-1,2-dichloroethylene
 Chloroform
 1,2-dichloroethane
 1,1,1-trichloroethane
 Carbon tetrachloride
 Bromodichloromethane
 1,2-dichloropropane
 trans-1,3-dichloropropene
 Trichloroethylene
 Benzene
 cis-1,3-dichloropropene
 1,1,2-trichloroethane
 Dibromochloromethane
 Toluene
 Chlorobenzene
 Ethylbenzene
 bis (chloromethyl) ether
 2-chloroethyl vinyl ether

Acid Extractables (µg/L)

Phenol
 2-chlorophenol
 2-nitrophenol
 2,4-dimethylphenol
 2,4-dichlorophenol
 p-chloro-m-cresol
 2,4,6-trichlorophenol
 2,4-dinitrophenol
 4-nitrophenol
 4,6-dinitro-o-cresol
 Pentachlorophenol

Base/Neutral Extractables (µg/L)

1,3-dichlorobenzene
 1,4-dichlorobenzene
 Hexachloroethane
 1,2-dichlorobenzene
 bis (2-chloroisopropyl) ether
 Hexachlorobutadiene
 1,2,4-trichlorobenzene
 Naphthalene
 bis (2-chloroethyl) ether
 Hexachlorocyclopentadiene
 Nitrobenzene
 bis (2-chloroethoxy) methane
 2-chloronaphthalene
 Acenaphthylene
 Acenaphthene
 Isophorene
 Fluorene
 2,6-dinitrotoluene
 1,2-diphenylhydrazine
 2,4-dinitrotoluene
 n-nitrosodiphenylamine

Base/Neutral Extractables (µg/L) (cont)

Hexachlorobenzene
 4-bromophenyl phenyl ether
 Anthracene
 Phenanthrene
 Dimethylphthalate
 Diethylphthalate
 Fluoranthene
 Pyrene
 Di-n-butyl phthalate
 Benzidine
 Butylbenzylphthalate
 Chrysene
 bis (2-ethylhexyl) phthalate
 Benzo (a) anthracene
 Benzo (b) fluoranthene
 Benzo (k) fluoranthene
 Benzo (a) pyrene
 Indeno (1,2,3-cd) pyrene
 Dibenzo (a,h) anthracene
 Benzo (g,h,i) perylene
 n-Nitrosodimethylamine
 n-Nitrosodi-n-propylamine
 4-chlorophenyl phenyl ether
 3,3'-dichlorobenzidine
 2,3,7,8-tetrachlorodibenzo-p-dioxin
 bis (chloromethyl) ether
 Di-n-octyl phthalate

Pesticides (µg/L)

Alpha-BHC
 Beta-BHC
 Delta-BHC
 Gamma-BHC (lindane)
 Heptachlor
 Aldrin
 Heptachlor Epoxide
 Dieldrin
 4,4'-DDE
 4,4'-DDD
 Endosulfan sulfate
 4,4'-DDT
 Chlordane
 Alpha endosulfan
 Beta endosulfan
 Endrin
 Endrin aldehyde
 Toxaphene
 PCB 1016
 PCB 1221
 PCB 1232
 PCB 1242
 PCB 1248
 PCB 1254
 PCB 1260

Inorganic Priority Pollutants

Antimony	Nickel
Arsenic	Selenium
Beryllium	Silver
Cadmium	Thallium
Chromium	Zinc
Copper	Total Cyanide
Lead	Total Phenol
Mercury	

Table 5-7. Water Quality Parameter Detection Levels and Analysis Methods (2006 – Present)

Parameter	Units	Lower Detection Limit	Method
Aluminum	mg/L	0.02	EPA 200.7
Ammonia Nitrogen (as N)	mg/L	0.1	EPA 350.1
Antimony	mg/L	0.003	EPA 200.8
Arsenic	mg/L	0.005	EPA 200.8
Barium	mg/L	0.1	EPA 200.8
Beryllium	mg/L	0.002	EPA 200.7
Bicarbonate as HCO ₃	mg/L	5	SM 2320B
Boron	mg/L	0.03	EPA 200.7
Cadmium	mg/L	0.0001	EPA 200.8
Calcium	mg/L	1	EPA 200.7
Carbonate as CO ₃	mg/L	5	SM 2320B
Chloride	mg/L	1	EPA 300.0
Chromium	mg/L	0.01	EPA 200.7
Cobalt	mg/L	0.01	EPA 200.8
Color	C.U.	5	SM 2120B
Copper	mg/L	0.001	EPA 200.8
Electrical Conductivity	µmhos/cm	5	SM 2510B
Fluoride	mg/L	0.1	SM 4500FC
Hardness (Ca/Mg as CaCO ₃)	mg/L	10	SM 2340B
Hydroxide as OH	mg/L	5	SM 2320B
Iron	mg/L	0.02	EPA 200.7
Lead	mg/L	0.0003	EPA 200.8
Lithium	mg/L	0.01	EPA 200.7
Magnesium	mg/L	1	EPA 200.7
Manganese	mg/L	0.01	EPA 200.7
Mercury	mg/L	0.00006	EPA 245.1
Molybdenum	mg/L	0.01	EPA 200.8
Nickel	mg/L	0.01	EPA 200.7
Nitrate Nitrogen (as N)	mg/L	0.1	EPA 300.0
Nitrate+Nitrite as N	mg/L	0.1	EPA 300.0
Nitrite Nitrogen (as N)	mg/L	0.1	EPA 300.0
pH	s.u.	0.1	EPA 150.1
Phosphorus (Orthophosphate as P)	mg/L	0.1	EPA 300.0
Potassium	mg/L	1	EPA 200.7
Selenium	mg/L	0.003	EPA 200.8
Silicon	mg/L	0.1	EPA 200.7
Silver	mg/L	0.0002	EPA 200.8
Sodium	mg/L	1	EPA 200.7
Strontium	mg/L	0.01	EPA 200.8
Sulfate	mg/L	1	EPA 300.0
Thallium	mg/L	0.001	EPA 200.8
Titanium	mg/L	0.01	EPA 200.8
Total Alkalinity (as CaCO ₃)	mg/L	5	SM 2320B
Total Dissolved Solids (180)	mg/L	10	SM 2540
Total Organic Carbon	mg/L	1	SM 5310B
Total Suspended Solids	mg/L	5	SM 2540
Turbidity	NTU	0.1	SM 2130
Vanadium	mg/L	0.01	EPA 200.8
WAD Cyanide	mg/L	0.01	SM4500
Zinc	mg/L	0.005	EPA 200.7

Measurements were taken in the field for temperature, pH, and conductivity. Detailed field procedures were as follows:

- Water temperature was measured using an Oakton pH/Con10 or a YSI model 33 SCT meter. The meters used for temperature measurements were calibrated against a thermometer traceable to an NBS standard (American Public Health Association, 1976).

- Conductivities were measured with an Oakton pH/Con10 or a YSI model 33 SCT meter and instream probe. A Lab-line model 11201 sproule-type cell was used to check conductivities during very cold weather. Calibration of the instrument was checked using a standard potassium chloride solution. Field conductivities were corrected to 25°C (American Public Health Association 1976; U.S. Environmental Protection Agency 1979b; Hem, 1978).
- Hydrogen ion activity (pH) was measured with an Oakton pH/Con10 or an Orion model 201 or 211 pH meter. Calibration was checked with buffer solutions traceable to an NBS standard (American Public Health Association, 1976).

As a quality control check, cation-anion balances were performed to assess the accuracy of the inorganic analyses. Theoretically, the sum of the anions expressed in milliequivalents per liter (meq/l) should match the sum of the cations expressed in milliequivalents per liter. In practice, the sums are seldom exactly equal. This inequality increases as the ionic concentration increases. An acceptable index of variation is considered to be one standard deviation of the anions, where the acceptable limits are given by the equation:

$$Z \text{ anions} - I \text{ cations} = \pm(0.1065 + 0.0155 F \text{ anions})$$

Where anions and cations are expressed in meq/l (American Public Health Association 1976).

5.4 Groundwater Quality

Baseline groundwater quality has been characterized by analyzing samples from wells located throughout the Chuitna Project study area. The station network has evolved throughout the course of the project. **Table 5-8** presents a comprehensive list of all wells with water quality data. Forty-seven wells were sampled in 1982-1983 up to four times each, in April 1982, July 1982, June 1983, and October 1983. The 2007 baseline characterization report utilized water quality data from 11 wells. A number of wells with water quality data were excluded from the 2007 baseline characterization for reasons that included multiple zone completions, a lack of seal between zones, etc (see **Table 4-3**).

Table 5-8. Groundwater Wells with Water Quality Data

Well ID	Hydrostratigraphic Unit	Period of Record	Number of Samples	2007 Baseline Report	2010 Baseline Report
05A1	Alluvium	1982-2008	13	X	X
35H1	Alluvium	1982-1983	4	X	
07A2	Glacial Drift	1982-1982	2		
22H2-G	Glacial Drift	2006-2006	3		
23T	Glacial Drift	2006-2010	15		X
26C	Glacial Drift	1982-1982	2		
26C1	Glacial Drift	1982-1982	1		
27B	Glacial Drift	1982-1983	4	X	
27G	Glacial Drift	1982-1983	3		
27M2	Glacial Drift	1982-1982	2	X	
28L1	Glacial Drift	1982-1983	4	X	
28S	Glacial Drift	2006-2009	11		
31C1	Glacial Drift	1982-1982	2		
35U	Glacial Drift	2006-2006	2		
36C1	Glacial Drift	1982-1982	2		
G19A	Glacial Drift	2007-2009	9		X
G19B	Glacial Drift	2006-2009	10		X
G20A	Glacial Drift	2006-2009	10		X
06A2	Minable Coal	1982-2006	4		
14A2	Minable Coal	2006-2009	11		X

Well ID	Hydrostratigraphic Unit	Period of Record	Number of Samples	2007 Baseline Report	2010 Baseline Report
20B1	Minable Coal	1982-2009	10	X	X
20C1	Minable Coal	1982-1983	4	X	
21J1	Minable Coal	1982-1982	2		
22H	Minable Coal	1982-2006	6		
24B2	Minable Coal	1982-1982	2		
25G	Minable Coal	1982-1982	2		
25H2	Minable Coal	1982-1983	4	X	
27A1	Minable Coal	1982-2009	13	X	X
27H1	Minable Coal	1982-1983	4	X	
28A1	Minable Coal	1982-1983	3		
28K1	Minable Coal	1982-2006	3		
31B1	Minable Coal	1982-1983	4		
22H1	Sub Red 1 Sand	1982-1983	4		
22H1-U	Sub Red 1 Sand	2006-2006	1		
24D2	Sub Red 1 Sand	1982-2010	17	X	X
27G1U	Sub Red 1 Sand	2006-2006	1		
35G1	Sub Red 1 Sand	1982-2009	16		X
08A1	Unknown	1982-2006	3		
14A	Unknown	2006-2006	2		
14A1	Unknown	1982-1983	4		
21H1	Unknown	1982-1982	2		
22B1	Unknown	1983-2006	3		
22D3	Unknown	2006-2006	1		
22H2	Unknown	1982-1982	2		
22P2	Unknown	2006-2006	1		
24C	Unknown	1982-1983	4		
24D1	Unknown	1982-2006	4		
24L	Unknown	1983-1983	2		
25C	Unknown	1982-1983	4		
25J	Unknown	1983-1983	2		
25S	Unknown	2006-2006	1		
25T	Unknown	2006-2006	3		
26B2	Unknown	1982-1982	1		
26C3	Unknown	2006-2006	2		
26K1	Unknown	1982-1982	2		
26K2	Unknown	1982-1982	2		
26T	Unknown	2006-2006	1		
27A2	Unknown	1982-1982	1		
27G1	Unknown	1982-1983	2		
27G2	Unknown	1982-1983	2		
27L1	Unknown	1982-1982	2		
28H2	Unknown	1983-1983	1		
33E1	Unknown	1982-1982	2		
34E1	Unknown	1982-1983	4		
35A1	Unknown	1982-1982	2		

Over time, wells have been discontinued from the monitoring program because they could not be relocated (i.e., 20C1, 27B, 27M2, 28L1) or because of damage (i.e., 25H2, 35H1, 27H1). In 2006, some of the historic wells were redeveloped and had low flow pumps installed, making them available for future water quality sampling (i.e., 14A2, 23T, 28S, 35G1). Three wells that were drilled in 2006 have

been incorporated into the water quality sampling program (i.e., G19A, G19B, G20A). In 2009, the monitoring program was reduced for maintenance mode to three wells: 23T, 24D2, and 35G1.

5.4.1 Data Suitability

The intent of this baseline report is to assess naturally occurring groundwater quality in the project area. All water quality data that have been collected from 1982-2010 are provided in *Appendix B-4*. However, the water quality data presented in the body of this report are limited based on well completion history and data quality for the period 2006-2010. The 2006-2010 data were measured using detection limits that are sufficiently low to compare against the current applicable water quality criteria.

Many of the wells sampled between 2006 and 2010 exhibit instances of high turbidity and total suspended solids (TSS). Although turbidity concentrations can be large and highly variable in surface waters, natural turbidity in groundwater is generally less than five turbidity units (Wilde 2005). Large turbidity concentrations measured in the groundwater samples even after redevelopment activities indicate inadequate well construction and development rather than natural water quality of the formation water.

High turbidity and TSS concentrations are often accompanied by large total metals concentrations (see *Table 5-9*) because the analysis methods for total metals require acidification of the groundwater sample to a pH of 2.0. The acid digestion drives the majority of particulate metal into solution. In the groundwater samples, the highest recorded turbidity concentrations are typically associated with high total metals concentrations but low (and in some cases, below detection limit) dissolved metals concentrations.

Table 5-9. Example Correlation Coefficients between Metals and Turbidity and TSS

Metal	Correlation Coefficient with Turbidity Concentration [R]	Correlation Coefficient with TSS Concentration [R]
Aluminum – Dissolved	0.18	0.47
Copper – Dissolved	0.06	0.11
Iron – Dissolved	0.08	0.11
Manganese – Dissolved	0.27	0.23
Zinc – Dissolved	-0.01	0.00
<hr/>		
Aluminum – Total	0.73	0.83
Copper – Total	0.64	0.76
Iron – Total	0.80	0.81
Manganese – Total	0.84	0.88
Zinc – Total	0.35	0.67

For the purposes of baseline characterization, two sets of water quality results are presented for each hydrostratigraphic unit. One set summarizes the water quality using all samples taken between 2006 and 2010 at suitable wells. The second set summarizes the water quality using selected samples that exhibit turbidity concentrations < 50 NTU and TSS concentrations < 20 mg/L. The selected water quality results are likely to better reflect naturally occurring groundwater quality in the project area than all water quality results, which appear affected by inadequately constructed wells.

5.4.2 Water Quality by Hydrostratigraphic Unit

Baseline water quality was summarized for the alluvial, glacial drift, minable coal sequence, and sub red 1 sand hydrostratigraphic units using all data samples between 2006-2010 and screened data samples from 2006-2010. Summary tables include the number of samples analyzed, the number of samples with values reported below detection limit, and the average, median, minimum, and maximum concentrations. In addition, the summary tables compare concentrations to the most stringent water quality criteria to

identify exceedances. For the purposes of baseline characterization, the water quality criteria that are a function of water hardness were computed assuming a nominal hardness value of 25 mg/L as CaCO₃. This value represents approximately the median surface water concentration and the 25th percentile groundwater concentration. Exceedances of the most stringent water quality criteria are shaded in pink. A detailed comparison of all of the samples collected by hydrostratigraphic unit is provided in *Appendix B-3*.

Alluvial Water Quality

The alluvial water quality is assessed using water quality data from well 05A1. Recent data at this well are available for the period 2006-2008. The groundwater in the alluvium is of calcium bicarbonate type. The pH is neutral to slightly alkaline, with pH values of 7.9 to 8.3 (*Table 5-10*). Groundwater concentrations of total dissolved solids range from 130 to 190 mg/l, with an average of 158 mg/l. Turbidity is low, with an average value less than 5 NTU and a maximum value less than 8 NTU. All samples have less than 20 mg/L TSS. Because none of the recent samples violated the screening criteria, only one set of summary statistics are presented.

Table 5-10. Water Quality Summary for Alluvial Hydrostratigraphic Unit¹⁰

Parameter	Units	Criteria	Average	Median	Minimum	Maximum	No.	Number of Non-Detect Samples
Total Dissolved Solids	mg/l		158	160	130	190	9	0
Total Suspended Solids	mg/l		4.7	nd	nd	20	9	7
ph_Field	su		7	7	6.5	7.5	2	0
pH_Lab	su		8.1	8.2	7.9	8.3	9	0
Conductivity_Field	umhos/cm		426	426	229	623	2	0
Conductivity_Lab	umhos/cm		232	230	223	254	9	0
Turbidity	NTU		4.4	4.7	1.7	7.7	9	0
Color	PCU		11	11	nd	33	9	3
Temperature	deg C		4.4	4.4	4	4.8	2	0
Oxygen_Dissolved	mg/l		2.2	2.2	0	4.5	2	0
Total Hardness as CaCO ₃	mg/l		95	94	90	100	9	0
Calcium	mg/l		26	26	26	28	9	0
Magnesium	mg/l		7	7	7	8	9	0
Sodium	mg/l		11	10	9	17	9	0
Potassium	mg/l		2	2	2	3	9	0
Ammonia as N	mg/l		0.27	0.3	nd	0.5	9	1
Total Alkalinity as CaCO ₃ _Lab	mg/l		120	124	88	130	9	0
Bicarbonate as HCO ₃	mg/l		147	152	108	158	9	0
Carbonate as CO ₃	mg/l		nd	nd	nd	nd	9	9
Hydroxide as OH	mg/l		nd	nd	nd	nd	9	9
Chloride	mg/l	230	1	nd	nd	1	9	5
Nitrite	mg/l	1	nd	nd	nd	nd	9	9

¹⁰ "nd" means not detected. Average concentrations were computed using 0.5x the detection limit for those samples having a concentration less than the detection limit. For those parameters that were not detected in any sample, the average was set to "nd". The results have been displayed using not more than the number of significant digits in the most recent detection limit.

For fecal coliform and total coliform results, TNTC means that there were too many colonies to count. If a TNTC was reported for any sample at a sample site, the average was not computed.

Parameter	Units	Criteria	Average	Median	Minimum	Maximum	No.	Number of Non-Detect Samples
Nitrate	mg/l	10	1	nd	nd	4	8	6
Nitrate + Nitrite as N	mg/l	10	0	nd	nd	4	9	7
Fluoride	mg/l	1	0	0	0	0	9	0
Sulfate	mg/l		1.33	nd	nd	8	9	8
Ortho-Phosphate as P	mg/l		nd	nd	nd	nd	9	9
Aluminum_Total	mg/l	0.087	0.021	nd	nd	0.11	9	8
Aluminum_Dissolved	mg/l	0.087	nd	nd	nd	nd	9	9
Antimony_Total	mg/l	0.006	nd	nd	nd	nd	9	9
Antimony_Dissolved	mg/l	0.006	nd	nd	nd	nd	9	9
Arsenic_Total	mg/l	0.01	0.01	0.01	nd	0.01	9	2
Arsenic_Dissolved	mg/l	0.01	0.01	0.01	nd	0.01	9	2
Barium_Total	mg/l	2	0	0	0	0	9	0
Barium_Dissolved	mg/l	2	0	0	0	0	9	0
Beryllium_Total	mg/l	0.004	nd	nd	nd	nd	9	9
Beryllium_Dissolved	mg/l	0.004	nd	nd	nd	nd	9	9
Boron_Total	mg/l	0.75	0.02	nd	nd	0.04	9	8
Boron_Dissolved	mg/l	0.75	nd	nd	nd	nd	9	9
Cadmium_Total	mg/l	0.00010	0.00005	nd	nd	0.0001	9	8
Cadmium_Dissolved	mg/l	0.00009	nd	nd	nd	nd	9	9
Chromium_Total	mg/l	0.1	nd	nd	nd	nd	9	9
Chromium_Dissolved	mg/l	0.1	nd	nd	nd	nd	9	9
Cobalt_Total	mg/l	0.05	nd	nd	nd	nd	9	9
Cobalt_Dissolved	mg/l	0.05	nd	nd	nd	nd	9	9
Copper_Total	mg/l	0.00285	0.00067	nd	nd	0.002	9	8
Copper_Dissolved	mg/l	0.00274	nd	nd	nd	nd	9	9
Iron_Total	mg/l	1	1	1	1	2	9	0
Iron_Dissolved	mg/l	1	1	1	1	1	9	0
Lead_Total	mg/l	0.00054	0.00047	nd	nd	0.0024	9	6
Lead_Dissolved	mg/l	0.00054	nd	nd	nd	nd	9	9
Lithium_Dissolved	mg/l	2.5	nd	nd	nd	nd	9	9
Manganese_Total	mg/l	0.05	0.2	0.2	0.18	0.22	9	0
Manganese_Dissolved	mg/l	0.05	0.2	0.19	0.18	0.22	9	0
Mercury_Total	mg/l	0.000012	nd	nd	nd	nd	9	9
Mercury_Dissolved	mg/l	0.000012	nd	nd	nd	nd	9	9
Molybdenum_Total	mg/l	0.01	nd	nd	nd	nd	9	9
Molybdenum_Dissolved	mg/l	0.01	nd	nd	nd	nd	9	9
Nickel_Total	mg/l	0.016	nd	nd	nd	nd	9	9
Nickel_Dissolved	mg/l	0.016	nd	nd	nd	nd	9	9
Selenium_Total	mg/l	0.0050	nd	nd	nd	nd	9	9
Selenium_Dissolved	mg/l	0.0046	nd	nd	nd	nd	9	9
Silver_Total	mg/l	0.00037	nd	nd	nd	nd	9	9
Silver_Dissolved	mg/l	0.00032	nd	nd	nd	nd	9	9
Strontium_Total	mg/l		0.222	0.24	0.15	0.25	9	0
Strontium_Dissolved	mg/l		0.222	0.24	0.15	0.24	9	0
Thallium_Total	mg/l	0.0017	nd	nd	nd	nd	9	9

Parameter	Units	Criteria	Average	Median	Minimum	Maximum	No.	Number of Non-Detect Samples
Thallium_Dissolved	mg/l	0.0017	nd	nd	nd	nd	9	9
Titanium_Total	mg/l		nd	nd	nd	nd	9	9
Titanium_Dissolved	mg/l		nd	nd	nd	nd	9	9
Vanadium_Total	mg/l	0.1	nd	nd	nd	nd	9	9
Vanadium_Dissolved	mg/l	0.1	nd	nd	nd	nd	9	9
Zinc_Total	mg/l	0.037	0.013	0.005	nd	0.049	9	4
Zinc_Dissolved	mg/l	0.036	0.006	nd	nd	0.014	9	6
WAD Cyanide	mg/l		nd	nd	nd	nd	9	9
Total Organic Carbon	mg/l		1	nd	nd	1	8	5

The concentrations of metals in the alluvial groundwater generally are low. A summary of the number of samples that exceeded the most stringent water quality criteria is contained in **Table 5-11**. All samples exceeded iron and manganese criteria. One exceedance of aluminum occurred for a sample that was also characterized by a relatively high TSS concentration of 20 mg/L and a dissolved aluminum concentration below detection limit. One exceedance of zinc criteria and two exceedances of lead criteria occurred using the nominal hardness value of 25 mg/L as CaCO₃. However, no exceedances of zinc or lead criteria occur using the observed hardness values at the well, which range from 90-100 mg/L as CaCO₃.

Table 5-11. Ground Water Exceedances - Alluvium

Parameter	Total Samples	Considered Samples	No. of Exceedances	Water Quality Criteria [mg/L]	Criteria Type
Aluminum_Total	9	9	1	0.087	Aquatic Life - Chronic
Iron_Total	9	9	9	1.0	Aquatic Life - Chronic
Lead_Total	9	9	2	0.00054	Aquatic Life - Chronic
Manganese_Total	9	9	9	0.05	Human Health - Water + Aquatic Organisms
Zinc_Total	9	9	1	0.037	Aquatic Life - Acute

Glacial Drift Water Quality

The glacial drift water quality in the proposed mine area is assessed using water quality data from well 23T for the period 2006-2010. The groundwater in the glacial drift is of calcium bicarbonate type. Overall, the water quality in the glacial drift is similar to the water quality in the alluvium. The pH is neutral, with pH determinations ranging from 7.1 to 8.0 (**Table 5-12**). Groundwater concentrations of total dissolved solids are low, with concentrations ranging from 80 to 150 mg/l, and an average of 112 mg/l. The turbidity levels are unusually high for a groundwater well, ranging from 18 to 589 NTU. Turbidity levels at this well showed a significant improvement after the 2006 redevelopment work (**Figure 5-1**). From June 2007 through December 2008, turbidity levels ranged from 18-32 NTU, with an average of 27 NTU. The recent turbidity values remain higher than expected for a clean groundwater well.

Table 5-12. Water Quality Summary for Glacial Drift Hydrostratigraphic Unit¹¹ - Proposed Mine Area - All Samples

Parameter	Units	Criteria	Average	Median	Minimum	Maximum	No.	Number of Non-Detect Samples
Total Dissolved Solids	mg/l		112	110	80	150	11	0
Total Suspended Solids	mg/l		37.7	nd	nd	304	15	9
ph_Field	su		6.4	6.4	6	6.8	2	0
pH_Lab	su		7.5	7.5	7.1	8	15	0
Conductivity_Field	umhos/cm		248	248	133	362	2	0
Conductivity_Lab	umhos/cm		133	126	116	222	15	0
Turbidity	NTU		100.07	31	17.7	589	11	0
Color	PCU		147	34	8	1040	11	0
Temperature	deg C		6.4	6.4	5.6	7.1	2	0
Oxygen_Dissolved	mg/l		8.5	8.5	6.9	10.2	2	0
Total Hardness as CaCO3	mg/l		51	50	50	60	15	0
Calcium	mg/l		14.47	14	13	17	15	0
Magnesium	mg/l		3.33	3	3	4	15	0
Sodium	mg/l		4.73	5	4	6	11	0
Potassium	mg/l		1.36	1	1	2	11	0
Ammonia as N	mg/l		0.08	nd	nd	0.2	11	9
Total Alkalinity as CaCO3_Lab	mg/l		68.27	67	52	83	15	0
Bicarbonate as HCO3	mg/l		83.4	82	64	101	15	0
Carbonate as CO3	mg/l		nd	nd	nd	nd	15	15
Hydroxide as OH	mg/l		nd	nd	nd	nd	14	14
Chloride	mg/l	230	1	nd	nd	1	15	14
Nitrite	mg/l	1	nd	nd	nd	nd	11	11
Nitrate	mg/l	10	nd	nd	nd	nd	10	10
Nitrate + Nitrite as N	mg/l	10	nd	nd	nd	nd	11	11
Fluoride	mg/l	1	0	0	0	0	11	0
Sulfate	mg/l		0.53	nd	nd	1	15	14
Ortho-Phosphate as P	mg/l		nd	nd	nd	nd	11	11
Aluminum_Total	mg/l	0.087	0.221	nd	nd	1.41	15	8
Aluminum_Dissolved	mg/l	0.087	nd	nd	nd	nd	15	15
Antimony_Total	mg/l	0.006	nd	nd	nd	nd	11	11
Antimony_Dissolved	mg/l	0.006	nd	nd	nd	nd	11	11
Arsenic_Total	mg/l	0.01	0	nd	nd	0.02	15	13
Arsenic_Dissolved	mg/l	0.01	nd	nd	nd	nd	15	15
Barium_Total	mg/l	2	0	nd	nd	0	11	10
Barium_Dissolved	mg/l	2	nd	nd	nd	nd	11	11
Beryllium_Total	mg/l	0.004	0.001	nd	nd	0.003	11	10

¹¹ "nd" means not detected. Average concentrations were computed using 0.5x the detection limit for those samples having a concentration less than the detection limit. For those parameters that were not detected in any sample, the average was set to "nd". The results have been displayed using not more than the number of significant digits in the most recent detection limit.

For fecal coliform and total coliform results, TNTC means that there were too many colonies to count. If a TNTC was reported for any sample at a sample site, the average was not computed.

Parameter	Units	Criteria	Average	Median	Minimum	Maximum	No.	Number of Non-Detect Samples
Beryllium_Dissolved	mg/l	0.004	nd	nd	nd	nd	11	11
Boron_Total	mg/l	0.75	0.02	nd	nd	0.04	15	13
Boron_Dissolved	mg/l	0.75	0.02	nd	nd	0.04	15	13
Cadmium_Total	mg/l	0.00010	0.00006	nd	nd	0.0002	11	10
Cadmium_Dissolved	mg/l	0.00009	nd	nd	nd	nd	11	11
Chromium_Total	mg/l	0.1	0	nd	nd	0.1	11	9
Chromium_Dissolved	mg/l	0.1	nd	nd	nd	nd	11	11
Cobalt_Total	mg/l	0.05	nd	nd	nd	nd	11	11
Cobalt_Dissolved	mg/l	0.05	nd	nd	nd	nd	11	11
Copper_Total	mg/l	0.00285	0.00213	0.001	nd	0.01	15	7
Copper_Dissolved	mg/l	0.00274	0.00103	nd	nd	0.004	15	14
Iron_Total	mg/l	1	11	4	4	59	15	0
Iron_Dissolved	mg/l	1	4	4	0	5	15	0
Lead_Total	mg/l	0.00054	0.0012	nd	nd	0.0068	15	10
Lead_Dissolved	mg/l	0.00054	nd	nd	nd	nd	15	15
Lithium_Dissolved	mg/l	2.5	nd	nd	nd	nd	11	11
Manganese_Total	mg/l	0.05	0.64	0.46	0.43	1.9	15	0
Manganese_Dissolved	mg/l	0.05	0.44	0.44	0.23	0.65	15	0
Mercury_Total	mg/l	0.000012	0.00002	nd	nd	0.00007	14	13
Mercury_Dissolved	mg/l	0.000012	nd	nd	nd	nd	14	14
Molybdenum_Total	mg/l	0.01	nd	nd	nd	nd	11	11
Molybdenum_Dissolved	mg/l	0.01	nd	nd	nd	nd	11	11
Nickel_Total	mg/l	0.01614	0.00733	nd	nd	0.04	15	14
Nickel_Dissolved	mg/l	0.01610	nd	nd	nd	nd	15	15
Selenium_Total	mg/l	0.0050	nd	nd	nd	nd	11	11
Selenium_Dissolved	mg/l	0.0046	nd	nd	nd	nd	11	11
Silver_Total	mg/l	0.00037	0.00047	nd	nd	0.0005	15	13
Silver_Dissolved	mg/l	0.00032	nd	nd	nd	nd	15	15
Strontium_Total	mg/l		0.067	0.07	0.06	0.09	11	0
Strontium_Dissolved	mg/l		0.062	0.06	0.04	0.07	11	0
Thallium_Total	mg/l	0.0017	nd	nd	nd	nd	11	11
Thallium_Dissolved	mg/l	0.0017	nd	nd	nd	nd	11	11
Titanium_Total	mg/l		0.011	nd	nd	0.04	11	7
Titanium_Dissolved	mg/l		nd	nd	nd	nd	11	11
Vanadium_Total	mg/l	0.1	nd	nd	nd	nd	11	11
Vanadium_Dissolved	mg/l	0.1	nd	nd	nd	nd	11	11
Zinc_Total	mg/l	0.03702	0.02407	nd	nd	0.184	15	11
Zinc_Dissolved	mg/l	0.03620	0.00773	nd	nd	0.044	15	13
WAD Cyanide	mg/l		nd	nd	nd	nd	11	11
Total Organic Carbon	mg/l		1	nd	nd	3	9	6

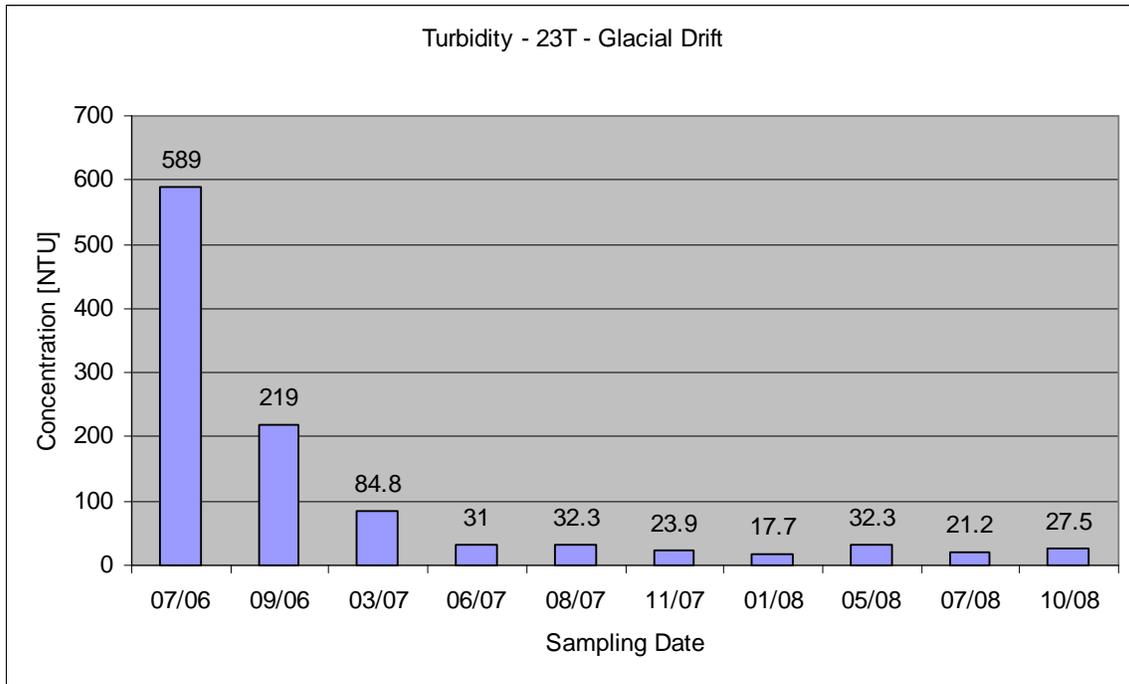


Figure 5-1. Turbidity Concentrations at Well 23T (Glacial Drift – Proposed Mine Area)

The high total metal concentrations appear related to the high turbidity values. *Figure 5-2* presents an example plot of total and dissolved iron concentrations over time. The total iron concentrations reduce over time, similar to the pattern observed in turbidity concentrations, while the dissolved iron concentrations remain relatively consistent.

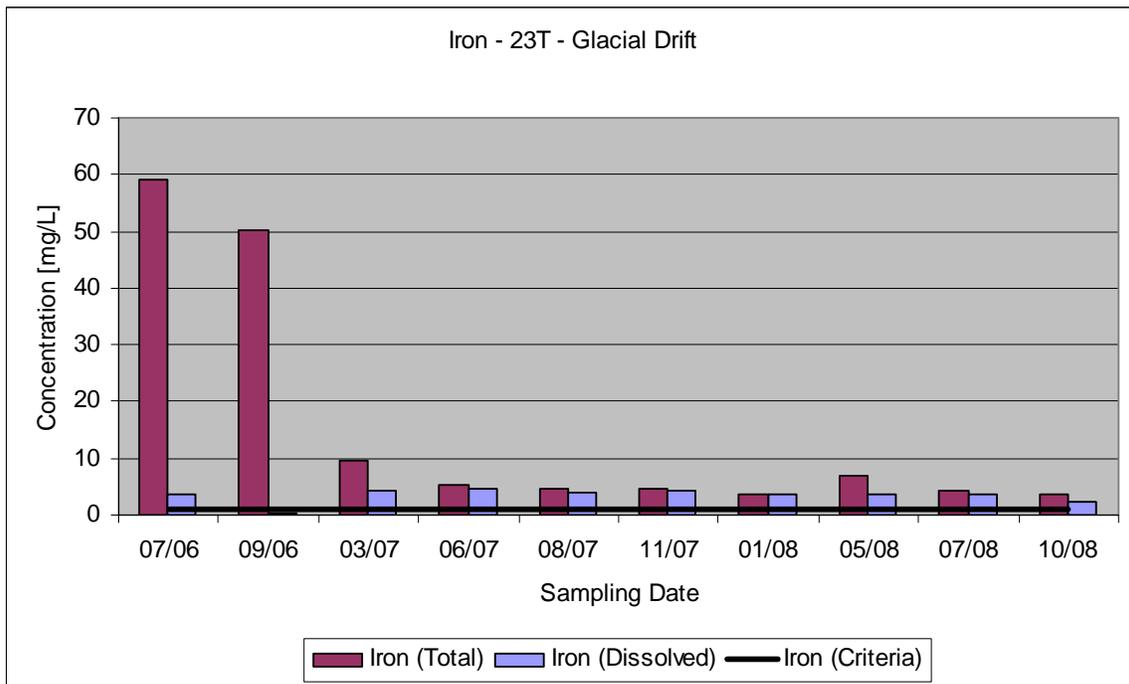


Figure 5-2. Iron Concentrations at Well 23T (Glacial Drift – Proposed Mine Area)

In screening samples with turbidity > 50 NTU or TSS > 20 mg/L, five of the fifteen samples at well 23T were excluded from the analysis. **Table 5-13** contains a summary of the water quality parameters for the selected samples.

Table 5-13. Water Quality Summary for Glacial Drift Hydrostratigraphic Unit ¹² - Proposed Mine Area - Selected Samples

Parameter	Units	Criteria	Average	Median	Minimum	Maximum	No.	Number of Non-Detect Samples
Total Dissolved Solids	mg/l		107	115	80	120	6	0
Total Suspended Solids	mg/l		2.8	nd	nd	5	10	9
pH_Lab	su		7.5	7.5	7.1	7.7	10	0
Conductivity_Lab	umhos/cm		127	126	120	134	10	0
Turbidity	NTU		26.55	27.45	17.7	32.3	6	0
Color	PCU		28	12	8	65	6	0
Total Hardness as CaCO ₃	mg/l		50	50	50	50	10	0
Calcium	mg/l		14.4	14	14	15	10	0
Magnesium	mg/l		3.5	3.5	3	4	10	0
Sodium	mg/l		5.17	5	4	6	6	0
Potassium	mg/l		1.5	1.5	1	2	6	0
Ammonia as N	mg/l		nd	nd	nd	nd	6	6
Total Alkalinity as CaCO ₃ _Lab	mg/l		69.7	67.5	52	83	10	0
Bicarbonate as HCO ₃	mg/l		85.2	82.5	64	101	10	0
Carbonate as CO ₃	mg/l		nd	nd	nd	nd	10	10
Hydroxide as OH	mg/l		nd	nd	nd	nd	9	9
Chloride	mg/l	230	1	nd	nd	1	10	9
Nitrite	mg/l	1	nd	nd	nd	nd	6	6
Nitrate	mg/l	10	nd	nd	nd	nd	5	5
Nitrate + Nitrite as N	mg/l	10	nd	nd	nd	nd	6	6
Fluoride	mg/l	1	0	0	0	0	6	0
Sulfate	mg/l		nd	nd	nd	nd	10	10
Ortho-Phosphate as P	mg/l		nd	nd	nd	nd	6	6
Aluminum_Total	mg/l	0.087	0.015	nd	nd	0.04	10	8
Aluminum_Dissolved	mg/l	0.087	nd	nd	nd	nd	10	10
Antimony_Total	mg/l	0.006	nd	nd	nd	nd	6	6
Antimony_Dissolved	mg/l	0.006	nd	nd	nd	nd	6	6
Arsenic_Total	mg/l	0.01	nd	nd	nd	nd	10	10
Arsenic_Dissolved	mg/l	0.01	nd	nd	nd	nd	10	10
Barium_Total	mg/l	2	nd	nd	nd	nd	6	6
Barium_Dissolved	mg/l	2	nd	nd	nd	nd	6	6
Beryllium_Total	mg/l	0.004	nd	nd	nd	nd	6	6
Beryllium_Dissolved	mg/l	0.004	nd	nd	nd	nd	6	6

¹² "nd" means not detected. Average concentrations were computed using 0.5x the detection limit for those samples having a concentration less than the detection limit. For those parameters that were not detected in any sample, the average was set to "nd". The results have been displayed using not more than the number of significant digits in the most recent detection limit.

For fecal coliform and total coliform results, TNTC means that there were too many colonies to count. If a TNTC was reported for any sample at a sample site, the average was not computed.

Parameter	Units	Criteria	Average	Median	Minimum	Maximum	No.	Number of Non-Detect Samples
Boron_Total	mg/l	0.75	0.02	nd	nd	0.04	10	8
Boron_Dissolved	mg/l	0.75	0.02	nd	nd	0.04	10	8
Cadmium_Total	mg/l	0.00010	nd	nd	nd	nd	6	6
Cadmium_Dissolved	mg/l	0.00009	nd	nd	nd	nd	6	6
Chromium_Total	mg/l	0.1	nd	nd	nd	nd	6	6
Chromium_Dissolved	mg/l	0.1	nd	nd	nd	nd	6	6
Cobalt_Total	mg/l	0.05	nd	nd	nd	nd	6	6
Cobalt_Dissolved	mg/l	0.05	nd	nd	nd	nd	6	6
Copper_Total	mg/l	0.00285	0.00125	nd	nd	0.002	10	6
Copper_Dissolved	mg/l	0.00274	nd	nd	nd	nd	10	10
Iron_Total	mg/l	1	5	4	4	7	10	0
Iron_Dissolved	mg/l	1	4	4	3	5	10	0
Lead_Total	mg/l	0.00054	0.00033	nd	nd	0.0008	10	8
Lead_Dissolved	mg/l	0.00054	nd	nd	nd	nd	10	10
Lithium_Dissolved	mg/l	2.5	nd	nd	nd	nd	6	6
Manganese_Total	mg/l	0.05	0.46	0.46	0.43	0.55	10	0
Manganese_Dissolved	mg/l	0.05	0.44	0.44	0.42	0.47	10	0
Mercury_Total	mg/l	0.000012	nd	nd	nd	nd	9	9
Mercury_Dissolved	mg/l	0.000012	nd	nd	nd	nd	9	9
Molybdenum_Total	mg/l	0.01	nd	nd	nd	nd	6	6
Molybdenum_Dissolved	mg/l	0.01	nd	nd	nd	nd	6	6
Nickel_Total	mg/l	0.01614	nd	nd	nd	nd	10	10
Nickel_Dissolved	mg/l	0.01610	nd	nd	nd	nd	10	10
Selenium_Total	mg/l	0.0050	nd	nd	nd	nd	6	6
Selenium_Dissolved	mg/l	0.0046	nd	nd	nd	nd	6	6
Silver_Total	mg/l	0.00037	0.00066	nd	nd	0.0005	10	8
Silver_Dissolved	mg/l	0.00032	nd	nd	nd	nd	10	10
Strontium_Total	mg/l		0.065	0.065	0.06	0.07	6	0
Strontium_Dissolved	mg/l		0.065	0.065	0.06	0.07	6	0
Thallium_Total	mg/l	0.0017	nd	nd	nd	nd	6	6
Thallium_Dissolved	mg/l	0.0017	nd	nd	nd	nd	6	6
Titanium_Total	mg/l		nd	nd	nd	nd	6	6
Titanium_Dissolved	mg/l		nd	nd	nd	nd	6	6
Vanadium_Total	mg/l	0.1	nd	nd	nd	nd	6	6
Vanadium_Dissolved	mg/l	0.1	nd	nd	nd	nd	6	6
Zinc_Total	mg/l	0.03702	0.003	nd	nd	0.005	10	9
Zinc_Dissolved	mg/l	0.03620	nd	nd	nd	nd	10	10
WAD Cyanide	mg/l		nd	nd	nd	nd	6	6
Total Organic Carbon	mg/l		nd	nd	nd	nd	5	5

Table 5-14 presents a summary of the number of samples that exceeded the most stringent water quality criteria. All selected samples exceeded the water quality criteria for iron and manganese. One sample exceeded lead criteria and two samples exceeded silver criteria using the nominal hardness value of 25 mg/L as CaCO₃, though none of the three samples would exceed water criteria using the observed hardness values of 50 mg/L as CaCO₃.

Table 5-14. Ground Water Exceedances – Glacial Drift – Proposed Mine Area - Selected Samples

Parameter	Total Samples	Considered Samples	No. of Exceedances	Water Quality Criteria [mg/L]	Criteria Type
Iron_Total	10	10	10	1.0	Aquatic Life - Chronic
Lead_Total	10	9	1	0.00054	Aquatic Life – Chronic
Manganese_Total	10	10	10	0.05	Human Health – Water + Aquatic Organisms
Silver_Total	10	9	2	0.00037	Aquatic Life - Acute

The glacial drift water quality in the proposed Ladd Landing area is assessed using water quality data from wells G19A, G20A, and G20B for the period 2006-2009. *Table 5-15* presents a summary of the water quality at the three wells. Compared to the glacial drift in the proposed mine area, the water quality in the glacial drift in the Ladd Landing area is characterized by lower pH, conductivity, hardness, dissolved solids, and alkalinity. However, the concentrations of chloride and sulfate in the glacial drift in the Ladd Landing area are higher than measured in the proposed mine area. Samples at each of three wells exhibited high turbidity and TSS concentrations immediately after the wells were developed, though concentrations have generally reduced over time (*Figure 5-3*).

Table 5-15. Water Quality Summary for Glacial Drift Hydrostratigraphic Unit¹³ - Ladd Landing Area - All Samples

Parameter	Units	Criteria	Average	Median	Minimum	Maximum	No.	Number of Non-Detect Samples
Total Dissolved Solids	mg/l		71	60	20	340	29	0
Total Suspended Solids	mg/l		357.3	nd	nd	5950	29	17
ph_Field	su		5.7	5.7	5.3	6.1	2	0
pH_Lab	su		6.8	6.9	6.1	7.2	29	0
Conductivity_Field	umhos/cm		58	58	55	61	2	0
Conductivity_Lab	umhos/cm		66	64	39	124	29	0
Turbidity	NTU		419.65	5.6	0.7	8120	29	0
Color	PCU		41	8	nd	630	29	7
Temperature	deg C		3.8	3.8	3.7	3.9	2	0
Oxygen_Dissolved	mg/l		6.1	6.1	4.5	7.8	2	0
Total Hardness as CaCO ₃	mg/l		20	20	nd	40	29	2
Calcium	mg/l		5.03	5	3	10	29	0
Magnesium	mg/l		1.83	2	nd	4	29	2
Sodium	mg/l		3.86	4	3	7	29	0
Potassium	mg/l		nd	nd	nd	nd	29	29
Ammonia as N	mg/l		0.07	nd	nd	0.2	29	26
Total Alkalinity as CaCO ₃ _Lab	mg/l		18.1	17	11	28	29	0
Bicarbonate as HCO ₃	mg/l		22.1	21	13	34	29	0
Carbonate as CO ₃	mg/l		nd	nd	nd	nd	29	29
Hydroxide as OH	mg/l		nd	nd	nd	nd	29	29

¹³ “nd” means not detected. Average concentrations were computed using 0.5x the detection limit for those samples having a concentration less than the detection limit. For those parameters that were not detected in any sample, the average was set to “nd”. The results have been displayed using not more than the number of significant digits in the most recent detection limit.

For fecal coliform and total coliform results, TNTC means that there were too many colonies to count. If a TNTC was reported for any sample at a sample site, the average was not computed.

Parameter	Units	Criteria	Average	Median	Minimum	Maximum	No.	Number of Non-Detect Samples
Chloride	mg/l	230	3	3	2	4	29	0
Nitrite	mg/l	1	nd	nd	nd	nd	29	29
Nitrate	mg/l	10	0	nd	nd	3	28	21
Nitrate + Nitrite as N	mg/l	10	0	nd	nd	3	29	22
Fluoride	mg/l	1	nd	nd	nd	nd	29	29
Sulfate	mg/l		5.03	3	2	25	29	0
Ortho-Phosphate as P	mg/l		0.05	nd	nd	0.1	29	28
Aluminum_Total	mg/l	0.087	8.233	0.11	nd	150	29	6
Aluminum_Dissolved	mg/l	0.087	0.019	nd	nd	0.14	28	23
Antimony_Total	mg/l	0.006	nd	nd	nd	nd	29	29
Antimony_Dissolved	mg/l	0.006	nd	nd	nd	nd	28	28
Arsenic_Total	mg/l	0.01	0.03	nd	nd	0.32	29	23
Arsenic_Dissolved	mg/l	0.01	nd	nd	nd	nd	28	28
Barium_Total	mg/l	2	0	nd	nd	2	29	27
Barium_Dissolved	mg/l	2	nd	nd	nd	nd	28	28
Beryllium_Total	mg/l	0.004	nd	nd	nd	nd	29	29
Beryllium_Dissolved	mg/l	0.004	nd	nd	nd	nd	28	28
Boron_Total	mg/l	0.75	0.04	nd	nd	0.38	29	27
Boron_Dissolved	mg/l	0.75	0.02	nd	nd	0.04	28	26
Cadmium_Total	mg/l	0.00010	0.00035	nd	nd	0.00552	29	24
Cadmium_Dissolved	mg/l	0.00009	0.00007	nd	nd	0.00069	28	25
Chromium_Total	mg/l	0.1	0	nd	nd	0.3	29	26
Chromium_Dissolved	mg/l	0.1	nd	nd	nd	nd	28	28
Cobalt_Total	mg/l	0.05	0.02	nd	nd	0.27	29	27
Cobalt_Dissolved	mg/l	0.05	nd	nd	nd	nd	28	28
Copper_Total	mg/l	0.00285	0.04369	0.002	nd	0.88	29	10
Copper_Dissolved	mg/l	0.00274	0.00064	nd	nd	0.002	28	24
Iron_Total	mg/l	1	9	2	nd	110	29	1
Iron_Dissolved	mg/l	1	1	0	nd	3	28	3
Lead_Total	mg/l	0.00054	0.01584	nd	nd	0.323	29	16
Lead_Dissolved	mg/l	0.00054	0.00016	nd	nd	0.0004	28	27
Lithium_Dissolved	mg/l	2.5	nd	nd	nd	nd	28	28
Manganese_Total	mg/l	0.05	0.69	0.07	nd	8.05	29	7
Manganese_Dissolved	mg/l	0.05	0.15	0.05	nd	1.3	28	10
Mercury_Total	mg/l	0.000012	nd	nd	nd	nd	29	29
Mercury_Dissolved	mg/l	0.000012	nd	nd	nd	nd	28	28
Molybdenum_Total	mg/l	0.01	nd	nd	nd	nd	29	29
Molybdenum_Dissolved	mg/l	0.01	nd	nd	nd	nd	28	28
Nickel_Total	mg/l	0.01614	0.02207	nd	nd	0.34	29	26
Nickel_Dissolved	mg/l	0.01610	nd	nd	nd	nd	28	28
Selenium_Total	mg/l	0.0050	0.0016	nd	nd	0.005	29	28
Selenium_Dissolved	mg/l	0.0046	nd	nd	nd	nd	28	28
Silver_Total	mg/l	0.00037	0.00021	nd	nd	0.003	29	27
Silver_Dissolved	mg/l	0.00032	nd	nd	nd	nd	28	28
Strontium_Total	mg/l		0.063	0.03	0.02	0.6	29	0

Parameter	Units	Criteria	Average	Median	Minimum	Maximum	No.	Number of Non-Detect Samples
Strontium_Dissolved	mg/l		0.035	0.03	0.02	0.06	28	0
Thallium_Total	mg/l	0.0017	0.0006	nd	nd	0.002	29	28
Thallium_Dissolved	mg/l	0.0017	nd	nd	nd	nd	28	28
Titanium_Total	mg/l		0.171	nd	nd	2.95	29	16
Titanium_Dissolved	mg/l		nd	nd	nd	nd	28	28
Vanadium_Total	mg/l	0.1	0	nd	nd	0.5	29	26
Vanadium_Dissolved	mg/l	0.1	nd	nd	nd	nd	28	28
Zinc_Total	mg/l	0.03702	0.04366	nd	nd	0.787	29	18
Zinc_Dissolved	mg/l	0.03620	0.00398	nd	nd	0.015	28	23
WAD Cyanide	mg/l		nd	nd	nd	nd	29	29
Total Organic Carbon	mg/l		1	nd	nd	2	26	21

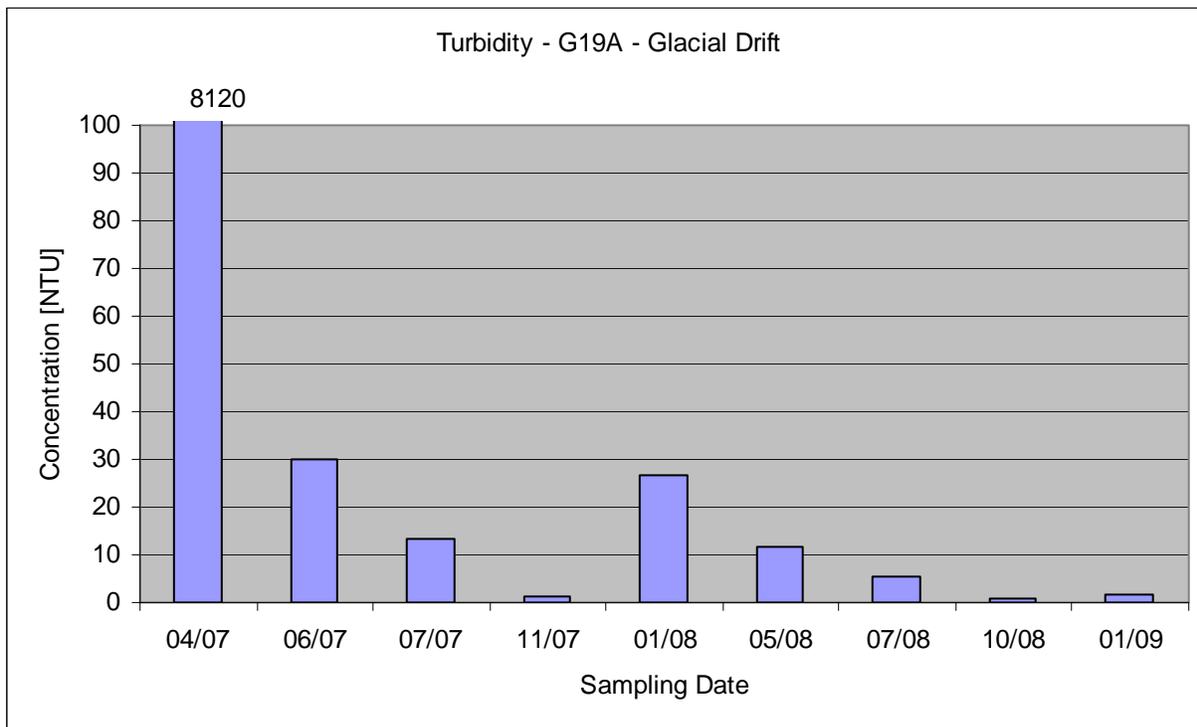


Figure 5-3. Turbidity Concentrations at Well G19A (Glacial Drift – Proposed Ladd Landing Area)

In applying the screening criteria of turbidity < 50 NTU and TSS < 20 mg/L, nine of the 29 samples at the three wells were excluded from analysis. **Table 5-16** presents a summary of the water quality for the selected samples. The glacial drift water in the Ladd landing area is characterized by neutral pH (average 6.8) and low hardness values (average 20 mg/L as CaCO₃).

Table 5-16. Water Quality Summary for Glacial Drift Hydrostratigraphic Unit¹⁴ - Ladd Landing Area - Selected Samples

Parameter	Units	Criteria	Average	Median	Minimum	Maximum	No.	Number of Non-Detect Samples
Total Dissolved Solids	mg/l		56	55	20	90	20	0
Total Suspended Solids	mg/l		3.8	nd	nd	18	20	17
pH_Lab	su		6.8	6.8	6.1	7.1	20	0
Conductivity_Lab	umhos/cm		68	63	39	124	20	0
Turbidity	NTU		4.37	2.05	0.7	13.2	20	0
Color	PCU		8	5	nd	41	20	7
Total Hardness as CaCO ₃	mg/l		21	20	nd	40	20	1
Calcium	mg/l		5.3	5	3	10	20	0
Magnesium	mg/l		1.93	2	nd	4	20	1
Sodium	mg/l		4.05	4	3	7	20	0
Potassium	mg/l		nd	nd	nd	nd	20	20
Ammonia as N	mg/l		0.07	nd	nd	0.2	20	18
Total Alkalinity as CaCO ₃ _Lab	mg/l		17.4	17	11	24	20	0
Bicarbonate as HCO ₃	mg/l		21.3	21	13	30	20	0
Carbonate as CO ₃	mg/l		nd	nd	nd	nd	20	20
Hydroxide as OH	mg/l		nd	nd	nd	nd	20	20
Chloride	mg/l	230	3	3	2	4	20	0
Nitrite	mg/l	1	nd	nd	nd	nd	20	20
Nitrate	mg/l	10	0	nd	nd	3	19	13
Nitrate + Nitrite as N	mg/l	10	0	nd	nd	3	20	14
Fluoride	mg/l	1	nd	nd	nd	nd	20	20
Sulfate	mg/l		5.7	4	2	25	20	0
Ortho-Phosphate as P	mg/l		nd	nd	nd	nd	20	20
Aluminum_Total	mg/l	0.087	0.119	0.07	nd	0.47	20	6
Aluminum_Dissolved	mg/l	0.087	0.011	nd	nd	0.02	19	18
Antimony_Total	mg/l	0.006	nd	nd	nd	nd	20	20
Antimony_Dissolved	mg/l	0.006	nd	nd	nd	nd	19	19
Arsenic_Total	mg/l	0.01	nd	nd	nd	nd	20	20
Arsenic_Dissolved	mg/l	0.01	nd	nd	nd	nd	19	19
Barium_Total	mg/l	2	nd	nd	nd	nd	20	20
Barium_Dissolved	mg/l	2	nd	nd	nd	nd	19	19
Beryllium_Total	mg/l	0.004	nd	nd	nd	nd	20	20
Beryllium_Dissolved	mg/l	0.004	nd	nd	nd	nd	19	19
Boron_Total	mg/l	0.75	nd	nd	nd	nd	20	20
Boron_Dissolved	mg/l	0.75	0.02	nd	nd	0.04	19	18
Cadmium_Total	mg/l	0.00010	nd	nd	nd	nd	20	20

¹⁴ "nd" means not detected. Average concentrations were computed using 0.5x the detection limit for those samples having a concentration less than the detection limit. For those parameters that were not detected in any sample, the average was set to "nd". The results have been displayed using not more than the number of significant digits in the most recent detection limit.

For fecal coliform and total coliform results, TNTC means that there were too many colonies to count. If a TNTC was reported for any sample at a sample site, the average was not computed.

Parameter	Units	Criteria	Average	Median	Minimum	Maximum	No.	Number of Non-Detect Samples
Cadmium_Dissolved	mg/l	0.00009	nd	nd	nd	nd	19	19
Chromium_Total	mg/l	0.1	nd	nd	nd	nd	20	20
Chromium_Dissolved	mg/l	0.1	nd	nd	nd	nd	19	19
Cobalt_Total	mg/l	0.05	nd	nd	nd	nd	20	20
Cobalt_Dissolved	mg/l	0.05	nd	nd	nd	nd	19	19
Copper_Total	mg/l	0.00285	0.0012	nd	nd	0.005	20	10
Copper_Dissolved	mg/l	0.00274	0.00055	nd	nd	0.001	19	17
Iron_Total	mg/l	1	1	1	nd	3	20	1
Iron_Dissolved	mg/l	1	1	0	nd	3	19	3
Lead_Total	mg/l	0.00054	0.00023	nd	nd	0.0007	20	16
Lead_Dissolved	mg/l	0.00054	nd	nd	nd	nd	19	19
Lithium_Dissolved	mg/l	2.5	nd	nd	nd	nd	19	19
Manganese_Total	mg/l	0.05	0.09	0.06	nd	0.42	20	7
Manganese_Dissolved	mg/l	0.05	0.09	0.05	nd	0.41	19	7
Mercury_Total	mg/l	0.000012	nd	nd	nd	nd	20	20
Mercury_Dissolved	mg/l	0.000012	nd	nd	nd	nd	19	19
Molybdenum_Total	mg/l	0.01	nd	nd	nd	nd	20	20
Molybdenum_Dissolved	mg/l	0.01	nd	nd	nd	nd	19	19
Nickel_Total	mg/l	0.01614	nd	nd	nd	nd	20	20
Nickel_Dissolved	mg/l	0.01610	nd	nd	nd	nd	19	19
Selenium_Total	mg/l	0.0050	nd	nd	nd	nd	20	20
Selenium_Dissolved	mg/l	0.0046	nd	nd	nd	nd	19	19
Silver_Total	mg/l	0.00037	0.00011	nd	nd	0.0003	20	19
Silver_Dissolved	mg/l	0.00032	nd	nd	nd	nd	19	19
Strontium_Total	mg/l		0.037	0.03	0.03	0.06	20	0
Strontium_Dissolved	mg/l		0.036	0.03	0.02	0.06	19	0
Thallium_Total	mg/l	0.0017	nd	nd	nd	nd	20	20
Thallium_Dissolved	mg/l	0.0017	nd	nd	nd	nd	19	19
Titanium_Total	mg/l		0.009	nd	nd	0.03	20	16
Titanium_Dissolved	mg/l		nd	nd	nd	nd	19	19
Vanadium_Total	mg/l	0.1	nd	nd	nd	nd	20	20
Vanadium_Dissolved	mg/l	0.1	nd	nd	nd	nd	19	19
Zinc_Total	mg/l	0.03702	0.00348	nd	nd	0.011	20	17
Zinc_Dissolved	mg/l	0.03620	0.00339	nd	nd	0.015	19	17
WAD Cyanide	mg/l		nd	nd	nd	nd	20	20
Total Organic Carbon	mg/l		1	nd	nd	1	17	14

Table 5-17 presents a summary of the number of selected samples that exceeded the most stringent water quality criteria. More than half of the selected samples exceeded the criteria for iron and manganese. Seven of 20 samples exceeded the criteria for aluminum. These exceedances did not correspond to elevated turbidity or TSS concentrations, though most were associated with dissolved aluminum concentrations below detection limit, indicating that the aluminum was particulate. The January 2008 sample exceeded water quality criteria for both copper and lead.

Table 5-17. Ground Water Exceedances – Glacial Drift – Ladd Landing Area – Selected Samples

Parameter	Total Samples	Considered Samples	No. of Exceedances	Water Quality Criteria [mg/L]	Criteria Type
Aluminum_Total	20	20	7	0.087	Aquatic Life – Chronic
Copper_Total	20	20	1	0.00285	Aquatic Life – Chronic
Iron_Total	20	20	11	1.0	Aquatic Life – Chronic
Lead_Total	20	20	1	0.00054	Aquatic Life – Chronic
Manganese_Total	20	20	11	0.05	Human Health – Water + Aquatic Organisms

Minable Coal Sequence Water Quality

The water quality in the minable coal sequence unit is assessed using water quality data from wells 14A2, 20B1, and 27A1 for the period 2006-2009. The groundwater in the minable coal sequence is of calcium bicarbonate type. The pH is neutral to slightly alkaline, with pH determinations ranging from 7.5 to 8.4 (**Table 5-18**). Groundwater concentrations of total dissolved solids increase in the lower coal seams, with concentrations ranging from 70 to 380 mg/l, and an average of 189 mg/l. Turbidity is highly variable, ranging from 1-299 NTU, with an average value of 25 NTU and a median value of 4 NTU.

Table 5-18. Water Quality Summary for Minable Coal Sequence Hydrostratigraphic Unit¹⁵ - All Samples

Parameter	Units	Criteria	Average	Median	Minimum	Maximum	No.	Number of Non-Detect Samples
Total Dissolved Solids	mg/l		189	190	70	380	31	0
Total Suspended Solids	mg/l		13	nd	nd	150	31	21
ph_Field	su		6.2	6.2	6	6.3	3	0
pH_Lab	su		8	8	7.5	8.4	31	0
Conductivity_Field	umhos/cm		342	342	311	373	2	0
Conductivity_Lab	umhos/cm		286	297	140	558	31	0
Turbidity	NTU		25.35	4.2	1	299	31	0
Color	PCU		35	12	nd	340	31	3
Temperature	deg C		5.2	5.2	4	6.3	3	0
Oxygen_Dissolved	mg/l		3.7	5.3	0	5.7	3	0
Total Hardness as CaCO ₃	mg/l		106	100	20	140	31	0
Calcium	mg/l		24.71	24	5	37	31	0
Magnesium	mg/l		11.03	11	2	15	31	0
Sodium	mg/l		20.81	9	4	111	31	0
Potassium	mg/l		2.45	3	nd	4	31	4
Ammonia as N	mg/l		0.3	0.3	nd	0.7	31	5
Total Alkalinity as CaCO ₃ _Lab	mg/l		157.19	165	57	323	31	0
Bicarbonate as HCO ₃	mg/l		191.45	201	69	394	31	0
Carbonate as CO ₃	mg/l		nd	nd	nd	nd	31	31

¹⁵“nd” means not detected. Average concentrations were computed using 0.5x the detection limit for those samples having a concentration less than the detection limit. For those parameters that were not detected in any sample, the average was set to “nd”. The results have been displayed using not more than the number of significant digits in the most recent detection limit.

For fecal coliform and total coliform results, TNTC means that there were too many colonies to count. If a TNTC was reported for any sample at a sample site, the average was not computed.

Parameter	Units	Criteria	Average	Median	Minimum	Maximum	No.	Number of Non-Detect Samples
Hydroxide as OH	mg/l		nd	nd	nd	nd	31	31
Chloride	mg/l	230	1	nd	nd	1	31	25
Nitrite	mg/l	1	nd	nd	nd	nd	31	31
Nitrate	mg/l	10	nd	nd	nd	nd	30	30
Nitrate + Nitrite as N	mg/l	10	nd	nd	nd	nd	31	31
Fluoride	mg/l	1	0	0	0	1	31	0
Sulfate	mg/l		0.76	nd	nd	3	31	27
Ortho-Phosphate as P	mg/l		0.06	nd	nd	0.2	31	28
Aluminum_Total	mg/l	0.087	0.109	nd	nd	1.21	31	21
Aluminum_Dissolved	mg/l	0.087	nd	nd	nd	nd	31	31
Antimony_Total	mg/l	0.006	nd	nd	nd	nd	31	31
Antimony_Dissolved	mg/l	0.006	nd	nd	nd	nd	31	31
Arsenic_Total	mg/l	0.01	0.02	0.02	nd	0.06	31	8
Arsenic_Dissolved	mg/l	0.01	0.02	0.01	nd	0.04	31	9
Barium_Total	mg/l	2	0	0	0	1	31	0
Barium_Dissolved	mg/l	2	0	0	nd	1	31	1
Beryllium_Total	mg/l	0.004	0.001	nd	nd	0.002	31	30
Beryllium_Dissolved	mg/l	0.004	nd	nd	nd	nd	31	31
Boron_Total	mg/l	0.75	0.02	nd	nd	0.05	31	25
Boron_Dissolved	mg/l	0.75	0.02	nd	nd	0.04	31	29
Cadmium_Total	mg/l	0.00010	0.00014	nd	nd	0.00219	31	26
Cadmium_Dissolved	mg/l	0.00009	0.00006	nd	nd	0.00047	31	30
Chromium_Total	mg/l	0.1	0	nd	nd	0	31	27
Chromium_Dissolved	mg/l	0.1	nd	nd	nd	nd	31	31
Cobalt_Total	mg/l	0.05	nd	nd	nd	nd	31	31
Cobalt_Dissolved	mg/l	0.05	nd	nd	nd	nd	31	31
Copper_Total	mg/l	0.00285	0.00116	nd	nd	0.01	31	24
Copper_Dissolved	mg/l	0.00274	nd	nd	nd	nd	31	31
Iron_Total	mg/l	1	4	1	0	35	31	0
Iron_Dissolved	mg/l	1	2	1	0	8	31	0
Lead_Total	mg/l	0.00054	0.00369	nd	nd	0.0496	31	17
Lead_Dissolved	mg/l	0.00054	0.00017	nd	nd	0.0008	31	30
Lithium_Dissolved	mg/l	2.5	0	nd	nd	0	31	28
Manganese_Total	mg/l	0.05	0.36	0.09	0.04	2.44	31	0
Manganese_Dissolved	mg/l	0.05	0.32	0.09	0.04	2.27	31	0
Mercury_Total	mg/l	0.000012	nd	nd	nd	nd	31	31
Mercury_Dissolved	mg/l	0.000012	0.00003	nd	nd	0.00008	31	29
Molybdenum_Total	mg/l	0.01	nd	nd	nd	nd	31	31
Molybdenum_Dissolved	mg/l	0.01	nd	nd	nd	nd	31	31
Nickel_Total	mg/l	0.01614	0.00565	nd	nd	0.02	31	29
Nickel_Dissolved	mg/l	0.01610	nd	nd	nd	nd	31	31
Selenium_Total	mg/l	0.0050	nd	nd	nd	nd	31	31
Selenium_Dissolved	mg/l	0.0046	nd	nd	nd	nd	31	31
Silver_Total	mg/l	0.00037	0.00012	nd	nd	0.0004	31	29
Silver_Dissolved	mg/l	0.00032	nd	nd	nd	nd	31	31

Parameter	Units	Criteria	Average	Median	Minimum	Maximum	No.	Number of Non-Detect Samples
Strontium_Total	mg/l		0.239	0.22	0.06	0.43	31	0
Strontium_Dissolved	mg/l		0.231	0.22	0.06	0.41	31	0
Thallium_Total	mg/l	0.0017	nd	nd	nd	nd	31	31
Thallium_Dissolved	mg/l	0.0017	nd	nd	nd	nd	31	31
Titanium_Total	mg/l		0.009	nd	nd	0.04	31	23
Titanium_Dissolved	mg/l		nd	nd	nd	nd	31	31
Vanadium_Total	mg/l	0.1	nd	nd	nd	nd	31	31
Vanadium_Dissolved	mg/l	0.1	nd	nd	nd	nd	31	31
Zinc_Total	mg/l	0.0370	0.03553	nd	nd	0.392	31	19
Zinc_Dissolved	mg/l	0.0362	0.01669	nd	nd	0.246	31	23
WAD Cyanide	mg/l		0.0055	nd	nd	0.02	31	30
Total Organic Carbon	mg/l		2	1	nd	6	27	4

The groundwater quality varies between the three wells in the minable coal sequence. The water quality measured at 14A2 shows improvement over time, including reductions in turbidity and TSS concentrations, that is likely related to redevelopment efforts at the well. Well 20B1 shows frequently high concentrations of turbidity (median value 19 NTU), TSS, and metals that do not exhibit a predictable pattern over time. The water quality at 27A1 has been characterized by consistently low turbidity and metals concentrations. The variation in water quality collected at these wells may be a reflection of how the wells were developed or natural variability in the materials being characterized.

In screening samples that demonstrated turbidity > 50 NTU or TSS > 20 mg/L, five of the 31 samples from the three wells were excluded from analysis. Four of the excluded samples were taken from well 14A2, and the fifth sample was taken from well 20B1. *Table 5-19* presents a summary of the water quality in the minable coal sequence using the selected samples.

Table 5-19. Water Quality Summary for Movable Coal Sequence Hydrostratigraphic Unit¹⁶ - Selected Samples

Parameter	Units	Criteria	Average	Median	Minimum	Maximum	No.	Number of Non-Detect Samples
Total Dissolved Solids	mg/l		197	190	70	380	26	0
Total Suspended Solids	mg/l		4.5	nd	nd	20	26	21
ph_Field	su		6.1	6.1	6	6.2	2	0
pH_Lab	su		8	8.1	7.5	8.4	26	0
Conductivity_Field	umhos/cm		311	311	311	311	1	0
Conductivity_Lab	umhos/cm		298	301	140	558	26	0
Turbidity	NTU		7.93	2.7	1	33.6	26	0
Color	PCU		15	11	nd	75	26	3
Temperature	deg C		4.6	4.6	4	5.2	2	0

¹⁶“nd” means not detected. Average concentrations were computed using 0.5x the detection limit for those samples having a concentration less than the detection limit. For those parameters that were not detected in any sample, the average was set to “nd”. The results have been displayed using not more than the number of significant digits in the most recent detection limit.

For fecal coliform and total coliform results, TNTC means that there were too many colonies to count. If a TNTC was reported for any sample at a sample site, the average was not computed.

Parameter	Units	Criteria	Average	Median	Minimum	Maximum	No.	Number of Non-Detect Samples
Oxygen_Dissolved	mg/l		5.5	5.5	5.3	5.7	2	0
Total Hardness as CaCO ₃	mg/l		107	105	20	140	26	0
Calcium	mg/l		24.65	24	5	33	26	0
Magnesium	mg/l		11.35	11	2	15	26	0
Sodium	mg/l		23.92	9	4	111	26	0
Potassium	mg/l		2.56	3	nd	4	26	3
Ammonia as N	mg/l		0.28	0.25	nd	0.5	26	4
Total Alkalinity as CaCO ₃ _Lab	mg/l		165.12	166	70	323	26	0
Bicarbonate as HCO ₃	mg/l		201.31	202	85	394	26	0
Carbonate as CO ₃	mg/l		nd	nd	nd	nd	26	26
Hydroxide as OH	mg/l		nd	nd	nd	nd	26	26
Chloride	mg/l	230	1	nd	nd	1	26	20
Nitrite	mg/l	1	nd	nd	nd	nd	26	26
Nitrate	mg/l	10	nd	nd	nd	nd	25	25
Nitrate + Nitrite as N	mg/l	10	nd	nd	nd	nd	26	26
Fluoride	mg/l	1	0	0	0	1	26	0
Sulfate	mg/l		0.71	nd	nd	3	26	23
Ortho-Phosphate as P	mg/l		0.06	nd	nd	0.2	26	23
Aluminum_Total	mg/l	0.087	0.051	nd	nd	0.45	26	19
Aluminum_Dissolved	mg/l	0.087	nd	nd	nd	nd	26	26
Antimony_Total	mg/l	0.006	nd	nd	nd	nd	26	26
Antimony_Dissolved	mg/l	0.006	nd	nd	nd	nd	26	26
Arsenic_Total	mg/l	0.01	0.02	0.02	nd	0.04	26	7
Arsenic_Dissolved	mg/l	0.01	0.02	0.01	nd	0.04	26	7
Barium_Total	mg/l	2	0	0	0	1	26	0
Barium_Dissolved	mg/l	2	0	0	0	1	26	0
Beryllium_Total	mg/l	0.004	0.001	nd	nd	0.002	26	25
Beryllium_Dissolved	mg/l	0.004	nd	nd	nd	nd	26	26
Boron_Total	mg/l	0.75	0.02	nd	nd	0.04	26	22
Boron_Dissolved	mg/l	0.75	0.02	nd	nd	0.03	26	25
Cadmium_Total	mg/l	0.00010	0.00006	nd	nd	0.00037	26	24
Cadmium_Dissolved	mg/l	0.00009	nd	nd	nd	nd	26	26
Chromium_Total	mg/l	0.1	0	nd	nd	0	26	23
Chromium_Dissolved	mg/l	0.1	nd	nd	nd	nd	26	26
Cobalt_Total	mg/l	0.05	nd	nd	nd	nd	26	26
Cobalt_Dissolved	mg/l	0.05	nd	nd	nd	nd	26	26
Copper_Total	mg/l	0.00285	0.00077	nd	nd	0.004	26	22
Copper_Dissolved	mg/l	0.00274	nd	nd	nd	nd	26	26
Iron_Total	mg/l	1	2	1	0	7	26	0
Iron_Dissolved	mg/l	1	1	1	0	7	26	0
Lead_Total	mg/l	0.00054	0.00193	nd	nd	0.0174	26	17
Lead_Dissolved	mg/l	0.00054	nd	nd	nd	nd	26	26
Lithium_Dissolved	mg/l	2.5	0	nd	nd	0	26	24

Parameter	Units	Criteria	Average	Median	Minimum	Maximum	No.	Number of Non-Detect Samples
Manganese_Total	mg/l	0.05	0.25	0.09	0.04	2.08	26	0
Manganese_Dissolved	mg/l	0.05	0.23	0.09	0.04	1.8	26	0
Mercury_Total	mg/l	0.000012	nd	nd	nd	nd	26	26
Mercury_Dissolved	mg/l	0.000012	nd	nd	nd	nd	26	26
Molybdenum_Total	mg/l	0.01	nd	nd	nd	nd	26	26
Molybdenum_Dissolved	mg/l	0.01	nd	nd	nd	nd	26	26
Nickel_Total	mg/l	0.01614	0.00558	nd	nd	0.02	26	25
Nickel_Dissolved	mg/l	0.01610	nd	nd	nd	nd	26	26
Selenium_Total	mg/l	0.0050	nd	nd	nd	nd	26	26
Selenium_Dissolved	mg/l	0.0046	nd	nd	nd	nd	26	26
Silver_Total	mg/l	0.00037	0.00012	nd	nd	0.0004	26	24
Silver_Dissolved	mg/l	0.00032	nd	nd	nd	nd	26	26
Strontium_Total	mg/l		0.235	0.22	0.06	0.43	26	0
Strontium_Dissolved	mg/l		0.228	0.215	0.06	0.41	26	0
Thallium_Total	mg/l	0.0017	nd	nd	nd	nd	26	26
Thallium_Dissolved	mg/l	0.0017	nd	nd	nd	nd	26	26
Titanium_Total	mg/l		0.007	nd	nd	0.02	26	20
Titanium_Dissolved	mg/l		nd	nd	nd	nd	26	26
Vanadium_Total	mg/l	0.1	nd	nd	nd	nd	26	26
Vanadium_Dissolved	mg/l	0.1	nd	nd	nd	nd	26	26
Zinc_Total	mg/l	0.0370	0.01415	nd	nd	0.161	26	18
Zinc_Dissolved	mg/l	0.0362	0.0066	nd	nd	0.055	26	21
WAD Cyanide	mg/l		nd	nd	nd	nd	26	26
Total Organic Carbon	mg/l		2	1	nd	4	22	4

Table 5-20 presents a summary of the number of selected samples that exceeded the most stringent water quality criteria. The types of exceedances vary by monitoring well. Every sample from wells 14A2 and 27A1 exceed the drinking water criteria for arsenic, while no samples from well 20B1 exceed the arsenic criteria. All samples from wells 20B1 and 27A1, and one sample from well 14A2, exceed the manganese criteria. Approximately half of the samples exceed the iron criteria; those samples were taken from wells 14A2 and 20B1. Occasional exceedances of cadmium, copper, lead, nickel, and zinc occur in samples from well 20B1. In these cases, the exceedance analysis is sensitive to the hardness concentration that is used to compute the criteria values. The observed hardness values at well 20B1 range from 20-80 mg/L as CaCO₃. Some of the samples do not result in exceedances if the observed hardness values are used to compute the criteria values.

Table 5-20. Ground Water Exceedances – Minable Coal – Selected Samples

Parameter	Total Samples	Considered Samples	No. of Exceedances	Water Quality Criteria [mg/L]	Criteria Type
Aluminum_Total	26	26	4	0.087	Aquatic Life – Chronic
Arsenic_Total	26	26	19	0.01	Drinking Water
Cadmium_Total	26	26	2	0.00010	Aquatic Life – Chronic
Copper_Total	26	26	2	0.00285	Aquatic Life – Chronic
Iron_Total	26	26	11	1.0	Aquatic Life – Chronic
Lead_Total	26	26	7	0.00054	Aquatic Life – Chronic
Manganese_Total	26	26	20	0.05	Human Health – Water

Parameter	Total Samples	Considered Samples	No. of Exceedances	Water Quality Criteria [mg/L]	Criteria Type
					+ Aquatic Organisms
Nickel_Total	26	26	1	0.01614	Aquatic Life – Chronic
Silver_Total	26	26	2	0.00037	Aquatic Life - Acute
Zinc_Total	26	26	2	0.037	Aquatic Life - Acute

Sub Red 1 Sand Unit Water Quality

The water quality in the Sub Red 1 Sand unit is assessed using water quality data from wells 24D2 and 35G1 for the period 2006-2010. The groundwater in the sub red 1 sand unit is a bicarbonate type water with variable concentrations of sodium and calcium. The pH is neutral to slightly alkaline, with pH determinations ranging from 7.7 to 8.6 (*Table 5-21*). Groundwater concentrations of total dissolved solids are low, with concentrations ranging from 40 to 380 mg/l and an average value of 255 mg/l. Turbidity is very low, with values ranging from below detection limit to 2.2 NTU and an average value of 0.4 NTU. TSS values were below detection limit in all samples. Because none of the samples violated the screening criteria, only one set of water quality results is presented.

Table 5-21. Water Quality Summary for Sub Red 1 Sand Hydrostratigraphic Unit¹⁷ - All Samples

Parameter	Units	Criteria	Average	Median	Minimum	Maximum	No.	Number of Non-Detect Samples
Total Dissolved Solids	mg/l		255	315	40	380	20	0
Total Suspended Solids	mg/l		nd	nd	nd	nd	27	27
ph_Field	su		7.3	7.3	6.8	7.8	2	0
pH_Lab	su		8.3	8.3	7.7	8.6	27	0
Conductivity_Field	umhos/cm		602	602	567	636	2	0
Conductivity_Lab	umhos/cm		413	546	226	584	27	0
Turbidity	NTU		0.43	0.2	nd	2.2	20	2
Color	PCU		6	6	nd	12	20	8
Temperature	deg C		7.3	7.3	6.7	8	2	0
Oxygen_Dissolved	mg/l		4.3	4.3	4.3	4.3	1	0
Total Hardness as CaCO ₃	mg/l		43	10	nd	90	27	11
Calcium	mg/l		12.07	3	2	24	27	0
Magnesium	mg/l		3.41	nd	nd	7	27	14
Sodium	mg/l		87.1	133	15	156	20	0
Potassium	mg/l		2	2	2	2	20	0
Ammonia as N	mg/l		0.36	0.4	nd	0.6	20	1
Total Alkalinity as CaCO ₃ _Lab	mg/l		238.89	296	106	382	27	0
Bicarbonate as HCO ₃	mg/l		284.56	346	129	467	27	0
Carbonate as CO ₃	mg/l		4.41	nd	nd	12	27	18
Hydroxide as OH	mg/l		nd	nd	nd	nd	25	25
Chloride	mg/l	230	2	3	nd	5	27	13

¹⁷ “nd” means not detected. Average concentrations were computed using 0.5x the detection limit for those samples having a concentration less than the detection limit. For those parameters that were not detected in any sample, the average was set to “nd”. The results have been displayed using not more than the number of significant digits in the most recent detection limit.

For fecal coliform and total coliform results, TNTC means that there were too many colonies to count. If a TNTC was reported for any sample at a sample site, the average was not computed.

Parameter	Units	Criteria	Average	Median	Minimum	Maximum	No.	Number of Non-Detect Samples
Nitrite	mg/l	1	nd	nd	nd	nd	20	20
Nitrate	mg/l	10	nd	nd	nd	nd	20	20
Nitrate + Nitrite as N	mg/l	10	nd	nd	nd	nd	20	20
Fluoride	mg/l	1	1	1	0	1	20	0
Sulfate	mg/l		0.52	nd	nd	1	27	26
Ortho-Phosphate as P	mg/l		0.07	nd	nd	0.1	20	14
Aluminum_Total	mg/l	0.087	0.011	nd	nd	0.03	27	26
Aluminum_Dissolved	mg/l	0.087	nd	nd	nd	nd	27	27
Antimony_Total	mg/l	0.006	nd	nd	nd	nd	20	20
Antimony_Dissolved	mg/l	0.006	nd	nd	nd	nd	20	20
Arsenic_Total	mg/l	0.01	nd	nd	nd	nd	27	27
Arsenic_Dissolved	mg/l	0.01	nd	nd	nd	nd	27	27
Barium_Total	mg/l	2	0	nd	nd	0	20	11
Barium_Dissolved	mg/l	2	0	nd	nd	0	20	11
Beryllium_Total	mg/l	0.004	nd	nd	nd	nd	20	20
Beryllium_Dissolved	mg/l	0.004	nd	nd	nd	nd	20	20
Boron_Total	mg/l	0.75	0.07	0.09	nd	0.13	27	9
Boron_Dissolved	mg/l	0.75	0.06	0.08	nd	0.12	27	13
Cadmium_Total	mg/l	0.00010	nd	nd	nd	nd	20	20
Cadmium_Dissolved	mg/l	0.00009	nd	nd	nd	nd	20	20
Chromium_Total	mg/l	0.1	nd	nd	nd	nd	20	20
Chromium_Dissolved	mg/l	0.1	nd	nd	nd	nd	20	20
Cobalt_Total	mg/l	0.05	nd	nd	nd	nd	20	20
Cobalt_Dissolved	mg/l	0.05	nd	nd	nd	nd	20	20
Copper_Total	mg/l	0.00285	0.00119	nd	nd	0.008	27	24
Copper_Dissolved	mg/l	0.00274	0.00085	nd	nd	0.001	27	26
Iron_Total	mg/l	1	0	0	0	1	27	0
Iron_Dissolved	mg/l	1	0	0	0	0	27	0
Lead_Total	mg/l	0.00054	0.00087	nd	nd	0.0057	27	19
Lead_Dissolved	mg/l	0.00054	0.00022	nd	nd	0.0004	27	26
Lithium_Dissolved	mg/l	2.5	0	nd	nd	0	20	19
Manganese_Total	mg/l	0.05	0.07	0.01	nd	0.24	27	12
Manganese_Dissolved	mg/l	0.05	0.07	0.01	nd	0.25	27	12
Mercury_Total	mg/l	0.000012	0.00003	nd	nd	0.00006	25	24
Mercury_Dissolved	mg/l	0.000012	nd	nd	nd	nd	25	25
Molybdenum_Total	mg/l	0.01	nd	nd	nd	nd	20	20
Molybdenum_Dissolved	mg/l	0.01	nd	nd	nd	nd	20	20
Nickel_Total	mg/l	0.01614	nd	nd	nd	nd	27	27
Nickel_Dissolved	mg/l	0.01610	nd	nd	nd	nd	27	27
Selenium_Total	mg/l	0.0050	nd	nd	nd	nd	20	20
Selenium_Dissolved	mg/l	0.0046	nd	nd	nd	nd	20	20
Silver_Total	mg/l	0.00037	0.00048	nd	nd	0.0005	27	25
Silver_Dissolved	mg/l	0.00032	nd	nd	nd	nd	27	27
Strontium_Total	mg/l		0.228	0.09	0.06	0.45	20	0
Strontium_Dissolved	mg/l		0.218	0.09	0.05	0.43	20	0

Parameter	Units	Criteria	Average	Median	Minimum	Maximum	No.	Number of Non-Detect Samples
Thallium_Total	mg/l	0.0017	nd	nd	nd	nd	20	20
Thallium_Dissolved	mg/l	0.0017	nd	nd	nd	nd	20	20
Titanium_Total	mg/l		0.005	nd	nd	0.01	20	19
Titanium_Dissolved	mg/l		nd	nd	nd	nd	20	20
Vanadium_Total	mg/l	0.1	nd	nd	nd	nd	20	20
Vanadium_Dissolved	mg/l	0.1	nd	nd	nd	nd	20	20
Zinc_Total	mg/l	0.0370	0.00469	nd	nd	0.026	27	21
Zinc_Dissolved	mg/l	0.0362	0.0042	nd	nd	0.029	27	23
WAD Cyanide	mg/l		0.0058	nd	nd	0.02	20	19
Total Organic Carbon	mg/l		1	nd	nd	2	17	9

Table 5-22 presents a summary of the number of samples that exceeded the most stringent water quality criteria. Approximately half the samples exceeded the criteria for manganese. All samples from well 24D2 exceeded the criteria for manganese, while none of the samples from well 35G1 did. The January 2008 sampling event at well 35G1 resulted in exceedances of copper, iron, and lead criteria. The hardness values used to compute the water quality criteria affect the exceedance analysis. For example, the observed hardness values at well 35G1 range from below detection limit to 10 mg/L as CaCO₃, lower than the assumed value of 25 mg/L as CaCO₃. The observed hardness values at well 24D2 range from 70-90 mg/L as CaCO₃, which if used to compute the criteria values would eliminate half the lead exceedances.

Table 5-22. Ground Water Exceedances – Sub Red 1 Sand – All Samples

Parameter	Total Samples	Considered Samples	No. of Exceedances	Water Quality Criteria [mg/L]	Criteria Type
Copper_Total	27	25	1	0.00285	Aquatic Life – Chronic
Iron_Total	27	27	1	1.0	Aquatic Life – Chronic
Lead_Total	27	25	5	0.00054	Aquatic Life – Chronic
Manganese_Total	27	27	13	0.05	Human Health – Water + Aquatic Organisms
Mercury_Total	25	6	1	0.000012	Human Health – Water + Aquatic Organisms
Silver_Total	27	25	1	0.00037	Aquatic Life - Acute

Summary of Groundwater Exceedances

The groundwater quality in all hydrostratigraphic units indicates that elevated concentrations of iron and manganese are naturally occurring. All units exhibited a high frequency of exceeding the applicable iron and/or manganese criteria. Occasional exceedances of other metals (e.g., aluminum, arsenic, cadmium, copper, lead, mercury, nickel, silver, zinc) also occurred. Some samples that exceeded water quality criteria were affected by relatively high concentrations of turbidity and TSS, which resulted in high total metals concentrations but low dissolved metal concentrations. For water quality criteria that are a function of water hardness, the exceedance analysis was sensitive to the hardness value assumed in the criteria computation.

The exceedances of water quality criteria that were observed in the groundwater were highly consistent with water quality exceedances for surface waters in the project area. Exceedances of aluminum, antimony, boron, copper, iron, lead, manganese, mercury, nickel, and zinc have been reported in the surface water (Riverside 2009).

5.4.3 Geochemical Trends

The concentration of anions and cations for water from wells completed in the alluvial, glacial drift, minable coal sequence and sub red 1 sand units are graphically displayed on Piper (*Figure 5-4*) and Stiff diagrams (*Figure 5-5, Figure 5-6, Figure 5-7, Figure 5-8, and Figure 5-9*) using data from 2006-2010.

The overall groundwater quality in the project area can be characterized as containing slightly higher concentrations of dissolved solids with depth and age of the hydrostratigraphic unit between the alluvium and the sub red 1 sand. For example, the upper flow system is characterized by an average TDS of 158 mg/L for the alluvium and 112 mg/L for the glacial drift. The lower flow system is characterized by an average TDS concentration of 189 mg/L for the minable coal sequence and 255 mg/L for the sub red 1 sand unit. This would be expected with the longer residence time in the lower aquifers. In addition, all of the groundwater samples collected between 2006 and 2010 have TDS concentrations that are less than 400 mg/L.

The variations in the relative percentage of anions and cations for groundwater and surface waters in the project area are graphically displayed on the Piper Diagram presented in *Figure 5-4*. The diagram illustrates that the water composition is generally similar but varies between locations. The Piper Diagram does not exhibit general and distinctive trends for cations related to spatial distribution or hydrostratigraphic unit, excepting a small number of outlying samples from the minable coal sequence and sub red 1 sand. For anions, all waters are predominately bicarbonate, though the composition of the glacial drift in the Ladd Landing area is distinctively different from the groundwater in the other units, though consistent with the composition in surface waters.

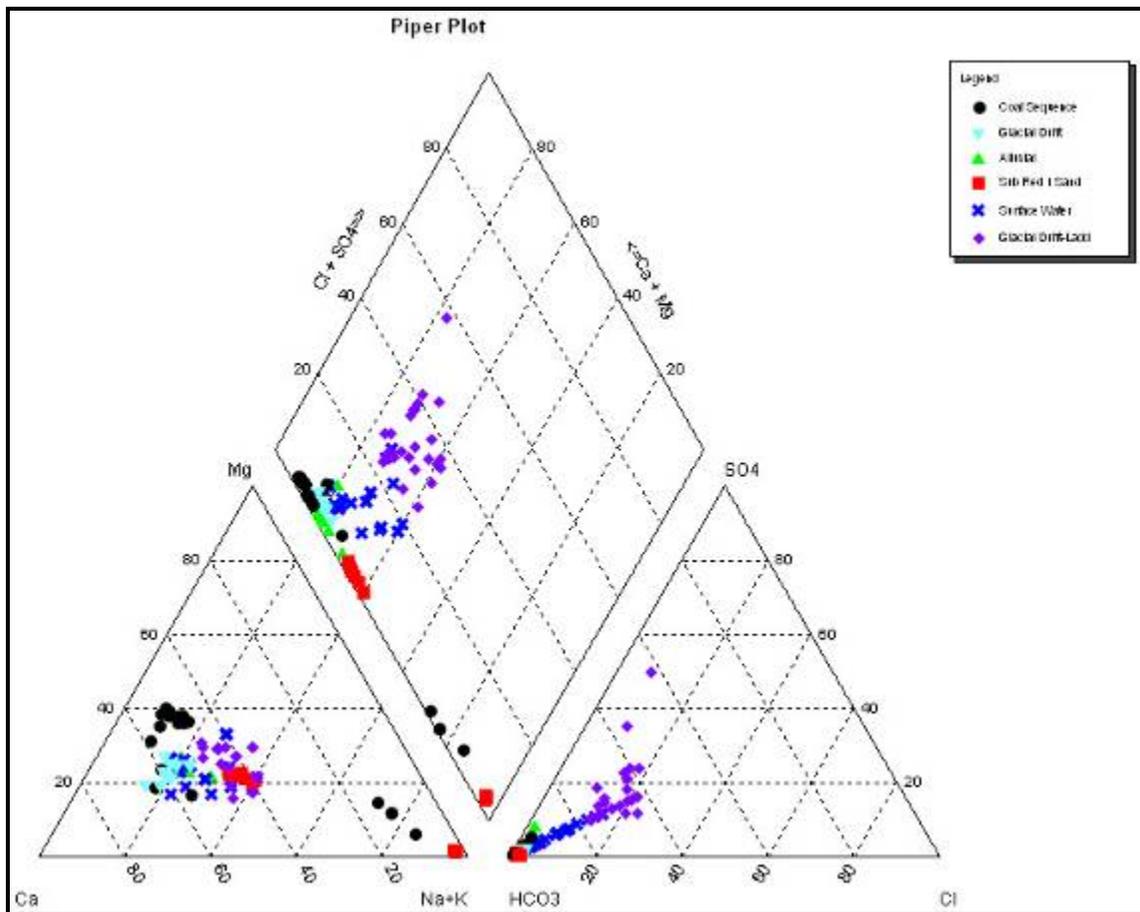


Figure 5-4. Piper Diagram of Groundwater and Surface Water Samples

Concentration of anions and cations for the different hydrostratigraphic units are graphically displayed on Stiff diagrams in *Figure 5-5*, *Figure 5-6*, *Figure 5-7*, *Figure 5-8* and *Figure 5-9*. The Stiff diagrams for the sub red 1 sand wells illustrate that the well water is a bicarbonate water that exhibits variable concentrations of sodium, calcium, and magnesium. The minable coal sequence is a calcium bicarbonate water. Increased concentrations of sodium, calcium, and magnesium probably reflect increased residence time for waters within the sequence. The glacial drift is a calcium bicarbonate water that is similar to surface water (Riverside, 2009). The alluvium is also a calcium bicarbonate water that is similar to surface water, though exhibits uniformly higher ionic concentrations.

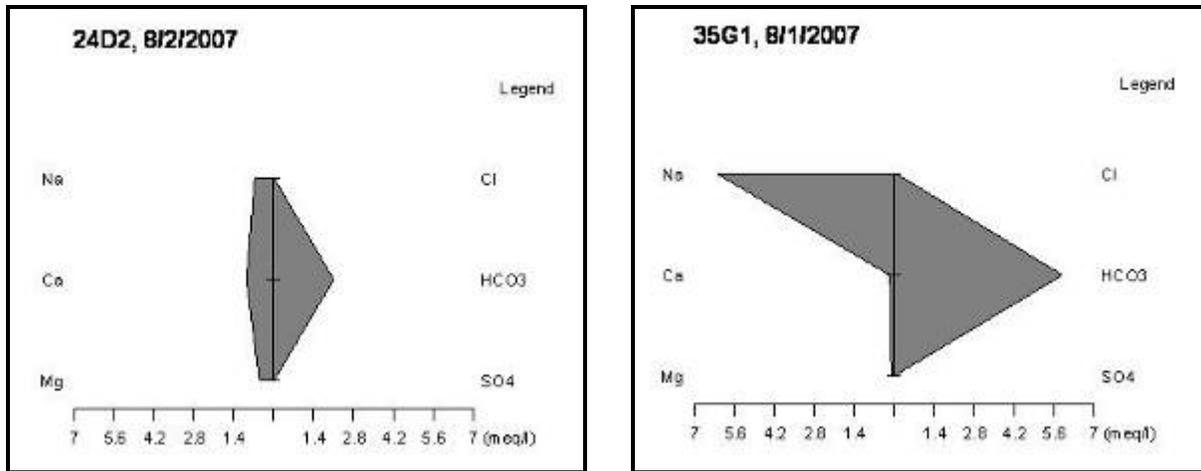


Figure 5-5. Stiff diagrams for representative water quality samples from monitoring wells completed within the sub red sand 1 hydrostratigraphic unit

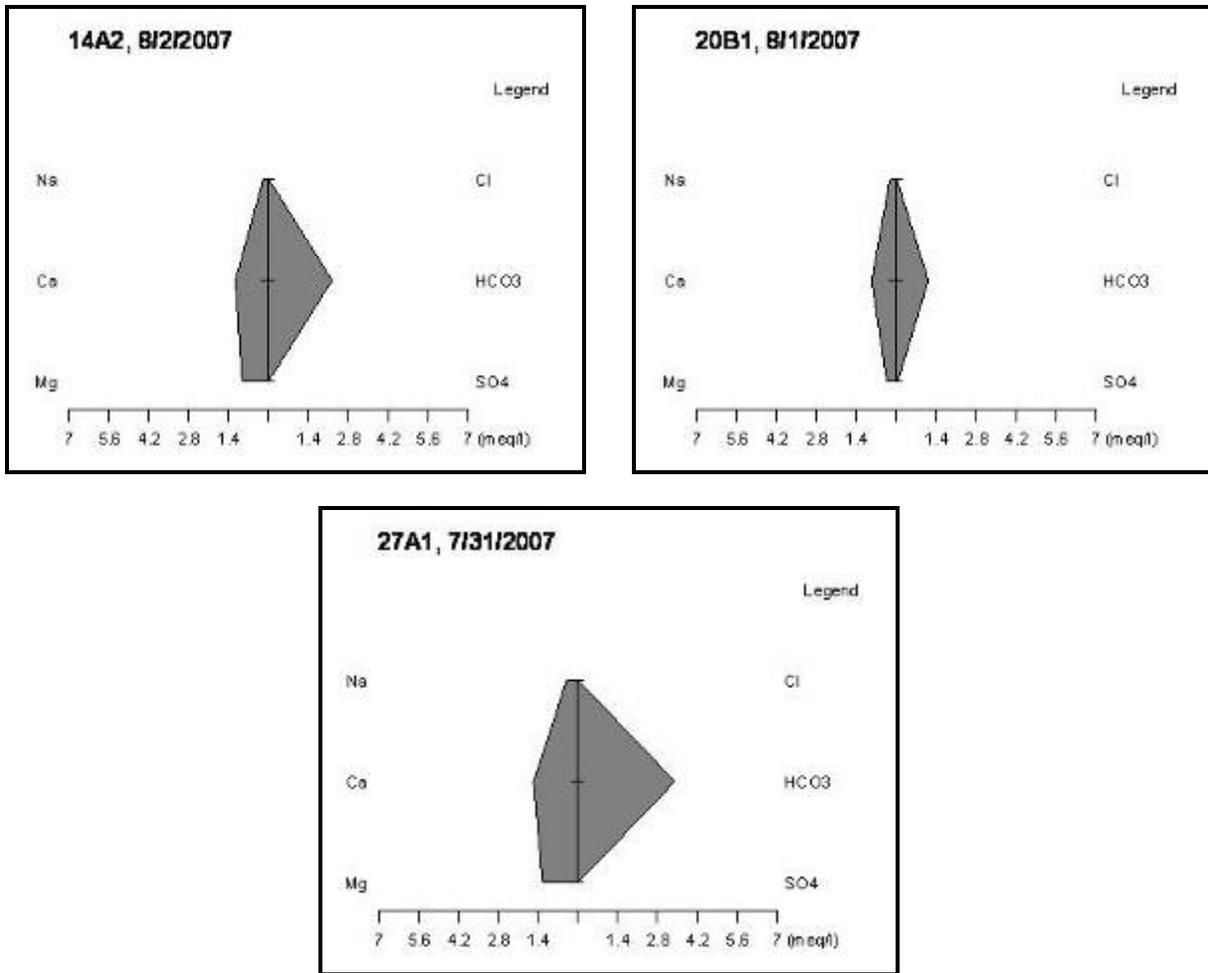


Figure 5-6. Stiff diagrams for representative water quality samples from monitoring wells completed within the minable coal sequence hydrostratigraphic unit

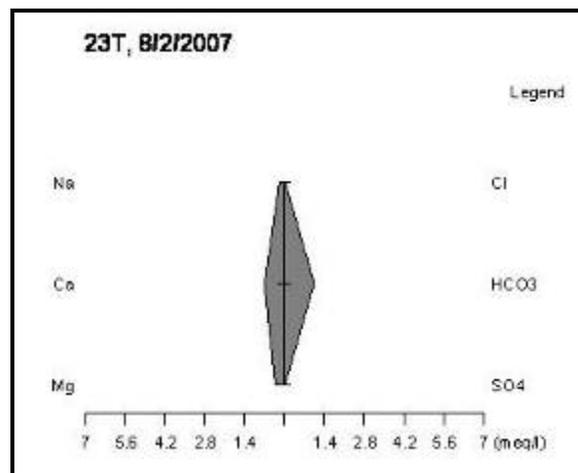


Figure 5-7. Stiff diagram for a representative water quality sample from a monitoring well completed within the glacial drift hydrostratigraphic unit (proposed mine area)

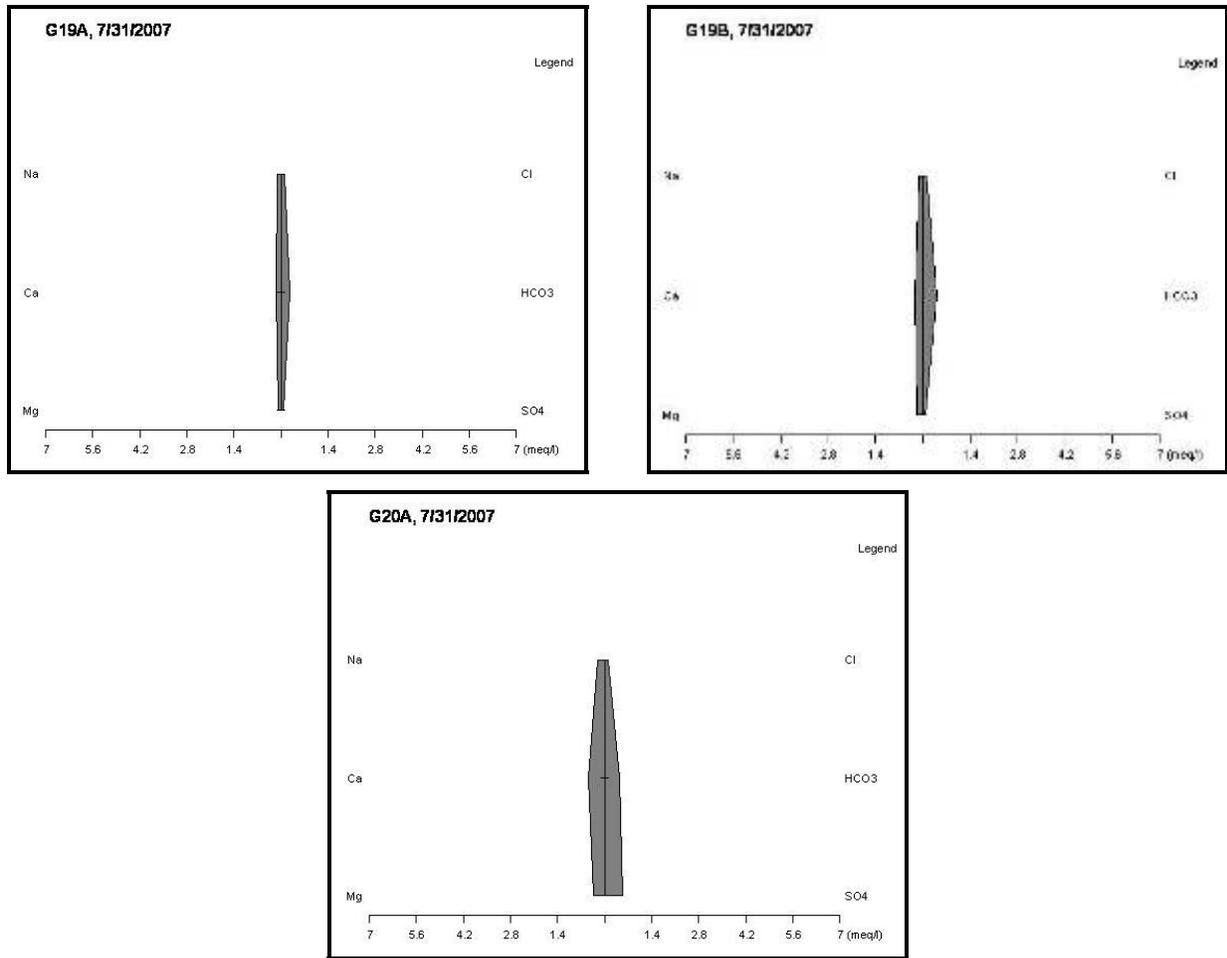


Figure 5-8. Stiff diagrams for representative water quality samples from monitoring wells completed within the glacial drift hydrostratigraphic unit (Ladd Landing area)

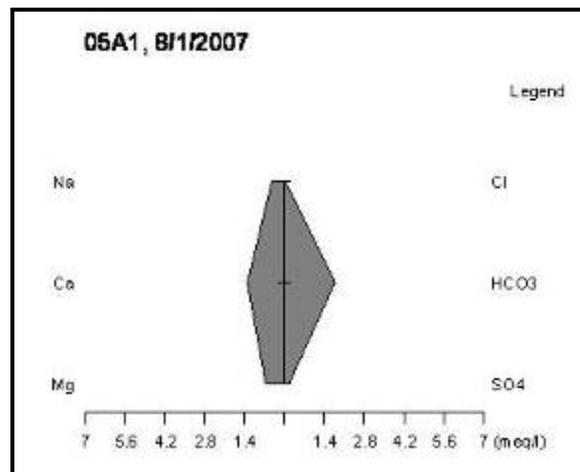


Figure 5-9. Stiff diagram for a representative water quality sample from a monitoring well completed within the alluvium hydrostratigraphic unit

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