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2.3 Geology

The following presentation of environmental resource information is in accordance with:

- Section 38-14.1-14(1)(r)(s)(q), North Dakota Century Code (NDCC);
- Section 38-14.1-14(2)(m), NDCC;
- Section 69-05.2-08-02, North Dakota Administrative Code (NDAC);
- Section 69-05.2-08-04, NDAC; and
- Section 69-05.2-08-05, NDAC.

The Geology Study Area (Study Area) includes the area within the Permit Boundary and additional areas outside the permit boundary as shown on Figure 2.3-1. The Study Area is located approximately two miles southwest of South Heart, Stark County, North Dakota.

2.3.1 Geology Narrative – General and Regional

The South Heart Lignite Mine (SHLM) is located in the western portion of Stark County, North Dakota within the Great Plains physiographic province. Within North Dakota this physiographic province is divided into the Missouri Plateau (or Missouri Slope Upland), Little Missouri Badlands, Coteau Slope, and Missouri Coteau (Biek and Murphy 1997). Stark County is located in the southwest part of the state, mostly within the unglaciated part of the Missouri Plateau. Stark County and the Study Area are characterized by rolling to hilly topography, the result of erosion of generally flat-lying, easily eroded sedimentary rocks (Missouri River Basin Commission 1978, Biek and Murphy 1995).

The Study Area is located on the southern flank of the Williston Basin. The Williston Basin is a structural and sedimentary basin that covers an area including the western half of North Dakota, part of northeastern Montana, northwest South Dakota, and parts of the Saskatchewan and Manitoba Provinces in Canada (Carlson and Anderson 1965). Initially, the Williston Basin was a depression in the regional craton in which a relatively complete sedimentary sequence has filled. The Williston Basin includes sedimentary rocks from every geologic period from the Cambrian through the Tertiary (Carlson and Anderson 1965).

Carlson and Anderson (1965) describe the sedimentary history of the North Dakota part of the Williston Basin. The stratigraphic record has been subdivided into Sequence subdivisions that are separated by unconformities. The Sequence and Periods, with their associated groups or formations, are summarized in Table 2.3-1.

Carlson and Anderson (1965) described the Sequences from oldest to youngest. The Sauk Sequence (Cambrian to Lower Ordovician) is predominantly composed of carbonate with basal sandstone that is overlain by shale, carbonate, and sandstone. The Tippecanoe Sequence (Middle Ordovician to Silurian) was deposited when the Williston Basin was a slight depression, and appears to be a transgressive event with the seas invading the area from the south and east. During most of this Sequence an extensive epicontinental sea covered the basin. During the Kaskaskia Sequence (Devonian and Mississippian), the Williston Basin was a more tectonically negative area than during the Sauk or Tippecanoe Sequences. The initial deposits appear to represent a transgressive sea spreading across the basin from the north and west as the Williston Basin was incorporated by a larger Devonian seaway. The Absaroka Sequence (Pennsylvanian, Permian, and Triassic) and Zuni Sequence (Jurassic and Cretaceous) contain predominantly clastic materials. During the Jurassic and Cretaceous sequence, a wide-spread sea covered the western interior of the North American continent, including North Dakota. The Tejas Sequence (Tertiary) is mostly non-marine deposits (Fort Union Group, Golden Valley, and White River) derived from a western source area. The only marine deposits in the Tejas Sequence are in the Cannonball Formation of the Fort Union Group (Carlson and Anderson 1965). These deposits were followed by glacial deposits in the northern part of the Williston Basin and outwash and alluvial deposits in the southern part of the Williston Basin.

The surface geology of southwestern North Dakota is characterized by thousands of square miles of semi-consolidated, flat-lying, Tertiary sedimentary formations (Tejas Sequence) and, in the extreme southwestern part of the state, marine Cretaceous sediments from the Hell Creek Formation of the Zuni Sequence (Bluemle 2000, Trapp and Croft 1975). In many areas of western North Dakota, these flat-lying sediments have been eroded into areas of buttes, mesas, and badlands topography (Bluemle 2000). Many of the local drainages and stream valleys are in-filled with Quaternary alluvium derived from the surrounding bedrock. Generally southwest of the Missouri River, glacial deposits are a minor occurrence, while north, northeast, and east of the Missouri River glacial deposits dominant the surface geology of North Dakota (Bluemle 2000).

2.3.2 Study Area Narrative

The Study Area is located within parts of Sections 9, 10, 11, 13, 14, 19, 20, 24, 28, 29, and 33 Township 139 North (T139N) Range 98 West (R98W), a portion of Section 3 T138N R98W, and all of Sections 15, 16, 17, 21, 22, 23, 27, 34 T139N R98W (Figure 2.3-1). Elevations within the Study Area vary from approximately 2,470 feet (ft) or 753 meters (m) above mean sea level (amsl) in the northeast corner of the Study Area near the Heart River to approximately 2,711 ft (826 m) amsl in the northwest.

As described above, the Study Area is within the Great Plains physiographic province and lies mostly within the unglaciated part of the Missouri Plateau. The Study Area is part of the Dickinson Lignite Area (Armstrong 1984) and exhibits landforms typical of unglaciated terrain, such as unglaciated rolling plains with scattered buttes (Roberts 1994). The physiographic features within the Study Area are shown on Figure 2.3-1. The Study Area is located southwest of the confluence of the South Branch Heart River with the Heart River and west and southwest of the town of South Heart, North Dakota. On the north side of the Study Area is the Heart River, while the South Branch Heart River transects diagonally, southwest to northeast across the Study Area. The Heart River flows downstream to the east, from the Study Area toward the town of Dickinson.

2.3.2.1 Study Area Geology

The primary coal-bearing stratigraphic units in the area are the relatively flat-lying Sentinel Butte Formation and the deeper Tongue River Formation. As shown in Table 2.3-1, the Sentinel Butte Formation, along with the Tongue River Formation (also referred to as the Bullion Creek Formation (Flores and Keighin 1999)), the Slope Formation, the Ludlow Formation, and the Cannonball Formation, make up the larger Fort Union Group (Trapp and Croft 1975, Clayton et al. 1977). Field mapping was conducted for the surficial geology within the Study Area from October 1 to October 8, 2006 and from June 19 to June 20, 2007. From the Fort Union Group, only the Tongue River Formation and the shallower Sentinel Butte Formation are found at or near the surface in the Study Area. It is the Sentinel Butte Formation and the Tongue River Formation with their numerous coal seams that are of primary interest in the Study Area. The Golden Valley Formation lies on top of the Sentinel Butte Formation and occurs in the western part of the Study Area (Trapp and Croft 1975) and occurs south of the South Branch Heart River (Murphy et al. 1993). Geology within the Study Area is shown on Figure 2.3-2A, Figure 2.3-2B, Figure 2.3-2C, and Figure 2.3-2D

The Fort Union Group and the Golden Valley Formation consist of palustrine to fluvio-deltaic sediments and may contain localized channel sandstone and overbank deposits. These deposits indicate that a network of anastomosing streams dominated this setting. The deposits are generally fine-grained and reflect a quiescent depositional environment (Hickey 1977, Clechenko et al. 2007).

The large regional structure of the Williston Basin is interrupted in many areas by small structures such as folds and faults (Biek and Murphy 1995). One such local structure is the southwest-northeast trending syncline that occurs in the Little Badlands. The northwest edge of the Little Badlands is approximately 1½ miles southeast from the southeast corner (Section 3 T138N R98W) of the Study Area. The Little Badlands syncline axis, approximately 2¼ miles southeast of the southeast corner of the Study Area, passes through Section 31, 30, 29, 21, 22 T138N R 98W, and bending more northeast in Section 23 T138N R98W and continuing up through Section 32 T139N R97W (Murphy et al. 1993). The Study Area is located on the northwest limb of the syncline, which generally results in dipping of beds to the southeast. In addition, Menge (1977) mapped a fault just outside of the town of South Heart. The fault is a normal fault with no more than 15 ft (4.6 m) of vertical displacement with the downthrown block on the west side and a trace of about 6 miles (10 km). The fault trends due north from the east side of Section 25, 24, 13, 12 T139N R98W and directly east of the town of South Heart, the fault then trends northwest through Section 12, 11, 2, 3 T13N R98W and Section 34 T140N R98W. However, this fault does not occur within the Study Area. This fault shows no evidence of Quaternary movement and, therefore, is not considered an active fault.

2.3.2.2 Study Area Stratigraphy (including coal)

Due to the relatively shallow nature of the coal and associated stratigraphic units that may be impacted during mining operations, this section is limited to formations above the Pierre Shale. These units are discussed below from oldest to youngest. Figure 2.3-3 presents the stratigraphic column. The discussion below is based on published articles, field observations from this baseline study, and data collected as part of the mine plan process.

Fox Hills Formation (Cretaceous)

The Fox Hills Formation total thickness ranges from 240 to 410 ft (73 to 125 m) in Hettinger and Stark counties (Trapp and Croft 1975). The Fox Hills Formation is Cretaceous in age and consists of interbedded very fine to medium-grained sandstone, siltstone, claystone, and rarely, a few thin beds of carbonaceous and lignitic shale (Trapp and Croft 1975). The Fox Hills Formation does not crop out in the Study Area, but occurs in the subsurface (Trapp and Croft 1975). Trapp and Croft (1975) mapped the top of Fox Hills Formation within the Study Area at an elevation of approximately 1,000 ft (305 m) amsl to 1,060 ft (323 m) amsl which is approximately 1,460 ft (445 m) to 1,540 ft (469 m) below the land surface. The Fox Hills Formation was not encountered during drilling for this baseline study program or observed in the field.

Hell Creek Formation (Cretaceous)

The Hell Creek Formation can be both conformable or unconformable (Daly 1986) with the underling Fox Hills Formation and its total thickness is 220 to 510 ft (67 to 155 m) in Hettinger and Stark counties (Trapp and Croft 1975). According to Trapp and Croft (1975), the total thickness for the Hell Creek Formation within the Study Area is approximately 440 to 490 ft (134 to 149 m). The Hell Creek Formation does not crop out in the Study Area; however, it does occur in the subsurface. Trapp and Croft (1975) mapped the top of the Hell Creek Formation within the Study Area at an elevation of approximately 1,500 ft (457 m) amsl to 1,560 ft (476 m) amsl, which is estimated to be approximately 990 ft (302 m) to 1,050 ft (320 m) below the land surface in the Study Area. These depths are estimated and based on literature values because boreholes drilled for this baseline study program in the Study Area did not penetrate to these depths.

The Hell Creek Formation is Cretaceous in age and consists of siltstone, bentonitic and carbonaceous claystone, shale, and fine- to medium-grained sandstone (Frye 1969, Trapp and Croft 1975). Sideritic nodules and concretions occur in zones (Trapp and Croft 1975).

Fort Union Group (Tertiary)

The Fort Union Group consists of, in ascending order, the Ludlow, Cannonball, and Slope Formations, the Tongue River Formation (Bullion Creek), and the Sentinel Butte Formation (Clayton et al. 1980), each of which is discussed below. Royse (1967) studied the Tongue River-Sentinel Butte contact in western North Dakota and determined that within the Fort Union Group these two units should be elevated to formational status from member status. The United States Geological Survey (USGS) confirmed the formational status; however, they have left the decision of member or formation status to the author (Biek and Murphy 1995). Therefore, in articles pre-1967 the Fort Union Group was known as Fort Union Formation, the Tongue River Formation was known as Tongue River Member and the Sentinel Butte Formation was known as Sentinel Butte Member.

Clayton et al. (1977) assigned the name Bullion Creek to replace Tongue River Formation and added Slope Formation to resolve problems of correlating Paleocene rocks between North Dakota, South Dakota, and Montana. The use of Bullion Creek Formation and Slope Formation are recognized by the North Dakota Geological Survey while USGS recognizes Tongue River for the Williston Basin in North Dakota (Flores and Keighin 1999). Therefore, papers before 1977 do not use the terminology Bullion Creek Formation or Slope Formation, but this terminology is now accepted in North Dakota.

Slope, Ludlow and Cannonball Formations

Trapp and Croft (1975), written prior to 1977, does not include the Slope Formation, but gives excellent descriptions of the Ludlow and Cannonball Formations within the Study Area. Within the Study Area, Trapp and Croft (1975) show both the Ludlow and Cannonball Formations present in the subsurface. The combined thickness of the two formations is 310 to 650 ft (94 to 198 m). The top of the Ludlow Formation occurs 275 to 755 ft (84 m to 230 m) below land surface. The Cannonball Formation occurs at a depth estimated to be approximately 700 ft (213 m) to 650 ft (198 m) below the land surface in the Study Area (Trapp and Croft 1975).

In the Williston Basin, the Ludlow and Cannonball Formations were deposited contemporaneously with the Ludlow Formation found in the western portion of the basin. The Ludlow Formation was deposited in a continental environment, whereas the Cannonball Formation was deposited in a marine environment. The Cannonball Formation is the youngest marine strata known in the northern Great Plains (Trapp and Croft 1975). The Ludlow Formation consists of green and brown carbonaceous claystone, siltstone, fine-grained sandstone, and lignite (i.e., coal). Herein, the terms ‘lignite’ and ‘coal’ may be used interchangeably since lignite actually refers to a specific quality or grade of coal. The sandstone is generally coarser-grained in the Ludlow Formation than the sandstone units in the Cannonball Formation. The Cannonball Formation consists of claystone and siltstone with a thickness of 50 to 200 ft (15 to 61 m) within the Study Area. These beds thin westward and interfinger with the Ludlow Formation (Trapp and Croft 1975).

The Slope Formation was first recognized by Clayton et al. (1977). In central North Dakota the Slope Formation lies on Cannonball Formation while on western North Dakota the Slope Formation lies on the Ludlow Formation (Clayton et al. 1977). The Slope Formation is lithologically nearly identical to the Ludlow Formation. The top of the Slope Formation is marked by an interpreted weathering zone called the “Rhame Bed” (Clayton et al. 1980). The Slope Formation is about 295 feet (90 meters) thick and consists of unlithified sediment of clay, silt, sand, and lignite. The color is usually brownish gray (Clayton et al. 1977).

Tongue River Formation (Bullion Creek Formation)

The thickness of the Tongue River Formation is approximately 250 to at least 570 ft (76 to 174 m). The Tongue River Formation is predominantly sandstone interbedded with claystone, coal, carbonaceous shale, and bentonitic claystone (Trapp and Croft 1975). The Tongue River Formation is not well cemented (Royse 1972). Throughout most of southwestern North Dakota, the contact between the Tongue River Formation and the overlying Sentinel Butte Formation is marked by lignite or lignitic shale referred to as the HT Butte lignite (or coal) (Biek and Gonzalez 2001). The HT Butte coal ranges from several inches to several tens of feet in thickness (Biek and Gonzalez 2001). The HT Butte coal is regionally extensive (Trapp and Croft 1975). A basal sandstone unit thickness in the Tongue River Formation is variable; typically it is 50 ft (15 m) thick, but can range up to 199 ft thick (61 m) (Trapp and Croft 1975). The formation is typically lighter in color than the overlying Sentinel Butte Formation (Trapp and Croft 1975).

Royse (1970, 1972) examined 350 samples and reports that Tongue River Formation (average mean phi is about 6.6 phi) is slightly coarser than the Sentinel Butte Formation (average mean phi is about 5.9 phi). The Sentinel Butte Formation is better sorted than the Tongue River Formation.

The Tongue River Formation was encountered in eleven boreholes (SHMW-04, SHMW-06, SHMW-10, SHOB-02R, SHOB-08R, SHOB-21R, SHOB-30C, SHOB-34R, SHOB-47R, SHMW-03HTB, and SHMW-08HTB) within the Study Area drilled for this baseline study program, based on lithologic and borehole geophysical logs. Based on these Study Area boreholes, the maximum depth to the Tongue River was 286 ft (87 m), the minimum depth was 170 ft (51.7 m), and the average depth was 211 ft (64 m). As documented in the geology database, the Tongue River Formation was encountered in four historical boreholes (84, 85, SH02-11C, and USGS-103) within the Study Area prior to this baseline study program. Golder did not observe the Tongue River Formation in outcrops during the geologic field mapping for this baseline study. The Tongue River Formation observed in the boreholes was either a sandy claystone (interbedded with well sorted, very fine-grained, clayey sandstone, shale, claystone, coal, siltstone), or fine sandy siltstone. The color of this formation in the baseline study boreholes is usually dark gray with some portions becoming light gray to medium gray and medium dark gray to olive gray. In SHMW-10D2, shale with very waxy surfaces was encountered at a depth of approximately 218 ft (66.4 m). Clayton et al. (1977) states the Bullion Creek is mostly light yellow.

Sentinel Butte Formation

The reported thickness of Sentinel Butte Formation is up to 600 ft (183 m) (Biek and Murphy 1995, Jacob 1976). Sentinel Butte sediments were deposited under low-energy alluvial conditions characterized by high sinuosity streams and flood plain systems that include swamps and lakes (Forsman 1985). They are freshwater deposits.

The Sentinel Butte Formation is predominantly composed of siltstones and mudstones and consists of silty fine-grained sandstones, siltstone, mudstone, claystone, and coal (Forsman 1985, Trapp and Croft 1975). A description of the coal deposits is presented later. The rocks are usually not well cemented; the well cemented beds are usually channel sandstones that form ledges or cap rocks (Biek and Murphy 1997). The claystone can be bentonitic or carbonaceous (Trapp and Croft 1975). The dominant clay-mineral fraction is smectite, usually sodium montmorillonite (Clechenko et al. 2007), while kaolinite and illite are minor (Forsman 1985). The framework grains include volcanic, metamorphic, and sedimentary rocks (Forsman 1985). However, Forsman (1985) stated that rock fragments in the Sentinel Butte Formation were difficult to classify due to grain size in many samples. Cement development in the siltstones and sandstones is pore-lining montmorillonite precipitation preceding pore-filling zeolite development, which was followed by calcite or dolomite cement (Forsman 1985). Pyrite does not appear to be common throughout the Sentinel Butte Formation (Forsman 1985); however, Moran et al. (1978) state that pyrite is associated with the Sentinel Butte coals. Thick beds of sandstone in the lower part of the Sentinel Butte Formation are important sources of ground water in the Study Area (Trapp and Croft 1975), which is discussed in more detail in Section 2.5.

The Sentinel Butte Formation is the most widespread near-surface Tertiary formation exposed in the Study Area (Bluemle 1975). The Sentinel Butte Formation is the predominant rock unit observed in the baseline study boreholes. This unit occurs above the D Coal (Fryburg) and above the HT Butte Coal (HT Butte). The Sentinel Butte Formation observed in baseline study boreholes is mostly siltstones and mudstones and consists of silty very fine- to fine-grained sandstones (occasional medium- to coarse-grained sandstone), siltstone, mudstone, claystone, shale, and coal. The rocks are usually not well cemented, but contain some well cemented beds. Some of the claystone appears to be laminated. Color (Munsell Color 1998) is usually gray and varies from light gray (N6 to N8), olive brown (5Y 5/6) medium olive brown (5Y 4/4) grayish olive (10Y 4/2), pale olive (10Y 6/2), olive gray (5Y 4/1), greenish gray (5GY 4/1), or light olive brown (2.5Y 5/4). The formation may contain carbonate nodules, layers, or stringers and may contain siderite nodules. Pyrite is commonly also observed in the vicinity of the coal. Fossils sometimes include wood fragments, seeds, and plant leaves. In the geologic field mapping, well cemented rock layers were observed to be associated with channel sandstones that form ledges or cap rocks. Ripple marks and cross-beds were observed in these channel sands.

Golden Valley Formation

The Golden Valley Formation's stratigraphic position is near the top of the depositional sequence and erosion has removed most of the formation in the general area; however, a maximum preserved thickness of 180 ft (55 m) has been observed (Hickey 1972). The basal contact of the Golden Valley Formation is conformable with the Sentinel Butte Formation except where channeling has occurred (Hickey 1977, Clechenko et al. 2007).

The Golden Valley Formation consists of claystone, mudstone, siltstone, micaceous sandstone, and coal. These rocks were deposited under predominantly fluvial conditions during the late Paleocene and early Eocene Epochs. The Formation occurs as scattered erosional remnants with a maximum thickness of 180 ft (55 m). The Golden Valley Formation is divisible into two members: the lower Bear Den Member and the upper Camels Butte Member (Hickey 1972, Clechenko et al. 2007).

The Bear Den Member is a light gray to brightly colored kaolinitic unit that is 5 to 65 ft (1.5 to 20 m) thick. The Bear Den Member usually has a basal gray zone, a middle orange zone, and a carbonaceous upper zone. The gray zone is usually 3 to 6 ft (0.9 to 1.8 m) thick, light to medium gray mudstone, siltstone, and fine- to medium-grained sandstone. The orange zone is usually 10 to 15 ft (3 to 4.6 m) thick, of light gray to white clay with limonite concretions creating an orange coloration in weathered exposures (Biek and Murphy 1997). The Alamo Bluff lignite or lateral equivalent, the Taylor bed, marks the upper boundary of the Bear Den Member.

The Alamo Bluff lignite is usually 1 inch to 3 inches (2.5 cm to 7.6 cm) thick, but at its type locality the Alamo Bluff lignite reaches up to 5.5 ft (1.7 m) thick. The Taylor bed is usually 3 to 10 inches (7.6 to 25 cm) thick and is usually silcrete strewn with plant stem molds (Biek and Murphy 1995). The silcrete is usually polished. Within the Study Area, silcrete is usually found in the gravel deposits.

The Camels Butte Member is a micaceous, illitic and montmorillonitic siltstone, claystone and sandstone that contains several discontinuous thin lignite beds that are occasionally silicified.

The sandstone beds are locally conglomeratic (Biek and Murphy 1995). The hill located in the northeast quarter Section 17 T139N R98W and the northwest quarter Section 18 T139N R98W is interpreted as the Camels Butte Member of the Golden Valley Formation by its stratigraphic position. The Camels Butte Member is as much as 150 ft (46 m) thick (Hickey 1977).

The Golden Valley Formation was observed during baseline geologic field mapping. It was not encountered during drilling for this baseline study program. As observed by baseline field mapping, the Golden Valley Formation consists of claystone, mudstone, siltstone, micaceous sandstone, micrite, and coal. The Golden Valley is recognized by a slight change in topographic slope and is weathered at the surface. The Formation is usually covered by vegetation and/or soil; however where sandstone outcrops occur the sandstone is usually a well sorted fine- to medium-grained sandstone and may be cemented with calcium carbonate ($CaCO_3$), but is usually poorly cemented. Poor cross-beds may also be present. Color (Munsell Color 1998) is variable from pale yellow (2.5Y 8/2), yellowish brown (10YR 5/8), light olive brown (2.5Y 5/6), or very pale brown (10YR 7/3).

White River Group and Arikaree Formation

The White River Group and the Arikaree Formation occur above the Golden Valley Formation; however, these formations do not occur within the Study Area and are not further discussed herein.

Regional Coal Deposits

Coal is found in the Hell Creek Formation, Ludlow Formation, Tongue River Formation, Sentinel Butte Formation, and Golden Valley Formation (Menge 1977). The coal seams within the Hell Creek Formation, Ludlow Formation, and the Golden Valley Formation are too thin and lenticular to be of significant economic importance. Coal seams with sufficient thickness and lateral continuity for economic value are restricted to the Tongue River and Sentinel Butte Formations (Menge 1977). The USGS and the Northern Pacific Railroad Company (NPRC) have both mapped the area extensively and each have established their own nomenclature for delineating specific coal beds. The terminology used by NPRC and the USGS for the major coal beds has been correlated with the coal beds identified for the SHLM (Table 2.3-2). A summary of this correlation is described in the Local Coal Deposits section of this report. Regional coal seam characteristics for these coal beds from NPRC and Menge (1977) are described below. The primary coal being targeted for the proposed mining activities is the D Coal (or Fryburg).

North of the Interstate 94, and thus north of the Study Area, Keim (1961) studied the coals of a 60 square mile area and indicated that the D Coal (Fryburg) is approximately 10 to 18 ft (3 to 5.5 m) thick with approximately 45 to 60 ft (14 to 18.3 m) of overburden above the D Coal, but below the E Coal (Heart River). The E Coal is 9 to 12 ft (3 to 3.7 m) thick and is separated by a 0 to 6 ft parting from the E1 coal, which is 0 to 3 ft (0 to 0.9 m) thick.

Menge's (1977) study area includes a 620 square mile area around the town of Dickinson, both north and south of the Interstate, including the Geologic Study Area. Menge (1977) concentrated on the C Coal, D Coal (Fryburg), E Coal (Heart River), Lehigh Coal, and Dickinson Coal. According to results from the Menge study, the C Coal has a maximum thickness of 44 ft (13.4 m). The C Coal only occurs north of the Interstate in T141N R98W, T141N R97W, T142N R98W, T142N R97W, and pinches out to the south in the northern part of T140N. Menge (1977) states that the D Coal has a maximum thickness of 20 ft (6 m) and an average thickness of 10 ft (3 m) and has significant recoverable resources. The E Coal (or Heart River) has a maximum thickness of 29 ft (8.8 m) with an average thickness of 8 ft (2.4 m). The E Coal pinches out to the northwest and is an important recoverable resource. The Lehigh Coal is relatively thin and is not thick enough to mine economically; therefore, Menge (1977) did not discuss it in detail. The Dickinson Coal is a pod-shaped deposit and only occurs around the town of Dickinson (Menge 1977).

Local Coal Deposits

The coal beds identified for the SHLM correlate to coal beds identified by NPRC and the USGS as shown in Table 2.3-2. The F Coal appears to be a local stringer and could not be correlated with previous mapped coal beds. The E Coal and E1 Coal both correlate with the E (Heart River Coal) mapped in Menge (1977). The D Coal correlates with the D (Fryburg) and the HT Butte Coal correlates with the HT Butte 1 and HT Butte 2 (or HT Butte) mapped in Armstrong (1984) and Menge (1977). The F Coal, E Coal, E1 Coal, D Coal, and the HT Butte Coal isopach maps (with outcrop and subcrop lines) are described and presented in Section 2.3.2.3. The D Coal quality is discussed in Section 2.3.7.

Clinker

Clinker (locally referred to as scoria) is sediment that has been thermally altered from burning of underground coal. The age of alteration is not known and could be Tertiary to Holocene. The degree of alteration for clinker may range from completely melted (a slag-like mass of dark rock that contains numerous voids cased by escaping gases) to rock that is heated just enough to change density and color (Biek and Gonzalez 2001), which will still have original sedimentary structures, fossils, and grain-size. The Study Area has small, scattered outcrops of clinker which occur as reddish layers of brick-like masses of baked and fused clay, shale, and sandstone (Bluemle 2000). In places, the clinker can be resistant to erosional forces and can form local topographic highs. The location of these clinker outcrops are shown on Figure 2.3-2A, Figure 2.3-2B, Figure 2.3-2C, and Figure 2.3-2D.

Quaternary Age Deposits

The Quaternary glacial deposits (such as till) do not occur within the Study Area. However, quaternary deposits such as sand and gravel do occur as terrace deposits above the modern floodplain of the Heart River and associated tributaries. When glacial events occurred to the north of the Study Area the major streams in the area were flowing at a greater volume than they do today because of the large amount of melt water associated with the edge of glaciers (Holland 1957). These streams then deposited the sand and gravel (QTg) found within the Study Area (Figure 2.3-2A, Figure 2.3-2B, Figure 2.3-2C, and Figure 2.3-2D). The sand and gravel deposits (QTg) may also occur as a thin veneer on the ground surface. These deposits are recognized by scattered gravel on the surface. Older alluvial deposits (Qoa) have the same composition as the alluvium found within the modern channels and floodplains but occur above the current modern channels (Figure 2.3-2A, Figure 2.3-2B, Figure 2.3-2C, and Figure 2.3-2D). Finally, the youngest Quaternary deposit is the Holocene alluvium within the modern channels and floodplains (Qal), which have been mapped and are shown on Figure 2.3-2A, Figure 2.3-2B, Figure 2.3-2C, and Figure 2.3-2D. These deposits occur along the Heart River, South Branch Heart River, and along the unnamed stream discharging into the South Branch Heart River at the northwest quarter of Section 27 T139N R98W. This unnamed stream flows from Little Badlands and the alluvium is usually silty clay or clayey silt (ASTM 2000) with only occasional coarse-grained material. In additional, the South Branch Heart River also derives most of its material from the Little Badlands and this alluvium is a silty clay or clayey silt (ASTM 2000).

Tychsen (1950) states that alluvium grades downward toward coarse gravel and sand that overlies the Fort Union Group and documents that 5.5 ft (1.7 m) of coarse gravel overlying sandstone was observed in a large pit in the alluvium.

Fill

Artificial fill occurs in the Study Area, particularly where dams were built to retain water. Fill also occurs in areas disturbed by construction activities such as roads, bridges, and areas where buildings occur. Areas of artificial fill are shown on Figure 2.3-2A, Figure 2.3-2B, Figure 2.3-2C, and Figure 2.3-2D.

2.3.2.3 *Study Area Subsurface Geologic Analysis*

This section provides cross-sections and maps as required by Chapter 69.05.2 of the NDAC. The data used to generate the cross-sections and maps are based on previous boreholes and drilling performed for this baseline study and permit application compiled into a geologic database by Norwest Corporation (Norwest). The geology database was created by examining logs or data from boreholes drilled during previous programs and the data generated by the 2002, Phase I, Phase II, ~~and~~ Phase III, and 2010 drilling programs. Locations of the boreholes in the geologic database are shown on Figure 2.3-1. Additional borehole information is provided in Section 2.3.5. Copies of the geologist logs and geophysical logs for the 2002, Phase II ~~and~~ ,Phase III, and 2010 drilling programs are provided in, Appendix 2.3-13, Appendix 2.3-14, Appendix 2.3-16 and Appendix 2.3-17. Copies of the geologist logs and geophysical logs for the Phase I drilling program are present in Section 2.5.

The cross-sections, structure maps, and isopach maps were created by Norwest as part of the mine planning process. These maps were generated with SurfCAD software using inverse distance squared and triangulation calculations from the geology database. These contours are based on best fit curves and as a result, there are occasional contouring breaks where data are not honored. Data collected in the 2009 drilling program, which included two boreholes drilled for the purpose of monitoring well installation in the HT Butte coal, were checked for consistency with the geologic database but have not been included in the geologic database or used in generating the cross sections, structure maps or isopach maps. As such, the locations of the 2009 drilling program boreholes are not shown on the cross-sections, structure maps, and isopach maps.

The cross-sections generated by SurfCAD (Figure 2.3-4) show the depth of the D Coal (Fryburg) and the depth of weathering horizon that impacts the quality of the coal. The cross-sections also show the D Coal is 12 to 22 ft (3.7 to 6.7 m) thick. For additional descriptions and conceptual cross-sections showing the subsurface geology see Section 2.5.

The isopach, overburden and structure data in the vicinity of the Study Area were based on geologic information from ~~218~~ 220 boreholes from the geologic database; ~~106~~ 107 of these boreholes were drilled prior to 2006, while ~~112~~ 113 of the boreholes were drilled for this baseline study. ~~The~~ As described above, the two boreholes drilled as part of the 2009 drilling program are not included on the figures or in the discussion below.

Of the 220~~18~~ boreholes in the database, 10 penetrated the HT Butte Coal as indicated on Figure 2.3-5. Seven out of the 10 boreholes used in this mapping that go through the HT Butte Coal were drilled for this baseline study. The maximum thickness was 14 ft (4.3 m), the minimum thickness was 9.8 ft (3.0 m), and the average thickness was 12.55 ft (3.8 m) for the ~~7~~ 10 boreholes.

The D Coal thickness map (Figure 2.3-6) is based on ~~198~~ 201 boreholes that penetrated the D Coal. One hundred ~~and two~~and three ~~-~~of these boreholes were drilled for this baseline study. The maximum thickness of the D Coal was ~~22.9~~23.5 ft (7.2 m), the minimum thickness was 1 foot (0.3 m) and the average thickness was 16.~~1~~ 1 ft (4.9 m)~~,~~ based on the ~~198~~ 201 boreholes in the geologic database. Several of these boreholes were drilled in the Heart River valley where the D Coal appears to be eroded away by the Heart River (Figure 2.3-6). The D Coal overburden map (Figure 2.3-7) demonstrates the overburden thickness over the D Coal for this baseline study. The maximum overburden thickness is 178 ft (54 m), the minimum thickness is 17 ft (5.2 m), and the average thickness is 67.~~8~~ 9 ft (20.7~~7~~ m).

The E1 Coal thickness map (Figure 2.3-8) is based on ~~88~~ 89 boreholes which penetrated the E1 Coal. ~~Forty-eightsix~~ Forty-eight of these boreholes were drilled for this baseline study. The maximum thickness was ~~10~~ 4.7 ft (~~3~~ 1.43 m), the minimum thickness was ~~0.1~~0 foot (0.03 m), and the average thickness was 2.~~2~~ 1 ft (0.~~7~~ 6 m).

The E Coal thickness map (Figure 2.3-9) is based on ~~55~~ 56 boreholes that penetrated the E Coal. Twenty-~~three~~ four of these boreholes were drilled for this baseline study. The maximum thickness was 9 ft (2.7 m), the minimum thickness was ~~0.5~~0.5 foot (0.2 m), and the average thickness was 3.~~6~~ 5 ft (1.1 m).

The F Coal thickness map (Figure 2.3-10) is based on 10 boreholes that penetrated the F Coal. Two of these boreholes were drilled for this baseline study. The maximum thickness was 4 ft (1.2 m), the minimum thickness was 0.6 ft (0.2 m), and the average thickness was 2.5 ft (0.8 m).

2.3.2.4 Study Area Geologic Structure

Similar to Section 2.3.2.3, the data used to generate geologic structure maps, are based on previous boreholes and drilling performed for this baseline study and permit application compiled into a geologic database by Norwest~~ Corporation (Norwest)~~. The geology database was created by examining logs or data from boreholes drilled during previous programs and the data generated by the 2002, Phase I, Phase II, ~~and~~ Phase III, and 2010 drilling programs. The two boreholes drilled as part of the 2009 drilling program are not included on the figures or in the discussion below.

The HT Butte Coal bottom structure map (Figure 2.3-11) shows a low spot in Section 22 T139N R98W with a rise to the Southwest. The D Coal bottom structure map (Figure 2.3-12) shows a high in Section 28 T139N R98W where the D Coal subcrop occurs. The E1 Coal bottom structure map (Figure 2.3-13) shows a high in Section 20 T139N R98W. The E Coal bottom structure map (Figure 2.3-14) shows: 1) the extent of E Coal removal, 2) the E Coal dipping to the southeast in the southern portion, 3) the E Coal dipping to the north in the northern portion, and 4) a structural high exists in the southwest corner of Section 20 T139N R98W.

2.3.2.5 Previous Mining

A search for abandoned mines was completed as part of the baseline study. One abandoned mine was identified within the Study Area. This mine is shown on Figure 2.3-15. The North Dakota Abandoned Mined Lands (AML) Printout #349, provided by the Public Service Commission (PSC), includes a description of this mine. This mine was a strip surface mine located in the N½ Section 16 T139N R98W. Several tons of coal was produced from this mine every winter for local use prior to 1902. A copy of the AML Printout #349 is provided in Appendix 2.3-1 (Dodd 2007, Nelson 2007).

Appendix 2.3-1 also contains an additional 18 AML Printouts numbers (mine location sites). Twelve of these sites are located within 5 miles of the Study Area while an additional 6 are located just outside 5 miles of the Study Area. The results from this previous mine search are summarized in Table 2.3-3.

2.3.2.6 Oil and Gas Wells Within and Near the Study Area

The locations of oil and gas wells in and near the Study Area were identified using the North Dakota Industrial Commission (NDIC) Department of Mineral Resources (DMR), Oil and Gas Division

(2010) website, which allows for search based on the entire township and range. The website was most recently accessed in January 2010. A search was conducted for all oil and gas wells within all sections of T138N R98W and T139N R98W. The result from this oil and gas well search, including locations outside the Study Area, (NDIC DMR Oil and Gas Division 2010) is presented in Appendix 2.3-2.

Two oil and gas well locations are located within or near the Study Area and are shown on Figure 2.3-16. One of the wells, Perdaems 1 (File No. 6369), is a dry well located within the Permit Boundary. Tuhy 1 (File No. 4975) is a plugged and abandoned well located approximately 32 ft (9.8 m) outside of the Study Area. No other oil and gas wells are located within the Study Area or within 500 ft (152 m) of the Study Area.

Perdaems 1 was plugged with cement on December 19, 1977 from a total depth of 8,155 ft below ground surface (bgs) to the 0 ft bgs. Tuhy 1 has casing of 5 ½ inch (in.) from 8,092 ft bgs to 5,350 ft bgs and 8 5/8 in. from 611 ft bgs to 0 ft bgs and was plugged on June 13, 1997. Appendix 2.3-3 contains information available for Perdaems 1 (File No. 6369) and Appendix 2.3-4 contains information available for Tuhy 1 (File No. 4975) (Holweger 2007).

2.3.2.7 Uranium Deposits in Southwest North Dakota

In southwestern North Dakota, the presence of uranium-bearing lignite has been documented (Moore et al. 1959, Denson and Gill 1965, Murphy 2006a, b, 2007b, and 2008). Moore et al. (1959) and Murphy (2007b) indicate that the volcanic-rich White River Group and the Arikaree Formation are the most likely source of the uranium found in the lignite, sandstones, and carbonaceous rocks in the geologic formations from Hell Creek to Golden Valley inclusive. The uranium found in the volcanic-rich White River Group and the Arikaree Formation is leached by ground water and moved downward into the underlying rocks (Murphy 2008). These leached constituents are concentrated in the coal, organic lenses or carbonaceous material as the uranium complexes with the organic materials. Murphy (2006a) indicates that, based on this mechanism, uranium would then be concentrated in the stratigraphically highest lignite or carbonaceous material below these formations. Following this, if stratigraphic layers with elevated uranium occur, they are generally within 200 feet of the unconformity between the White River Group and Arikaree Formations and the underlying formations, whether Golden Valley or Bullion Creek Formations (Murphy 2007b).

The Study Area is located in the area of North Dakota where the unconformity occurs on the Golden Valley Formation and the potential zone where uranium could be located is within 200 feet below this contact. However, within the Study Area, the unconformity has been eroded (removed) and the 200 foot depth delineating the zone where uranium may occur cannot be definitively determined. Given this unconformity is not present in the Study Area, gamma logs for Study Area boreholes were evaluated to determine if strata with elevated uranium may be present (Murphy 2007b). Gamma logs are useful for defining the extent of uranium deposits (Murphy 2007b) because the gamma ray log measures the natural radioactivity of the formations (Schlumberger 1989). Gamma ray logs within within the Study Area do not display signatures or spikes related to elevated uranium, as is discussed in Section 2.3.6.4. The lack of these signatures in the gamma ray logs indicates that there are not uranium containing strata in the Study Area, and if one ever were present in the past it has since eroded away.

Twenty-seven composites samples of the E, E1, D or HT Butte Coal were analyzed for uranium content (Section 2.3.7 and Appendix 2.3-19) as part of the 2002, Phase I, Phase II, Phase III, and 2009 drilling programs. The highest uranium concentration detected in these coal composites was 4.6 mg/kg. That concentration is relatively low compared to coal found in other areas of southwestern North Dakota. Moore et al. (1959) report that uranium bearing lignite in southwestern North Dakota has an average concentration of 130 mg/kg. With a maximum concentration of 4.6 mg/kg, the coal composites in the Study Area do not represent coal that would be considered an economic deposit for uranium ore. Towse (1957) and Denson et al. (1959) report that 1,000 mg/kg (0.1% as cited in the reports) uranium is a lower bound for economic deposits of uranium in lignite and Murphy (2008) indicates a range of 50 to 2,000 mg/kg (0.005 to 0.2% as cited in the report) represent low grade ore deposits of uranium.

Further discussion of the geophysical logs relative to uranium and overburden geochemistry is provided in Section 2.3.6.4. Further discussion of uranium with respect to overburden geochemistry is provided in Section 2.3.4.

2.3.3 Overburden Sampling and Analysis

The objective of the overburden baseline study was to characterize overburden within the Overburden Study Area that will be disturbed or exposed during mine development. The intent of this baseline study was to characterize the overburden with respect to its geochemical characteristics, based on guidance provided by: 1) the NDAC, specifically in Chapters 69-05.2-01, 69-05.2-08, 69-05.2-09, 69-05.2-15, and 69-05.2-21; 2) PSC Policy Memorandum (e.g., PSC 1995a & 1995b); and 3) meetings and conversations with PSC personnel.

2.3.3.1 Overburden Sampling

To evaluate overburden characteristics, overburden samples were collected and analyzed from ~~129~~ 131 boreholes drilled and logged boreholes across the Overburden Study Area. Overburden samples were collected and analyzed as a part of several programs, which are summarized in Table 2.3-4. These programs include: a 2002 program~~,~~; the Phase I and Phase II baseline programs completed in October 2006~~,~~; the Phase III baseline program completed in October 2007~~,~~; ~~and~~ the Shallow Overburden program completed in December 2007; and the 2010 drilling program completed in June 2010. Other drilling programs have been performed at the site, but overburden samples were not collected or analyzed. During the ~~more recent~~ 2009 drilling program overburden samples were not collected; therefore, these boreholes are not included in this discussion.

Golder performed the Phase I, Phase II, Phase III, ~~and~~ 2010, and Shallow Overburden programs as a part of the current Overburden Baseline Study. The 2002 program was performed by Kiewit Mining Group, Inc. (Kiewit) of Omaha, Nebraska in 2002.

Phase I, Phase II, Phase III ~~and~~ , 2002, and 2010 overburden sampling locations are shown on Figure 2.3-17A, along with the Overburden Study Area, the Permit Boundary, and the Mine Pit Boundary. Sampling locations for the Shallow Overburden program are shown on Figure 2.3-17B. In addition, borehole location survey data for Phase I, Phase II, Phase III ~~and~~, 2002, and 2010 programs are provided in Table 2.3-5, along with total depth, depth to the D Coal, and D Coal thickness for each borehole. These data are also provided for the 2009 drilling program boreholes in Table 2.3-5 for reference, though overburden samples were not collected from these boreholes. Borehole location data for the Shallow Overburden boreholes, along with total depth and availability of geochemical results are provided in Table 2.3-6. In general, boreholes for the Phase I, Phase II, ~~and~~ Phase III, and 2010 programs were drilled in a grid pattern across the Overburden Study Area with boreholes located near the center of each quarter-quarter section. Some locations were moved within the quarter-quarter section in order to accommodate coal exploration needs, monitor well needs, access issues (e.g., steep slope that prevented drill rig access), or other logistical issues. S~~ixty-eight~~ eventy boreholes from the Phase I, Phase II, Phase III, ~~and~~ 2002, and 2010 programs are located within the 2617.7 acre Mine Pit Boundary, providing a spacing of approximately one borehole per ~~38~~

37 acres. This borehole density is higher than a density of one borehole per 40 acres for overburden characterization as required by Chapter 69-05.2-08 of the NDAC.

Chapter 69-05.2-08-05 of the NDAC indicates that samples “must be collected and analyzed down through the deeper of either the stratum immediately below the lowest coal seam to be mined or any lower aquifer which may be adversely affected by mining.” However, given uncertainty in location and continuity of aquifers prior to initiation of the SHC drilling programs, PSC indicated that drilling and sampling to a depth of 10 ft (3 m) below the D Coal was acceptable (Moos 2006). All boreholes were extended to a depth of at least 10 ft (3 m) below the D Coal, if present, with the exception of one 2002 borehole, which was only drilled to the D Coal. To provide some indication as to material characteristics beyond this depth, ~~15~~ 1~~6~~7 boreholes were drilled and sampled to depths beyond 10 ft (3 m) below the D Coal, as shown in Table 2.3-5. However, underburden is not expected to be disturbed during mining, while overburden will be removed, stockpiled, and replaced. In addition, overburden results from above the D Coal will be used to determine cover thickness, as based on methods provided in PSC Policy Memo No. 17 (PSC 1995b) for cover thickness determination for mining of one coal seam. Therefore, this characterization generally focuses on overburden, even though underburden samples were collected and analyzed.

For 2002, Phase I, Phase II, ~~and~~ Phase III, and 2010 programs overburden and underburden samples were generally collected from boreholes at 5-foot intervals per Chapter 69-05.2-08-05 of the NDAC, though some Phase III samples were collected every 2.5 for the first 20 ft (6 m) bgs. Samples were collected as composite samples across the entire 2.5-foot or 5-foot interval, with the exception of some Phase I samples, which were discrete samples. Following this protocol, 2,~~100~~ 147 samples were collected from the 2002, Phase I, Phase II, ~~and~~ Phase III, and 2010 programs across the Overburden Study Area, with a total drilled linear footage of approximately 11,~~360~~ 630 ft (3,~~463~~ 545 m) over which samples were collected. Occasionally, sample recovery for a particular interval was insufficient for all laboratory analyses. These occurrences were not restricted to any particular borehole, interval, or geologic formation, and are considered a negligible data gap for purposes of the characterization of the overburden.

Overburden samples were examined and geologically logged in the field; lithologic logs are discussed and provided in Section 2.3.5. Samples were submitted for laboratory analysis of physical and chemical properties per Chapter 69-05.2-08-05 of the NDAC, as described in Section 2.3.3.3 and

Section 2.3.3.4. In addition, geophysical logging was performed at all Phase I, Phase II, ~~and~~ Phase III, and 2010 locations, as described in Section 2.3.6.

Borehole locations for the Shallow Overburden program were selected to further characterize overburden in support of mine planning activities (Figure 2.3-17B). Locations were selected based on analytical results available and mine planning needs at the time. Locations for the Shallow Overburden program were selected where available results indicated low SAR and EC values. All of the Shallow Overburden boreholes were completed within the Permit Boundary and the Mine Pit Boundary.

Samples for the Shallow Overburden program were generally collected every 2 feet for a total depth of 20 ft (6 m) bgs. A total of 583 samples were collected from 50 boreholes with a total drilled linear footage of 981 ft (299 m). Of the 583 samples collected as part of the Shallow Overburden program, 310 samples from 30 boreholes (594 linear feet) were selected for laboratory analysis. Samples were selected for analysis based on field observations, specifically the absence of coal stringers, low salt content (based on the visible presence or absence of salts), and no water encountered in the borehole.

2.3.3.2 Borehole Abandonment

Phase I boreholes and 2009 drilling program boreholes were completed as monitoring wells upon completion of the borehole. Well construction and completion are described in Section 2.5.

If a well was not constructed, boreholes were abandoned and surface reclamation was completed. The Phase II boreholes were abandoned following industry standards (Murphy 2007a) upon completion of drilling, sampling, and geophysical logging. Phase II boreholes were backfilled with cuttings to between 4 and 5 ft bgs, where a cap was installed. Boreholes were further filled with cuttings to between 12 and 15 inches below the surface where a surface cap was installed. Cuttings were then placed to the surface and excess cuttings were thin spread and raked. Surface re-seeding was performed as needed in the area surrounding the boreholes. All Phase II borehole locations were examined in July 2007 to confirm that abandonment and reclamation had been satisfactorily completed.

All Phase III boreholes were also abandoned upon completion of drilling, sampling, and geophysical logging. Phase III boreholes were abandoned using a similar method to the Phase II and 2010 boreholes, except that bentonite chips were used to backfill to at least 20 ft (6 m) above the estimated ground water surface. Bentonite was used for backfill at the recommendation of PSC. Cuttings were then used to backfill the holes to the surface, similar to the Phase II program. Caps were also installed, similar to the Phase II program. Excess cuttings were thin spread and raked. Surface re-seeding was performed as needed in the area surrounding the boreholes. All Phase III borehole locations were examined in October 2007 to confirm that abandonment and reclamation had been satisfactorily completed. All 2010 borehole locations were examined in June 2010 to confirm that abandonment and reclamation had been satisfactorily completed.

The Shallow Overburden boreholes were drilled to maximum depth of 20 ft and were backfilled with a combination of cuttings, bentonite, and/or purchased soil. When sufficient cuttings were available, boreholes were backfilled completely with cuttings. If sufficient cuttings were not available, boreholes were partially backfilled with cuttings or bentonite and capped with purchased soil. At two locations, SOSH-10 and SOSH-35, water was encountered, and boreholes were filled with bentonite to within two feet of the surface followed by cuttings or soil. Abandonment of Shallow Overburden boreholes was completed by February 2008.

2.3.3.3 Overburden Sample Analysis

Northern Analytical Laboratories Inc. (Northern Analytical) in Billings, Montana performed laboratory analyses for Phase I and Phase II samples.~~, while~~ Energy Laboratories Inc. (Energy) in Casper, Wyoming analyzed Phase III and Shallow Overburden samples. Pace Analytical Services, Inc. (Pace) of Billings, Montana performed laboratory analyses for the 2010 samples. Samples from the 2002 program were analyzed by Minnesota Valley Testing Laboratories Inc. (MVTL), in Bismarck, North Dakota.

All samples collected were analyzed for physical and chemical characteristics, in accordance with Chapter 69-05.2-08-05 of the NDAC, referred to by this program as the Suite One Overburden Analysis. Analytes for the Suite One Overburden Analysis are shown in Table 2.3-7.

A second analytical program, referred to as the Suite Two Overburden Analysis, was conducted on selected Phase I and Phase II samples to further evaluate materials for acid- or toxic-forming potential. Suite Two analytes, including the number of samples with results for each analysis, are provided in Table 2.3-8. A total of 143 samples were analyzed under the Suite Two program, which represents 12% of the total number of Phase I and Phase II samples collected (1,201 samples). All Suite Two analyses were performed by Northern Analytical.

Samples were selected from across the Overburden Study Area for Suite Two analysis from Phase I and Phase II boreholes. At least one sample for a Suite Two analysis was selected from every Phase I and Phase II borehole, with the exception of three boreholes. The spatial distribution of the selected samples is depicted on Figure 2.3-17C. Suite Two sample selection focused on selecting samples that would be representative of the dominant lithologic unit in each borehole. Identification of a dominant lithologic unit was not always clear given the interbedded nature of the geology; therefore, frequently several samples were selected from a borehole for Suite Two analysis.

Additionally, Suite Two samples were selected for testing in order to examine a specific strata or sample for potential acid- or toxic-forming properties. For example, a sample with a low paste pH value, as determined by the Suite One tests, may have been selected for acid base accounting (ABA) under the Suite Two program. This sample would have been selected even though it may have represented a relatively thin stratigraphic layer or a stratigraphic layer only found in limited areas within the Overburden Study Area.

2.3.3.4 Overburden Analyses

Appendix 2.3-5 and Appendix 2.3-6 provide tables of all Suite One overburden and underburden analyses by borehole for the 2002, Phase I, Phase II, ~~and~~ Phase III, and 2010 drilling programs across the Overburden Study Area. Results of the Suite One overburden analyses are summarized in Table 2.3-9 and are discussed further in Section 2.3.4. Appendix 2.3-7 provides tables of overburden analyses by borehole for the Shallow Overburden program within the Study Area. Results of these analyses are summarized in Table 2.3-10 and discussed further in Section 2.3.4.

Tables in Appendix 2.3-5, Appendix 2.3-6 and Appendix 2.3-7 include Suite One analytical results for the full run of each borehole, including overburden and underburden. For the Shallow Overburden program only selected intervals were analyzed at some locations. The tables in these appendices also include minimum, arithmetic average, and maximum values for each parameter (excluding texture). The minimum, arithmetic average, and maximum values were calculated using data for all overburden and underburden samples collected and also were calculated for overburden using only samples collected from above the D Coal.

A summary of the results of the Suite Two analyses are provided in Table 2.3-11, Table 2.3-12, Table 2.3-13 and Table 2.3-14. Results for the 48 acid base accounting (ABA) analyses are provided in Table 2.3-11. Table 2.3-12 provides the results for total metals by whole rock acid digestion as well as the average crustal abundances for the analyzed metals. Table 2.3-13 includes the results for the synthetic precipitation and leaching procedure (SPLP) performed on 122 samples. The ground water leaching procedure results are compared to those for the SPLP for 9 samples in Table 2.3-14.

Appendix 2.3-8[1] provides historic laboratory analysis sheets from MVTL for overburden samples from boreholes SH02-04C and SH02-10C, collected as a part of the 2002 drilling program. Appendix 2.3-9[1] contains original laboratory analysis sheets provided by Northern Analytical for overburden samples collected as a part of the Phase I and Phase II drilling programs in 2006 and sheets provided by Pace for overburden samples collected as part of the 2010 drilling program. Appendix 2.3-10[1] contains original laboratory analysis sheets provided by Energy Laboratories for overburden samples collected as a part of the Phase III program in 2007. Additionally, Appendix 2.3-10 and Appendix 2.3-11[1] contain analytical results for duplicate samples indicated on the lithologic logs; all duplicate sample identifications start with, "BD". Appendix 2.3-11 contains original laboratory analysis sheets provided by Energy Laboratories for overburden samples collected as a part of the Shallow Overburden program. Appendix 2.3-12 contains original laboratory analysis sheets provided by Northern Analytical for Suite Two analyses.

2.3.4 Summary of Overburden Characteristics

This section provides a summary of the overburden characteristics based on geology as examined in the field and analytical results from laboratory testing. Material characteristics are summarized in Table 2.3-9 and Table 2.3-10, which provides arithmetic averages of Suite One analytical results for all samples collected, as well as separate averages for samples collected from above the D Coal and averages for samples collected above the D Coal within the Mine Pit Boundary. Table 2.3-11, Table 2.3-12, Table 2.3-13 and Table 2.3-14 provide a summary of all Suite Two analytical results. Topsoil and subsoil depths in the Overburden Study Area range from 0 to 5 ft (1.5 m) bgs as discussed in Section 2.4. As the topsoil and subsoil must be collected, stockpiled, and re-placed separately from the overburden, topsoil and subsoil are not discussed in this section. These materials are characterized and discussed in Section 2.4.

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[1] For convenience, laboratory data sheets located in Appendix 2.3-8, Appendix 2.3-9, Appendix 2.3-10, Appendix 2.3-11 and Appendix 2.3-12 have been organized in numerical order by borehole, which can differ from the order of the sampling date, the lab invoice, sample number, or the page number printed on the original laboratory data sheets.

2.3.4.1 Summary of Overburden Geology

Overburden thickness within the Study Area ranges from 21 to 153 ft (6.4 to 46.6 m), based solely on depth to the D Coal from the 2002, Phase I, Phase II,~~ and~~ Phase III, and 2010 overburden boreholes located within the Overburden Study Area (Table 2.3-5). Overburden within the Study Area is predominantly Sentinel Butte Formation. The Sentinel Butte Formation was deposited in a freshwater fluvial system and consists of alternating beds of carbonaceous and bentonitic claystone, siltstone, shale, fine to medium grained sandstone, and coal (Trapp and Croft 1975, Menge 1977, and Armstrong 1984). Armstrong (1984) indicates that, with the exception of the coal seams, the lithologic units are generally lenticular and discontinuous. Furthermore, Armstrong (1984) indicates that sandstone lenses were deposited in stream channels that are nearly impossible to correlate between boreholes.

Borehole drilling within the Overburden Study Area indicates a similar geology to that described in the literature. Borehole lithologic logs (discussed in Section 2.3.5) indicate that the overburden consists of interbedded sandstone, claystone, siltstone, and shale. Several coal seams were encountered in the overburden within the Study Area, including the F1, E, and E1 coals. The lithology and interbedding encountered in the boreholes supports a fluvial depositional environment. As a result of this depositional environment, correlation of stratigraphy between boreholes is limited. It is possible to correlate coal layers across the Overburden Study Area. In addition, a sandstone layer of varying thickness from 5 to 50 ft (1.5 to 15 m) was generally observed above the D Coal. The sandstone layer was not present at all borehole locations within the Overburden Study Area (for example, it was not observed in boreholes SHOB-12R, SHOB-23R, SHOB-24R, SHOB-29R, or SHOB-40R). Limited correlation is occasionally possible between two or three proximal boreholes for a particular layer or sequence; however, Golder generally was not able to correlate particular siltstone, claystone, or shale layers across the Overburden Study Area. This limited correlation of stratigraphy between boreholes supports the conclusions of Armstrong (1984) as described above, i.e., that layers such as sandstone cannot be correlated between boreholes.

2.3.4.2 Sodium Adsorption Ratio

Analytical testing provided sodium adsorption ratio (SAR) values for Suite One overburden samples. The SAR is calculated from the sodium, magnesium, and calcium concentrations of the saturation extract according to the formula:

$$SAR = \frac{[Na]}{\sqrt{\frac{[Ca]+[Mg]}{2}}}$$

where sodium, magnesium, and calcium concentrations are in milliequivalents per liter (meq/L). The SAR values for overburden samples from above the D Coal across the Overburden Study Area range from 0.23 to 78.3, with an arithmetic average of approximately 17.6 for the 1,~~236~~ 277 overburden samples collected and tested as part of the 2002, Phase I, Phase II, ~~and~~ Phase III, and 2010 programs. The arithmetic average SAR value for all 2002, Phase I, Phase II, and Phase III samples collected and analyzed, including those collected below the D Seam coal, is 20.~~8~~7. SAR values from the 2007 Shallow Overburden program range from 0.14 to 30.1, with an arithmetic average of 8.39 based on the 310 samples analyzed.

Results indicate that SAR is the primary concern for overburden quality within the Study Area; therefore, SAR is considered in mine and reclamation planning for cover thickness (Section 4.1). This is consistent with the literature (Moran et al. 1978), which indicates that SAR and electrical conductivity (EC) are primary concerns for overburden materials in this region. In addition, through its regulations, the PSC recognizes SAR as the primary concern for coal mining in North Dakota. Policy Memorandum No. 3 (PSC 1995a) states:

> *“Based on the definition of toxic-forming materials and on research conducted in North Dakota, sodic spoil is the only common toxic forming material exposed, used or produced during mining.”*

Chapter 69-05.2-15-04 of the NDAC and Policy Memorandum No. 3 (PSC 1995a) indicate that non-toxic materials have SAR values below 12 and Policy Memorandum No. 17 (PSC 1995b) uses limits of 12 and 20 for establishing cover requirements. Approximately 57% of the overburden samples from above the D Coal in the Overburden Study Area, collected as a part of the 2002, Phase I, Phase II, ~~and~~ Phase III, and 2010 programs, have an SAR value greater than 12 and 35% have an SAR value greater than 20. For the Shallow Overburden program, 23% of the samples analyzed have an SAR value greater than 12 and 8% have an SAR value greater than 20.

The SAR values in a borehole generally increase with depth from the surface to the D Coal. This trend is demonstrated for selected boreholes in the Overburden Study Area on Figure 2.3-18A and Figure 2.3-18B, and is also apparent from the tables with analytical data for each borehole in

Appendix 2.3-6 and Appendix 2.3-7. This trend may be the result of several geochemical or hydrogeological processes. For example, flushing of salinity and sodium ions downward by infiltration may be occurring, as chemical characteristics of overburden materials are often controlled by the geochemical composition of the materials, infiltration, and the direction of ground water movement (Moran et al. 1978). However, the increase in SAR may also be related to a decrease in calcium and magnesium concentrations near the D Coal (Figure 2.3-18B). The decrease in these constituents may be related to the precipitation of minerals such as calcite. For example, when infiltrating waters with calcium encounter the sodium bicarbonate waters in the coal seam, calcite may precipitate. The SAR values were also found to be consistently higher in materials below the coal. This trend is supported by the fact that including data from all samples collected (overburden and underburden) results in a higher average SAR value (20.7~~8~~ for all samples versus 17.6 for overburden only) based on the 2002, Phase I, Phase II, ~~and~~ Phase III, and 2010 programs.

Consistent with the varying geology observed across the Overburden Study Area, the trend of increasing SAR with depth to the D Coal does not occur in every borehole. For example, SAR may be elevated (above 12) throughout the stratigraphic column of the borehole (e.g., boreholes SHMW-10D2, SHMW-12D, SHOB-48R, SHOB-38R, SHOB-31R, or SHMW-05D), or low (below 12) throughout the entire borehole (e.g., boreholes SHOB-42R, SHOB-28R, SHOB-22R, SHOB-2R, or SHOB-26R). In addition, boreholes with contrasting SAR trends are often in close proximity to each other. For example, SHMW-10D2 and SHOB-42R (locations shown on Figure 2.3-18B) are proximal to each other, yet SHOB-42R has very low SAR values above the D Coal, while SHMW-10D2 has high SAR values above the coal.

A consistent correlation between SAR and borehole geology was not observed, as shown on the geologic logs prepared in the field (Figure 2.3-18A and Figure 2.3-18B). For example, a sandstone unit above the coal in SHOB-14R (Figure 2.3-18A) has SAR values varying from 9 to 35, with the SAR data increasing with depth as described above. Also, correlation between SAR and laboratory derived texture was not observed. As shown on Figure 2.3-19, high and low SAR values are observed in almost every texture classification, and the distribution of SAR values is similar for coarse and fine classifications. In addition, Golder also evaluated whether the drilling method used (rotosonic coring, air rotary, or air rotary with added water) affected SAR results and found no correlation.

2.3.4.3 *Electrical Conductivity*

For samples from the 2002, Phase I, Phase II, ~~and~~ Phase III, and 2010 programs, saturation extract EC of the overburden samples within the Overburden Study Area above the D Coal ranges from 0.24 to 26.5 milliSiemens per centimeter (mS/cm), with an average of 3.9 mS/cm. Values below 6 mS/cm for EC with a SAR less than 12 indicate non-toxic soil based on Policy Memorandum No. 3 (PSC 1995a). Approximately 21% of the samples from above the D Coal have a saturation extract EC greater than 6 mS/cm. The majority (64~~5~~%) of these overburden samples with values above 6 mS/cm also have high (>12) SAR values. Materials with an EC greater than 8 mS/cm, regardless of SAR, are considered other toxic-forming materials based on Policy Memorandum No. 3. Approximately 10~~1~~% of the overburden samples have an EC greater than 8 mS/cm. Relative to the percentage of samples with elevated SAR; elevated EC is not as great a concern for the overburden materials. In addition, the PSC Policy Memoranda focuses on SAR over EC, indicating that SAR is of greater concern for toxicity and overburden quality.

For the 310 samples within the Overburden Study Area from the Shallow Overburden program, EC values range from 0.25 to 12 mS/cm, with an average of 3.3 mS/cm. Approximately 17% of the samples have an EC above 6 mS/cm, with 37% of those samples also having a SAR value above 12.

2.3.4.4 *Paste pH*

Paste pH values range from 3.3 to 9.8, with an average of 8.0 for overburden samples in the Overburden Study Area above the D Coal (1,~~237~~278 samples) from the 2002, Phase I, Phase II, ~~and~~ Phase III, and 2010 programs. Paste pH values were predominantly alkaline, with only 9% below a pH of 7, and 6~~5~~% below a pH value of 6. Paste pH values for samples from the Shallow Overburden program are also predominantly alkaline. Values range from 5.6 to 9.1, with an average of 8.1. Only about 2% of samples have a paste pH value less than 7.

The majority of paste pH values below a value of 6 were measured in samples from strata containing coal or from samples immediately above or below a coal layer, likely due to oxidation of pyrite associated with the coal. While low measured paste pH values may indicate the presence of potentially acid-forming materials, the vast majority of the materials are alkaline and would be expected to neutralize the few acid forming materials present. The Suite Two ABA testing (Section 2.3.4.7) provides further discussion of this point.

2.3.4.5 Saturation Percentage

Saturation percentages for overburden samples within the Overburden Study Area from the 2002 Phase I, Phase II, and Phase III programs above the D Coal range from 16.3% to 634% and average ~~95.3~~96.7%. Saturation percentages for overburden samples from the Shallow Overburden program range from 22% to 250% and average 87%.

The relatively high saturation percentage values indicate a relatively high clay content, such as bentonite, that can absorb water in its structure (Merrill et al. 1987). This result is consistent with the literature description of the Sentinel Butte geology and lithologic descriptions from the field geologists.

2.3.4.6 Texture

Overburden samples in the Overburden Study Area were predominantly classified as clay, silty clay, silty clay loam, clay loam, silt loam, loam, sandy clay loam, and sandy loam. Also present are loamy sand and sand. These laboratory-derived classifications correspond with the geology described in the literature and in the field programs of the baseline study (Section 2.3.5). These classifications are based on the percent sand, percent silt, and percent clay in each sample.

The percent sand for overburden samples above the D Coal within the Overburden Study Area ranges from less than 0% to 91.3%, with an average of 31.4~~3~~%. The percent silt for overburden samples ranges from 4.9% to 76%, with an average of 39.3~~5~~%. The percent clay for overburden samples ranges from 1.3% to 73%, and averages 29.~~2~~4%.

For the Shallow Overburden program, the percent sand ranges from 1% to 84%, with an average of 27.1% for the 310 samples analyzed. The percent silt for Shallow Overburden samples ranges from 9% to 73%, with an average of 44.5%. The percent clay for overburden samples ranges from 2% to 69%, and averages 28.5%.

2.3.4.7 Acid Base Accounting

Testing for ABA properties was performed as a part of the Suite Two analysis to assist with evaluation of acid forming properties. Results are shown in Table 2.3-11. The ABA testing included neutralization potential (NP) and pyritic-sulfur, sulfate-sulfur, and total-sulfur. Acid potential (AP) was calculated using total-sulfur, which is conservative as it will over estimate the AP if non-sulfide minerals, such as gypsum, are present. The net neutralizing potential (NNP) was then calculated by subtracting AP from NP. Results for ABA analyses are generally evaluated with paste pH values, which are described in Section 2.3.4.4. In summary, paste pH values were predominantly alkaline, with only 9% below a pH of 7.

Generally, samples have NNP values greater than 20 tons of calcium carbonate per kiloton ($tCaCO_3/kt$), indicating the materials are non-acid generating (US EPA 1994). Twenty-eight of 48 samples are classified as non-acid generating. Fifteen of 48 samples are classified as uncertain (NNP values between -20 and +20 $tCaCO_3/kt$) and five of 48 samples are classified as having acid generation potential (NNP values less than -20 $tCaCO_3/kt$). The majority of samples classified as uncertain (10 of 15) have low pyritic sulfur values (i.e., <0.3%), indicating very limited acid-generating potential (Price 1997). Samples classified as potentially acid generating were all associated with coal riders or stringers, an expected result due to pyrite associated with the coal.

Although paste pH and ABA testing indicate that potentially acid forming materials are present, these materials are not likely to be a concern for two reasons. First, the potentially acid forming materials constitute a small percentage of the total material, 5 of 48 samples (10%). Those 5 samples represent relatively small acid forming layers between massive alkaline layers. Second, mixing of potentially acid forming materials with the predominant alkaline materials will neutralize any acid that may be produced. The sulfide contents are generally low, so even if acid is generated it will be small compared to the massive formations of alkaline material surrounding it.

2.3.4.8 Whole Rock Acid Digestion for Metals Analysis

Whole rock acid digestion for metals analysis was performed on a set of 35 samples within the Study Area. Results are provided in Table 2.3-12. The results provide an indication as to the elemental metals content of the materials. These results are for the entire material, and do not represent metals that will be mobilized. For comparison, the average concentration of each metal in crustal materials is provided from Krauskopt and Bird (1995).

2.3.4.9 Synthetic Precipitation Leaching Procedure/Ground Water Leaching Procedure

The synthetic precipitation leaching procedure (SPLP) was performed as a part of the Suite Two testing to assist with the evaluations of toxic forming properties and to assist with mine planning needs. Results for the SPLP testing are shown in Table 2.3-13. Additional discussion of the SPLP results is provided in this section to assist in interpretation of the SPLP results. These tests, which are not required by North Dakota regulations, do not have set standards or limits to which the results can be compared.

In the SPLP (EPA Method 1312), a sample is leached with a synthetic precipitation solution. The SPLP test is designed to evaluate the mobility of constituents present in materials. The test is not designed to definitively predict water quality for surface water or ground water for a specific site, as this is dependent on a number of complex factors, such as exposure, weathering rates, and actual water to rock ratios. Rather, the test provides an indication of potential constituents that may be mobilized under testing conditions.

The leachate solution utilized had a pH of 5.0 to simulate rainfall (extraction fluid #2 in EPA Method 1312, appropriate for sites west of the Mississippi River). The leachate was analyzed for chemical composition by various methods, depending on the constituents of interest. For example, metals were generally analyzed by EPA Methods 200.7 or 200.8 (ICP and ICP-MS). Results for the 122 samples analyzed are provided in Table 2.3-13.

Observations associated with SPLP results are presented below.

- Leachate SAR values were greater than 12 for 30 of 122 samples. Chapter 69-05.2-15-04 of the NDAC and Policy Memorandum No. 3 (PSC 1995a) indicate that non toxic materials have SAR values below 12. As discussed in Section 2.3.4.2, SAR is generally considered the primary toxic concern in North Dakota coal mining. Given the saturation extract SAR values (Suite One results, Table 2.3-9; discussed in Section 2.3.4.2), elevated SAR values were expected. Elevated SAR is addressed via cover thickness (See Section 4.1).

- Several samples containing coal resulted in elevated acidity and depressed pH, likely due to oxidation of pyrite associated with the coal during the course of the test. As discussed in Section 2.3.4.7 with respect to ABA testing, acid forming materials are known to be present, but are not a concern due to the abundance of neutralizing materials and overall high NP values.

- Relative to EPA Secondary Drinking Water Standards, maximum leachate concentrations of aluminum, iron, and manganese are elevated at 12, 8, and 1, mg/L, respectively. The concentrations of those metals are likely elevated due to the dissolution of pyrite, iron-oxides, and/or the clays observed in the materials. In this context, it is important to remember that the EPA Secondary Drinking Water Standards are intended to assist public water systems in managing their drinking water for taste, color, odor and public acceptance of drinking water. These constituents are not considered to present a risk to human health at the standard concentrations and therefore these standards do not fit the toxic forming criteria.

- Total dissolved solids (TDS) concentrations are also above the EPA Secondary Drinking Water Standards, indicating that dissolution of some solids by the synthetic precipitation leaching solution occurred. Determination of the exact source of dissolved solids is not possible because complete anions and cations cannot be run on an SPLP test of this type. However, an increase in TDS is expected due to dissolution of salts and minerals common in the overburden materials such as calcite, gypsum, and pyrite (Moran et al. 1978).

- Selenium and zinc in the SPLP leachate were detected at concentrations greater than the corresponding North Dakota acute aquatic life standards found in NDAC Chapter 33-16-02.1. For purposes of comparison to the standards, a hardness of 100 mg/L (as $CaCO_3$) is assumed. The SPLP tests where selenium and zinc were detected at concentrations greater than the corresponding standards are limited. Of 122 tests conducted, 2 tests showed selenium at concentrations greater than standard and 43 tests showed zinc at concentrations greater than standard. Those results indicate that selenium and zinc are found and are mobile in the overburden in some locations and at some depths, but not others. The overburden will be mixed throughout the mining process and as a result, overburden with relatively higher leached concentrations of both selenium and zinc will be mixed with overburden with relatively lower leached concentrations of those metals. In addition, runoff from overburden stockpiles will be collected in the sedimentation pond where it will be mixed with water originating from other sources, as described in Section 2.6.5.2 and shown in Table 2.6-19. That mixing is expected to dilute any concentrations of selenium or zinc in the pond to levels below the standards. Considering all of these factors, selenium and zinc are not expected to be present in concentrations that would result in exceedance of surface water or ground water quality standards and therefore the overburden is not considered to contain toxic forming material with respect to these metals.

- Relative to the North Dakota chronic aquatic life standards in NDAC Chapter 33-16-02.1, several maximum SPLP metals' concentrations are greater than the chronic standard, including cadmium, copper, lead, mercury, and nickel (assuming a hardness of 100 mg/L as $CaCO_3$). However, considering the results in the context of the overall mining plan, these metals are not expected to be present in concentrations that would result in exceedance of water quality standards as a result of mining activities for several reasons. First, the chronic standard is based on a four-day average concentration that cannot be exceeded more than once every three years. Water that has been in contact with the overburden from the SHLM will be collected in a sedimentation pond, and will be monitored to ensure discharge meets water quality standards following the water management plan laid out in Section 3.6.5. Thus, discharge from the pond will be managed to avoid exceedance of the chronic standard. Second, surface water originating from the overburden runoff will be diluted by water in the pond originating from other sources, as described in Section 2.6.5.2. Finally, the SPLP results indicating concentrations greater than standards are limited (for example only 2 tests have concentrations greater than the standard for nickel of 122 total tests) and represent a small portion of the overburden material as a whole. As the overburden is mixed during mining processes, it is expected that the mixed material will not leach these metals at concentrations over standards.

- Other trace metals in the leachate were generally observed at low concentrations. For example, leachate molybdenum concentrations were below detection limits for all but 10 of the 122 samples, and the maximum concentration detected was 0.1 mg/L. The highest uranium concentration measured in the SPLP leachates was 0.013 mg/L, well below the EPA Maximum Contaminant Limit (MCL) of 0.03 mg/L. The SPLP testing demonstrates that uranium is not expected to be mobilized to surface water or ground water at significant concentrations relative to standards. In fact, the uranium SPLP results were relatively low compared to regional uranium concentrations in ground water compiled by Roberts (1994), which indicated an average uranium concentration of 0.054 mg/L in Stark County.

- One exception to the trends for trace metals was arsenic, which was detected in 105 of 122 leachate samples (using a detection limit of 0.001 mg/L). Results for arsenic in the leachate were analyzed using ICP-MS (EPA Method 200.8) and confirmed using hydride generation/atomic absorption (Standard Methods 3114C). These results were not unexpected given that naturally occurring arsenic is not uncommon in the region. For example, Erickson and Barnes (2005) noted that in the upper Midwest, 12% of public water systems in glacial drift aquifers exceed the EPA MCL for arsenic and Berkas and Komor (1996) measured elevated arsenic in soils and groundwater in northern North Dakota.

- Arsenic was detected in 12 of 97 baseline ground water samples (December 2006 to August 2007) collected from 31 wells at 15 different well-nest locations within the Study Area. In 11 of the 12 baseline ground water samples arsenic was detected at concentrations less than half the EPA drinking water standard (ranging from 0.003 to 0.005 mg/L). In one sample arsenic was detected at a concentration of 0.014 mg/L, which is greater than the EPA drinking water standard (0.01 mg/L). Nine surface water sites were tested for total arsenic in September 2006 and returned concentrations between 0.0025 and 0.075 mg/L. All of these concentrations were below the acute and chronic standards, though six sites had concentrations above the EPA drinking water standard.

- Analysis of arsenic in overburden was conducted via whole rock acid digestion (Section 2.3.4.8). Results report that 13% of the samples contained arsenic above the detection limit (10 mg/kg).

- Although arsenic was detected in the SPLP leachate samples, the laboratory results do not reflect the expected field concentrations. As described at the beginning of this section, the SPLP test is designed to evaluate the mobility of constituents present in materials. The test is not designed to definitively predict concentrations in surface water or ground water for a specific site for direct comparison to standards. Actual concentrations in the field depend on a number of complex factors, such as: material exposure, weathering rates, contact time, actual field water to rock ratios, and actual field chemistry of precipitation, ground water, or runoff, including pH and redox conditions. Several of these factors are expected to influence arsenic mobility. For example, the high water to rock ratio in the SPLP test, combined with the pH of the lixiviant, can result in dissolution of iron oxides and release of sorbed arsenic. In the field, the water to rock ratio will vary and runoff from an overburden stockpile will likely be alkaline due to the overburden properties (Section 2.3.4.7), even if the initial rainwater is near a pH of 5.0. These factors will reduce arsenic concentrations in water.

- While the SPLP may not predict actual water quality concentrations, the SPLP testing results do indicate that arsenic should be included as an analyte in the surface water and ground water quality monitoring programs for the SHLM. Discussion regarding comparison of the leachate results to water quality standards, the EPA Drinking Water MCL, and background concentrations of arsenic are presented below for reference.

    - Comparing results to aquatic life standards set in NDAC Chapter 33-16-02.1, no arsenic SPLP leachate concentrations were greater than the acute standard (0.34 mg/L). Two of the 122 leachate samples had arsenic detected at concentrations above the chronic aquatic life standard (0.15 mg/L).

    - Just over half of the leachate samples (66 of 122 samples) had concentrations detected at concentrations greater than the EPA Drinking Water MCL for arsenic of 0.01 mg/L.

Additional leachate testing, referred to as the ground water leach procedure (GWLP) tests were performed based on the results for arsenic from the SPLP tests. The GWLP test was developed by Golder and Northern Analytical in order to develop a better understanding of the potential mechanisms for arsenic mobilization from the SHLM overburden and underburden materials. Discussion regarding this additional leachate testing is presented below.

The GWLP test was performed using ground water from monitor well SHMW-10C as the lixiviant. Ground water from SHMW-10C is considered representative of ground water present in the overburden within the Study Area and that which would be expected to infiltrate the reclaimed spoils. Ground water from SHMW-10C has a pH of 7.1, alkalinity of 567 mg/L as $CaCO_3$, and total dissolved solids (TDS) of 2,038 mg/L. Arsenic has not been detected in SHMW-10C. For comparison, the synthetic precipitation solution of the SPLP has a pH of 5.0 and relatively low TDS concentration.

Results from the GWLP tests for arsenic are compared to those of the SPLP tests in Table 2.3-14. Results between the SPLP and GWLP were consistent to the extent samples that leached relatively elevated arsenic by SPLP also leached relatively elevated arsenic by the GWLP. Samples that did not leach arsenic by SPLP also did not leach arsenic by GWLP. However, leached arsenic concentrations by GWLP were lower than those leached by SPLP. For example, for sample SHMW-05 (collected between 146 to 151 ft bgs) SPLP leachate had an arsenic concentration of 0.018 mg/L and the GWLP leachate had an arsenic concentration of 0.008 mg/L. The latter is below the EPA MCL. These data indicate that:

- Leaching of arsenic from the overburden is more likely to occur during mining, when the overburden is exposed to surface conditions in the stockpiles. However, runoff from the stockpiles is not expected to impact offsite water quality since it will be contained in sedimentation ponds, diluted with other sources of water to the ponds, and not discharged from the ponds unless it meets applicable regulatory standards (Section 3.6).

- Leaching of arsenic will be reduced once the material has been reclaimed and is in contact with ground water and the conditions of the subsurface environment. However, some leaching is expected to continue based upon the results of baseline studies. The detection of arsenic in ground water from baseline sampling (as described above) indicates this processes is currently occurring to some degree.

Overall, results from the leach tests (SPLP and GWLP), the literature, and the baseline studies indicate that arsenic is present naturally in the Study Area and should be expected to be detected in the surface and ground water monitoring programs for the SHLM.

2.3.4.10 Summary of Overburden within Mine Pit Boundaries

~~Sixty-eight~~Seventy boreholes from the 2002, Phase I, Phase II, ~~and~~ Phase III, and 2010 overburden programs are located within the Mine Pit Boundary (Figure 2.3-17A). In general, laboratory results discussed in Section 2.3.3 and Section 2.3.4 from all 2002, Phase I, Phase II, ~~and~~ Phase III, and 2010 samples above the D Coal are consistent with results from boreholes located within the Mine Pit Boundary (Table 2.3-9). All of the Shallow Overburden boreholes are located within the Mine Pit Boundary (Figure 2.3-17B)

For samples above the D Coal from the ~~68~~ 70 boreholes drilled as part of the 2002, Phase I, Phase II, ~~and~~ Phase III, and 2010 programs within the Mine Pit Boundary (i.e., materials expected to be disturbed), SAR values range from 0.23 to 65.0, with an arithmetic average of 17.0~~1~~. Paste pH values range from 3.3 to 9.7, with an average of 7.9. EC values range from 0.24 to 26.5 mS/cm and average 4.~~11~~ 04 mS/cm for samples. Saturation percentages range from 21 to 634%, with an average of

97~~5~~%. The percent sand, percent silt, and percent clay for samples above the D coal within the Mine Pit Boundary averages 31.2%, 39.4~~7~~% and 29.4~~2~~%, respectively.

Suite Two analyses were performed on samples from some of the boreholes within the Mine Pit Boundaries (Figure 2.3-17C). These analyses included ABA, SPLP, whole rock acid digestions for metals, and ground water leaching procedure of samples from 22, 18, 36, and 7 boreholes respectively, within the Mine Pit Boundary. Results for Suite Two analyses performed on samples in the Mine Pit Boundary are shown in bold in Table 2.3-11, Table 2.3-12, Table 2.3-13, and Table 2.3-14. Suite Two results for these samples are consistent with Suite Two results for the remainder of the Study Area.

2.3.5 Lithologic Logs

2.3.5.1 2002 Lithologic Logs

Available lithologic logs for boreholes drilled as a part of the 2002 drilling program are provided in Appendix 2.3-13. While only two boreholes were sampled for overburden during the 2002 drilling program, at least 29 boreholes were drilled and lithologic logs recorded. The locations of these 29 boreholes are shown on Figure 2.3-20 and they are listed in Table 2.3-15.

2.3.5.2 Phase I and 2009 Lithologic Logs

Lithologic logs for Phase I and 2009 boreholes, including SHMW-04D, SHMW-05D, SHMW-06D, SHMW-10D2, SHMW-12D, SHMW-03HTB, and SHMW-08HTB, are discussed in Section 2.5. These boreholes were drilled as a part of baseline study hydrogeologic investigation for monitor well installation.

2.3.5.3 Phase II,~~ and~~ Phase III, and 2010 Lithologic Logs

For Phase II and Phase III boreholes, lithologic logging was performed in the field and subsequently prepared electronically using the gINT® software program. The lithologic logs provide, at a minimum, the information listed below.

- Headers, including:
    - Date and times of borehole drilling;

  - Drilling contractor and driller’s name;
  - Drilling method;
  - Drill rig type;
  - Drill hole location in the designated coordinate system;
  - Elevation;
  - Name or initials of Golder field geologist;
  - Total depth drilled;
  - Scale; and
  - Inclination.
- Geologic logs on an appropriate scale noting the depths and thickness of strata.
- Lithologic descriptions for soil and rock encountered.
- Additional information (as pertinent), such as:
  - Moisture or depth of subsurface water:
  - Drilling fluids addition (water only[2]):
  - Lost circulation:
  - Driller’s comments or notes;
  - Drilling joint lubricants used; and
  - Location and type of samples collected.

The lithologic logs for all Phase II~~ and~~, Phase III, and 2010 boreholes in the Overburden Study Area are provided in Appendix 2.3-14. In addition, the location of subsurface water encountered during Phase I, Phase II ~~and~~ Phase III, and 2010 drilling is summarized on Table 2.3-16. The location of subsurface water is considered approximate or may not be available because determination of the exact depth at which water was encountered was difficult given the drilling method and the occasional addition of drilling fluids (as noted on lithologic logs).

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[2] Limited water was added as a drilling fluid as deemed necessary by field staff and the driller. Water was obtained from the South Heart pump house or fire station.

2.3.5.4 Shallow Overburden Lithologic Logs

For Shallow Overburden boreholes, lithologic logging was performed in the field by Catena Consulting, LLC (Billings, Montana). The lithologic logs are provided in Appendix 2.3-15 for all boreholes in the Shallow Overburden Study Area (Figure 2.3-17B). Field notes provided at the end of Appendix 2.3-15 apply to all of the Shallow Overburden borehole logs. The lithologic logs provide, at a minimum, the information listed below.

- Site Number;
- Drill hole location;
- Sample interval in inches;
- Lithologic description of soil or rock encountered;
- Soil texture;
- Presence and extent of visible salts; and
- Soil or rock color.

Subsurface water was only encountered in two boreholes (SOSH-10 and SOSH-35).

2.3.6 Geophysical Logs

2.3.6.1 2002 Geophysical Logs

Geophysical logging was performed during the 2002 drilling program. Based on geophysical logs available to Golder, geophysical logging was performed on at least 14 boreholes during this drilling program. The boreholes with geophysical logs are listed in Table 2.3-17 and shown on Figure 2.3-21. Geophysical logs are provided in Appendix 2.3-16. The logs provide a general indication of the location and characteristics of the coal, as well as characteristics of the overburden strata. The geophysical logs include gamma ray, density, resistivity, and caliper. The logs generally include an overview of the entire log, followed by a close-up of the coal layer with British thermal unit (BTU) values.

2.3.6.2 Phase I and 2009 Geophysical Logs

Geophysical logs for Phase I boreholes, including SHMW-04D, SHMW-05D, SHMW-06D, SHMW-10D2, SHMW-12D, SHMW-03HTB, and SHMW-08HTB,~~,~~ are described and provided in Section 2.5. These boreholes were drilled as a part of the baseline study hydrogeologic investigation for monitor well installation.

2.3.6.3 Phase II ~~and~~ , Phase III, and 2010 Geophysical Logs

Geophysical logging for boreholes drilled as a part of the Phase II and Phase III drilling programs were performed by Century Geophysical. Geophysical logging for boreholes drilled as a part of the 2010 drilling program were performed by Braun Intertec. Geophysical logging was performed in all Phase II, ~~and~~ Phase III, and 2010 boreholes immediately following completion of borehole drilling and overburden sampling. Adjacent to SHOB-133R and SHOB-120R, a total of 11 additional boreholes were drilled (e.g., SHOB-120R-4) at the request of Norwest for mine planning purposes. Analytical samples were not collected and lithologic logs were not recorded for these boreholes. Geophysical logging was performed on the 8 boreholes that did not collapse. Boreholes were logged for gamma ray and density, per Chapter 69-05.2-08-05 of the NDAC, as well as resistivity and caliper. The geophysical logs for the entire Phase II ~~and~~ , Phase III, and 2010 drilling programs in the Overburden Study Area are provided in Appendix 2.3-17 and locations shown on Figure 2.3-21.

2.3.6.4 Geophysical Logs Relative to Overburden Geochemistry

The gamma ray log on the geophysical log provides a record of the natural radioactivity of the formations (Schlumberger 1989). These radioactive elements include potassium, thorium, and uranium which are commonly found in clay minerals (Cant 1984). Gamma ray logs are measured in API units with increasing radioactivity correlating to increasing API units (Cant 1984). In sedimentary formations, this log is usually used to identify the shale content of the formations because radioactive elements tend to concentrate in clay and shales (Schlumber 1989).

In addition to identifying geologic strata, gamma logs may also be used to identify geologic formations elevated in uranium (Cant 1984; Lamarre 2003). Murphy (2006a, b) provides locations in North Dakota where geophysical logs contain one or more spikes in the gamma ray log, likely indicating the presence of strata where uranium has concentrated. Some of these locations are in the vicinity of the Study Area: one mile west of the Study Area (SW SW corner of Sec 7, T139N, R98W), three miles south of the Study Area (Sec 21, 22, 23, 26, 27, 28, 29, 30, 31, 32, 33, 34, T138N, R98W) and two miles southeast of the Study Area (Sec 1, 12 T138N, R98W; Sec 31, T139N R97W; Sec 6,7 T138N, R97W).

The gamma ray logs for the Phase I, Phase II, Phase III, and 2009 drilling programs are typical for sandstones, claystones/shales, and coals. Within the Study Area, sandstone generally has a higher API value than coal, and claystone/shale generally has a higher API value than both. Figure 2.3-22 provides examples of gamma log signatures typical for the site. The typical log in Figure 2.3-22 demonstrates how coal has a low API value (< 80 API units).

Examining the gamma ray logs from the Phase I, Phase II, Phase III, 2009, and 2010 drilling programs shows 5 gamma ray logs with an API value greater than 200 and an additional 8 logs with an API value greater than 180. Three of the four ~~G~~gamma logs from the 2009 and 2010 drilling programs have~~both each had~~ at least one peak above 150 API, the maximum measured value on these ~~2009~~ geophysical logs. While all of these these instances may be elevated API values relative to the site, they are not of the same magnitude as those logs described by Murphy (2006a,b). Murphy (2006a,b) indicates that spikes in the gamma log values were three to nine times that of background and these spikes indicated the location of strata with elevated uranium. The lack of gamma ray log spikes of this magnitude associated with the D Coal is consistent with the coal quality results that indicate that the D Coal does not contain elevated concentrations of uranium (Section 2.3.2.7).

Of the 16~~3~~ Phase I, Phase II, and Phase III gamma logs with elevated API values (above 180 or 150, depending on the maximum scale provided), only one is associated directly with a coal, which is relevant because lignite is generally the type of geologic strata from which uranium has been mined in North Dakota. That gamma log is for SHOB-41R, where API values spike at 9 feet bgs and coal was logged from 8 to 11 feet bgs. An additional ~~six~~11 gamma logs have API values above 180 (or 150, in the case of the 2009 and 2010 boreholes) in strata either directly above a coal strata (~~4~~5 gamma logs) or directly below a coal strata (~~4~~6 gamma logs). ~~For the 2009 gamma logs, one three of the logs has an API above 150 directly below or above a coal stringer.~~ None of the elevated API values are within with the D Coal and only one elevated API value is stratigraphically near the D Coal (a sandstone in borehole SHOB-02R below the D coal which will not be disturbed by mining). Furthermore, the elevated API values generally occur at relatively shallow depths. Eleven~~Ten~~ of the ~~thirteen~~ sixteen Phase I, Phase II and Phase III logs with API values elevated above 180 occur at a depth of less than 20 feet bgs. ~~Both Two of the 2009 and 2010 logs with a API above 150 occur at a depth of less than 20 feet bgs.~~

Gamma logs were then compared to overburden uranium content analyzed by whole rock acid digestion (Section 2.3.4.8). Thirty-six samples were analyzed for uranium content, and the results are shown in Table 2.3-12. As shown in Table 2.3-12, uranium was not detected in 34 of the 36 samples. Uranium was detected in two samples: SHOB-41, 20-25’ with a value of 10 mg/kg, and SHOB-36, 15-20’ with a value of 7 mg/kg. Those two samples were from coal and sandstone/coal intervals, respectively. The SHOB-41 (20-25’) interval has API values of 75 to 150, while the SHOB-36 (15-20’) interval has API values of 85 to 150 based on the gamma ray logs. These API values are elevated relative to other coal units at the site, which are typically less than 80 API units; however, those API values are not of the same magnitude as those logs described by Murphy (2006a,b), as described above. Thus, sample SHOB-41 (20-25’), which has both an elevated gamma log (up to 150 API units) and the highest detected uranium concentration within the Study Area (based on the overburden and coal composite samples), does not have a gamma spike that would represent a high uranium strata based on the work by Murphy (2006a,b). Additionally, its uranium concentration is at least an order of magnitude below that which would be considered economic for mining (as described in Section 2.3.2.7). Overall, the gamma logs, overburden whole rock analysis, and coal composite samples do not indicate the presence of elevated or economic uranium in the Study Area.

2.3.7 Coal Quality Characteristics Narrative and Data

According to ASTM classification of coals, the South Heart coal is classified as Lignite A in rank which is characterized by generally high sulfur content, low to moderate ash content, high moisture content, and low heating value. Table 2.3-18 shows the core holes with available coal quality data in the Study Area.

2.3.7.1 Coal Quality Data

Pre-2006 Coal Quality Data

Prior to the 2006 and later drilling programs, the coal quality at South Heart was defined by coal from 14 core holes. These core holes, which are identified by the SH02 nomenclature, were drilled by Kiewit Mining Group for GNP in 2002. Core recovery of the D Coal ranged from 87% to 100%. The coal cores were shipped to MVTL in Bismarck where short proximate analyses were run on various coal plies within each seam to determine the coal quality variability within the seam. All samples were tested in accordance with ASTM standards and these coal ply analyses were used to determine the composite intervals for each seam in each hole. Analyses included:

- Full proximate;
- Ultimate;
- Eight point fusion temperature;
- Equilibrium moisture; and
- Apparent specific gravity.

The above analyses were run on the full seam composites for all 14 holes. Sulfur forms and mineral ash were run on only eight of the full seam composites. The laboratory analysis of the cores collected in 2002 had an average as-received BTU heating value of 6,006 BTU per pound (BTU/lb), an ash content of 8.5%, a moisture content of 42.7% and a sulfur content ranging from 0.41 to 1.97% (Table 2.3-19).

2006 and 2007 Coal Quality Data

A total of 33 holes were cored, sampled and analyzed within the Study Area during the 2006 and 2007 drilling programs. Appendix 2.3-18 contains core logs of 16 core holes from the 2006 drilling program and core logs of 17 core holes from the 2007 drilling program within the Study Area. Sample preparation and handling were supervised by Norwest. The coal seams were sampled continuously through the coal zones and coal core samples prepared in the field. Cores were quickly placed and sealed in airtight core tubing boxes for shipping. Analytical work was performed to ASTM standards by MVTL in Bismarck, North Dakota.

The incremental sample intervals were selected by Norwest geologists to represent the plies within each seam or seam bench and were evaluated by reviewing both the geophysical and core logs. The laboratory was instructed to test these increments for short proximate analysis and sodium content of the ash. Short proximate analyses contain the basic coal quality parameters of moisture, ash, and sulfur percentages on an as-received and dry basis along with the heating value. The incremental sampling and testing allowed Norwest to model each coal seam in a way that the coal will likely be mined. A coal quality database was constructed from these incremental sample results and was incorporated into the full geologic database. The following as-received parameters were included in the modeled coal quality database:

- Moisture content (%);
- Ash content (%);
- Sulfur content (%);
- Heating value (BTU/lb); and
- Sodium content (%).

Mathematical composites of the incremental sample results were used to compile the coal quality database for geologic modeling and forecasting of coal quality. A digital grid was made for each quality parameter for each mineable seam identified within the Study Area.

The top 6 inches of a seam were identified as high in sulfur and ash in the modeling results. This bench may be removed prior to mining to effectively help reduce out-of-seam dilution and to optimize the as-shipped coal quality parameters. In addition, the bottom 6 inches of coal seams are typically also high in ash content and commonly are not mined.

Twenty eight full seam physical composite samples were also subjected to a suite of analytical tests. These composite analyses included at a minimum:

- Proximate;
- Ultimate;
- Sulfur forms; and
- Mineral analysis of ash.

In addition, incremental cutting samples were collected from the 35 air-rotary overburden holes in 2006 and 34 air-rotary overburden holes in 2007 that were not cored, and short-proximate analysis was completed on each incremental sample.

2.3.7.2 Summary of Coal Core Laboratory Data

The coal quality summary for core holes found in Table 2.3-20 shows the composite quality by seam for the South Heart reserve base. The summary includes quality on an as-received basis for moisture, ash, sulfur and heat content; sodium and calcium oxide, and sulfur forms (organic, pyritic, and sulfate). This table also includes the minimum, maximum, mean and median values for all the coal quality parameters. The coal seams within the Study Area can be characterized as being moderate to high in ash content. The as-received heat content is slightly lower than what would be expected for coal of this rank due to its higher ash content. Sulfur content values are generally high and nearly all sulfur occurs as pyritic sulfur. Appendix 2.3-19 shows the detailed incremental analyses for all of the cored holes in the Study Area.

~~Table 2.3-21 summarizes the coal quality of all samples taken from the drill cuttings from all the air rotary holes drilled in 2006, and 2007 and 2010~~.

2.3.7.3 Coal Analysis Summary within the Study Area

A total of forty seven (47) core holes were modeled using increment analysis and the location of these holes are shown on Figure 2.3-23. In addition to core holes, sixty nine (~~69~~71) air rotary holes were sampled for coal quality and the air rotary hole locations are shown on Figure 2.3-24. These analyses, however, were not used in developing the coal quality model, as there was too much contamination from the drillhole walls above the sample points. Detailed incremental analyses for all of air the rotary holes within the Study Area are shown in Appendix 2.3-20.

Table 2.3-21 summarizes the coal quality of all samples taken from the drill cuttings from all the air rotary holes drilled in 2006, 2007 and 2010~~.~~

Upper seams (F Coal, E Coal and E1 Coal)

The upper seams present in the Study Area are generally weathered (oxidized) and are located in the mine areas where the total cover to the D Coal is high. There are ten quality data points for the E Coal and eight quality data points for the E1 Coal.

To date, there are no coal quality samples collected to represent F Coal.

E Coal

The E Coal within the Study Area is characterized by relatively low heating value and high sulfur content. The average E Coal heat content (BTUs) value is illustrated on Figure 2.3-25. Several "bullseye" patterns indicate areas where the E Coal heating values vary abruptly, ranging from 3,300 to 5,900 BTU/lb are present. Note, the heating value differences are present between the pre-2006 core hole quality and the 2007 core hole quality in Sections 15 and 16 in the north and Sections 26 and 27 in the south. These heating value differences are due to a variance in sample depth, high ash, and seam oxidation. The E Coal sulfur and sodium content is illustrated on Figure 2.3-26 and Figure 2.3-27, respectively. Figure 2.3-28 is an isopleth map of moisture content of the E Coal while Figure 2.3-29 is the isopleth of the ash content.

E1 Coal

The E1 Coal within the Study Area is characterized by relatively low heating value and high sulfur content. The average E1 Coal heat content (BTUs) value is illustrated on Figure 2.3-30. The "bullseye" patterns indicate an area where the E1 Coal heating values vary abruptly, ranging from 5,700 to 6,200 BTU/lb. Note, the heating value differences are present between the pre-2006 core hole quality and the 2007 core hole quality in Section 27 in the south. These heating value differences are due to variance n sample depth, high ash, and seam oxidation. The E1 Coal sulfur and sodium content are illustrated on Figure 2.3-31 and Figure 2.3-32, respectively. Figure 2.3-33 is an isopleth map of moisture content of the E1 Coal while Figure 2.3-34 is the isopleth of the ash content.

D Coal

The D Coal within the Study Area is characterized by relatively low heating value and high sulfur content. The average D Coal heat content (BTUs) value is illustrated on Figure 2.3-35. The "bullseye" patterns indicate an area where the D Coal heating values are relatively low, ranging from 5,200 to 5,600 BTU/lb. Note, the bullseye pattern around hole SH02-07c in Section 16 is due in part to oxidization of the top 5.5 ft of the seam. Additional drilling in 2007 delineates the extent of the oxidation in this area of the seam. The D Coal has significantly higher sulfur content and a moderate to high sodium content than typical lignite (based on qualities seen at other lignite operations) as illustrated on Figure 2.3-36 and Figure 2.3-37, respectively. Figure 2.3-38 is an isopleth map of moisture content of the D Coal while Figure 2.3-39 is the isopleth of the ash content.

HT Butte Coal

There are only three quality data points in the computer generated geologic model for HT Butte Coal which is the deepest coal seam in the reserve area (Figure 2.3-40). The HT Butte Coal quality data shows it is generally low in heating content, has moderate ash and moisture content and is high in sulfur content.

In 2009 two water monitoring wells were cored (HQ-size) to below HT Butte Coal. A total of 21 incremental and 4 composite core samples were taken from these two holes. The composite samples focused on the D Coal and HT Butte Coal. Survey data along with total depth, depth to the D Coal, and D Coal thickness for these two holes are provided in Table 2.3-5. The composite quality summary for these two cored holes can be found in Table 2.3-20 and incremental analysis results in Appendix 2.3-19. Geophysical logs (gamma, density, resistivity) were used to validate the depth intervals of the E Coal, D Coal and HT Butte Coal. These two holes have not been included in the computer generated geologic model given that no significant material changes in seam thickness and/or coal quality was observed from the core samples. The location of these two holes, relevant seam thickness, and coal quality results are posted in the seam thickness and coal quality figures for reference.

2.3.7.4 Coal Quality Summary within the Permit Area

As previously mentioned, the coals within the Study Area are classified as Lignite A in rank according to the ASTM classification system. Coals within the Study Area have been modeled and characterized by core samples from forty-seven holes which were completed between 2002 and 2007. Details regarding data collection, sampling and analytical testing have been described in previous sections of this application.

Results of computer modeling for the D Coal over the entire Study Area have been described and presented on Figure 2.3-35, Figure 2.3-36, Figure 2.3-37, Figure 2.3-38, and Figure 2.3-39. The D Coal within the Permit Area is approximately 17.24 ft thick and contains approximately 118.2 million tons of in-place coal resource. Average, as-received, in-place quality characteristics for the D Coal within the 4,581-acre Permit Boundary are as follows:

- Moisture: 42.5%;
- Ash: 8.3%;

- Sulfur: 0.88%;
- Heating content: 6,016 BTU/lb; and
- Sodium: 5.0%.

The quality parameters are shown on Figure 2.3-35, Figure 2.3-36, Figure 2.3-37, Figure 2.3-38, and Figure 2.3-39.

The E Coal within the Permit Area is approximately 2.65 ft thick and contains approximately 1.5 million tons of in-place coal resource. Average, as-received, in-place quality characteristics for the E Coal within the 4,581-acre Permit Boundary are as follows:

- Moisture: 45.9%;
- Ash: 11.4%;
- Sulfur: 1.16%;
- Heating content: 4,850 BTU/lb; and
- Sodium: 5.1%.

The quality parameters are shown on Figure 2.3-25, Figure 2.3-26, Figure 2.3-27, Figure 2.3-28, and Figure 2.3-29.

The E1 Coal within the Permit Area is approximately 1.8 ft thick and contains approximately 3.7 million tons of in-place coal resource. Average, as-received, in-place quality characteristics for the E1 Coal within the 4,581-acre Permit Boundary are as follows:

- Moisture: 42.6%;
- Ash: 8.9%;
- Sulfur: 1.69%;
- Heating content: 6,101 BTU/lb; and
- Sodium: 5.4%.

The quality parameters are shown on Figure 2.3-30, Figure 2.3-31, Figure 2.3-32, Figure 2.3-33, and Figure 2.3-34.

TABLES

FIGURES

APPENDIX 2.3-1

PREVIOUS MINE SEARCH RESULTS

APPENDIX 2.3-2

NDIC DMR, OIL AND GAS DIVISION WELL SEARCH RESULTS

APPENDIX 2.3-3

WELL NO. 6369

APPENDIX 2.3-4

WELL NO. 4975

APPENDIX 2.3-5

SUMMARY OF 2002 OVERBURDEN ANALYSES BY BOREHOLE

APPENDIX 2.3-6

SUMMARY OF PHASE I, PHASE II, PHASE III, AND 2010 OVERBURDEN ANALYSES BY BOREHOLE WITHIN THE STUDY AREA

APPENDIX 2.3-7

SUMMARY OF SHALLOW OVERBURDEN ANALYSES BY BOREHOLE WITHIN THE STUDY AREA

APPENDIX 2.3-8

2002 OVERBURDEN LABORATORY DATA SHEETS

APPENDIX 2.3-9

PHASE I, PHASE II AND 2010 OVERBURDEN LABORATORY DATA SHEETS

APPENDIX 2.3-10

PHASE III OVERBURDEN LABORATORY DATA SHEETS

APPENDIX 2.3-11

SHALLOW OVERBURDEN LABORATORY DATA SHEETS

APPENDIX 2.3-12

SUITE TWO ANALYSES LABORATORY DATA SHEETS

APPENDIX 2.3-13

2002 LITHOLOGIC LOGS WITHIN THE STUDY AREA

APPENDIX 2.3-14

PHASE II, PHASE III AND 2010 LITHOLOGIC LOGS WITHIN THE STUDY AREA

APPENDIX 2.3-15

SHALLOW OVERBURDEN LITHOLOGIC LOGS WITHIN THE STUDY AREA

APPENDIX 2.3-16

2002 GEOPHYSICAL LOGS WITHIN THE STUDY AREA

APPENDIX 2.3-17

PHASE II, PHASE III, AND 2010 GEOPHYSICAL LOGS WITHIN THE STUDY AREA

APPENDIX 2.3-18

COAL LOGS 2007 WITHIN THE STUDY AREA

APPENDIX 2.3-19

DETAILED INCREMENTAL ANALYSES FOR THE CORED HOLES WITHIN THE STUDY AREA

APPENDIX 2.3-20

DETAILED INCREMENTAL ANALYSES FOR THE ROTARY HOLES WITHIN THE STUDY AREA