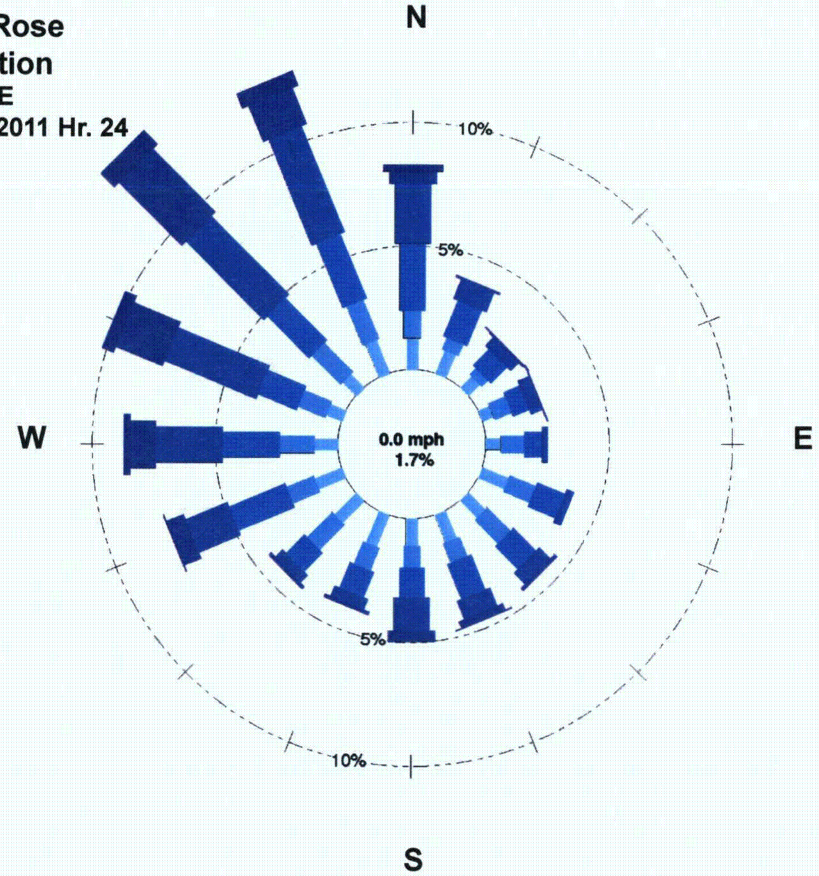
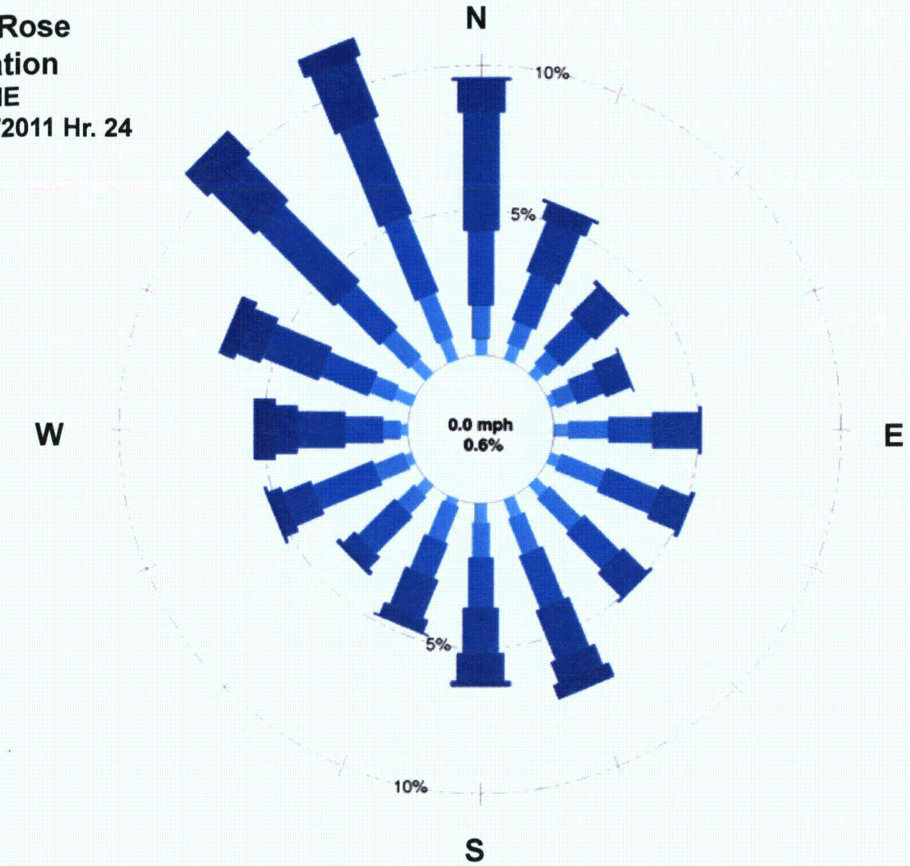
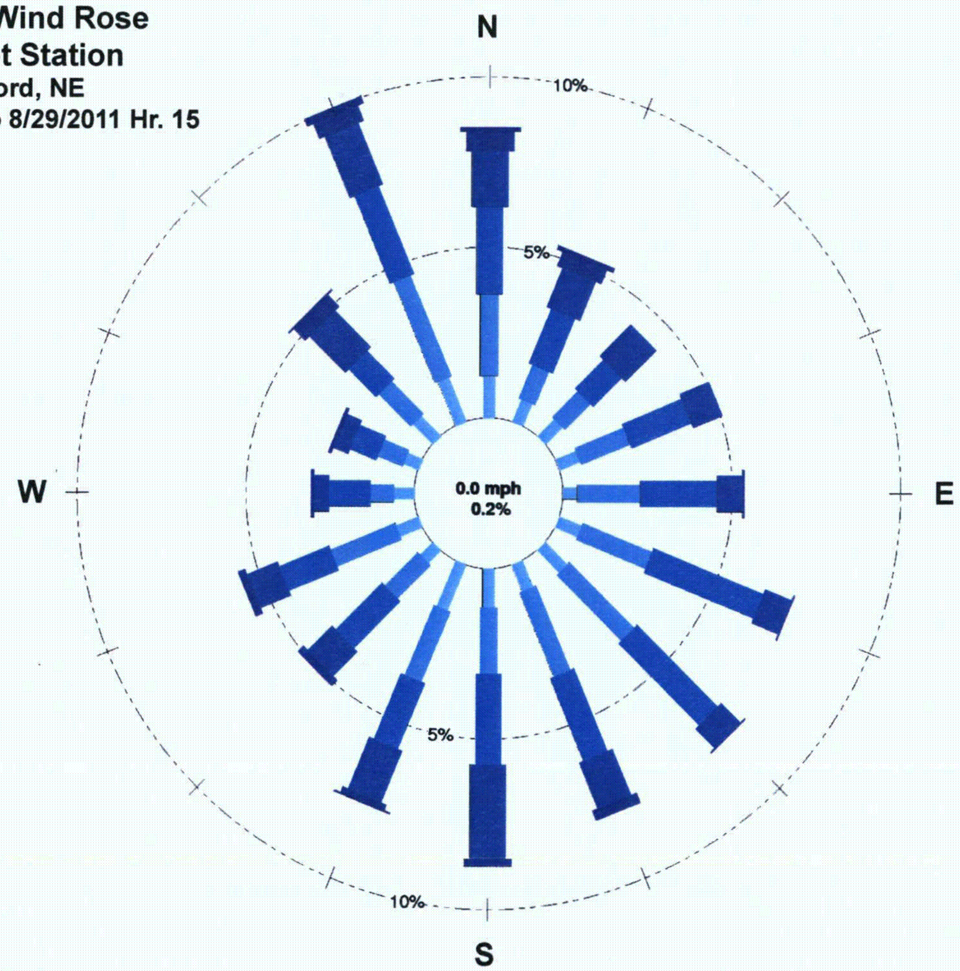
## Winter Wind Rose
**MEA Met Station**
**Crawford, NE**
**1/1/2011 Hr. 1 to 3/31/2011 Hr. 24**



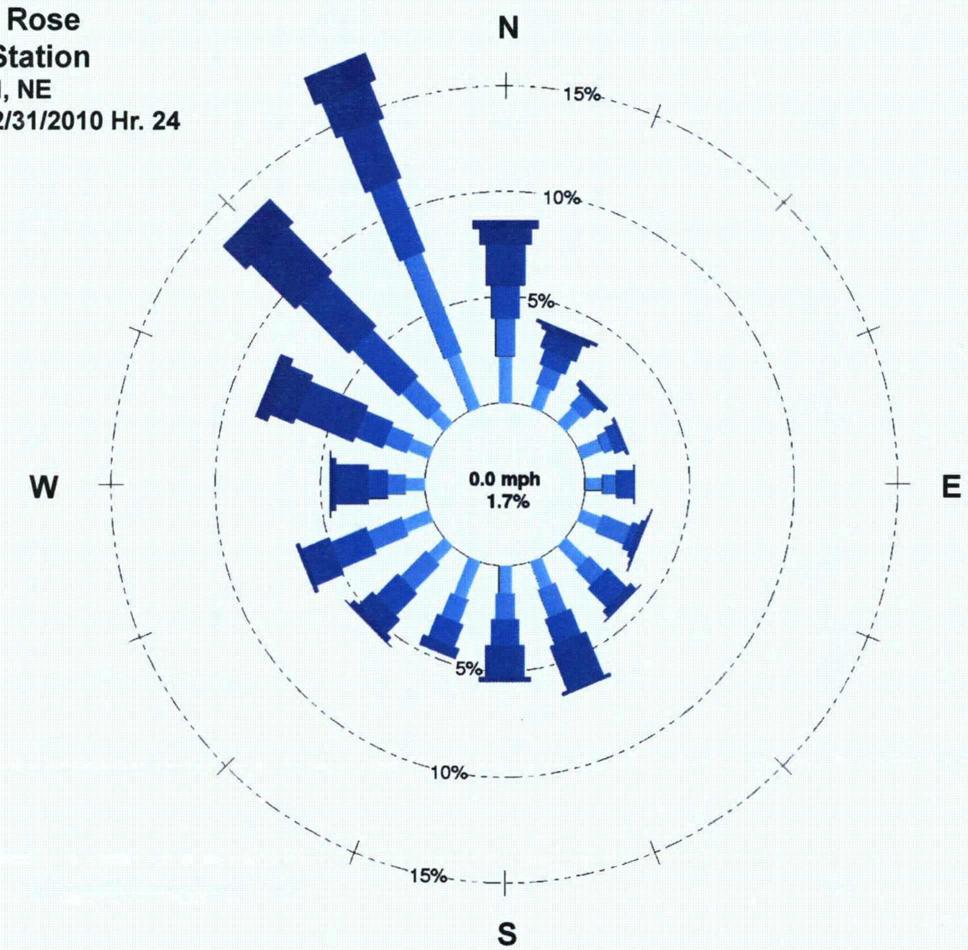

## Spring Wind Rose
**MEA Met Station**
**Crawford, NE**
**4/1/2011 Hr. 1 to 6/30/2011 Hr. 24**



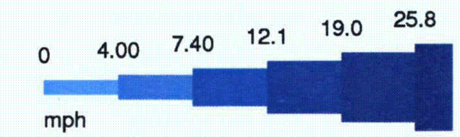

## Summer Wind Rose
**MEA Met Station**
**Crawford, NE**
**9/7/2010 Hr. 8 to 8/29/2011 Hr. 15**




## Fall Wind Rose
**MEA Met Station**
**Crawford, NE**
**10/1/2010 Hr. 1 to 12/31/2010 Hr. 24**




**Note:** The "summer" wind rose represents the 3rd calendar quarter, which includes July, August and September. Because the monitoring year spans parts of two calendar years, the summer wind rose software program utilized all of the available summer data from both years. This turned out to be September of 2010 (beginning with the 7th), July of 2011, and August of 2011 (up to the 29th). So the summer months are extracted from the stated date range.




*Source:*
*Inter-Mountain Lab (IML) Air Science, 2011*

CROW BUTTE RESOURCES, INC.

**FIGURE 2.5-21**
**MARSLAND EXPANSION AREA**
**SEASONAL WIND ROSES**

PROJECT: CO001636 | MAPPED BY: JC | CHECKED BY: JEC

ARCADIS
630 Plaza Drive, Ste. 100
Highlands Ranch, CO 80129
P: 720-344-3500 F: 720-344-3535
www.arcadis-us.com

K:\CBR_Projects\CO001636_Marsland\3_IMAGES\Illustrator\TR Figure 2_5-21 Marsland Expansion Area Seasonal Wind Roses_11x17.ai @ 10/17/2011

**Figure 2.5-22 Marsland Expansion Area Diurnal Wind Speeds**

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**Figure 2.5-23 Marsland Expansion Area Wind Speed Distribution**

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Figure 2.5-24 Project Area Monthly Average Wind Speeds

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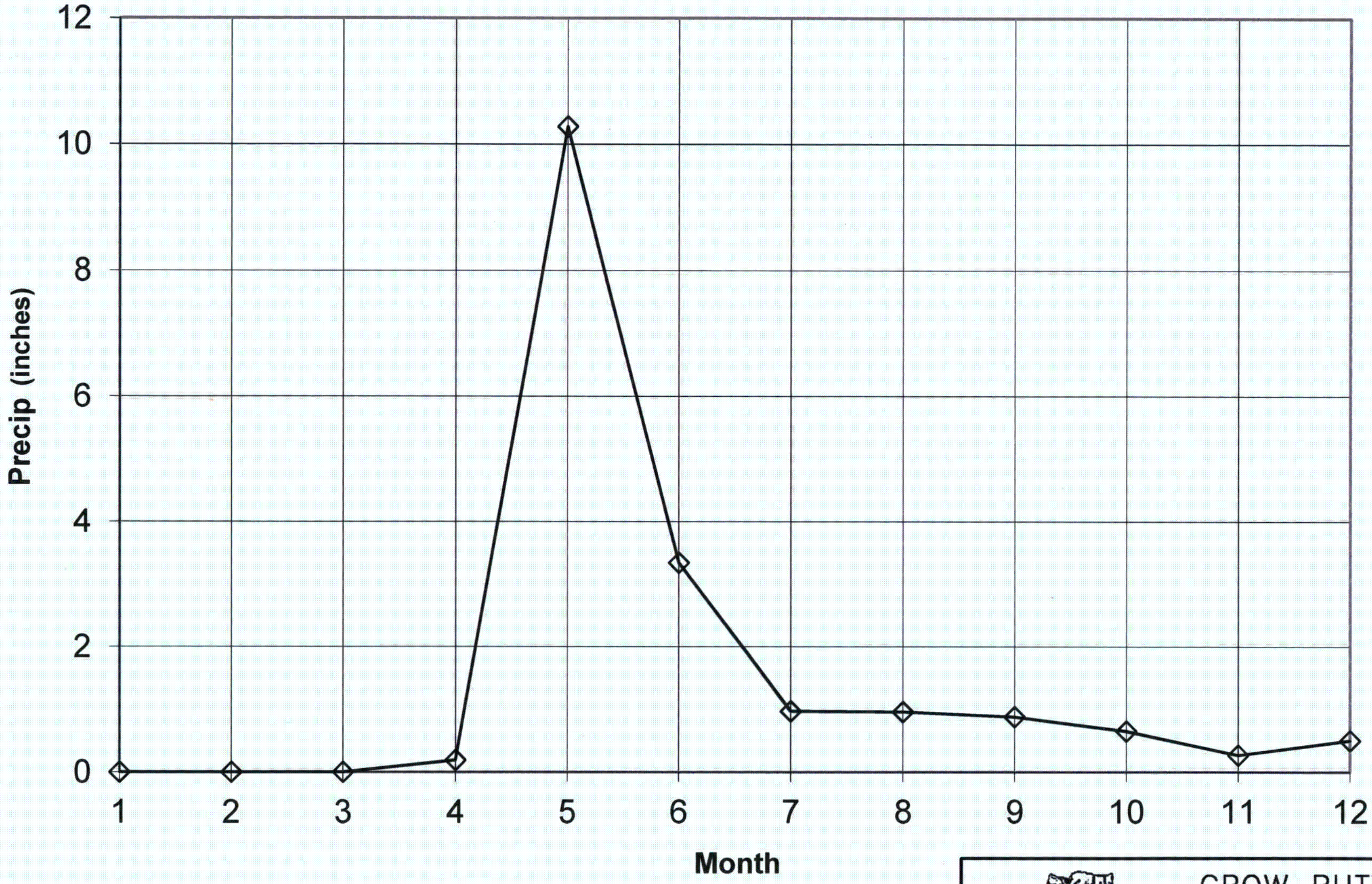


CROW BUTTE RESOURCES, INC.

**FIGURE 2.5-25**
**MARSLAND EXPANSION AREA**
**TOTAL MONTHLY PRECIPITATION**

PROJECT: CO001636 MAPPED BY: JC CHECKED BY: JEC

ARCADIS
630 Plaza Drive, Ste. 100
Highlands Ranch, CO 80129
P: 720-344-3500 F: 720-344-3535
www.arcadis-us.com

*Source: Cameco Resources, 2011, data from 8/24/2010 to 8/29/2011.*

K:\CBR_Projects\CO001636_Marsland\3_IMAGES\Illustrator\TR Figure 2_5-25 MEA Monthly Precipitation.ai @ 07/18/2013

**Figure 2.5-26 Marsland Expansion Area Potential Monthly Evapotranspiration**

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**Figure 2.5-27 Scottsbluff 15-Year vs. Baseline Year Wind Roses**

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Figure 2.5-28 Scottsbluff 15-Year vs. Baseline Year Wind Directions

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**Figure 2.5-29 Scottsbluff 15-Year vs. Baseline Year Wind Speeds**

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**Figure 2.5-30 Scottsbluff 15-Year vs. Baseline Year Wind Speed Distributions**

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**Figure 2.5-31 Scottsbluff 15-Year vs. Baseline Year Wind Direction Distributions**

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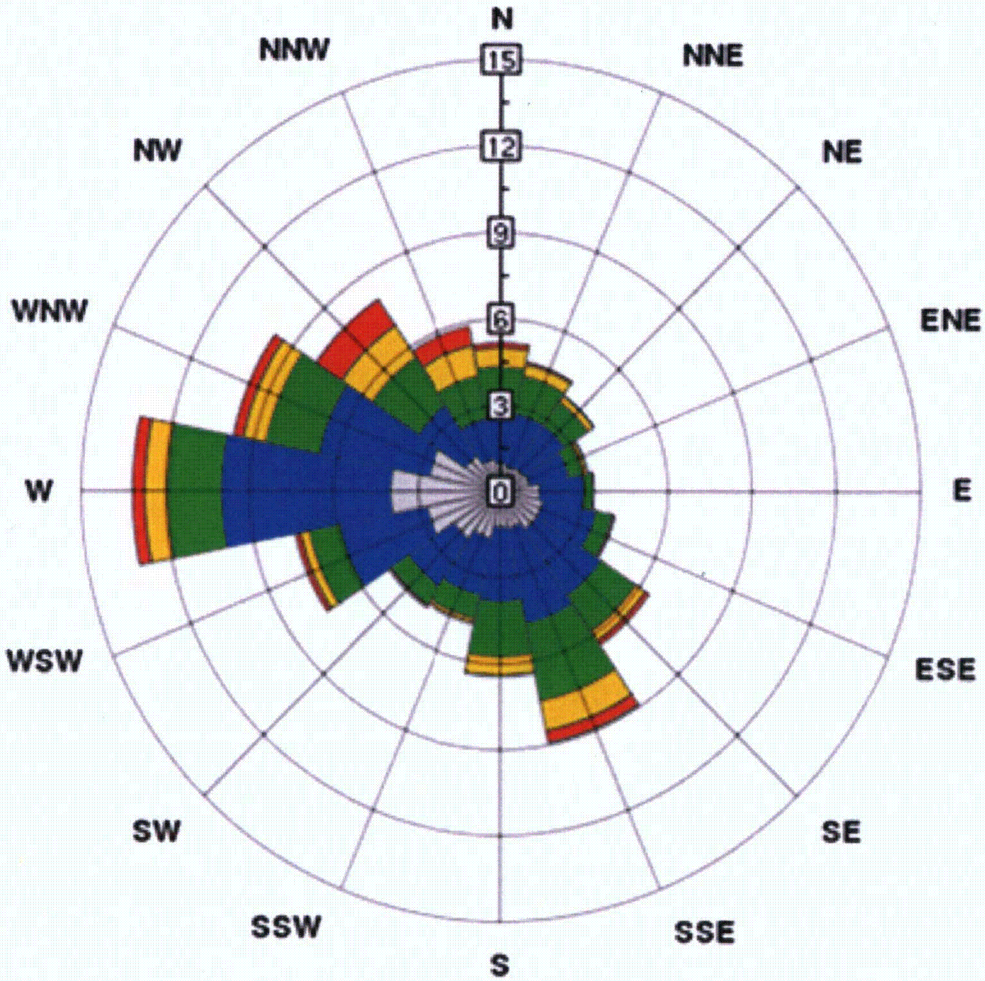


**Alliance West**

Station ID: a250138

Location: 42.02, -103.13

Elevation: 3978 Feet

Source: Smith 2013.

CROW BUTTE RESOURCES, INC.

**FIGURE 2.5-32**
**ALLIANCE WEST 10-YEAR WIND ROSE**
**1996-2005**

| PROJECT: CO001636 | MAPPED BY: JC | CHECKED BY: JEC |
|---|---|---|

ARCADIS 630 Plaza Drive, Ste. 100 Highlands Ranch, CO 80129 P: 720-344-3500 F: 720-344-3535 www.arcadis-us.com

K:\CBR_Projects\CO001636_Marsland\3_IMAGES\Illustrator\TR Figure 2_5-32 SAlliance West 10-Year Wind Rose 1996 -2005.ai @ 12/02/2013

**Figure 2.5-33 Locations of Regional Ambient Air Monitoring Sites**

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## 2.6 Geology and Seismology

This section describes the regional and local geology and seismology of the MEA area. The geology of the CPF, NTEA, and TCEA has been discussed in previous license applications submitted to the NRC. Detailed information contained in those reports (e.g., laboratory results and field data that describe formation characteristics [lithology, mineralogy, permeability] for the Pierre Shale, Chadron Formation, and the Brule Formation at the CPF), also applies in a general sense to the MEA. These data, in addition to new information from exploratory drilling/logging activities within the MEA, are used to describe the geology and seismology in this section.

### 2.6.1 Geology and Seismology

#### 2.6.1.1 Regional Setting

As shown on **Figure 4.2-1**, the centerpoint proposed MEA satellite building is approximately 15.1 miles (24.3 km) south-southeast to the centerpoint of the City of Crawford, Nebraska in sections 26 and 35 Township 30 North, Range 51 West; sections 1, 2, 11, 12, and 13 Township 29 North, Range 51 West; and sections 7, 18, 19, 20, 29, and 30 Township 29 North, Range 50 West. The City of Crawford is 25 miles (40.2 km) west of Chadron, Nebraska and 70 miles (112.6 km) north of Scottsbluff, Nebraska. The City of Crawford is 21 miles (33.8 km) south of the South Dakota state line and 33 miles (53.1 km) east of the Wyoming state line. The Marsland area is located near the northern limits of the High Plains section of the Great Plains physiographic province. Topography of the Marsland area includes gently sloping, rolling hills with outlying, broad ridges dissected by intermittent and perennial streams. The most prominent physiographic feature in the region is the Pine Ridge Escarpment, which rises roughly 300 to 900 feet above the basal plain and bounds three sides of the Crawford Basin. Colluvial and alluvial deposits originating from this escarpment cover the license area. The elevation of the MEA ranges from 3,880 to 4,400 feet above mean sea level (amsl).

**Deleted:** northwest corner of the

**Deleted:** license boundary

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**Deleted:** of the southeast corner of the city limits of the

Regional Stratigraphy

**Table 2.6-1** summarizes the regional stratigraphic section for northwest Nebraska that includes the White River Group (Brule Formation through basal sandstone of the Chadron Formation). A geologic map of bedrock in northwestern Nebraska is shown on **Figure 2.6-1**. The bedrock map depicts the occurrence of the Miocene Ogallala Group, Miocene Arikaree Group, the Eocene-Oligocene White River Group, and Upper Cretaceous strata belonging to the Montana Group and Colorado Group. The Upper Cretaceous Pierre Shale, the unconformably overlying White River Group (Brule Formation, Chadron Formation, and Chamberlain Pass Formation), and the Arikaree Group outcrop in the vicinity of the City of Crawford and MEA (**Figure 2.6-1**, see inset). In general, the stratigraphic nomenclature of Schultz and Stout (1955) is used in this application for consistency with historical permitting.

MEA Stratigraphy

The local stratigraphy at the MEA consists of the following geological units in descending order: alluvial sediments, upper Harrison Beds, Monroe Creek - Harrison Formation, Gering Formation, Brule Formation, upper Chadron Formation, upper/middle Chadron Formation, middle Chadron Formation, basal sandstone of the Chadron Formation, and Pierre Shale. The channel sandstone facies of the basal sandstone of the Chadron Formation represents the production zone and target

of solution mining in the MEA. The general stratigraphic section for the MEA is summarized in **Table 2.6-2**. **Figure 2.6-2** is a cross-section index map depicting the locations of 14 north-south and east-west cross-sections through the MEA depicted on **Figures 2.6-3a** through **2.6-3n**. Expanded views of two cross-sections are presented as **Figure 3-4o** through **Figure 3-4u** to provide more detailed examples of the geophysical logs within the basal sandstone of the Chadron Formation. Typical geophysical log responses for the geologic units encountered within the MEA are shown on a typical (i.e., type) log on **Figure 2.6-4**.

CBR completed coring programs in 2011 and 2013 across the MEA. In 2011, two core holes were completed and an additional five were completed in 2013. Data were collected from these cores to provide site-specific information across the project area. The site-specific results of the coring programs have been incorporated into discussions of stratigraphy, lithology, and hydraulic properties throughout the document. A summary of the coring programs is presented in **Table 2.6-3**, and coring locations are illustrated on **Figure 2.6-4**.

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A thick (approximately 1,200 to 1,500 feet), regionally extensive stratigraphic section of sedimentary units underlies the Pierre Shale; however, those units are not relevant to this proposal. The absence of sandstone units for more than 1,000 feet below the top of the Pierre Shale precludes the need for monitoring zones below the surface of the Pierre Shale. Discussion in this report is limited to the Arikaree Group, White River Group, and Pierre Shale (Petrotek 2004; Wyoming Fuel Company 1983).

This section provides a detailed description of the stratigraphy of the MEA based on an extensive review of existing site-specific drilling logs and published literature. Geological units are described from stratigraphically youngest to stratigraphically oldest. Revised nomenclature for these stratigraphic units is discussed, where applicable, and referred to throughout this application. To be consistent with historical permitting, the majority of stratigraphic nomenclature used in previous submittals to the NRC and the NDEQ has been preserved.

Alluvium

Quaternary alluvium as thick as 30 feet overlies the Arikaree Group along drainages in the study area. In general, the alluvium consists of fragments of locally outcropping Oligocene-Miocene sedimentary rocks, sand, gravel, sandy soil horizons, and may include weathered portions of the Arikaree Group. Because alluvium is unconsolidated and may incorporate one or both of the vadose and phreatic (shallow groundwater) zones, log signatures within this unit vary in comparison with those of geologic units in the underlying units. On most MEA logs, resistivity values for alluvium are very high, beyond the log scale, indicating the presence of either soil vapor or fresh water (**Figure 2.6-5**). In general, shallow zones with elevated resistivity are also distinguished by a negatively deflected spontaneous potential (SP) curve, suggesting the presence of a permeable zone and formation fluid with lower resistivity than the fluid within the borehole. Although these log signatures suggest that the base of the alluvium can be readily identified in geophysical logs, the base of the alluvium is best defined by observations of drill cuttings. Therefore, the alluvium-Arikaree Group contact illustrated on cross-section **Figure 2.6-3a** through **Figure 2.6-3n** is based on lithologic descriptions of drill cuttings recovered from individual boreholes.

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Deleted: this relationship has not been verified at the MEA.

Deleted: an inferred contact.

Arikaree Group (Oligocene-Miocene)

The Oligocene–Miocene Arikaree Group lies unconformably above the Brule Formation and is subdivided from youngest to oldest into the upper Harrison Beds, Harrison-Monroe Creek and Gering Formations, respectively (**Table 2.6-2;** Collings and Knode 1984; Swinehart et al. 1985; LaGarry 1998; McFadden and Hunt, Jr. 1998).

**Deleted:** The Oligocene–Miocene Arikaree

**Deleted:** Group is a water-bearing unit overlain by alluvium. The thickness varies from 50 to 210 feet depending upon the degree of erosion. The Arikaree

**Deleted:** composed of

**Deleted:** aged youngest to oldest,

Literature has named the upper Harrison Beds the Marsland Formation or split into the Harrison and Monroe Creek Formations. This application uses nomenclature presented in Swinehart et al. (1985), which uses the upper Harrison Beds, Harrison-Monroe Creek, and Gering Formations.

The Arikaree Group contains numerous interbedded channel and flood plain deposits, along with the eolian volcaniclastics. Grain size analyses of core samples (**Appendix G-2**) support observations of drill cuttings and cores, which demonstrate that a wide range of interbedded lithologies are present within the Arikaree Group, including illite/smectite-dominated mudstones (e.g., M-533C Run 5 Sample 1), siltstones (e.g., M-533 Run 1 Sample 2), and fione-grained sandstones e.g., M-1912C Run 1 Sample 1) and fine-grained sandstones (e.g., M-1912C Run 1 Sample 1). The coarsest materials are epiclasts from the White River Group and the Rocky Mountains (Bradley and Rainwater 1956; Tedford et al. 1985; Hoganson et al. 1998).

An isopach map of the undifferentiated Arikaree Group is shown on **Figure 2.6-6**. Within the license boundary, the thickness of the Arikaree Group ranges from approximately 40 to 160 feet and averages about 105 feet. The unit is thickest in the northern portion of the license boundary, and generally thins southward. The unit is stratigraphically continuous across the MEA. All three subunits of the Arikaree Group are represented on the northern end of the project, but due to stratigraphic pinch-out and erosion from the Niobrara River, it is likely that only portions of the Monroe Creek and Gering Formations are present on the south end of the project.

**Deleted:** but thins on both the northwest and southeast ends of the project.

On geophysical logs, the Arikaree Group is characterized by an off-scale resistivity signature (**Figure 2.6-5**). The SP curve exhibits small fluctuations and is relatively straight. The SP curve can also be off the scale. The gamma curve indicates no anomalous radioactivity. No distinguishing features are seen within the geophysical logs to ascertain contacts within the Arikaree Group. The contact between the Arikaree Group and the overlying alluvium is difficult to ascertain. Often, the SP curve will begin on scale near the base of the alluvium and resistivity will remain off scale. The contact between the Arikaree Group and Brule Formation is characterized by a decrease in resistivity from the overlying coarser-grained Arikaree Group. A corresponding decrease in the SP curve is often observed from Arikaree Group to the Brule Formation, and the SP curve typically fluctuates due to interbedded fluvial sediments within the Arikaree Group. Little distinction can be made within the gamma curves between the Arikaree Group and Brule Formation.

**Deleted:** or N-N

**Deleted:** will move sharply to the right.

**Deleted:** indicated where the resistivity begins to move left (becomes lower).

Upper Harrison Beds

Lithologically, the Upper Harrison Beds are composed of eolian volcaniclastic sandstones interbedded with lenticular freshwater limestones. Regionally, thickness of this unit can be up to 150 feet. The thickness of this unit at MEA is interpreted to be significantly thinner than 150 feet within the MEA license boundary based on observations of outcrops in the northern MEA; however, distinction between the Upper Harrison Beds and underlying Harrison-Monroe Creek Formation based on geophysical logs is difficult. Published grain size and mineralogic analysis

indicate that the upper Harrison Beds contain three dominant units of buff to gray fine sand without abundant silt and clay, white sand with abundant silt and clay, and a siliceous pedogenic horizon.

Convolute laminae occur within the fine sand and contain very little silt or clay. The massive unlaminated white sand has been previously interpreted to have been deposited by sheet flow following rains and/or flooding after a heavy ash fall. The lower part of the upper Harrison Beds contains large blocks of sandstone derived from underlying strata, indicating fluvial channel deposition. Cross stratified beds are also found (Cook 1915Hunt 1981; Vicars and Breyer 1981).

The Upper Harrison Beds also contain silica-cemented paleosols, some of which (e.g., Agate paleosurface) have preserved paleotopographic features due to the resistant nature of the silica cement. Freshwater ostracods have been observed within limestone units, whereas abundant animal burrows and root casts characterize paleosols within the Upper Harrison Beds (Hunt 1981).

Harrison - Monroe Creek Formation

Upper and middle portions of the formation consist of fine-grained grey sandstone. In the northern MEA, outcrops of this formation consist of massively bedded, fine-grained, grey, poorly consolidated sandstone. Grey concretions, which weather into elongated irregular masses, are common. The massive grey sandstones of the Harrison-Monroe Creek Formation are interpreted to represent channel fill deposits (McFadden and Hunt Jr. 1998).

The lower portion of the formation is composed of compact fine sandy silt and clay, pinkish to buff in color, and a fine to medium grained gray sand (McFadden and Hunt 1998) Grey concretions composed of long, irregular, fine grained cylindrical masses are found in the middle and lower portions of the Harrison-Monroe Creek Formation (Lugn 1939; Collings and Knode 1984). According to Schultz (1941) and Svoboda (1950), the concretions were formed when groundwater enriched with calcium carbonate flowed through deposited sediments and calcite was precipitated "...in a situation similar to stalactite formation only in a horizontal direction" (Svoboda 1950). Schultz (1941) mapped the orientations of the concretions and found that, within northwest Nebraska, the orientation trend was to the southeast and away from uplift.

Gering Formation

The Gering Formation is mainly composed of gray, grayish-brown volcaniclastic fine to medium grained sandstones; silty sandstones; silt and local beds of ash; coarse sand; and fine gravel. Most of the sand is laminated and contains local cross beds. Beds of greenish-white bentonitic diatomaceous earth, which weathers into hard white layers, are found throughout most of the Gering. Wellman (1964) divided the Gering into upper and lower units. The two portions of the Gering Formation are separated by a volcanic ash which is up to 6 feet thick (Cady and Scherer 1946; Collings and Knode 1984; McFadden and Hunt 1998). The upper portion of the Gering is finer grained than the lower portion. It is composed of sandy siltstones and silty, fine grained sandstones which were deposited by floodplains. Some clay pebble conglomerates and clay lenses are present.

The lower portion of the Gering contains coarse to fine grained sandstone, silty fine grained sandstone, sandy siltstone, and silty claystone. Coarse to fine grained sandstones are interpreted

**Deleted:** Thickness of this unit can be up to 150 feet.

**Deleted:** The upper Harrison Beds contain preserved paleosurfaces which were overlain by silica cement. The paleosurfaces are valleys, which were infilled by ephemeral stream deposits and overlain by aeolian volacnoclasitc sands. Freshwater ostracods, animal burrow, and root casts are abundant (Hunt 1981).¶

**Deleted:** Harrison-Monroe Creek Formation

**Deleted:** can be divided into upper, middle, and lower portions. All of the portions are similar, and the middle and lower portions are sometimes undistinguished. ¶

**Deleted:** The upper

**Deleted:** and middle portions of the Harrison-Monroe Creek Formation isconsist

**Deleted:** This sand is generally 200 feet thick and is massively bedded.

**Deleted:** were deposited from

**Deleted:** In the vicinity of Harrison and Crawford, the middle portion of the Harrison-Monroe Creek Formation is 285 to more than 360 feet thick, and the lower portion ranges in thickness from 185 to 220 feet (Witzel 1974; McFadden and Hunt, Jr. 1998). ¶

**Deleted:** Witzel 1974;

**Deleted:** This finding agrees with groundwater flow at the time of formation (Witzel 1974).

**Deleted:** At some localities outside of the MEA, the Gering Formation is up to 200 feet thick. Towards Chadron, the Formation thins to about 70 feet (Cady and Scherer 1946; Witzel 1974; Collings and Knode 1984; McFadden and Hunt, Jr. 1998). ¶

**Deleted:** It is distinguished from the overlying Harrison-Monroe Creek Formation by having pipy concretions which are less elongated in form (Witzel 1974).

**Deleted:** Channel deposits formed the c

to have been deposited in fluvial channels, whereas the sandy siltstone and silty claystone units are interpreted to have been deposited on proximal and distal floodplains, respectively. Lithologic observations of outcrops in the northern MEA and Pine Ridge area north of MEA, drill cuttings, and interpretation of geophysical logs indicate that the Gering Formation makes up the majority of the stratigraphic thickness of the Arikaree Group at MEA.

The unconformable contact between the Brule and Gering Formations is readily observed when coarse sediments of the Gering Formation are in contact with the finer grained Brule Formation. When the sediments of the Gering are fine grained, the contact is more difficult to discern based on observations of drill cuttings.

White River Group (Eocene-Oligocene)

At the MEA, the Eocene-Oligocene White River Group consists of the Chadron Formation overlain by the Brule Formation (**Table 2.6-2**). Strata assigned to this group were deposited within fluvial, lacustrine, and eolian environments (Terry and LaGarry 1998). In northwest Nebraska, the White River Group rests unconformably on weathered Pierre Shale. The bulk of the White River Group consists of air fall and reworked volcaniclastics derived from sources in Nevada and Utah (Larson and Evanoff 1998; Terry and LaGarry 1998).

There have been various interpretations of the history of stratigraphic nomenclature for the White River Group of Nebraska and South Dakota as described by Harksen and Macdonald (1969). The following stratigraphic nomenclature retains the formal and informal members based on nomenclature by Schultz and Stout (1955), but also includes more recent nomenclature (Terry and LaGarry 1998; Terry 1998; LaGarry 1998; Hoganson et al. 1998).

Brule Formation

The Oligocene Brule Formation represents the youngest unit within the White River Group present in the subsurface of the MEA. The Brule Formation conformably overlies the Chadron Formation and is unconformably overlain by the Arikaree Group (**Figure 2.6-1**). The Brule Formation was originally subdivided by Swinehart et al. (1985) and later revised by LaGarry (1998) into three members, from youngest to oldest: the "brown siltstone" member, the Whitney Member, and underlying Orella Member (**Table 2.6-2**). The "brown siltstone" member consists of pale brown and brown, nodular, cross bedded eolian volcaniclastic siltstones and sandy siltstones.

The contact with the underlying Whitney Member varies from a gradational contact to a sharp disconformity where the "brown siltstone" fills valleys incised into the older strata of the Whitney Member. As observed in drill cuttings, the Whitney Member consists mostly of pale brown, massive, typically nodular eolian siltstones with rare thin interbeds of brown and bluish-green sandstone, and volcanic ash. The basal 10 meters of the Whitney Member consist of white or green laminated fluvial siltstones and thin sheet sandstones. The contact between the Whitney Member and the underlying Orella Member is intertonguing. The Orella Member consists of pale brown, brown, and brownish-orange volcaniclastic overbank clayey siltstones and silty claystones, brown and bluish-green overbank sheet sandstones, and thin volcanic ashes. Thick, fine to medium grained, channelized sandstones appear near the base of the Orella Member. These sandstones are present across the MEA. The overall thickness of the Brule Formation within the MEA ranges from approximately 100 to 320 feet. In approximately the northern third

**Deleted:** Distal and proximal floodplains formed the sandy siltstone and silty claystone, respectively.

**Deleted:** (Witzel 1974; Collings and Knode 1984; McFadden and Hunt Jr. 1998). The contact can also be determined by a change in slope or color. The Gering Formation is white in color and forms steeper slopes than the underlying Whitney Member of the Brule Formation (Witzel 1974).

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**Deleted:** throughout most of the Crow Butte area.

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**Deleted:** , and channel sandstones.

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of the MEA, the Brule Formation is generally 200 feet thick or more, whereas in the southern two thirds of the MEA, the thickness is generally between 70 and 150 feet. An isopach map of the undifferentiated Brule Formation is shown on **Figure 2.6-7**. **Figure 2.6-10** illustrates the elevation of the top of the Brule Formation across the MEA.

The contact between the Brule Formation and underlying Chadron Formation is difficult to identify in some places, as the contact between the two formations is intertonguing (LaGarry 1998). Regionally, the contact is recognized as the lithologic change from thinly interbedded and less pedogenically modified brown, orange, and tan volcaniclastic clayey siltstones and sheet sandstones of the Orella Member to pedogenically modified green, red, and pink volcaniclastic silty claystones of Big Cottonwood Creek Member in the upper Chadron Formation (Terry and LaGarry 1998).

**Deleted:** An isopach map of the undifferentiated Brule Formation is shown on **Figure 2.6-6**. The thickness ranges from approximately 50 to 350 feet and averages about 170 feet. The unit steadily increases in thickness from the southeast to the northwest end of the project, and the unit is stratigraphically continuous. ¶

On geophysical logs, the Brule Formation is characterized by rapidly fluctuating geophysical log curves, or "log chatter" (**Figure 2.6-5**). This response is recognized in resistivity curves, and to a lesser extent in SP curves, throughout the MEA. Such fluctuations result from resistivity contrasts between the thinly interbedded siltstones and sandstones of the Orella Member. Because the sandstones are porous and constitute a part of the regional aquifer, the contacts with the interbedded, dry siltstones are sharp and easily recognized on logs (Gutentag et al. 1984). These interbedded sandstones and siltstones are present across the entire MEA project area, and constitute the first overlying aquifer above the production zone. Lateral correlation of most individual water-bearing sandstones within the Brule Formation is difficult due to thinness and spatial variability of these braided channel deposits. However, a water-bearing sandstone present at the base of the Brule Formation is laterally continuous across the MEA. This lithologic unit is interpreted to represent the base of the first overlying aquifer above the production zone. **Figures 2.6-7 and 2.6-10** depict the thickness and elevation of the top of the Brule Formation across the MEA, respectively.

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The contact between the interbedded siltstones and sandstone of the Brule Formation and the underlying silty claystones of the Upper Chadron Formation is distinguished by a change from highly variable log readings (i.e., "log chatter") to relatively flat or straight curves (i.e., the shale baseline) on both resistivity and SP logs (**Figure 2.6-5**). Because of the intertonguing nature of the lower Brule and upper Chadron Formations, thin, isolated sandstones and siltstones may be present in the upper Chadron. .As a result, the formation contact appears deeper on some geophysical logs and varies locally on the Brule Formation isopach map (**Figure 2.6-7**). **Figures 2.6-3a** through **2.6-3n** depict the subsurface geology of the Brule Formation within the MEA.

## Chadron Formation

The Eocene-Oligocene Chadron Formation is in the lower part of the White River Group (**Table 2.6-2**). The Chadron Formation unconformably overlies the Cretaceous Pierre Shale. From top to bottom, the Chadron Formation historically consists of the following stratigraphic units: Big Cottonwood Creek Member (herein referred to as the informal upper Chadron and upper/middle Chadron to be consistent with historical permitting), Peanut Peak Member (herein referred to as the informal middle Chadron to also be consistent with historical permitting), and basal sandstone of the Chadron Formation (also known formally as the Chamberlain Pass Formation). The basal sandstone of the Chadron Formation represents the production zone and target of ISR mining within the MEA. **Figures 2.6-3a** through **2.6-3n** depict the subsurface geology of the Chadron Formation within the MEA. **Figure 2.6-11** illustrates the elevation of the top of the Chadron

**Deleted:** basal sandstone and is conformably overlain by the Brule Formation.

Formation across the MEA. A unit locally referred to as the upper/middle Chadron has been observed in regional outcrops and in the subsurface at other CBR operations (e.g., Three Crow Expansion Area); however, this unit has been determined to be absent at MEA based on geophysical logs and observations of cores and drill cuttings, and is not discussed in this application.

Upper Chadron Formation

The upper Chadron is the youngest subdivision of the Chadron Formation recognized at MEA (**Table 2.6-2**). Descriptions of the upper Chadron at Toadstool Park (approximately 22 miles [35.4 km] northwest of MEA) indicate that the unit is composed primarily of volcaniclastic overbank silty claystones interbedded with tabular and lenticular channel sandstones, lacustrine limestones, pedogenic calcretes, marls, volcanic ashes, and gypsum (Terry and LaGarry 1998). Drill cuttings, cores, and geophysical logs from MEA support these observations, except the presence of limestones which have not been observed. At MEA, the upper part of the upper Chadron is light green-gray bentonitic clay grading downward to green and frequently red clay, though thin interbedded sheet sandstones also occur. This observation is consistent with Terry and LaGarry's (1998) observation of thin (0.1 to 0.15 meter) sandstones at Toadstool Park. Water has not been observed in upper Chadron sandstones at MEA. Tuffs in the Toadstool Park area that occur in the upper Chadron were dated by 40Ar/39Ar methods as late Eocene (~34 million years ago [Ma]) in age (Terry and LaGarry 1998). Based on available well control data, the upper Chadron is continuous across the MEA. The available data suggest that the upper Chadron ranges in stratigraphic thickness from approximately 480 to 520 feet and averages about 510 feet across the MEA (**Figure 2-6a** through **Figure 2-6n**).

As supported by observations at the MEA, the lower boundary of this unit is an intertonguing contact with the underlying middle Chadron (Terry and LaGarry 1998; **Table 2.6-2**). The upper boundary is recognized by a lithologic change from thinly bedded and less pedogenically modified brown, orange, and tan volcaniclastic clayey siltstones and sheet sandstones of the overlying Orella Member of the Brule Formation to more pedogenically modified green, red, and pink volcaniclastic silty claystones of the upper Chadron Formation (Terry and LaGarry 1998; **Table 2.6-2**).

Four core samples (M-1454c, Run 1; M-1624c, Run 1; M-1635c Run 3 Sample 1; and M-2169c, Run 5 Sample 1) were collected from the upper Chadron by CBR at boreholes M-1454c, M1624c, and M-2169c (**Figure 2.6-4; Appendix G-1 and G-2**). X-ray diffraction (XRD) analyses of upper Chadron core samples indicate varied mineralogical compositions. Sample M-1454c Run 1 was primarily composed of calcite, montmorillonite, and quartz with minor amounts of plagioclase, potassium feldspar, and illite/mica. The samples from M-1653c and M-2169c were both primarily composed of montmorillonite, calcite, quartz, and plagioclase with minor amounts of illite/mica and potassium feldspar.

Particle size distribution analysis of all four upper Chadron core samples produced median grain sizes between 0.056 and 0.040 millimeter (mm), which are within the silt size range. The weight percent of sand in these samples ranged from 28.79 (M-1635c) to 43.11 (M-1454c). The samples from M-2169c and M-1454c contained significant proportions of medium sand (13.87 and 24.31 weight percent, respectively). The weight percent of clay in the upper Chadron samples ranged from 8.73 percent (M-1624c) to 10.20 percent (M-2169c). M-1454c Run 1 and M-1624c Run 1 give median grain sizes of 0.056 millimeter (mm; silt) and 0.049 mm (silt), respectively. Both

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**Deleted:** Drill cuttings, cores, and geophysical logs from MEA support these observations, except the presence of limestones which have not been observed. At MEA, the upper part of the upper Chadron is light green-gray bentonitic clay grading downward to green and frequently red clay, though thin interbedded sheet sandstones also occur. This observation is consistent with Terry and LaGarry's (1998) observation of thin (0.1 to 0.15 meter) sandstones at Toadstool Park. Water has not been observed in upper Chadron sandstones at MEA. Tuffs in the Toadstool Park area that occur in the upper Chadron were dated by 40Ar/39Ar methods as late Eocene (~34 million years ago [Ma]) in age (Terry and LaGarry 1998). Based on available well control data, the upper Chadron is continuous across the MEA. The available data suggest that the upper Chadron ranges in stratigraphic thickness from approximately 480 to 520 feet and averages about 510 feet across the MEA (**Figure 2-6a** through **Figure 2-6n**).¶

**Deleted:** The upper Chadron is the youngest member of the Chadron Formation (**Table 2.6-2**). The upper part of the upper Chadron is light green-gray bentonitic clay grading downward to green and frequently red clay, though interbedded sandstones also occur. An isopach map of the upper Chadron is shown on **Figure 2.6-7**. The available data suggest that the upper Chadron ranges in stratigraphic thickness from approximately 410 to 650 feet and averages about 507 feet across the MEA (**Figure 2.6-3a** through **2.6-3n**). Two

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**Deleted:** M-1454c Run 1 and M-1624 Run 1 samples

samples are dominated by silt-sized grains; however, M-1454c Run 1 contained more medium sand than M-1624c, which increased the median grain size. M-1454c Run 1 contained 47.25 percent silt and 9.64 percent clay. M-1624c Run 1 contained 54.65 percent silt and 8.73 percent clay. All upper Chadron samples contained 54.65 percent silt and 8.73 percent clay. As M-1454c Run 1 and M-1624c Run 1 both contain greater than 50 percent combined silt and clay-sized particles, and because greater than 67 percent of the silt+clay component was silt in each sample, they are classified as siltstones (Brown and Harrell 1991). Hydraulic properties of the upper Chadron based on grain size analysis of core samples are discussed in Section 2.7.2.3 (confining layers).

Typical gamma ray (GR), SP, and resistivity log signatures for the upper Chadron exhibit curves representative of the relatively flat shale baseline (**Figure 2.6-5**). Fluctuations are present among upper Chadron log curves, representing interbedded siltstones, sandstones, limestones, and volcanic ash deposits that occur less commonly than in the overlying Brule Formation. Logging tools/procedures and other tests are described in Section 3.1.2.4.

The middle Chadron is a variegated clay-rich interval that may be red, grey, grey-green, or bluish-green in color with interbedded bentonitic clay and sands. A light green-gray "sticky" clay within this unit serves as an excellent marker bed in drill cuttings and has been observed in virtually all regional test holes within the MEA, TCEA, NTEA, and the CPF. The middle Chadron unconformably overlies the basal sandstone of the Chadron Formation (Chamberlain Pass Formation) in South Dakota and Nebraska (Terry 1998; **Table 2.6-2**). As described above, this unit is overlain by the upper Chadron at the MEA (**Table 2.6-2**). The middle Chadron differs from the overlying Chadron in that the middle Chadron is composed of bluish-green, smectite-rich mudstone and claystone, is less variegated in color; and contains less silt (Terry 1998). The predominantly clay lithology of the middle Chadron represents a distinct and rapid facies change from the underlying basal sandstone of the Chadron Formation. The available data suggest that the middle Chadron typically ranges in thickness from approximately 150 to 290 feet and averages about 180 feet across the MEA.

Two core samples (M-1454c, Run 2 and M-1624c, Run 2) were collected from the middle Chadron by CBR at boreholes M-1454c and M1624c (**Figures 2.6-2 and 2.6-4; Appendix G-1**). XRD analyses of M-1454c Run 2 and M-1624 Run 2 samples indicate varied compositions. Samples M-1454c Run 2 and M-1624c Run 2 are primarily composed of mixed layered illite/smectite; however, M-1454c Run 2 also contains a high amount of calcite. Other minor minerals found within the samples include quartz, plagioclase, potassium feldspar, chlorite, and illite/mica. Particle size distribution analyses of M-1454c Run 2 and M-1624c Run 2 give median grain sizes of 0.027 mm (silt) and 0.065 (very fine sand) mm, respectively. Both were mainly composed of silt-sized particles; however, M-1624c Run 2 contained more medium sand than M-1454c Run 2, which increased the median grain size. M-1454c Run 2 contained 46.36 percent silt and 20.65 percent clay. M1624c Run 2 contained 34.6 percent silt and 16.54 percent clay. Both are classified as siltstones (Brown and Harrell 1991). Hydraulic properties of the middle Chadron based on grain size analysis of core samples are discussed in Section 2.7.2.3 (confining layers).

Typical GR, SP, and resistivity log signatures for the middle Chadron exhibit curves representative of the shale baseline (**Figure 2.6-5**). At the MEA, the contact between the top of the middle Chadron and the overlying upper Chadron is difficult to ascertain due to similarities in grain size and geophysical log responses. Therefore, **Figures 2.6-3a** through **Figure 2.6-3n** show

**Deleted:** M-1624c was primarily composed of mixed layered illite/smectite, calcite, and quartz. Minor amounts of plagioclase, potassium feldspar, magnetite, and illite/mica were recorded. Particle size distribution analyses of M-1454c Run 1 and M-1624c Run 1 give median grain sizes of 0.056 mm (silt) and 0.049 mm (silt), respectively. Both samples are dominated by silt-sized grains; however, M-1454c Run 1 contained more medium sand than M-1624c, which increased the median grain size. M-1454c Run 1 contained 47.25 percent silt and 9.64 percent clay. M-1624c Run 1 contained 54.65 percent silt and 8.73 percent clay. As M-1454c Run 1 and M-1624c Run 1 both contain more than 50 percent combined silt and clay-sized particles, and because more than 67 percent of the silt+clay component is silt, they are classified as siltstones (Brown and Harrell 1991).¶

**Deleted:** Upper/Middle Chadron Formation¶
The upper/middle Chadron is directly overlain by the upper Chadron (**Table 2.6-2**). At some locations, the upper/middle Chadron is similar in appearance to the channel sandstone facies of the upper portion of the basal sandstone of the Chadron Formation (described later in this section) and is typically very fine to fine grained, well-sorted, poorly cemented sandstone. However, within the MEA license boundary, the water-bearing sandstones of the upper/middle Chadron Formation, recognized in other locations such as NTEA, are not present within the ME[A.] Geophysical logs (discussed below) and core samples indicate the presence of a finer grained facies than is present at NTEA. Therefore, because the sandstones of the upper/middle Chadron are absent, the upper Chadron and middle Chadron Formation comprise a thick continuous mudstone and siltstone sequence within the MEA. Fig[u] ... [2]

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an inferred stratigraphic location for the contact between the upper Chadron and middle Chadron across the license area, as based upon lithologic report observations of drill cuttings.

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Together, the upper and middle Chadron units represent the upper confining zone for the basal sandstone of the Chadron Formation within the MEA (see detailed discussion in Section 2.7.2.3). An isopach map created for the combined upper and middle Chadron Formation that comprises the upper confining zone is presented on **Figures 2.6-8.** The total thickness of the upper confining zone ranges from approximately 650 to 710 feet, averages about 690 feet, and generally appears to thicken toward the south and southwest across the MEA.

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Basal Sandstone of the Chadron Formation – Mining Unit

The basal sandstone of the Chadron Formation is the oldest unit in the White River Group. The Upper Interior Paleosol, occurring as a persistent clay horizon, typically brick red in color (referred to locally as the "red clay"), developed on top of the basal sandstone of the Chadron Formation and generally marks the upper limit of the basal sandstone of the Chadron Formation (**Table 2.6-2**). **Figure 2.6-12** illustrates the elevation of the top of the basal sandstone of the Chadron Formation across the MEA. The "red clay" horizon is indicated on more than half of the geophysical logs and driller's notes that were reviewed. The Upper Interior Paleosol is interpreted to represent pedogenically modified distal overbank deposits of a distinct fluvial system developed on the surface of the basal sandstone of the Chadron Formation prior to deposition of the remainder of the Chadron Formation (Terry 1998).

Below the Upper Interior Paleosol, the basal sandstone of the Chadron Formation consists of coarse grained, arkosic sandstone with common, discontinuous interbedded thin silt and clay lenses of varying thickness. Cross sections providing a more detailed view of the basal sandstone of the Chadron Formation are presented as **Figure 2.6-3o** through **Figure 2.6-3u**.

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The basal sandstone of the Chadron Formation overlies a distinct regional unconformity with the underlying Yellow Mounds Paleosol (Terry 1998). The lower contact is easily recognized as a change from the underlying black or bright yellow, pedogenically modified surface of the Pierre Shale (i.e., the Yellow Mounds Paleosol) to white channel sandstone. In places, the basal sandstone of the Chadron Formation grades upward to fine sandstone containing varying amounts of interstitial clay and persistent clay interbeds. Vertebrate fossils from the basal sandstone of the Chadron Formation in northwestern Nebraska and South Dakota indicate a late Eocene age Chadronian (Clark et al. 1967; LaGarry et al. 1996; Lillegraven 1970; Vondra 1958).

Deleted: The Upper Interior Paleosol, occurring as a persistent clay horizon, typically brick red in color, developed on top of the basal sandstone of the Chadron Formation and generally marks the upper limit of the basal sandstone of the Chadron Formation (**Table 2.6-2**). The Upper Interior Paleosol represents pedogenically modified distal overbank deposits of a distinct fluvial system developed on the surface of the basal sandstone of the Chadron Formation, which predates deposition of the Chadron Formation.

The basal sandstone of the Chadron Formation occurs at depths ranging from about 817 to 1,130 feet bgs and was encountered in all exploration holes. An isopach map of the basal sandstone of the Chadron Formation across the MEA is presented on **Figure 2.6-9**. Stratigraphic thickness of the unit within the MEA ranges from approximately 25 to 90 feet and averages about 55 feet. The thickest sections of the unit occur in the western portions of the MEA (**Figure 2.6-9**). Up to four distinct sandstone packages are present in the thickest portions of this unit and are separated by variable amounts of interbedded clay. Cross-sections depicting the basal sandstone of the Chadron Formation in detail are presented as **Figures 2.6-3o** through **2.6-3u**. Variations in the number and thickness of individual sandstone packages present in individual boreholes is interpreted to have resulted from facies changes and from varying degrees of erosion of fine-grained interbedded sediments and stacking of multiple channel deposits.

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A structure contour map was generated of the contact between the basal sandstone of the Chadron Formation and the Pierre Shale (**Figure 2.6-13**). The structure map indicates that the elevation of the unconformity separating the Chadron Formation from the underlying Pierre Shale decreases to the south-southeast across the MEA from approximately 3,240 to 3,160 feet amsl (**Figure 2.6-13**).

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The greenish-white channel sandstones of the basal sandstone of the Chadron Formation are the target of ISR mining activities in the MEA. Regionally, deposition of the basal sandstone of the Chadron Formation has been attributed to large, high-energy braided streams (Collings and Knode 1984; Hansley et al. 1989; Hansley and Dickinson 1990). This depositional environment produced lenticular sandstone deposits with numerous facies changes occurring within short distances. Interbedded thin silt and clay lenses most likely represent flood plain or low velocity deposits normally associated with fluvial sedimentation.

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Core samples (M-1454C, Runs 3 and 4, and M-1624C, Runs 3 and 4) were collected from the basal sandstone of the Chadron Formation by CBR at boreholes M-1454c and M-1624c in sections 1 and 7, T29N, R51W (**Figures 2.6-2 and 2.6-4; Table 2.6-3**). A core sample was also collected in 2013 from the basal sandstone of the Chadron Formation at borehole M-1912C (M-1912C Run 4 Sample 2). However, three separate analyses of the same sample produced median grain sizes ranging from 0.003 mm (clay) to 0.850 mm (medium sand); therefore, the results from grain size analysis of this sample are not included in this document. Particle size distribution analyses of M-1454c, Run 3 and M-1624c, Run 4 give median grain sizes of 0.075 mm (very fine sand) and 0.711 mm (coarse sand), respectively. M-1454c, Run 3 contained 29.85 percent silt and 19.92 percent clay. M1624c, Run 4 contained 11.56 percent silt and 4.5 percent clay. Both are classified as sandstones (Brown and Harrell 1991).

XRD analysis of the M1454c sample indicates a varied composition. Run 3 is mainly composed of quartz, whereas Run 4 is mainly composed of mixed-layered smectitie. Minor amounts of plagioclase feldspar, potassium feldspar, kaolinite, and illite/mica were found in both samples. Run 3 also yielded trace amounts of calcite, siderite, pyrite, magnetite, and magnesium vanadium oxide, while run 4 had minor amounts of dolomite and chlorite. The sample from M-1912c was primarily composed of quartz and mixed-layered illite/smectite with minor amounts of potassium and plagioclase feldspars, illite/mica, calcite, and ferroan dolomite. The sandstones of the basal sandstone of the Chadron Formation within the CPF are dominated by quartz (50 percent monocrystalline) and feldspar (30 to 40 percent undifferentiated feldspar) with the remainder made up of chert, pyrite, various heavy metals, and polycrystalline and chalcedonic quartz (Collings and Knode 1984). XRD analyses indicate that the basal sandstone of the Chadron Formation within the area of the CPF is 75 percent quartz, with the remaining 25 percent consisting of a combination of potassium feldspar, plagioclase, illite, smectite, expandable mixed layer illite-smectite, and kaolinite (Collings and Knode 1984).

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Geophysical logs record a unique signature for the basal sandstone of the Chadron Formation (**Figure 2.6-5**). A distinct GR spike is often present at the base of the unit in most of the MEA exploration boreholes, indicating an abundance of radioactive material. Increased resistivity (i.e., log curve shift to the right) and a decreased SP (i.e., log curve shift to the left) are often associated with GR spikes. These log signatures support interpretations of a uranium-bearing, fluid-filled sandstone interval. Other channel sandstone intervals present in the unit may have lower GR readings, indicative of both lower amounts of radioactive materials and potentially non-

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uranium-bearing intervals. Such intervals are typically marked by increased resistivity and decreased SP curve deviations (log curves shift to the left) without the associated GR spike. Pervasive interbedded clay intervals are indicated by high GR responses accompanied by lower resistivity (i.e., reduced porosity and decrease in water content), an interpretation that is further supported by driller or geologist's notes. The high radioactivity of these clay-rich units suggests the presence of rhyolitic ash (Hansley and Dickinson 1990). The top of the formation is marked by a gradual return of SP and resistivity curves to the shale baseline.

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Sediments rich in rhyolitic ash contained both within and above the basal sandstone are considered to be the most likely source of the uranium compounds that make up the ore body (Gjelsteen and Collings 1988). Larson and Evanoff (1998) used 40AR/39AR dating methods on nine known White River tuff deposits. The ages ranged from 35.97 Ma to 30.05 Ma. Dissolution of these uranium compounds most likely occurred shortly after deposition. This period represents the time of greatest permeability for solutions to liberate the uranium compounds as they moved through the various ash-rich zones prior to compaction and alteration.

The White River volcaniclasts were first described by Darton (1901), who proposed the Black Hills uplift as the source for the material (Darton 1912). Further study by Wanlass (1923) argued that the Black Hills plutons were too small to have produced the volume of material seen throughout the White River Formation. Other studies have continued to pursue the source area of the volcaniclastic material. Larson and Evanoff (1998) identified the Great Basin in eastern Nevada and western Utah as the most likely source area based on age, grain size, and thickness observations. The Great Basin region was active with explosive rhyolitic volcanism during the ~36 to 29 mya time period of White River deposition.

**Montana Group**

Interior Paleosol (Yellow Mounds Paleosol)

The Interior Paleosol of Schultz and Stout (1955) was subsequently divided into the younger Eocene Upper Interior Paleosol and the older Cretaceous Yellow Mounds Paleosol (Pierre Shale) (Terry 1991; Evans and Terry 1994; Terry and Evans 1994; Terry 1998; **Table 2.6-2**). As noted above, the Upper Interior Paleosol is interpreted to represent pedogenically modified distal overbank deposits of a distinct fluvial system developed on the surface of the basal sandstone of the Chadron Formation which predates deposition of the middle Chadron Formation. The Yellow Mounds Paleosol developed on the Cretaceous Pierre Shale and altered the normally black marine shale to bright yellow, purple, light bluish-grey, and orange.

Review of available data for the MEA indicates that neither of the two paleosol units could be consistently interpreted based solely on geophysical logs. For simplicity, these units are not represented on the type log or cross-sections.

Pierre Shale

Offshore deposition in the Cretaceous Interior Seaway produced the late Cretaceous Pierre Shale (**Table 2.6-2**). The Pierre Shale is a thick, homogenous black marine shale with low permeability that represents one of the most laterally extensive formations of northwest Nebraska. Regional geologic data indicate that this formation can be up to 1,500 feet thick in the Dawes County area (Wyoming Fuel Company 1983; Petrotek 2004). The southward retreat of the Cretaceous Interior Seaway resulted in the subaerial exposure and weathering of rock units from Early Cretaceous to

Eocene age across the northern Great Plains (Lisenbee 1988). This event resulted in the erosion and pedogenic modification of the surface of the Pierre Shale and formation of the brightly colored Yellow Mounds Paleosol (Terry and LaGarry 1998;**Table 2.6-2**). Consequently, the pedogenically modified surface of the Pierre Shale marks a major unconformity with the overlying White River Group and exhibits a paleotopography with considerable relief (DeGraw 1969). The Pierre Shale is underlain by organic-rich shale and marl with minor amounts of sandstone, siltstone, limestone, and chalk of the Niobrara Formation (**Table 2.6-1**). The structure contour map of the top of the Pierre Shale indicates that the contact between the Pierre Shale and the overlying basal sandstone of the Chadron Formation dips slightly to the south-southeast across the MEA (**Figure 2.6-13**). This sloping surface is consistent with the surface described by DeGraw (1971) and rises to the axial crest of the Cochran Arch located north of the MEA.

Seven core samples were collected from the Pierre Shale by CBR at boreholes M-1454c, M-1624c, M-2169c, M-533c, M-1956c, M-1912c, and M-1635c, as summarized in **Table 2.6-3** (**Figure 2.6-4** and **Appendix G-1** and **G-2**). XRD analysis of the samples indicated a primary composition of mixed layered illite/smectite and quartz, with minor amounts of plagioclase, potassium feldspar, dolomite, pyrite, kaolinite, chlorite, and illite/mica. Particle size distribution analyses of the samples indicated clay weight percentages ranging from 30.40 (M-1454c Run 4) to 75.95 (M-1635c Run 6 Sample 1). Median grain sizes for four of the seven samples were within the range for clay and within the range of silt for three samples (**Appendix G-1** and **G-2**). Fine grained sand was only detected in the two samples collected in 2011, with a maximum weight percent of 1.28 in the sample collected from core M-1624c. All samples from the Pierre Shale submitted for particle size analysis are classified as claystones (Brown and Harrell 1991).

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Typical geophysical log responses for the Pierre Shale exhibit shale baseline curves that are relatively flat or straight (**Figure 2.6-5**; **Appendix C**). On resistance logs, the top of the Pierre Shale is noted where the curves break either sharply to the left (SP) or to the right (resistivity) and represent the occurrence of the basal sandstone of the Chadron Formation. Spontaneous potential and resistivity curves qualitatively indicate a lack of permeable water-bearing zones within the Pierre Shale.

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Six deep oil and gas exploration wells were drilled in the vicinity of the MEA: Chicoine 1, Chiocoine 1A, Hollibaugh No. 1, Porter, Roscoe Royal #1, and #1-A Smith (**Appendix C**). Oil and gas exploration wells have typically been drilled to depths much greater than on-lease uranium exploration wells. The character of the entire Pierre Shale in the vicinity of the MEA can best be observed in geophysical logs from three of the six nearby abandoned oil and gas wells (Hollibaugh No. 1, Roscoe Royal #1, and #1-A Smith), and the CBR DDW (CBR UIC #1), which were completed through the entire thickness of the unit. Based on observations from logging, the thickness of the Pierre Shale in the vicinity of the MEA ranges from approximately 750 to more than 1,000 feet.

The top of the Pierre Shale was encountered in all wells at depths ranging from approximately 925 to 1,200 feet bgs. The Hollibaugh No. 1 well is located within the license boundary (T29N, R51W, section 12) and has a total depth of 3,283 feet bgs. The Pierre Shale was encountered at 1,025 to 1,915 feet bgs. The Roscoe Royal #1 is located about 0.5 mile (0.8 km) north of the license boundary (T30N, R51W, section 23) and has a total depth of 3,956 feet bgs. The Pierre Shale was encountered at 1,200 to 2,287 feet bgs. The #1-A Smith well is located about 0.25 mile (0.4 km) east of the license boundary (T29N, R50W, section 29) and has a total depth of

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2,902 feet bgs. The Pierre Shale was encountered at 947 to 1,716 feet bgs. DDW CBR UIC #1 (T31N, R52W, section 19) is located approximately 10.7 miles (17.2 km) northwest of the MEA license boundary and has a total depth of 3,910 feet bgs. At UIC #1, the Pierre Shale was encountered from 925 to 1,560 feet bgs, where the base of the Pierre Shale is indicated by an increase in resistivity at the contact with the underlying Niobrara Formation (**Appendix C**). Plugging records for these wells are shown in **Appendix D-1.**

**Stratigraphy of Units Below the Pierre Shale**

Underlying the Pierre Shale is a thick sequence of Mississippian through Cretaceous age strata that unconformably overlie Precambrian granite (**Table 2.6-1**). Together with the Pierre Shale, the underlying Niobrara Formation, Carlile Shale, Greenhorn Limestone, and Graneros Shale compose a composite lower confining interval approximately 2,500 feet thick which immediately underlies the basal sandstone of the Chadron Formation. With exception of the hydrocarbon-bearing "D", "G", and "J" sandstones of the Dakota Group (occasionally interbedded with the Graneros and Huntsman Shales; **Table 2.6-1**), there do not appear to be significant sandstone units within this thick sequence of low-permeability strata.

All geologic units encountered during the drilling of oil and gas exploration wells in the vicinity of the MEA appear to be consistent with known regional stratigraphy. Geologic units that are consistently identified in all wells include the Niobrara Formation, Carlile Shale, Greenhorn Limestone, "D" and "J" sandstones of the Dakota Group, and the Skull Creek Formation (**Table 2.6-1**).

2.6.1.2 Geochemical Description of the Mineralized Zone

The depth to the ore body within the basal sandstone of the Chadron Formation in the MEA ranges from approximately 800 to 1,250 feet bgs (**Table 2.6-2**). The ore grade as $U_3O_8$ ranges from 0.11 to 0.33 percent with an average ore grade of 0.17 percent.

Hansley et al. (1989) conducted detailed geochemical analysis of the Crow Butte uranium ore to assess both ore genesis and composition. The Crow Butte deposits, including Marsland, the current Crow Butte site, North Trend, and Three Crow are roll-type deposits with coffinite being the predominant uranium mineral species present. The origin of the uranium is rhyolitic ash, which is abundant within the matrix of the basal sandstone of the Chadron Formation (Hansley et al. 1989). Coffinite is associated with pyrite, and high silica activity due to dissolution of the rhyolitic ash which favored formation of coffinite over uraninite in most parts of this sandstone. In addition, smectite is present in the samples examined, with the most common minerals in the sandstone being quartz, plagioclase, K-feldspar, coffinite, pyrite, marcasite, calcite, illite/smectite, and tyuyamunite. The heavy mineral portion of the samples contained several minerals including those above as well as garnet, magnetite, marcasite, and illmenite. Vanadium was detected in the samples primarily as an amorphous species presumed to have originated from the *in-situ* ash. Hansley et al. state that at least some uranium and vanadium remain bound to amorphous volcanic material and/or smectite rather than as discrete mineral phases.

Petrographic data obtained and examined by Hansley et al. (1989) suggest that uranium mineralization occurred before lithification of the basal sandstone of the Chadron formation. Hansley states: *"Dissolution of abundant rhyolitic volcanic ash produced uranium (U) and silicon (Si) rich ground waters that were channeled through permeable sandstone at the base of*

*the Chadron by relatively impermeable overlying and underlying beds. The precipitation of early authigenic pyrite created a reducing environment favorable for precipitation and accumulation of U in the basal sandstone. The U has remained in a reduced state, as evidenced by the fact that the unoxidized minerals, coffinite and uraninite, comprise the bulk of the ore."*

Based on similar regional deposition, the MEA ore body is expected to be similar mineralogically and geochemically to that of the ore body at the CPF. The ore bodies in the two areas are within the same geologic unit (the basal sandstone of the Chadron Formation) and have the same mineralization source. The sites are separated by only a few miles, and the cause of mineral deposition in the two areas appears to be similar. Neither site is anticipated to be significantly affected by recharge or other processes.

2.6.1.3 Structural Geology

Regional uplift during the Laramide Orogeny forced the southward retreat of the Cretaceous Interior Seaway, resulting in the subaerial exposure and weathering of rock units from Early Cretaceous to Eocene age across the northern Great Plains (including the Pierre Shale). The depositional basin associated with deformation of the Wyoming thrust belt and initial Laramide uplifts to the west of Nebraska, represented a structural foredeep. The greatest uplift occurred in the Black Hills, which lie north of Sioux and Dawes Counties in southwestern South Dakota. Lisenbee (1988) provides a comprehensive summary of the tectonic history of the Black Hills uplift. The pre-Oligocene Black Hills uplift (<37 Ma) occurred prior to the deposition of the Eocene-Oligocene strata of the White River Group. Strata of the White River Group cover most of the eroded roots of the Black Hills uplift as well as the syntectonic sedimentary rocks in the Powder River and Williston basins. The Hartville, Laramie, and Black Hills uplifts supplied sediment for rivers that flowed east-southeast across the study area (Clark 1975; Stanley and Benson 1979; Swinehart et al. 1985).

The most prominent structural expression in northwest Nebraska is the Chadron Arch (**Figures 2.6-15** and **2.6-16**). Together with the Chadron Arch, the Black Hills Uplift produced many of the prominent structural features presently observed in the region. The Chadron Arch is an anticlinal feature that strikes roughly northwest-southeast along the northeastern boundary of Dawes County. Swinehart et al. (1985) suggested multiple phases of probable uplift in northwestern Nebraska near the Chadron Arch between about 28 Ma and <5 Ma. The only known surficial expressions of the Chadron Arch are outcroppings of Cretaceous rocks that predate deposition of the Pierre Shale in the northeastern corner of Dawes County, as well as in small portions of Sheridan County, Nebraska and Shannon County, South Dakota. The general locations of faults in northwest Nebraska are depicted on the State Geologic Map shown on **Figure 2.6-1**.

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The 230-mile (370-km) long Pine Ridge escarpment exhibits an average of 1,200 feet of relief (Nixon 1995). The Pine Ridge is an arc roughly concentric to the Black Hills Dome, which suggests an apparent structural relationship. Nixon (1995) interpreted the escarpment as representing the southern outermost cuesta of the Black Hills Dome. The escarpment is capped by sandstone of the Arikaree Group with exposed deposits of the White River Group mapped along the topographically lower northern side of the escarpment.

Crow Butte operations, including the CPF, NTEA, and TCEA, are within the Crawford Basin (DeGraw 1969). The proposed MEA lies just outside of the southern boundary of the basin along

the Cochran Arch. DeGraw (1969) substantiated known structural features and proposed several previously unrecognized structures in western Nebraska based on detailed studies of primarily deep, oil test hole data collected from pre-Tertiary subsurface geology. The Crawford Basin was defined by DeGraw (1969) as a triangular asymmetrical basin about 50 miles (80 km) long in an east-west direction and 25 miles (40.2 km) to 30 miles (48.3 km) wide. The basin is bounded by the Toadstool Park Fault on the northwest, the Chadron Arch and Bordeaux Fault to the east, and the Cochran Arch and Pine Ridge Fault to the south (**Figures 2.6-15** and **2.6-16**). The Crawford Basin is structurally folded into a westward-plunging syncline that trends roughly east-west. Note that the Bordeaux Fault, Pine Ridge Fault, and Toadstool Park Fault proposed by DeGraw (1969) are not presented on the State Geologic Map (**Figure 2.6-1**). The Toadstool Park Fault has been mapped at one location (T33N, R53W) and is estimated to have had approximately 60 feet of displacement (Singler and Picard 1980). The City of Crawford is located near the axis of the Crawford Basin. More recent fault interpretations by Hunt (1990) for northwest Nebraska are also shown on **Figure 2.6-16**, which include the Whetstone Fault, Eagle Crag Fault, Niobrara Canyon Fault, and Ranch 33 Fault in the vicinity of the Town of Harrison in Sioux County. The faults identified by Hunt (1990) all trend to the northeast-southwest, sub-parallel to the Pine Ridge Fault (**Figure 2.6-16**).

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Niobrara River Fault

The structural map by DeGraw (1969) referenced above, was subsequently modified by DeGraw (1971) to include additional features. Of these, the Niobrara River Fault is most relevant to the MEA. DeGraw (1971) mapped the Niobrara River Fault as occurring parallel to the Niobrara River in southernmost Dawes County and northernmost Box Butte County (**Figure 2.6-16**). No description of the Niobrara River Fault is provided, nor is evidence provided in DeGraw (1971) to support the interpretation of its location. As described above, many of the fault locations (e.g., Pine Ridge Fault) interpreted by DeGraw (1969), were based on the apparent displacement of the pre-Tertiary geologic surface (e.g., top of Pierre Shale) or an unpublished structural contour map of western Nebraska. It is unknown whether the published location of the Niobrara River Fault (DeGraw 1971) is based on an unpublished revision of the pre-Tertiary geologic surface provided in DeGraw (1969) or other data sources. Structural contour mapping of the pre-Tertiary surface by CBR does not provide evidence of displacement by the Niobrara River Fault within the MEA.

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As presented by DeGraw (1971), the Niobrara River Fault appears to be a western extension of the Hyannis-North Platte Fault and forms the northern boundary of a graben which contains the Niobrara River valley. An unnamed fault forms the southern boundary of the graben. These faults appear to be generally continuous with the Agate Spring Fault complex of eastern Sioux County (Hunt 1990; **Figure 2.6-16**). Approximately 60 feet of vertical displacement of Arikaree Group sediments has occurred along the Agate Springs Fault in T28N, R55W. Radiometric dating of volcanic tuff displaced by the Agate Springs Fault indicates a maximum age of approximately 19.2 million years for the Agate Springs Fault, and by extension, the Niobrara River Fault (Hunt 1990). Because the Agate Springs and Niobrara River Faults are not included in the USGS Quaternary Fold and Fault Database (USGS 2010), a compendium of faults with evidence of movement between 1.6 million years and ago and the present), it can be inferred that the most recent movement along both faults was between 19.2 and 1.6 million years ago. Neither the exact location of the Niobrara River Fault, nor the amount of potential offset of the fault at depth in the vicinity of the MEA can be determined based on known information.

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Cameco geophysical data was reviewed to determine if additional data supports the location of the Niobrara River Fault and associated graben proposed by Stout et al. (1971). **Figure 2.6-14** presents a regional structural contour map of the top of the Pierre Shale. Boring data indicate the presence of a west-east trending structural trough along the top of the Pierre Shale in the vicinity of the Niobrara River. This trough is generally parallel to, but slightly to the north of the proposed graben location (**Figure 2.6-16**). The best evidence of the structural trough is from Cameco exploration borings located west of the MEA license boundary and the feature may extend to the southern portion of the MEA license boundary. Due to lithologic similarities between the lower Arikaree Group and upper Brule Formation, identifying the geologic contact between those units based on geophysical logs or drill cuttings observation is tenuous; therefore, potential offset of the Arikaree Group correlative to that observed in outcrop at the Agate Springs Fault has not been assessed. It cannot be determined from existing data whether the structural trough represents a graben related to the proposed Niobrara River Fault, a synclinal feature related to the southern limb of the Cochran Arch, or a paleotopographical feature. As further work is completed at MEA, more data will become available regarding the potential presence of the proposed Niobrara River Fault. Additional aquifer pumping tests will be conducted to provide coverage to all areas to be mined to demonstrate the natural confinement of the basal sandstone of the Chadron Formation in the southern portion of the MEA.

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Diffendal (1994) performed lineament analyses on a mosaic of early Miocene synthetic-aperture radar images and largely confirmed known faults in the vicinity of Chadron. Lineaments in the radar image along Pine Ridge, located to the south of Chadron, are attributed to jointing or faulting and trend N40E and N50W (Diffendal 1982). Similar features were also noted west of Fort Robinson. Swinehart et al. (1985) report that these features are likely an extension of the Wheatland-Whalen trend in Wyoming (Hunt 1981; Wheeler and Crone 2001).

Structural features, such as faults and folds, can be identified and characterized using borehole geophysical data. These data, when correlated and combined with additional borehole data from other nearby holes, provides one of the best methods for identifying and describing subsurface features. Drill hole density (distance between successive drill holes) must be high enough to provide confidence that any observed potential structure seen between two drill holes is the result of movement along a fault and not the result of erosion, depositional variation, or lateral discontinuity. It is only when many of these individual data points (drill holes) are plotted together along with other observations that they can be interpreted to discover the presence of these structural features. As drilling density increases, the minimum size of offset required for detection decreases. Within MEA, the drill holes are located mostly on 100-foot centers with scattered areas of greater density. CBR estimates that with this density of drilling, it would require an offset of at least 10 to 15 feet to be obviously notable, and the offsets would need to be noted within multiple holes across more than a single horizon.

Former drilling activities at the Crow Butte Project identified a structural feature, referred to as the White River Fault, located between the CPF Class III permit area and the NTEA (**Figure 2.6-16**). Evidence of a fault was identified during the exploration drilling phase of the Crow Butte Project (Collings and Knode 1984). The fault is manifested in the vicinity of the NTEA as a significant northeast-trending subsurface fold. The detailed kinematics of the White River Fault were investigated during preparation of the NTEA Petition for Aquifer Exemption. An extensive review of drilling and logging data determined that, while the White River Fault may cut the Pierre Shale at depth along with stratigraphically lower units, there is no evidence that a fault

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offsets the geologic contact between the Pierre Shale and overlying White River Group or individual members of the White River Group. This fault does not appear to be present in the vicinity of the MEA.

Pine Ridge Fault

Approximately 5 miles (8 km) north of the MEA is the inferred Pine Ridge Fault, located along the northern edge of the Pine Ridge Escarpment (**Figure 2.6-16**). The east-west trending fault is inferred from several lines of evidence, but no detailed study of it has yet been published. The fault was initially proposed by DeGraw (1969) based on subsurface data, which indicated the presence of a normal fault, with north side down displacement of about 300 feet. The fault is sub-parallel to the Cochran Arch (**Figure 2.6-1**). Swinehart et al. (1985) reported normal faulting along the feature that post-dates the Upper Harrison (Arikaree Group).

CBR geologists have reviewed the available drill data in an attempt to substantiate the presence of the inferred Pine Ridge Fault, and if present, to determine the extent and impact of this fault on operations. Using the single point resistance on geophysical logs, the depth to the contact between the Pierre Shale and overlying Chadron Formation was determined. Cross-sections were prepared for the TCEA Class III UIC Permit application, are 9 to 10 miles (14.5 and 16 km, respectively) northwest of the MEA, and show the contact surface elevations.

Cross-sections constructed south of the CPF and TCEA permit boundaries do not support the presence of the Pine Ridge Fault within the AOR for the TCEA permit as inferred by DeGraw (1969), nor do they support the presence within the MEA AOR. All five cross-sections are included in this application as **Appendix Z**. The cross-sections do not substantiate a reported north side down vertical displacement of 300 feet, and in two of the cross-sections, the top of the Pierre Shale surface elevations decrease southward, which is contradictory to a north side down vertical displacement. The cross-sections presented in **Appendix Z** show that gentle increases in the elevation for the top of the Pierre Shale are most likely a result of topographic lows on the eroded surface of the Pierre Shale or structural dip due to flexing associated with the formation of the Crawford Basin. Given the magnitude of folding observed elsewhere in the Crawford Basin, it is entirely feasible that displacement along an inferred fault would not be required to explain observed elevation changes for the top surface of the Pierre Shale. As none of the cross-sections completed for the TCEA Class III UIC Permit, nor do those completed for the MEA show indications of the Pine Ridge Fault, it is logical to conclude that the MEA and the MEA AOR are not affected by this supposed fault.

2.6.1.4 Seismology

**National Seismic Hazard Maps and Risks**

The USGS updated the National Seismic Hazard Maps in 2008, which includes changes in the methodology used to model potential seismicity in any given region (Petersen et al. 2008). Wheeler and Crone (2001) described Quaternary fault zones and their potential seismic activity. Their findings were used to develop the prior National Seismic Hazard Map. The revised maps incorporate new seismic, geologic, and geodetic information on earthquake rates and associated ground shaking. The maps supersede versions released in 1996 and 2002. The next update to the National Seismic Hazard Maps is scheduled for 2014.

The National Hazard Maps show the distribution of earthquake shaking levels that have a certain probability of occurring in the U.S. (**Figure 2.6-17**). The hazard rating ranges from the lowest hazard (0.4 %g) to the highest (64+ %g), with the City of Crawford area and the majority of Nebraska being located in a low hazard ranking level of 4 to 8 %g. The term "%g" is a unit of acceleration (movement of earth) measured in terms of gravity (g) (i.e., acceleration due to gravity). Peak acceleration refers to the maximum acceleration (movement) experienced during a non-uniform earthquake event (i.e., starts off small, achieves a maximum, and then decreases).

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The seismic hazard map for Nebraska (**Figure 2.6-18**), represents the peak acceleration (%g) with a 2 percent probability of exceedances in 50 years (USGS 2009a), meaning that in a given 50-year period, there is only a 2 percent chance of seismic shaking exceeding any given equivalent percentage of acceleration due to Earth's gravity. **Figure 2.6-18** also shows that the modeled peak acceleration due to seismic shaking in the City of Crawford area is very low: 6 to 8 %g for the majority of the immediate area and 8 to 10 %g in a much smaller area, meaning that the maximum shaking due to any given earthquake in the region during a 50-year period would be equivalent to only 10 percent or less of the force of gravity at Earth's surface. These estimates demonstrate that the Marsland and City of Crawford area are at the low end of the USGS' hazard ranking system for earthquake risks. Note that the differences between **Figures 2.6-17** and **2.6-18** in hazard ranking values are due to the use of different scales (i.e., 4 to 8 versus 6 to 8, respectively).

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## Earthquake Magnitude and Intensity

Earthquakes release different amounts of energy, and the strength of this energy can be measured by magnitude and intensity (CDERA 2009). A comparison of the magnitude and intensity scales is shown in **Table 2.6-4** as well as the USGS abbreviated descriptions of the 12 levels on the Modified Mercalli (MM) scale. The Richter Scale is used to measure the magnitude of an earthquake and is a measure of the physical energy released or the vibrational energy associated with the earthquake. In general, earthquakes below 4.0 on the Richter Scale do not cause damage, and earthquakes below 2.0 usually cannot be felt. However, earthquakes over 5.0 on the Richter Scale can cause damage. An earthquake of a magnitude 6.0 is considered strong, and a magnitude of 7.0 is considered a major earthquake.

The MM scale measures the intensity and consists of 12 increasing levels of intensity that range from imperceptible shaking to catastrophic destruction (USGS 2009b). It is an arbitrary ranking by the USGS based on observed effects rather than mathematics.

For states in the U.S. that had reported earthquakes with a magnitude of 3.5 or greater from 1974 to 2003, the State of Nebraska had a total of eight (less than 0.05 percent of the total of 21,080 earthquakes occurring in the U.S.; USGS 2009d). **Figure 2.6-18** is a seismic hazard map of Nebraska (USGS 2009e). A seismicity map of Nebraska that shows the distribution of earthquakes from 1973 through 2013 is shown on **Figure 2.6-19**.

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The first significant earthquake recorded in Nebraska occurred on April 24, 1867, apparently centered near Lawrence, Kansas. It affected an estimated area of 301,159 square miles ($mi^2$) (780,000 square kilometers [$km^2$]) including much of Nebraska. Since 1867, there have been at least seven earthquakes of MM Intensity V or greater originating within Nebraska's boundaries. It is thought that the strongest earthquake in Nebraska occurred on November 15, 1877. The total area affected was approximately 138,996 $mi^2$ (360,000 $km^2$) including most of Nebraska. The

most recent earthquake occurred on November 18, 2010 (depth of 3.1 miles [5 km]), approximately 15 miles (24.1 km) east-southeast of Columbus, Nebraska in Platte County, east central Nebraska (lat. 41.37N long. 97.07W). The magnitude of this earthquake was 3.3 on the Richter Scale. The epicenter was approximately 326 miles (525 km) east southeast of the City of Crawford.

**Earthquakes along the Chadron and Cambridge Arches in Western Nebraska**

The locations of the Chadron and Cambridge Arches in Nebraska are shown on **Figure 2.6-15**. Earthquakes that have occurred in Nebraska in the vicinity of the Chadron and Cambridge Arches from 1884 to 2009 are identified in **Table 2.6-5**. The MM Intensity of these earthquakes ranged from I to VI, with the majority between I and III. The strongest of these earthquakes centered in Dawes County (near Chadron) occurred July 30, 1934 with an intensity of VI. It affected an estimated area of approximately 23,166 mi$^2$ (60,000 km$^2$) in Nebraska, South Dakota, and Wyoming. This earthquake resulted in damaged chimneys, plaster, and china. An earthquake that occurred on March 24, 1938 near Fort Robinson had an intensity of IV; no additional information is available. An Intensity IV earthquake should be felt indoors by many and cause dishes, windows, and doors to be disturbed. An earthquake occurred on March 9, 1963 near Chadron, and was reported to last about a second. It was not accompanied by any damage or noise and was not even noticed by many of the residents of Chadron. An earthquake occurred on March 28, 1964 near Merriman, the vibrations from which lasted about a minute and caused much alarm, but no major damage occurred. Books were knocked off shelves, and closet and cupboard doors swung open. On May 7, 1978 an earthquake with Intensity V occurred in southwestern Cherry County, also near the Chadron Arch. No major damage was reported from this earthquake.

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Earthquakes occurring from 1992 through 2007 within 125 miles (201.2 km) of the City of Crawford in Wyoming and South Dakota are shown in **Table 2.6-6**. The Richter Magnitude measurements ranged from 3.0 to 3.8 for Wyoming and 2.5 to 4.0 for South Dakota. The MM Intensity values for Wyoming ranged from II to IV, with all but one of the total nine observations ranging from II to III. The MM Intensity values for South Dakota ranged from I to IV, with all but one of the total observations ranging from I to III. The most recent earthquake within the region occurred on November 19, 2011, in South Dakota with the epicenter located 30 miles (48.3 km) west-northwest of the City of Chadron. The earthquake had a magnitude of 2.8 with a depth of approximately 3.0 miles (4.9 km). The most recent earthquake in Wyoming occurred on November 19, 2011 and was located 69 miles (111 km) north of Jackson, Wyoming, a significant distance from the City of Crawford. It had a magnitude reading of 1.7 with a depth of approximately 1.0 mile (1.2 km).

Although the risk of major earthquakes in Dawes County and the State of Nebraska is low (Burchett 1990), some low to moderate tectonic activity has occurred (Rothe 1981). This tectonic movement is also suggested by geomorphic and sedimentation patterns during the Pleistocene (Rothe 1981), which reflect such movement. Previous seismic activity along the Cambridge Arch has been reported as possibly related secondary recovery of oil in the Sleepy Hollow oil field located in Red Willow County in southwest Nebraska (Rothe et al. 1981). However, deeper events suggest more recent low-level tectonic activity on the Chadron and Cambridge Arches.

Based on information discussed above, and the historical records for the proposed MEA in northwest Nebraska, no major effects would be expected from earthquakes on ISR activities in the MEA area.

2.6.1.5 Inventory of Economically Significant Deposits and Paleontological Resources

According to the NOGCC, there never has been any oil and gas production in Dawes County (NOGCC 2013a). There are no current applications for permits to drill in Dawes County. Two wells are currently producing in Sioux County, but are located at a significant distance southwest of MEA in section 8 Township 25 North, Range 55 West and section 11 Township 25 North, Range 56 West (NOGCC 2013b). The only non-fuel mineral produced in Dawes County is sand and gravel. Coal is not produced anywhere in Nebraska (Nebraska 2010), nor are coal beds expected to be encountered during drilling within the MEA.

Significant fossil resources, particularly mammalian, are recognized from the Arikaree Group and White River Group in northwestern Nebraska (Hunt 1981; LaGarry et al. 1996; Terry and LaGarry 1998; Tedford et al. 2004). The White River Group, Arikaree Group, and Ogallala Formation are all ranked as Class 5 geologic units in Wyoming under the Potential Fossil Yield Classification (PFYC) System (BLM 2008). Class 5 units are highly fossiliferous geologic units that predictably produce vertebrate fossils or scientifically significant invertebrate or plant fossils that are at risk of human-caused adverse impacts or natural degradation (BLM 2009). PFYC rankings have not been assigned for Nebraska, but due to the abundance of fossils known from these units nearby, similar potential for scientifically significant paleontological resources can be reasonably inferred.

Several quarries near Agate Fossil Beds National Monument, located in Sioux County, contain Miocene mammals. The sites are located about 25 miles (40.2 km) from the MEA. Mammalian orders represented within the upper Harrison Beds and the Harrison-Monroe Creek Formation include Carnivora, Canidae, Amphicyonidae, Ursidae, Mustelidae, Perissodactyla, and Artiodactyla. Fossilized terrestrial beaver burrows called *Daemonelix* are also found in these units (Hunt 1981; NPS 2010). Brontothere (ancient rhinoceros) fossils have been identified in the basal sandstone of the Chadron Formation (Chamberlin Pass Formation) of Sioux County (LaGarry et al. 1996).

2.6.1.6 Soils

The current Crow Butte License Area and the MEA are located in the semiarid northwest region of Nebraska in southern Dawes County. Climate is semiarid (precipitation averages approximately 18 inches per year; SCS 1977). Physiographically, the MEA is located along the southern flank of Pine Ridge, an area of steep dissected terrain. The numerous drainages present within and adjacent to the MEA are tributary to the Niobrara River, located immediately to the south. Box Butte is the dominant physiographic feature immediately south of the Niobrara River and is slightly lower than, but topographically similar to Pine Ridge. Native vegetative cover in the Pine Ridge region is typically mixed-grass prairie and Ponderosa pine trees, but varies across the MEA, with significant areas that are currently cultivated or are degraded rangeland.

An investigation of MEA soils included review of available published soils data. Soils data for the MEA were obtained from the United States Department of Agriculture (USDA), Natural Resource Conservation Service (NRCS) Web Soil Survey (SSS 2011). The sources for the Dawes County soils data available from the Web Soil Survey include the Soil Survey of Dawes County, Nebraska, published in February 1977 (SCS 1977), and updated unpublished materials derived from remote sensing images and other digitized soils mapping of Dawes County. Thirty-

one soil map units are identified in the project area. Their spatial distributions are illustrated on **Figure 2.6-20**, and their aerial extents summarized in **Table 2.6-7**.

Soils in the MEA formed through the weathering of Tertiary bedrock material, loess (windblown silt), colluvium, or unconsolidated alluvium. Soils in the project area are shallow to deep silt loams and loamy very fine sands. Soil depth, grain size, and drainage typically increase closer to the Niobrara River and away from the steeper uplands of the MEA (SCS 1977).

Due to the loamy and fine sandy texture of most soils in the MEA, wind and water erosion pose the most significant risks to soil health and productivity, especially where vegetation has been disturbed. These soil textures also dictate the good drainage and high infiltration rates characteristic of most soils in the MEA.

From specific to general, the MEA landscape is composed of various soil series (soils with similar profiles), complexes (two or more series or miscellaneous areas that cannot be mapped separately), and associations (two or more geographically associated series or miscellaneous areas that have a consistent pattern and relative proportion of soils). In certain areas, the soil material is so rocky, so shallow, so severely eroded, or so variable that it has not been classified by soil series. These areas are called land types and are given descriptive names. An example of this is "sandy alluvial land" found within the Busher-Tassel-Vetal association. The General Soil Map of Dawes County, Nebraska (SCS 1977) illustrates the three soil associations that dominate the MEA, which are generally segregated north-to-south according to topographic and physiographic regimes and parent material. The three soil associations described below are not depicted on **Figure 2.6-20**; however, the individual components of each association are illustrated and described fully later in this section. The Canyon-Alliance-Rosebud soil association is generally found in the northern portion of the MEA and makes up approximately 40 percent of the project area. This upland soil association consists of "deep to shallow, gently sloping to steep, well-drained loamy and silty soils that formed in material weathered from sandstone". Canyon series soils make up about 25 percent of this association, Alliance series soils about 24 percent, and Rosebud series soils about 16 percent. Minor soils and land types make up the remaining 35 percent (SCS 1977) .

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The Busher-Tassel-Vetal soil association is the most extensive within the MEA (35 percent of the project area) and is found on uplands and footslopes. This soil association consists of "deep and shallow, very gently sloping to steep, well-drained to somewhat excessively-drained, sandy soils that formed in colluvium and in material weathered from sandstone". Busher series soils make up about 35 percent of this association, Tassel series soils about 32 percent, and Vetal series soils about 15 percent. Minor soils and land types make up the remaining 18 percent (SCS 1977).

The Valent-Dwyer-Jayem soil association makes up about 25 percent of the project area and is typically found in uplands adjacent to the Niobrara River in the southern portion of the MEA. This soil association consists of "deep, gently sloping to steep, well-drained to excessively-drained sandy soils". Together, the Valent and Dwyer series soils (which are typically mapped as one unit) make up 68 percent of the association, with Jayem series soils and minor soils and land types both making up about 16 percent each (SCS 1977).

**Soil Limitations**

The NRCS characterizes soil mapping units and their limitations for a variety of uses based on a wide range of properties such as soil texture, slope, and thickness. In general, MEA soils are moderately to highly susceptible to water erosion, with K-factors (for all soil horizons) of dominant soil map units ranging from 0.15 to 0.55. Hazards for water erosion are lowest in the southern MEA and generally increase uphill and away from the Niobrara River. Hazards for wind erosion are generally high to moderately high within the proposed Mine Units. Exceptions include MU-6 and portions of MU-1, where the hazard is moderate. MEA soils are particularly susceptible to wind erosion where vegetation cover has been removed. Almost all soils in the MEA have severe or moderate potential for rutting and compaction and have limited suitability as natural road surfaces. Due to the high susceptibilities for wind and water erosion that are prevalent across the MEA, most soils are susceptible to degradation during disturbance. However, almost all MEA soils likely to be disturbed by project activities are also considered to have high soil resiliency (i.e., inherent ability to recover degradation) and high potential for successful restoration. The Tassel soils and Canyon soils in the northern MEA have moderate, or generally favorable, characteristics for restoration. Soil resilience and restoration potential is dependent upon adequate organic matter content, soil structure, low sodium levels, and other factors (SSS 2011).

**Soil Range Classifications**

Most land within the MEA is currently used for rangeland. Different soil units support different types and proportions of rangeland vegetation. Knowledge of which types of vegetation represent healthy or poor rangeland conditions facilitates evaluation of restoration efforts and selection of revegetation seed mixes. Five major rangeland site classifications are present within the MEA and are described below: sandy, savannah, shallow limey, silty, and subirrigated. Minor acreages of sandy lowland, shallow to gravel, silty overflow, and mixed rangelands are also present but are not described. Decreaser plants form the majority of climax cover in all range sites (SCS 1977).

Sandy Range Site

Map units 1881, 1882, 5070, 5978, 6091, and portions of unit 5118 are classified as sandy range. Moderately rapid to rapid permeability of the soils heavily influences vegetation types on these soils. A typical climax plant community is about 50 percent a mixture of decreaser plants such as sand bluestem, little bluestem, and prairie junegrass. The remaining 50 percent is perennial grass, forbs, and shrubs. The principal increasers are blue grama, threadleaf sedge, prairie sandreed, needle-and-thread, sand dropseed, western wheatgrass, fringed sagewort, and small soapweed. A site in poor condition will commonly have blue grama, threadleaf sage, sand dropseed, and western ragweed.

Savannah Range Site

Only map unit 5153 is classified as savannah range; however, this range site makes up approximately 10 percent of the MEA. The types of vegetation that occur on this range site are primarily influenced by the wide variations in soil depth, available water capacity, and relief. About 65 percent of climax plant cover is a mixture of such decreaser grasses as little bluestem, big bluestem, side-oats grama, plains muhly, green needlegrass, prairie junegrass, slender wheatgrass, bearded wheatgrass, and western wheatgrass. About 35 percent consists of other

perennial grasses, forbs, shrubs, and trees. A site in poor condition typically consists of Ponderosa pine and various species of shrubs and vines.

Shallow Limey Range Site

Map units 5152; 6028; and portions of units 1742, 5118, 5211, and 6043 are classified as shallow limey range sites. The alkaline nature of these soils, along with very low to low available water capacity and shallow rooting depths, influences vegetation types on these soils. Approximately 75 percent of climax plant cover is a mixture of decreaser grasses such as little bluestem, sand bluestem, side-oats grama, needle-and-thread, prairie sandreed, plains muhly, and western wheatgrass. Perennial grasses, forbs, and shrubs make up the remaining 25 percent. These increasers include blue grama, hairy grama, threadleaf sedge, fringed sagewort, common prickly pear, broom snakeweed, skunkbush sumac, and western snowberry.

Silty Range Site

Map units 1356, 1357, 1620, 5105, 5106, 5107, 5200, 5871, and 5947 are classified as silty range sites. The vegetation which grows on these sites is influenced mainly by the moderately slow or moderate permeability of the soils and by their moderate to high available water capacity. About 50 percent of the climax plant cover is a mixture of such decreaser grasses as big bluestem, little bluestem, side-oats grama, western wheatgrass, and prairie junegrass. About 50 percent consists of other perennial grasses, forbs, and shrubs. Blue grama; buffalograss; threadleaf sedge; needle-and-thread; Arkansas rose; and numerous forbs such as dotted gayfeather, false boneset, heath aster, skeletonplant, and scarlet globemallow are the principal increasers. A site in poor condition will typically have blue grama, buffalograss, threadleaf sedge, and sand dropseed.

Subirrigated Range Site

Bankard series soils within the MEA (units 1013 and 1014) are classified as subirrigated range sites. The water table in this range site is typically at a depth of 2 feet in the spring and 6 feet in the early fall. Moisture available from the high water table during the growing season is the main influence on vegetation types on these sites. About 70 percent of the climax cover is a mixture of such decreaser grasses as big bluestem, little bluestem, indiangrass, switchgrass, prairie cordgrass, and Canada wildrye. About 30 percent consists of other perennial grasses such as Kentucky bluegrass, green muhley, western wheatgrass, and sedges. A site in poor condition will typically have Kentucky bluegrass, redtop, foxtail barley, dandelion, western ragweed, blue verbena, and lesser amounts of western wheatgrass and sedges.

**Soil Mapping Units**

As defined by the NRCS, a map unit is identified and named according to the taxonomic classification of the dominant soils. Map unit delineation on a soil map represents an area dominated by one or more major kinds of soil or miscellaneous areas. **Table 2.6-7** summarizes the soils in map units found within the MEA. The table provides the map unit symbols, map unit names, and estimated acres of the dominant soils in the MEA. The description of each soil mapping unit includes the potential for wind erosion, water erosion, the farmland classification, and the hydric rating. The farmland classification identifies map units as prime farmland, farmland of statewide importance, farmland of local importance, or unique farmland by identifying which soils are best suited to food, feed, fiber, forage, and oilseed crops. The hydric rating indicates the proportion of the map units that meets the criteria for hydric soils, which are

an indicator for wetlands. The soils in the MEA are also shown as soil map units on **Figure 2.6-20**.

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Soil map units illustrated in **Figure 2.6-20** consist of soil series, soil complexes, and soil associations, as described above. In addition, certain soil map units represent undifferentiated soil groups, which are made up of two or more soils that could be delineated individually but are shown as one unit because similar interpretations can be made for use and management. The name states the two dominant soil series represented in the group, joined by "and". Four soil map units within the MEA (1742, 5118, 5211, and 6043) are soil complexes, two soil map units (1882 and 5070) are undifferentiated soil groups, and one soil map unit (6043) is a soil association with minor distribution within the MEA (**Figure 2.6-20**). The remaining soil map units represent soil series.

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The following section describes the soil series and mapping units for those soils in Dawes County which occur within the MEA as shown on **Figure 2.6-20**. Soil map units 1014, 1356, 1882, 5105, 5126, and 5153 depicted on **Figure 2.6-20** are composite map units consisting of multiple NRCS units. All units combined are divisions of the same soil series, complex, group, or association and were combined to provide a less complex soil map. The map unit number used to label composite map units on **Figure 2.6-20** represents the NRCS map unit with the greatest extent within the Proposed MEA. Soil map units that represent combined NRCS map units are noted below and their constituent NRCS map units are described individually. The descriptions of soil map units that occur within the MEA, as shown on **Figure 2.6-20** and listed in **Table 2.6-7**, are extracted from the NRCS custom Soil Resource Report as provided by the NRCS Web Soil Survey.

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Bankard Series Soils

The Bankard series consists of deep, somewhat poorly drained soils that formed in sandy alluvium on bottom lands along tributaries to the Niobrara River. Slopes range from 0 to 2 percent. Within the MEA, the water table is typically at a depth of 2 to 4 feet, and soils are occasionally frequently flooded. Permeability is rapid, and available water capacity is low. Natural fertility is medium to low, and organic matter content is low. Runoff is slow. Although suited for irrigation, most areas of Bankard series soils are in areas of native grass used for hay or grazing. These soils are not considered prime farmland. They are partially hydric. Bankard soils comprise approximately 7 percent of the MEA. They are mapped as composite unit 1014 on **Figure 2.6-20** and include the following map units:

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1013 – Bankard loamy coarse sand, frequently flooded

This soil is found in bottom lands in the southern portion of the MEA. It is similar to unit 1014 as described below, but is formed in coarser grained alluvial material. Approximately 127 acres of this soil unit are present in the MEA.

1014 – Bankard loamy fine sand, frequently flooded

This soil is found in bottom lands in the MEA. It is similar to other frequently flooded Bankard soils. Some areas are strongly affected by salts and alkali, and salts are visible on the surface in early spring. This soil is marginal for cultivation of alfalfa and forage crops, and drainage systems are necessary to lower the water table in this unit prior to irrigation. Deep-rooted

dryfarmed crops benefit from the high water table during dry periods. Soil blowing is a hazard if the soil surface is not protected. Approximately 189 acres of this soil unit are present in the MEA.

Glenberg Series Soils

The Glenberg series consists of very deep, well drained soils that formed in stratified calcareous alluvium on floodplains and river terraces. Slopes range from 0 to 8 percent. Permeability is rapid, and available water capacity is moderate. Natural fertility and organic content are moderate to low. Glenberg series soils are suitable for dryfarming and irrigated farming. Because they are restricted to steeper areas near drainages, only portions of the Glenberg soils within the MEA are currently cultivated. Glenberg soils comprise less than 1 percent of the MEA and include the following map unit:

1036 – Glenberg loamy very fine sand, 0 to 3 percent slopes

This map unit is located on high bottom land areas that are seldom flooded. A lime layer may be present at the surface, and stratification may be less distinct than in other Glenberg soils. Soil blowing is a hazard if the soil is unprotected. Runoff is slow. This map unit is dryfarmed for wheat, oats, and alfalfa and irrigated for alfalfa to a lesser extent. This map unit occurs in areas as large as 100 acres. Approximately 8.5 acres of this soil unit are present within the MEA.

Bridget Series Soils

The Bridget series consists of deep, well-drained soils that formed in loamy colluvial and alluvial sediment on foot slopes and stream terraces. Permeability is moderate, and available water capacity is high. Natural fertility is medium, and organic matter content is moderate. In areas where slopes are less than 9 percent, these soils are used mostly for cultivated dryfarmed wheat, oats, or alfalfa. These soils are prime farmland if irrigated. The Bridget soils present within the MEA are partially hydric. Bridget series soils comprise approximately 8 percent of the MEA. They are mapped as composite map unit 1356 on **Figure 2.6-20** and include the following map units:

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1356 – Bridget silt loam, 1 to 3 percent slopes

This soil occurs in areas as large as 500 acres on foot slopes and stream terraces near large drainages. Minor areas in higher landscape positions may have a fine sandy loam surface layer or transitional horizon. This soil is partially hydric. Water erosion and gullying are hazards in areas that receive runoff from adjacent slopes. Soil blowing is a hazard if the soil surface is unprotected. Runoff is slow to medium. Approximately 269 acres of this soil unit are present within the MEA.

1357 – Bridget silt loam, 3 to 6 percent slopes

This soil occurs in areas as large as 200 acres on colluvial foot slopes and uplands. It is similar to map unit 1356, but has a thinner surface layer and occurs on steeper slopes. Bayard, Keith, or Rosebud series soils may make up 25 percent of this unit in the Pine Ridge area. Water erosion is a hazard due to runoff received from adjacent higher areas. Soil blowing is a hazard if the soil surface is unprotected. Runoff is medium. Approximately 105 acres of this soil unit are present within the MEA.

Keith Series Soils

The Keith series consists of deep, well drained soils that formed in loess on uplands and tablelands. Permeability is moderate, and available water capacity is high. Natural fertility is medium, and organic matter content is moderate. Keith series soils are suited for dryfarmed and irrigated crops, primarily winter wheat and alfalfa. These soils are prime farmland if irrigated. Keith series soils comprise approximately 1 percent of the MEA and include the following map unit:

1620 – Keith silt loam, 1 to 3 percent slopes

This soil occurs in areas as large as 500 acres on uplands. The soil profile of this unit is similar to other Keith series soils but has a thicker subsoil and may have a loam or fine sandy loam surface layer. Small areas of Alliance, Duroc, and Richfield soils may be present within this map unit. Water erosion is a hazard in some areas, but soil blowing is the main hazard. Runoff is slow. This soil unit is partially hydric. Approximately 53 acres of this soil unit are present in the MEA.

Rosebud-Canyon Complex Soils

The Rosebud-Canyon soil complex consists of intricately adjoining areas of Rosebud series and Canyon series soils. Rosebud soils are moderately deep, well drained soils that formed in material weathered from sandstone on upland areas. Permeability is moderate, and available water capacity is moderate. Natural fertility is medium, and organic matter content immoderate. Rosebud soils are suited to both dryfarmed and irrigated crops, such as wheat, oats, and alfalfa. Canyon series soils are described further below. Rosebud-Canyon complex soils comprise approximately 4 percent of the MEA and include the following map unit:

1742 – Rosebud-Canyon loams, 3 to 9 percent slopes

These soils occur in areas as large as 500 acres on gently rolling and rolling uplands. Rosebud soils make up approximately 50 to 70 percent of the map unit, and Canyon soils approximately 15 to 30 percent. Lesser amounts of other soil series make up 10 to 25 percent. Rosebud soils are found on side slopes, and the Canyon soils are on ridgetops and knolls. Soil blowing and water erosion are hazards if these soils are cultivated and the soil surface is not protected. Runoff is medium to rapid, depending on slope gradient and the type and amount of vegetative cover. Canyon soils are shallow but may be cultivated where adjacent to deeper soils. This soil unit is partially hydric. Approximately 188 acres of this soil unit are present in the MEA.

Valent and Dwyer Group Soils

The Valent and Dwyer soil group consists of intermingled areas of Valent series and Dwyer series soils. Both Valent and Dwyer soils are deep, excessively drained soils that formed in eolian sands on uplands and stream terraces. Both soils have rapid permeability and low available water capacity. Natural fertility and organic matter content of both soils are low. Runoff is slow because both soils absorb water rapidly. Dwyer soils have lime higher in the profile than Valen soils, but are otherwise very similar. These soils are best suited for rangeland grasses, but not for dryland farming. Some irrigated alfalfa is grown in these soils. Both Valent and Dwyer soil units present within the MEA are partially hydric. These soils comprise approximately 23 percent of the MEA. Valent and Dwyer group soils are mapped as composite unit 1882 on **Figure 2.6-20** and include the following units:

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1881 – Valent and Dwyer loamy fine sands, 0 to 3 percent slopes

This map unit occurs in areas as large as 200 acres on uplands and stream terraces, either of which may be hummocky. Soil component distribution varies, and some areas consist almost entirely of either soil series or may have both. Dwyer soils may have pebbles on the surface and throughout the profile. Soil blowing is a hazard in cultivated areas. Approximately 284 acres of this soil unit are present in the MEA.

1882 – Valent and Dwyer loamy fine sands, 3 to 20 percent slopes

This map unit occurs in areas as large as 1,000 acres on uplands. It is very similar to map unit 1881, but occurs on steeper slopes. Wind erosion is a very severe hazard if grass is removed, and blowouts occur in some areas. Approximately 786 acres of this soil unit are present in the MEA.

Vetal and Bayard Group Soils

The Vetal and Bayard soil group consists of intermingled areas of Vetal series and Bayard series soils. Both Vetal and Bayard soils are deep, well-drained soils that formed in sandy alluvium and colluvium on foot slopes. Vetal soils are found on upland swales, and Bayard soils may be found on stream terraces as well as foot slopes. Both soils have moderately rapid permeability and moderate available water capacity. Natural fertility and organic matter content of both soils are moderate. Bayer soils have a thinner surface horizon than Vetal soils. Both soils are suited for dryfarmed and irrigated crops such as wheat, oats, and alfalfa. These soils are prime farmland if irrigated. Vetal and Bayard group soils comprise approximately 2.4 percent of the MEA and include the following map unit:

5070 – Vetal and Bayard soils, 1 to 6 percent slopes

This map unit occurs in areas as large as 300 acres on foot slopes and stream terraces. Vetal soils make up 55 to 75 percent of the map unit, and Bayard soils make up 25 to 45 percent. Areas may be dominated by a single component or may have both present. Soil blowing is a hazard in cultivated areas, and runoff is slow due to rapid absorption of rainfall. Approximately 111 acres of this soil unit are present in the MEA.

Alliance Series Soils

The Alliance series consists of deep, well drained soils that formed in material weathered from sandstone on uplands. Permeability is moderate, and available water capacity is high. Natural fertility is medium, and organic matter content is moderate. These soils are generally suited for dryfarmed and irrigated crops and are prime farmland if irrigated. All Alliance series soils present within the MEA are partially hydric. All Alliance soil units present within the MEA are partially hydric. Alliance series soils comprise approximately 8 percent of the MEA. Alliance series soils are mapped as composite unit 5105 on **Figure 2.6-20** and include the following map units:

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5105 – Alliance silt loam, 1 to 3 percent slopes

This map unit occurs in areas as large as 500 acres on smooth upland areas. This map unit is similar to other Alliance series soils but may have lime present below a depth of 30 inches. Small areas of Rosebud, Dwyer, and Richfield series soils may be present. Soil blowing and water

erosion are a moderate hazard if the soil surface is not protected. Runoff is slow. Most crops are dryfarmed, and wheat is the primary crop, with lesser amounts of oats and alfalfa. Corn is the main crop in irrigated areas. Approximately 242 acres of this soil unit are present in the MEA.

5106 – Alliance silt loam, 3 to 9 percent slopes

This map unit occurs in areas as large as 300 acres on uplands. The soil profile of this map unit is similar to other Alliance series soils, but has a slightly thinner surface layer. This soil is partially hydric. Water erosion and soil blowing are hazards in cultivated areas. Runoff is medium. This soil is used primarily for rangeland or native grass hay. It is suited for cultivation, but effective management practices and cropping systems are needed to help control erosion. Approximately 88 acres of this soil unit are present in the MEA.

5107 – Alliance silt loam, 3 to 9 percent slopes, eroded

This map unit is similar to unit 5106, but has a surface layer thinner than 7 inches which has been at least partially removed by erosion. Lime may be present at the surface, and the subsoil may be thinner than other Alliance series soils. Slope steepness limits irrigation development. Approximately 29 acres of this soil unit are present in the MEA.

Busher and Tassel Complex Soils

The Busher and Tassel soil complex consists of intricately adjoining areas of Busher series and Tassel series soils on uplands. Busher soils are found on the middle and lower portions of slopes and Tassel soils are on ridgetops, knolls, and sides of small drainages. This soil unit is not hydric. Busher and Tassel complex soils comprise approximately 4 percent of the MEA and include the following map unit:

5118 – Busher and Tassel loamy very fine sands, 6 to 20 percent slopes

This map unit occurs in areas as large as 100 acres on uplands. Slopes are mostly from 9 to 20 percent, but may be as low as 6 percent. Busher loamy very fine sand makes up about 60 percent of this unit, and Tassel loamy very fine sand makes up about 40 percent. Areas of shallower soils are present where bedrock is at a depth of 20 to 36 inches. Soil blowing and water erosion are serious hazards if the native grass cover is removed. Runoff is medium. Most of this soil unit is used for native grass rangeland. Approximately 185 acres of this soil unit are present in the MEA.

Busher Series Soils

The Busher series consists of deep, well drained to somewhat excessively drained soils that formed in material weathered from sandstone on uplands. Permeability is moderately rapid, and available water capacity is moderate. Natural fertility is medium to low, and organic matter content is moderate. Soil blowing and water erosion are serious hazards on all Busher series soils if the protective vegetation cover is removed. Where slopes are less than 9 percent, these soils are suited for cultivation and irrigation. Areas with slopes less than 6 percent (map units 5123 and 5124 below) are considered Farmland of Statewide Importance. No other Busher soils are considered prime farmland. Soil units 5123, 5124, and 5128 are partially hydric, but unit 5126 is

not. Busher series soils comprise approximately 15 percent of the MEA. Busher series soils are mapped as composite unit 5136 on **Figure 2.6-20** and include the following map units:

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5123 – Busher loamy very fine sand, 1 to 6 percent slopes

This map unit occurs in areas as large as 100 acres on uplands. This unit is similar to other Busher series soils, but may have a surface layer consisting of very fine sandy loam or sandy loam, a transitional layer of loam or very fine sandy loam, or areas of shallower soil where bedrock is at a depth of 20 to 40 inches. Areas of Bridget, Jayem, Vetal, and Tassel soils may be present and make up as much as 15 percent of this unit. Management concerns include conserving soil moisture and maintaining soil fertility. This soil unit typically occurs in areas of native grass. Approximately 142 acres of this soil unit are present in the MEA.

5124 – Busher loamy very fine sand, 1 to 6 percent slopes, eroded

This map unit is similar to unit 5123, but occurs in areas as large as 200 acres and typically has a thinner (4 to 7 inches) surface layer due to erosion. This soil unit typically occurs in areas cultivated for dryfarmed wheat, alfalfa, and oats. Approximately 131 acres of this soil unit are present in the MEA.

5126 – Busher loamy very fine sand, 6 to 9 percent slopes

This map unit occurs in areas as large as 250 acres on uplands. This unit is similar to other Busher series soils, but may have a surface layer thinner than 7 inches and may have lime at a depth of 12 to 18 inches. Areas of Bridget, Jayem, Vetal, and Tassel soils are present and make up as much as 15 percent of this unit. This soil unit typically occurs in areas of native grass. Approximately 162 acres of this soil unit are present in the MEA.

5128 – Busher loamy very fine sand, 6 to 9 percent slopes, eroded

This map unit is similar to unit 5126, but occurs in areas as large as 100 acres and has a surface layer that is 4 to 7 inches thick. Bedrock may be present in areas of shallow soils at a depth of 20 to 36 inches. Small areas of rock outcrop may be present within this unit. This soil is somewhat droughty and typically occurs in areas cultivated for dryfarmed wheat, alfalfa, and oats. Approximately 135 acres of this soil unit are present in the MEA.

5129 – Busher loamy very fine sand, 9 to 20 percent slopes

This map unit occurs in areas as large as 200 acres on uplands. This unit is similar to other Busher series soils, but has a surface layer that is 4 to 7 inches thick and lime at a depth of 10 to 18 inches in places. Bedrock may be present in areas of shallow soils at a depth of 20 to 36 inches. Conserving soil moisture is a major management concern in this soil. Runoff is medium. This unit occurs primarily in areas of native grass. Areas with flatter slopes are cultivated, but the steepness of this unit makes most areas unsuitable. Approximately 141 acres of this soil unit are present in the MEA.

Canyon Series Soils

The Canyon series consists of shallow, well drained soils that formed in material weathered from sandstone on ridges, knolls, and the sides of upland drainages. These soils are found only in the northern half of the MEA. Canyon soils are typically loams that are at 15 inches or shallower. Permeability is moderate, and available water capacity is low. Natural fertility and organic matter content are also low. Because Canyon soils are steep and shallow, cultivation is limited to areas where they are adjacent to deeper, more suitable soils. These soils are not hydric. Canyon series soils comprise approximately 12 percent of the MEA. Canyon series soils are mapped as composite unit 5153 on **Figure 2.6-20** and include the following map units:

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5152 – Canyon soils, 3 to 30 percent slopes

This map unit occurs in areas as large as 500 acres. This unit is similar to other Canyon series soils, but has a surface layer that may be silt loam or very fine sandy loam. Bedrock may be present at depths of less than 10 inches. Areas of Bridget, Rosebud, Oglala, and Tassel series soils make up less than 20 percent of this unit. Water erosion and soil blowing are very severe hazards if the soil surface is unprotected. These soils are droughty due to low available water capacity and shallow root zones. Conserving soil moisture is a management concern. Runoff is medium until soils are saturated, and then becomes rapid. This unit is typically found in areas of native grass used for grazing. Approximately 13 acres of this soil unit are present in the MEA.

5153 – Canyon soils, 30 to 50 percent slopes

This map unit occurs in areas as large as 500 acres on the sides of upland drainages. These soils are similar to map unit 5152, but occur in areas of steeper slopes that may also contain rock outcroppings. Very steep slopes, shallowness, and rock outcrops limit the use of these soils to range, woodland, and wildlife habitat. Runoff is very rapid. Approximately 537 acres of this soil unit are present in the MEA.

Oglala Series Soils

The Oglala series consists of deep, well drained soils that formed in material weathered from fine-grained sandstone on the middle and lower parts of side slopes in uplands. These soils are found only in the northern half of the MEA. Oglala soils typically have a loam surface layer overlying a silt loam subsoil. Permeability is moderate, and available water capacity is high. Natural fertility and organic matter content are moderate. In general, these soils are better suited to native grass than cultivation due to steep slopes. These soils are not hydric. Oglala series soils comprise less than 1 percent of the MEA and include the following map unit:

5200 – Oglala loam, 9 to 30 percent slopes

This map unit occurs in areas as large as 200 acres on hillsides. The surface horizon of this unit may be thinner (3 to 6 inches) in areas and lime may be present at depths of less than 20 inches. Areas of Bridget, Canyon, Rosebud, and Ulysses soils may be present and make up less than 15 percent of this unit. Water erosion and soil blowing are hazards if the soil surface is not protected. Runoff is medium to rapid, depending on slope steepness and type and amount of vegetative cover. Most of this unit is used for livestock grazing on native grass. Approximately 2 acres of this soil unit are present in the MEA.

Oglala-Canyon Complex Soils

The Oglala-Canyon soil complex consists of intricately adjoining areas of Oglala series and Canyon series soils on side slopes, ridges, and knolls in the northern portion of the MEA. Oglala soils are found on the middle and lower part of side slopes, and Canyon soils are on ridgetops and knolls. These soils are not hydric. The Oglala-Canyon complex comprises approximately 5 percent of the MEA and includes the following map unit:

5211 – Oglala-Canyon loams, 9 to 20 percent slopes

This map unit is found in areas as large as 1,000 acres. Oglala soils make up approximately 60 to 75 percent of this unit, and Canyon soils approximately 25 to 40 percent. Areas of Bridget, Duroc, Keith, Rosebud, and Ulysses soils may be present and make up 25 percent or less of this unit. Fragments of sandstone may be present at the surface in some areas. Water erosion is a hazard if the soil surface is not protected. Runoff is medium to rapid, depending on slope steepness and the type and amount of vegetative cover. This unit is not suited for cultivation and is typically found in areas of native grass. Approximately 236 acres of this soil unit are present in the MEA.

Schamber Series Soils

The Schamber series consists of shallow, somewhat excessively drained soils that occur on escarpments of stream terraces along tributaries of the Niobrara River in the southern portion of the MEA. Schamber series soils typically have a gravelly, very fine sandy loam surface layer and subsoil overlying coarse sandstone gravel at a depth of approximately 12 inches. Permeability is rapid to very rapid, and available water capacity is very low. Natural fertility and organic matter content are low. These soils are not well suited for cultivation and are not hydric. Schamber series soils comprise less than 1 percent of the MEA and include the following map unit:

5254 – Schamber soils, 3 to 30 percent slopes

This map unit is found in areas as large as 50 acres. The surface layer of this unit may be gravelly loam in areas. Areas of deeper soil exist where gravel is present at a depth of 20 to 40 inches. Areas of Keith, Mitchell, and Pierre series soils are present at lower elevations and may comprise up to 15 percent of this unit. Soil blowing and water erosion are hazards if the soil surface is not protected. Runoff is medium to rapid. These soils are typically found in areas of native grass that are used for grazing. The substrate of these soils may be a useful source of gravel for construction activities. Approximately 13 acres of this soil unit are present in the MEA.

Haverson Series Soils

The Haverson series consists of deep, well-drained soils that formed in stratified silty and loamy alluvium on bottom lands and low stream terraces. Areas on very low bottom lands are subject to occasional to frequent flooding. Haverson soils are found only in the northern portion of the MEA. Permeability is moderate to moderately slow, and the available water capacity is high. Natural fertility is medium to low, and organic matter content is low. These soils are rich in lime, which typically occurs at the surface, and are suited for grass and irrigated crops. Haverson soils comprise approximately 1 percent of the MEA and include the following map unit:

5640 – Haverson loam, frequently flooded

This map unit is found in areas of irregular size and shape on low bottom lands and low stream terraces. Flooding frequently occurs due to their low position on the landscape. Areas of Glenberg soils may be included in higher elevation portions of this unit. Flooding is the main hazard and management concern in this unit. Soil blowing can also be a hazard if the soil surface is unprotected. Runoff is slow. Alfalfa is the main crop where cultivated and is suited for irrigation if flooding can be controlled. This soil unit is partially hydric. Approximately 50 acres of this soil unit are present in the MEA.

Tripp Series Soils

The Tripp series consists of deep, well drained soils that formed in silty and loamy alluvium on stream terraces along major drainages. Permeability is moderate in the upper part of the subsoil and decreases with depth where lime has accumulated. Available water capacity is high, natural fertility is medium, and organic matter content is moderate. These soils are suited for dryfarming and irrigation. Tripp soils comprise less than 1 percent of the MEA and include the following map unit:

5871 – Tripp silt loam, 1 to 3 percent slopes

This map unit occurs in areas as large as 200 acres on stream terraces in the north-central portion of the MEA. This unit is similar to other Tripp soils, but may be thinner and may have lime at shallower depths. This map unit may include areas of Bayard and Bridget soils at high elevations and Duroc and Halverson soils at low elevations. Soil blowing and water erosion are hazards if the soil surface is not protected. Runoff is slow. If irrigated, this soil is categorized as prime farmland; however, it is mostly used for dryfarming of alfalfa, wheat, and oats. This soil unit is partially hydric. Approximately 20 acres of this soil unit are present in the MEA.

Duroc Series Soils

The Duroc series consists of deep, well drained soils that formed in colluvium and alluvium derived from loess and weathered sandstone. Permeability is moderate, and available water capacity is high. Natural fertility and organic matter content are moderate. These soils are well suited to cultivation and irrigation. Duroc soils are primarily found as minor components of other soil map units within the MEA. Areas mapped as Duroc soils comprise less than 1 percent of the MEA and include the following map unit:

5947 – Duroc very fine sandy loam, 1 to 3 percent slopes

This map unit occurs on the northern boundary of the MEA on a stream terrace. It occurs in areas as large as 300 acres elsewhere in Dawes County. Alliance, Bridget, Keith, Richfield, and Rosebud soils may be associated with this unit at higher elevations. This soil is partially hydric. Runoff is slow. This unit is suited to irrigation but is mostly dryfarmed for wheat, oats, and alfalfa. This soil is prime farmland if irrigated. Less than 1 acre of this soil unit is present in the MEA.

Jayem Series Soils

The Jayem series consists of deep, well drained to somewhat excessively drained soils that formed in eolian sands on uplands. Permeability is moderately rapid, and available water capacity is moderate. Natural fertility and organic matter content are moderate. These soils are suited to both dryfarmed and irrigated crops. Jayem soils comprise less than 1 percent of the MEA and include the following map unit:

5978 – Jayem loamy very fine sand, 1 to 6 percent slopes

This map unit is found in areas as large as 200 acres on uplands. The surface horizon may consist of very fine sandy loam, and lime occurs at a depth of 10 to 26 inches. Areas of Keith, Sarben, and Vetal soils make up less than 15 percent of this unit. Soil blowing is a hazard if the soil surface is unprotected. Runoff is slow due to moderately rapid infiltration of rainfall. This unit is primarily found in areas of native grass used for grazing or hay, but is well suited for irrigation. This unit is considered to be Farmland of Statewide Importance. Wheat and alfalfa are the most commonly cultivated crops. This soil unit is partially hydric. Approximately 11 acres of this soil unit are present in the central portion of the MEA.

Tassel Series Soils

The Tassel series consists of shallow, well drained soils that formed in material weathered from fine grained sandstone on uplands. The surface horizon and subsoil of Tassel soils are typically composed of loamy very fine sand. Permeability is moderately rapid, and available water capacity is very low. Natural fertility and organic matter content are low. The shallow nature of these soils makes them poorly suited for commonly cultivated crops and better suited for range and wildlife habitat. Lime is typically present at the surface of Tassel series soils. These soils are not hydric. Tassel soils comprise approximately 8 percent of the MEA and include the following map unit:

6028 – Tassel soils, 3 to 30 percent slopes

This map unit is found in areas as large as 500 acres on ridges, knolls, and the sides of upland drainages in the northern and central portions of the MEA. Areas of shallow soils where sandstone occurs at depths of 4 to 10 inches and areas of deeper soils where sandstone occurs at depths of 20 to 40 inches are present within this unit. Small outcrops of sandstone are also included in this unit. Areas of Bayard, Busher, Canyon, Jayem, and Sarben soil comprise up to 20 percent of this unit. Soil blowing is a hazard if the grass cover is removed or damaged. These soils are often droughty, and conserving moisture is a management concern. Runoff is slow to rapid, depending on the slope steepness and type and amount of vegetative cover. This unit is primarily found in areas of native grass used for grazing. Because shallowness and steep slopes make this unit unsuitable for cultivation, it is typically only cultivated where adjacent to deeper soils. Approximately 346 acres of this soil unit are present in the MEA.

Tassel-Ponderosa-Rock Outcrop Association

The Tassel-Ponderosa-Rock outcrop soil association consists of well drained soils that are mapped together in steep upland areas. Tassel series soils are found on ridges. Ponderosa series soils are deep, well drained, very fine sandy loams that formed from residuum weathered from fine-grained sandstone on side slopes. Available water capacity of Ponderosa soils is moderate

and permeability is high (SSS 2011). Rock outcrops are very shallow, excessively drained weathered sandstone that occur on ridges. These soils are not hydric. This soil association comprises less than 1 percent of the project area and includes the following map unit:

6043 – Tassel-Ponderosa-Rock outcrop association, 9 to 70 percent slopes

This map unit occurs along the western margin of the MEA in areas smaller than 10 acres. These soils have a very high potential for wind and water erosion. Runoff is medium to rapid, depending on the slope steepness, type and amount of cover, and presence of rock outcrops. This association is unsuited for cultivation due to steep slopes and shallow soils. Approximately 1 acre of this soil unit is present in the MEA.

Sarben Series Soils

The Sarben series consists of deep, well drained soils that formed in eolian sands on uplands. Permeability is moderately rapid and available water capacity is moderate. Natural fertility is medium to low, and organic matter content is low. Lime occurs at a depth of 24 inches. These soils are suited to dryfarming and irrigation and are considered prime farmland if irrigated. Sarben series soils present within the MEA are not hydric. Sarben soils comprise less than 1 percent of the MEA and include the following map unit:

6091 – Sarben fine sandy loam, 1 to 6 percent slopes

This map unit occurs in areas as large as 100 acres on gently rolling uplands in the south-central portion of the MEA. This unit is similar to other Sarben soils, but has lime deeper in the profile and may be deeper than other variations. Soil blowing and water erosion, to a lesser extent, are hazards if vegetative cover is removed. These soils are moderately droughty, and conserving moisture and improving fertility are management concerns. Runoff is slow. Dryfarmed wheat, alfalfa, and oats are the main uses of this unit, but grass for grazing and hay is also cultivated. Approximately 19 acres of this soil unit are present in the MEA.

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**Table 2.6-1 General Stratigraphic Chart for Northwest Nebraska**

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## Table 2.6-2 Representative Stratigraphic Section – Marsland Expansion Area

| Elevation (ft amsl) | Average Depth (ft bgs) | Group | Formation & Member (Schultz and Stout 1955) | | | Formation and Member (Revised) | | References (Revised) | Formation & Member (USGS) | |
|---|---|---|---|---|---|---|---|---|---|---|
| Varying 4150 -4,380 | 15 - 135 | Arikaree Group | Monroe Creek Formation | | | Upper Harrison Beds | | Swinehart et al. (1985) | Arikaree Group | Harrison Sandstone |
| | | | | | | Monroe Creek-Harrison Formation | | | | Monroe Creek Sandstone |
| | | | Gering Formation | | | Gering Formation | | | | Gering Formation |
| Varying 4,140 -4.020 | 135 - 285 | White River Group | Brule Formation | Whitney Member | | Brule Formation | "Brown Siltstones" | LaGarry (1998) | Brule Formation | Whitney Member |
| | | | | | | | Whitney Member | | | |
| | | | | Orella Member | Orella D | | Orella Member | | | Orella Member |
| | | | | | Orella C | | | | | |
| | | | | | Orella B | | | | | |
| | | | | | Orella A | | | | | |
| 4,020 – 3,890 | 285 – 650 | | Chadron Formation | Upper Chadron | Chadron C | Chadron Formation | Big Cottonwood Creek Member | Terry (1998) Terry and LaGarry (1998) | Chadron Formation | |
| | | | | Upper/Middle Chadron | Chadron B | | | | | |
| 3,890 – 3,380 | 650 -925 | | | Middle Chadron | | | Peanut Creek Member | Terry (1998) Terry and LaGarry (1998) | | |
| 3,380 -3,180 | 925 – 1,025 | | | Upper Interior Paleosol | Chadron A | Chamberlain Pass Formation | Upper Interior Paleosol | Terry (1998) | | |
| | | | | basal sandstone of the Chadron Formation | | | Channel Sandstone | Terry (1998) Terry and LaGarry (1998) | | |
| 3,180 – 3,130 | 1,025 - ? (Bottom not seen in logs) | Montana Group | Pierre Shale | Interior Paleosol | | Pierre Shale | Yellow Mounds Paleosol | Retallack (1983) Terry (1998) | Pierre Shale | |
| | | | | Pierre Shale | | | Pierre Shale | Terry (1998) Terry and LaGarry (1998) | | |

**Notes:**

1) The Shultz and Stout conventions for Formation & Member are utilized throughout this document for consistency with historical permitting, with the exception of the Red Clay Horizon, which is referred to as the Upper Interior Paleosol.
2) Topsoil, colluvial and alluvial deposits are not shown, but are Quaternary in age and range in thickness from 0 to 30 ft-bgs.
3) The terms "Arikaree Group", "Arikaree Formation", and "Arikaree Sandstone" are accepted usages by USGS in Nebraska.
4) The terms "Gering Formation" and "Gering Sandstone" are both accepted usages by USGS in Nebraska.
5) Subdivisions of the Chadron Formation are not formally recognized by USGS in Nebraska.
6) ft amsl = feet above mean sea level; ft bgs = feet below ground surface.
7) Elevations are representative averages for MEA only, and based on Log M-1252.
8) USGS = U.S. Geological Survey

Table 2.6-3 Marsland Expansion Area Coring Summary

| Boring ID Date Completed | Latitude Longitude (deg min sec) | Core Interval (feet bgs) | Core Barrel Type | Geologic Unit | Dominant Observed Lithologies | Core Runs Collected |
|---|---|---|---|---|---|---|
| **Borings Completed in 2011** | | | | | | |
| M-1454C 3/23/2011 | 42 30 45.96736 -103 15 39.46470 | 600-605 | Randolf | Upper Chadron | Siltstone | Run 1 |
| | | 910-915 | Randolf | Middle Chadron | Siltstone | Run 2 |
| | | 1051-1056 | Randolf | Basal Sandstone[1] | Sandstone | Run 3 |
| | | 1056-1061 | Randolf | Pierre Shale | Shale | Run 4 |
| M-1624C 3/28/2011 | 42 30 02.24164 -103 14 49.32652 | 580-585 | Randolf | Upper Chadron | Siltstone | Run 1 |
| | | 860-865 | Randolf | Middle Chadron | Siltstone | Run 2 |
| | | 1020-1025 | Randolf | Basal Sandstone[1] | Sandstone | Run 3 |
| | | 1025-1030 | Randolf | Basal Sandstone[1] | Sandstone | Run 4 |
| | | 1035-1040 | Randolf | Pierre Shale | Shale | Run 5 |
| **Borings Completed in 2013** | | | | | | |
| M-2169C 8/12/2013 | 42 32 11.26329 -103 15 53.03808 | 110-115 | Randolf | Arikaree | Silt | Run 1 |
| | | 155-160 | Randolf | Arikaree | Sandstone | Run 2 |
| | | 355-360 | Randolf | Brule | Sandstone | Run 3 |
| | | 370-380 | Christensen | Brule | Siltstone/Mudstone | Run 4 |
| | | 600-610 | Christensen | Upper Chadron | Mudstone | Run 5 |
| | | 1103-1113 | Christensen | Basal Sandstone[1] | Sandstone | Run 6 |
| | | 1130-1140 | Christensen | Pierre Shale | Shale | Run 7 |
| M-533C 8/12/2013 | 42 30 44.61003 -103 15 38.52320 | 60-70 | Christensen | Arikaree | Sandstone/Siltstone | Run 1 |
| | | 297-307 | Christensen | Brule | Sandstone/Siltstone/Mudstone | Run 3 |
| | | 1038-1043 | Randolf | Basal Sandstone[1] | Sandstone | Run |
| | | 1043-1053 | Christensen | Basal Sandstone[1] / Pierre Shale | Sandstone/Shale | Run 5 |
| M-1956C 8/20/2013 | 42 29 39.82221 -103 14 27.90156 | 42-52 | Christensen | Arikaree | Sandstone | Run 1 |
| | | 72-82 | Christensen | Arikaree | Siltstone | Run 3 |
| | | 193-203 | Christensen | Brule | Sandstone/Siltstone/Mudstone | Run 4 |
| | | 425-435 | Christensen | Brule | Mudstone/Siltstone | Run 5 |
| | | 1004-1014 | Christensen | Basal Sandstone[1] / Pierre Shale | Sandstone/Shale | Run 6 |

Table 2.6-3 Marsland Expansion Area Coring Summary

| Boring ID Date Completed | Latitude Longitude (deg min sec) | Core Interval (feet bgs) | Core Barrel Type | Geologic Unit | Dominant Observed Lithologies | Core Runs Collected |
|---|---|---|---|---|---|---|
| **Borings Completed in 2013 (continued)** | | | | | | |
| M-1912C 8/15/2013 | 42 29 07.30429 -103 14 02.26635 | 63-73 | Christensen | Arikaree | Sandstone | Run 1 |
| | | 128-138 | Christensen | Arikaree | Siltstone | Run 2 |
| | | 255-265 | Christensen | Brule | Sandstone/Siltstone/Mudstone | Run 3 |
| | | 965-975 | Christensen | Basal Sandstone[1] / Pierre Shale | Sandstone/Shale | Run 4 |
| M-1635C 8/23/2013 | 42 28 23.73852 -103 13 32.61933 | 70-80 | Christensen | Arikaree | Sandstone/Siltstone | Run 1 |
| | | 197-207 | Christensen | Brule | Sandstone/Siltstone/Mudstone | Run 2 |
| | | 530-540 | Christensen | Upper Chadron | Siltstone/Mudstone | Run 3 |
| | | 960-965 | Randolf | Basal Sandstone[1] | Sandstone | Run 4 |
| | | 965-975 | Christensen | Basal Sandstone[1] | Sandstone | Run 5 |
| | | 985-995 | Christensen | Pierre Shale | Shale | Run 6 |

**Notes:**

1 Basal Sandstone of the Chadron Formation

feet bgs - feet below ground surface

Revised December 2013

**Table 2.6-4 USGS Abbreviated Modified Mercalli (MM) Intensity Scale**

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Table 2.6-5 Historical Earthquakes in Northwestern Nebraska in Proximity to the Chadron and Cambridge Arches (1884 – 2009)

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**Table 2.6-6 Earthquakes in Wyoming and South Dakota Within 125 Miles of City of Crawford, NE (1992 – 2009)**

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**Table 2.6-7 Summary of MEA Soil Resources**

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**Figure 2.6-1 Bedrock Geology of the Marsland Expansion Area**

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**Figure 2.6-2 Marsland Cross-Section Map Showing Artificial Penetrations**

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*Source: Cameco Resources, 2013*

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**FIGURE 2.6-3a**
**MARSLAND CROSS-SECTION A-A'**

PROJECT: CO001636 FORMATTED BY: JC CHECKED BY: JA

ARCADIS 630 Plaza Drive, Ste. 100
Highlands Ranch, CO 80129
P: 720-344-3500 F: 720-344-3535
www.arcadis-us.com