5.0 ATTACHMENT D - MAPS AND CROSS SECTIONS OF USDWs

This attachment includes regional scale maps and cross sections that show the geologic structure and overlying and underlying USDWs relevant to the Dewey-Burdock Project.

5.1 Regional Hydrogeologic Setting

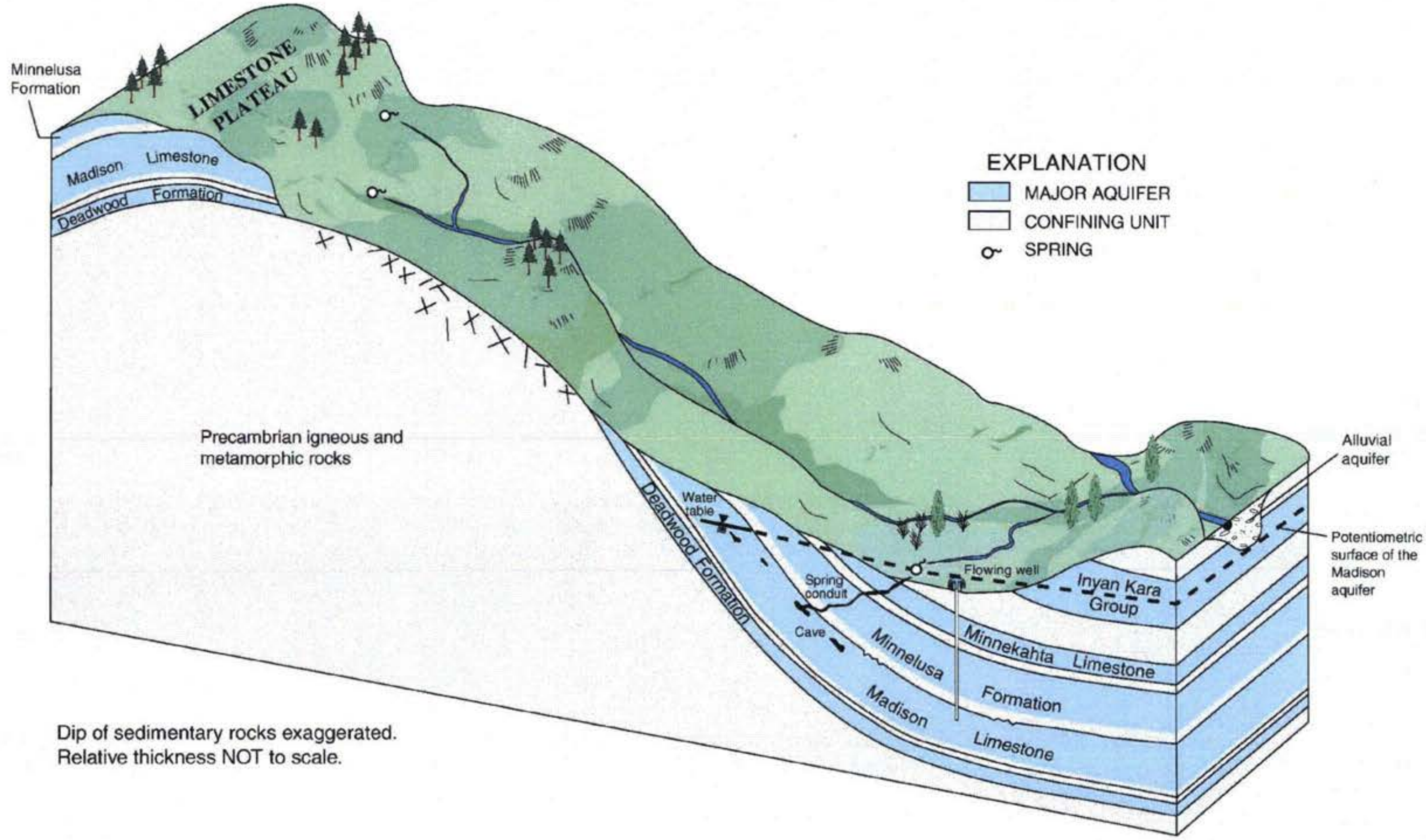
The geology of the southwestern Black Hills in South Dakota and the project area is described in Section 6. In this section, groundwater occurrence and flow are described specifically as they relate to the Dewey-Burdock Project. While the project area is generally similar to the Black Hills regional setting, the site hydrogeology has several unique characteristics as described below.

5.1.1 Regional Hydrostratigraphic Units

The Black Hills Uplift is the principal recharge area for the regional bedrock aquifer systems in southwestern South Dakota and northeastern Wyoming. The stratigraphy of the Black Hills area is summarized on Figure 6.2. Figure 5.1 provides an overview of the hydrologic setting and general hydrogeologic flow within the Black Hills. Regionally, four aquifers are utilized as major sources of water supply. These are the Inyan Kara Group, Minnelusa Formation, Madison Limestone, and Deadwood Formation. In addition to these four major aquifers, other units including the Precambrian, Minnekahta Limestone, Sundance Formation, and Unkpapa Sandstone are utilized locally as sources of water supply at or near the outcrop areas in the central portion of the Black Hills. Within the AOR, none of the deeper regional aquifers below the Sundance is used as a water supply, mainly because of the availability of shallower sources and/or the poor water quality in the deeper aquifers. There are no water supply wells within the AOR completed in aquifers below the Sundance Formation. The closest municipal wells are the Edgemont Madison wells, which are approximately 15 miles to the south-southeast of the center of the project area.

In the 1990s, the U.S. Geological Survey (USGS) undertook an extensive study focusing on the evaluation of the hydrologic significance of selected bedrock aquifers in the Black Hills area – specifically the Deadwood, Madison, Minnelusa, Minnekahta, and Inyan Kara aquifers. In these evaluations, the USGS placed priority on the Madison and Minnelusa aquifers, both of which are used extensively elsewhere in the region for water supplies.

While the review of regional hydrology is prudent and necessary for this application, it should be noted that the site hydrology within the project area is unique compared to the regional Black Hills hydrology. In this regard, intermediate groundwater flow systems in the Fall River Formation and the Chilson Member of the Lakota Formation are independent of the regional



Source: Carter et al. (2003)

Figure 5.1
Diagram Showing a Simplified View of the Hydrogeologic Setting of the Black Hills Area

Dewey-Burdock Project

DRAWN BY	Mays, Hetrick
DATE	24-Jul-2012
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flow system. These intermediate flow systems have their origin in the areas within the eastern portion of the project area (Fall River) and immediately to the east and north of the project area (Fall River and Chilson) where the Fall River and Chilson crop out at the land surface. Both of these flow systems are recharged directly by precipitation and infiltration of surface runoff along the outcrops in and near the eastern portion of the project area.

5.1.1.1 Inyan Kara Aquifer

At distance from the central core of the Black Hills Uplift, the Inyan Kara Group typically contains the first significant aquifer encountered. The Inyan Kara includes two sub-aquifers, the Chilson Member of the Lakota Formation and the Fall River Formation, which are separated by the Fuson Shale confining unit. Refer to Section 6.2.2 for a description of confining units relevant to ISR. The Inyan Kara aquifer is heterogeneous, which results in the two sub-aquifers exhibiting large variations in their hydraulic characteristics at some locations. Regionally, the Inyan Kara ranges from 250 to 500 feet thick, exhibits a large effective porosity (17 percent), and can yield considerable quantities of water from storage (Driscoll et al., 2002). Within the Black Hills, the transmissivity of the Inyan Kara ranges from 1 to 6,000 ft^2/day. Table 5.1 summarizes the hydraulic properties of the major regional aquifers, including the Inyan Kara, determined in previous investigations. The Inyan Kara is confined below by the Jurassic Morrison Formation and above by the Cretaceous Graneros Group.

5.1.1.2 Minnelusa Aquifer

The Minnelusa Formation consists of interbedded siltstone, sandstone, anhydrite, and limestone. The Minnelusa aquifer occurs primarily in saturated sandstone and anhydrite beds within the upper part of the formation (Williamson and Carter, 2001). Within the Black Hills, the Minnelusa ranges in thickness from 375 to 1,175 feet (Driscoll et al., 2002). The porosity is dominantly primary porosity within the sandstone beds, although secondary porosity is present in association with fractures and dissolution features (Williamson and Carter, 2001). Various studies have found the transmissivity of the Minnelusa to range from 1 to 12,000 ft^2/day (Table 5.1). The Minnelusa aquifer is confined above by the Opeche Shale and below by the lower permeability layers at the base of the Minnelusa.

Locally, the Minnelusa produces oil and gas in the Barker Dome to the east of the AOR.

5.1.1.3 Madison Aquifer

The Madison Limestone, also known as the Pahasapa Limestone, is the source of municipal water supplies in numerous communities within and near the Black Hills including Rapid City and Edgemont.

Table 5.1: Estimates of Hydraulic Properties of Major Aquifers from Previous Investigations

Source	Hydraulic conductivity (ft/d)	Transmissivity (ft²/d)	Storage coefficient	Total porosity/ effective porosity	Area represented
Precambrian aquifer					
Rahn, 1985	--	--	--	0.03/0.01	Western South Dakota
Galloway and Strobel, 2000		450 - 1,435		0.10/--	Black Hills area
Deadwood aquifer					
Downey, 1984	--	250 - 1,000	--	--	Montana, North Dakota, South Dakota, Wyoming
Rahn, 1985	--	--	--	0.10/0.05	Western South Dakota
Madison aquifer					
Konikow, 1976	--	860 - 2,200	--	--	Montana, North Dakota, South Dakota, Wyoming
Miller, 1976	--	0.01 - 5,400	--	--	Southeastern Montana
Blankennagel and others, 1977	$2.4x10^{-5}$ - 1.9	--	--	--	Crook County, Wyoming
Woodward-Clyde Consultants, 1980	--	3,000	$2x10^{-4}$ - $3x10^{-4}$	--	Eastern Wyoming, western South Dakota
Blankennagel and others, 1981	--	5,090	$2x10^{-5}$	--	Yellowstone County, Montana
Downey, 1984	--	250 - 3,500	--	--	Montana, North Dakota, South Dakota, Wyoming
Plummer and others, 1990	--	--	$1.12x10^{-6}$ - $3x10^{-5}$	--	Montana, South Dakota, Wyoming
Rahn, 1985	--	--	--	0.10/0.05	Western South Dakota
Cooley and others, 1986	1.04	--	--	--	Montana, North Dakota, South Dakota, Wyoming, Nebr.
Kyllonen and Peter, 1987	--	4.3 - 8,600	--	--	Northern Black Hills
Imam, 1991	$9.0x10^{-6}$	--	--	--	Black Hills area
Greene, 1993	--	1,300 - 56,000	0.002	0.35/--	Rapid City area
Tan, 1994	5 - 1,300	--	--	0.05	Rapid City area
Greene and others, 1999	--	2,900 - 41,700	$3x10^{-4}$ - $1x10^{-3}$	--	Spearfish area
Carter, Driscoll, Hamade, and Jarrell, 2001	--	100 - 7,400	--	--	Black Hills area
Minnelusa aquifer					
Blankennagel and others, 1977	<$2.4x10^{-5}$ - 1.4	--	--	--	Crook County, Wyoming
Pakkong, 1979	--	880	--	--	Boulder Park area, South Dakota
Woodward-Clyde Consultants, 1980	--	30 - 300	$6.6x10^{-5}$ - $2.0x10^{-4}$	--	Eastern Wyoming, western South Dakota

Table 5.1: Estimates of Hydraulic Properties of Major Aquifers from Previous Investigations (cont'd)

Source	Hydraulic conductivity (ft/d)	Transmissivity (ft^2/d)	Storage coefficient	Total porosity/ effective porosity	Area represented
Minnelusa aquifer—Continued					
Rahn, 1985	--	--	--	0.10/0.05	Western South Dakota
Kyllonen and Peter, 1987	--	0.86 - 8,600	--	--	Northern Black Hills
Greene, 1993	--	12,000	0.003	0.1/--	Rapid City area
Tan, 1994	32	--	--	--	Rapid City area
Greene and others, 1999	--	267 - 9,600	$5.0x10^{-9}$ - $7.4x10^{-5}$	--	Spearfish area
Carter, Driscoll, Hamade, and Jarrell, 2001	--	100 - 7,400	--	--	Black Hills area
Minnekahta aquifer					
Rahn, 1985	--	--	--	0.08/0.05	Western South Dakota
Inyan Kara aquifer					
Niven, 1967	0 - 100	--	--	--	Eastern Wyoming, western South Dakota
Miller and Rahn, 1974	0.944	178	--	--	Black Hills area
Gries and others, 1976	1.26	250 - 580	$2.1x10^{-5}$ - $2.5x10^{-5}$	--	Wall area, South Dakota
Boggs and Jenkins, 1980	--	50 - 190	$1.4x10^{-5}$ - $1.0x10^{-4}$	--	Northwestern Fall River County
Bredehoeft and others, 1983	8.3	--	$1.0x10^{-5}$	--	South Dakota
Rahn, 1985	--	--	--	0.26/0.17	Western South Dakota
Kyllonen and Peter, 1987	--	0.86 - 6,000	--	--	Northern Black Hills

Source: Driscoll et al., 2002

The hydraulic characteristics of the Madison aquifer have been extensively studied; aquifer characteristics of the Madison based on the numerous regional investigations are summarized in Table 5.1. The Madison aquifer is mainly a dolomite unit and is characterized by extensive secondary porosity resulting from fractures and associated karstic features (Williamson and Carter, 2001). The thickness of the Madison ranges from 200 feet in the southern Black Hills to 1,000 feet regionally. In the Rapid City area, Greene (1993) found the transmissivity to vary between 1,300 and 56,000 ft^2/day. The aquifer varies from unconfined at its outcrop areas to confined, where reported storativity values range from 10^{-3} to 10^{-6} (Table 5.1). Regionally, water quality data indicate that low-permeability layers within the overlying Minnelusa Formation isolate the Madison from the Minnelusa. At some locations distant from the project area on the core of the Black Hills Uplift, these confining layers may be absent or exhibit poorly confining hydraulic characteristics such that communication between the Madison and Minnelusa occurs.

Regionally, the Madison may be in direct communication with the underlying Deadwood aquifer where the Whitewood and Winnipeg confining units are absent; locally, however, the available data indicate that the Madison Limestone and Deadwood Formations are isolated beneath the project area (Powertech, 2010).

5.1.1.4 Deadwood Aquifer

The Cambrian Deadwood Formation overlies the Precambrian basement and consists of basal conglomerates, sandstone, limestone, and mudstone. The Deadwood ranges from zero to 500 feet thick (Driscoll et al., 2002). Rahn (1985) estimated the effective porosity of the Deadwood to be about 5 to 10 percent. In the northern Black Hills, the effective porosity is presumably lower where the formation has undergone hydrothermal alteration. The transmissivity of the Deadwood is estimated to be in the range of 250 to 1,000 ft^2/day (Table 5.1) (Downey, 1984). Regionally, the Precambrian rocks act as a lower confining unit to the Deadwood although a localized direct connection between the two units can occur at or near the outcrop areas (Williamson and Carter, 2001). Regionally, the Deadwood may be in contact with the overlying Madison aquifer except where the Whitewood and Winnipeg Formations are present and act as semi-confining units (Strobel et al., 1999). As noted, available data indicate that the Madison and Deadwood Formations are isolated beneath the project area.

5.1.1.5 Minor Aquifers

Minor aquifers in the Black Hills include the Minnekahta Limestone, Sundance Formation, Unkpapa Sandstone, Newcastle Sandstone, and Quaternary alluvium. Where present and saturated, these units can yield small amounts of water. In isolated locations distant from the project area, beds within the confining units may also contain water-bearing units (Driscoll et al., 2002). These minor aquifers are generally not widely utilized because of the availability of more reliable water-supply sources.

5.1.2 Regional Potentiometric Surfaces

As part of its 1990s study of the hydrologic significance of selected bedrock aquifers, the USGS developed 1:100,000-scale potentiometric contour maps for the Inyan Kara, Minnekahta, Minnelusa, Madison, and the Deadwood (Strobel et al., 2000a thru 2000e). These maps provide a basis for evaluating regional groundwater flow direction and hydraulic gradients in the Black Hills. Appendix D depicts these regional potentiometric surfaces in relation to the project area. In the development of these potentiometric maps, structural features such as faults and folds were considered. Of significance, no major structural features were identified in or within the immediate vicinity of the project area other than the Dewey Fault, which is located north of the project area, and the Long Mountain Structural Zone, which is located approximately 7 miles south of the project area.

Based on the USGS potentiometric contour maps, regional groundwater flow within the five major aquifers is generally consistent and radially outward from the central Black Hills highlands toward the plains. All five of the aquifers are hydraulically unconfined (partially saturated) near their outcrops in the central highlands and become confined by the overlying strata with distance away from the central highlands. Locally, the potentiometric surface of the aquifers may be above land surface.

The Black Hills are relatively arid with the annual precipitation ranging from about 12 to 28 inches regionally and averaging approximately 16 inches in the project area. While most precipitation can be accounted for as surface runoff and evapotranspiration, regionally, the percentage of precipitation that recharges the aquifers is estimated to vary from 30 percent in the northwestern Black Hills to 2 percent or less in the drier southwestern Black Hills, which includes the project area.

Other sources of recharge to individual units can occur from leakage between aquifers. In general, the potentiometric elevation increases with depth within the stratigraphic section, which provides an upward potential for groundwater flow and limits the potential for downward recharge, which occurs regionally but not locally.

Most interconnection between aquifers appears to be associated with the thinning or absence of confining units between aquifers. Some investigators have suggested that solutioning and subsequent collapse (i.e., karsting) of the overlying strata may provide a pathway for upward groundwater movement (Gott et al., 1974). This is reported to occur some 6 miles northeast of the project area, but no evidence of karsting has been observed in the project area. A detailed analysis of the potential occurrence of breccia pipes and karsting north and east of the project area is presented in Appendix E.

5.2 Site Hydrogeology

The only aquifer in which Class III injection wells will be completed (the Inyan Kara) is recharged locally and isolated from the deep regional flow system in the Paleozoic formations that typically characterize regional groundwater flow and are the focus of numerous USGS research studies.

In the project area, the sedimentary rocks dip gently to the southwest at 2 to 6 degrees. As the land surface is generally flatter than the dip of the underlying bedrock strata, younger strata crop out at the ground surface sequentially from east to west.

The structure is illustrated by the structural contour maps on top of the Fall River (Plate 6.5), Chilson Member of the Lakota (6.3) and Unkpapa Sandstone (Plate 6.1). Based on the logs for thousands of exploration holes, no major faults or other structural features have been identified within the project area.

5.2.1 Site Hydrostratigraphic Units

Refer to Figure 6.2 in Section 6 for a regional stratigraphic column and Section 6.2.2 for a more detailed discussion of the site stratigraphy. The Fall River Formation and Chilson Member of the Lakota Formation are the principal sources of water in the vicinity of the project area for domestic, livestock, and agricultural uses. These same formations are the host rocks for the uranium mineralization within the project area. Within the project area, the deeper regional aquifers are not used as a source of water supply mainly because of their depth of occurrence, availability of shallower sources, relatively low productivity and low historical water demands. There are no water supply wells within the AOR completed in aquifers below the Sundance Formation. The closest municipal wells are the Edgemont Madison wells, which are approximately 15 miles south-southeast of the center of the project area.

In the following discussion, the site hydrogeological characterization focuses on groundwater occurrence and the groundwater flow regimes above the Morrison Formation. The Morrison Formation is the lowermost confining unit for the Dewey-Burdock Project. (See Section 6.2.2 for a discussion of the major confining units.) Because of the low vertical permeability, thickness and continuity of the Morrison Formation across the entire project area and due to the existence of an upward hydraulic gradient between the underlying Unkpapa Sandstone and the Inyan Kara, the proposed ISR activities will not impact any of the formations below the Morrison Formation. The only exception is potential pumping from the Madison or another suitable deep formation for aquifer restoration makeup water and for CPP water supply or use of the Minnelusa and/or Deadwood for management of wastewater in Class V disposal wells.

The Morrison Formation is underlain, in turn, by the Unkpapa Sandstone, Sundance Formation and Spearfish Formation. Based on the results of limited exploratory drilling, the Spearfish in the project area averages approximately 320 feet thick and due to its low vertical permeability is considered a hydrologic barrier between the overlying Jurassic and Cretaceous aquifers and the underlying Paleozoic aquifers.

The Spearfish Formation is overlain by the Sundance Formation, which consists of a 250 to 450-foot thick sequence of red shale and siltstone. In the project area, the Sundance consists mainly of shale and sandstone with an average thickness of 280 feet. In turn, the Sundance is overlain by the Unkpapa Sandstone. Where present, the Unkpapa consists of 50 to 80 feet of well-sorted, fine-grained, aeolian sandstone. Since there is not an intervening confining unit separating the two, the Sundance and Unkpapa are generally considered to be a single hydrostratigraphic unit. The Sundance/Unkpapa is used locally as a water supply within the project area.

5.2.1.1 Morrison Formation

The Morrison Formation, because of its low permeability and continuity beneath the project area, is the lowermost confining unit for the proposed ISR operations. The Morrison averages 100 feet thick and is composed of waxy, calcareous, non-carbonaceous massive shale with numerous limestone lenses and a few thin fine-grained sandstones. Analyses of core samples within the project area have shown the vertical permeability of the Morrison clays to be very low and to range from 9×10^{-9} to 3×10^{-8} cm/sec (0.012 to 0.043 millidarcies, see Table 8.2).

5.2.1.2 Inyan Kara Group

The Jurassic Morrison Formation is unconformably overlain by the Inyan Kara Group, which consists of the Lakota and the Fall River Formations. The sandstone packages within the Fall River and Chilson Member of the Lakota Formations are the host rocks to the uranium mineralization at the Dewey-Burdock Project. The Inyan Kara consists of interbedded sandstone, siltstone, and shale. Based on measured outcrop sections and drill hole data, the Inyan Kara averages about 350 feet thick in the project area.

The Lakota Formation regionally consists of three members which are, from oldest to youngest, the Chilson, Minnewaste Limestone, and the Fuson Members. The Minnewaste Limestone Member is not present in the project area.

Chilson Member

The Chilson Member consists of a complex of fluvial channel sandstone deposits and their fine-grained lateral equivalents and varies from about 100 to 240 feet thick. The Chilson Member is confined below by the Morrison Formation and above by the Fuson Shale. Analyses of core samples of Chilson sandstones within the project area indicate these units exhibit high horizontal permeabilities, ranging from 2.6×10^{-3} to 4.1×10^{-3} cm/sec (2,697 to 4,161 millidarcies, see Table 8.2).

Fuson Member

The Fuson Member is the uppermost member of the Lakota and separates the Chilson Member from the Fall River Formation. As discussed in Section 6.2.2, Powertech has differentiated the Fuson Shale from the Fuson Member of the Lakota Formation for the purpose of characterizing site geology. The Fuson Shale has been mapped by Powertech and consists of 20 to 80 feet of low-permeability shales and clays, which generally occur at or near the base of the unit (Plate 6.8).

The shales and mudstones within the Fuson Shale are highly stratified. Due to this stratification, the vertical permeability is several orders of magnitude smaller than the horizontal permeability. Based on analyses of core samples from the Fuson Shale within the project area, vertical permeabilities range from about 7.8×10^{-9} to 2.2×10^{-7} cm/sec (0.008 to 0.228 millidarcies, see Table 8.2). Estimates of vertical hydraulic conductivity of the Fuson Shale from the 1979 pumping tests conducted in the Fall River and Chilson near Burdock range from 4.6×10^{-8} to 1×10^{-7} cm/sec (Boggs and Jenkins, 1980). Well field-scale pumping tests will be conducted after NRC license issuance (refer to Section 8.2.3). This additional testing will provide further quantification of the low hydraulic conductivity of the confining units.

Fall River Formation

The Fall River Formation is composed of carbonaceous interbedded siltstone and sandstone, channel sandstones, and a sequence of interbedded sandstone and shale. The Fall River ranges from about 120 to 160 feet thick.

The Fall River is confined above by the Graneros Group, a thick sequence of dark shales that varies in thickness from zero, where the Inyan Kara outcrops near the eastern edge of the project area, to more than 500 feet in the northwestern portion of the project area. Because of its thickness and low permeability, the Graneros Group precludes vertical migration of water between the Inyan Kara, overlying alluvial aquifers, and the ground surface.

5.2.1.3 Graneros Group

The Cretaceous Graneros Group consists of several geologic units, including the Skull Creek Shale, Newcastle Sandstone (where present), Mowry Shale, and Belle Fourche Shale, which act as a single confining unit overlying the Inyan Kara. In the project area, the thickness of the Graneros Group ranges from zero at the outcrop of the Fall River to more than 500 feet (Plate 6.10).

The Skull Creek Shale, which directly overlies the Fall River Formation, consists of dark gray to black shale, organic material, and some silt-size quartz grains. The Skull Creek Shale has a thickness of approximately 200 feet and together with the overlying shales of the Graneros Group is the uppermost confining unit for the proposed ISR operations. Analyses of core samples of the Skull Creek clays within the project area indicate low vertical permeabilities on the order of 6.8×10^{-9} cm/sec (0.007 millidarcies, see Table 8.2). The Skull Creek and overlying Mowry Shales have been removed by erosion from the eastern parts of the project area.

The Mowry Shale consists of light gray marine shale with minor amounts of siltstone, fine-grained sandstone, and a few thin beds of bentonite. Dark gray to purple and black iron and manganese concretionary zones are common within the shale.

The Newcastle Sandstone, which is normally present between the Skull Creek Shale and the Mowry Shale, is absent across the project area.

The uppermost unit of the Graneros Group is the Belle Fourche Shale. This 300-foot thick unit consists of thin-bedded gray to black soft shale, containing black to reddish-brown ironstone concretions, which are particularly abundant in the basal 20-30 feet. There is bentonite production from the lower part of the Belle Fourche Shale, but not within the project area or AOR.

5.2.1.4 Terrace Deposits and Quaternary Alluvium

The most recent sedimentary units within the Dewey-Burdock project area are the Quaternary alluvial deposits present along the major drainages and their tributaries. The alluvium varies from 0 to 50 feet thick and consists of an unconsolidated mixture of silt, clay, sand and gravel.

An isopach map depicting the thickness of the alluvium in the Beaver Creek and Pass Creek drainages is shown on Plate 6.11.

5.2.2 Groundwater Occurrence and Flow

Potentiometric contour maps for the Fall River and the Chilson Member of the Lakota are shown on Figures 5.2 and 5.3, respectively. These maps were revised from those presented in the December 2008 Class III application and include more representative water level measurements taken over a 5-day period from April 25 through April 29, 2011. The data used to generate Figures 5.2 and 5.3 are presented in Appendix F, and the procedures for measuring the static water level are described in Powertech (2011).

The potentiometric surface map for the Fall River (Figure 5.2) shows a relatively uniform hydraulic gradient across the project area, with the potentiometric levels decreasing to the southwest. The potentiometric surface for the Chilson (Figure 5.3) shows a slight flattening of the hydraulic gradient across the northwestern portion of the project area but with heads also decreasing to the southwest.

5.2.2.1 Groundwater Flow Systems

Based on the regional and site-specific hydrogeological characterization, groundwater occurrence and flow in the project area can be subdivided into three main components, or flow regimes. These include the deep regional flow system, a shallow perched alluvial groundwater

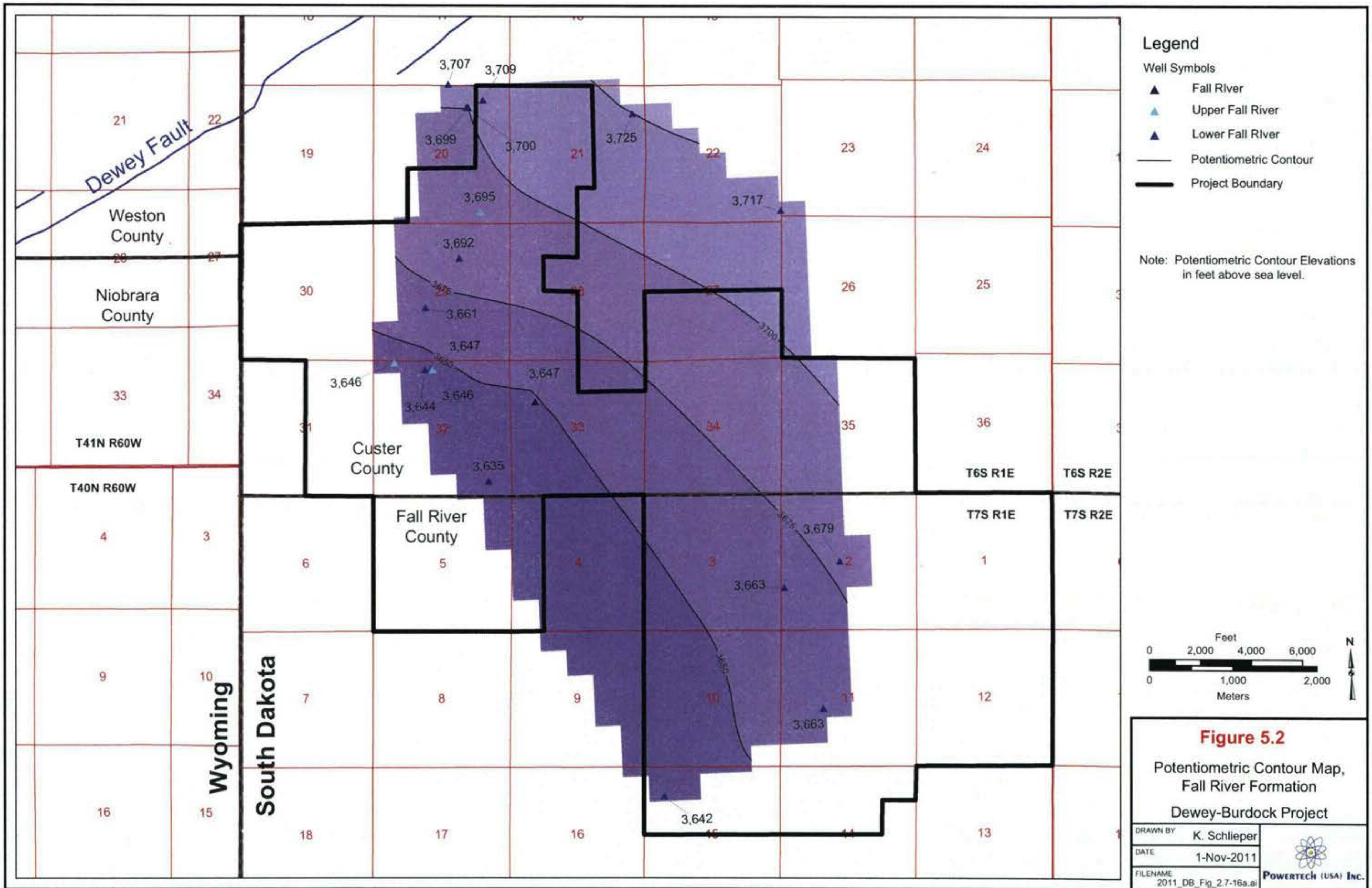

Figure 5.2

Potentiometric Contour Map, Fall River Formation

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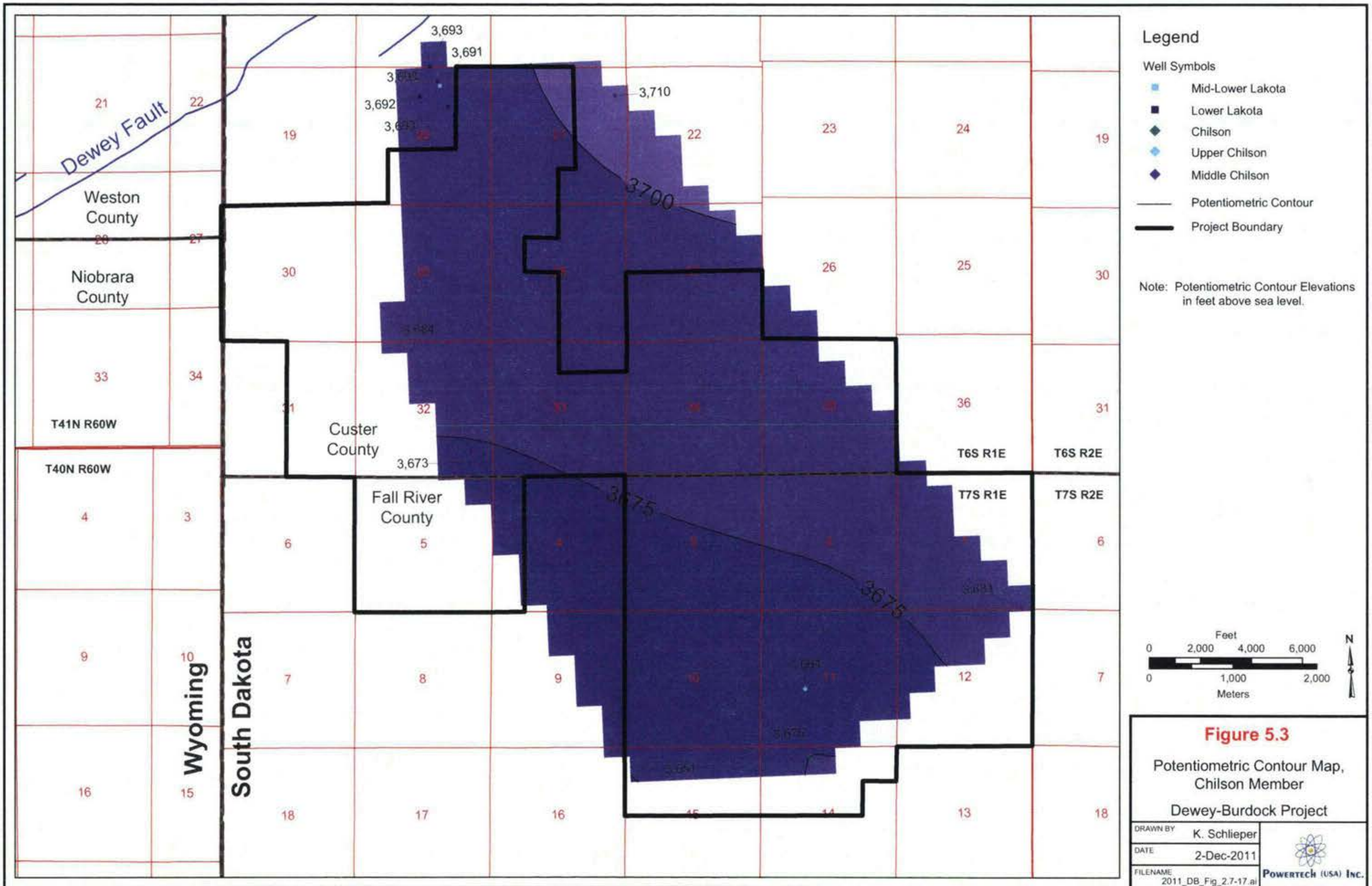

Figure 5.3

Potentiometric Contour Map, Chilson Member

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flow system, and an intermediate groundwater flow system that includes the Fall River and Chilson aquifers.

As described in Driscol et al. (2002), there are multiple deep regional groundwater flow systems within the Paleozoic section. These regional flow systems are associated with the permeable strata within various geologic formations at depth within the Deadwood, Madison, Minnelusa, Sundance/Unkpapa, and the minor aquifers. These deep regional flow systems and associated aquifers are isolated from the shallower formations that are the target of the proposed ISR operations in the Inyan Kara Group in the project area by low-permeability layers, or confining beds.

Shallow, perched groundwater systems exist within the alluvium associated with Beaver Creek, Pass Creek, and Bennett Canyon. These alluvial systems are perched above the top of the Graneros on the western portion of the project area. Groundwater flow within the alluvium is controlled by the configuration of the drainage channel on the top of bedrock and in most situations is generally parallel to surface drainage patterns. In the case of Bennett Canyon, the alluvium directly overlies the Chilson Member of the Lakota. As such, the alluvial groundwater is a potential source of recharge to the underlying Chilson. Bennett Canyon is approximately ½ mile east of the easternmost potential well fields within the project area.

Intermediate groundwater flow systems exist within the Fall River Formation and the Chilson Member of the Lakota. These intermediate flow systems have their origins in the areas within the eastern portion of the project area (Fall River) and immediately to the east and north of the project area where the Fall River and Chilson crop out at the land surface. Both of these flow systems are recharged directly by precipitation that falls on the land surface and by infiltration of surface runoff, primarily in the Pass Creek and Bennett Canyon drainages north and east of the project area, respectively.

Within the project area, the Fall River and the Chilson dip gently to the southwest at 2 to 6 degrees away from their outcrop areas. As a result, groundwater flow within the Fall River and the Chilson generally occurs from the northeast to the southwest toward the Powder River Basin. On a broad regional basis, water from lower Cretaceous aquifers including the Inyan Kara eventually moves northeastward to discharge areas in eastern North Dakota and South Dakota (Whitehead, 1996).

5.2.2.2 Groundwater Recharge and Discharge

The hydrologic characterization for the project area included the measurement of water levels in wells completed in the Inyan Kara, overlying alluvium, and the underlying Sundance/Unkpapa. The current data collection programs began in 2007 and are continuing.

Potentiometric surface maps for the Fall River and Chilson (Lakota) are shown on Figures 5.2 and 5.3, respectively. The water level data collected to date from the Unkpapa within the project area do not have sufficient spatial variability or temporal consistency to construct a potentiometric contour map of the Unkpapa. Information available to date shows substantially higher potentiometric head in the Unkpapa than in the Fall River and Chilson. Powertech anticipates that, with installation of additional wells, the monitoring in the Unkpapa conducted as part of the operational groundwater monitoring network (Section 14.3) will provide sufficient information to construct an Unkpapa potentiometric contour map prior to operations.

Alluvial groundwater flow systems occur within the alluvial deposits in the Pass Creek and Beaver Creek drainages, which are within the project area, and in Bennett Canyon, which is located on and beyond the eastern edge of the project area. Where these alluvial deposits overlie the Fall River and Chilson in Bennett Canyon, they represent a potential source of recharge to these underlying units.

The Pass Creek watershed north of the project area is a major source of recharge to both the Fall River and Chilson where they are exposed at the land surface or subcrop beneath the alluvium.

The Fall River Formation rises to the north and east and crops out at the ground surface. To the southwest the Fall River Formation dips at a steeper angle than the ground surface and is mantled by the overlying Graneros Group. The recharge areas for the Fall River and Lakota (Chilson) are where they are exposed at the ground surface and are shown on Figure 5.4.

The recharge areas for the regional groundwater flow systems within the Minnelusa Formation, Madison Limestone, and Deadwood Formation are in their outcrop areas further to the east on the flanks of the Black Hills Dome. As a result of the rise in elevation, the older formations outcrop closer to the center of the dome at higher elevations and exhibit greater potentiometric elevations. Because of this, the potentiometric levels within the geologic section increase with depth, as noted previously.

5.2.2.3 Groundwater/Surface Water Interactions

Extensive site investigations undertaken by Powertech and others have revealed no known natural springs within the project area. There is, however, an isolated area in the southwest corner of the Burdock portion of the project area, known as the "alkali area," where groundwater

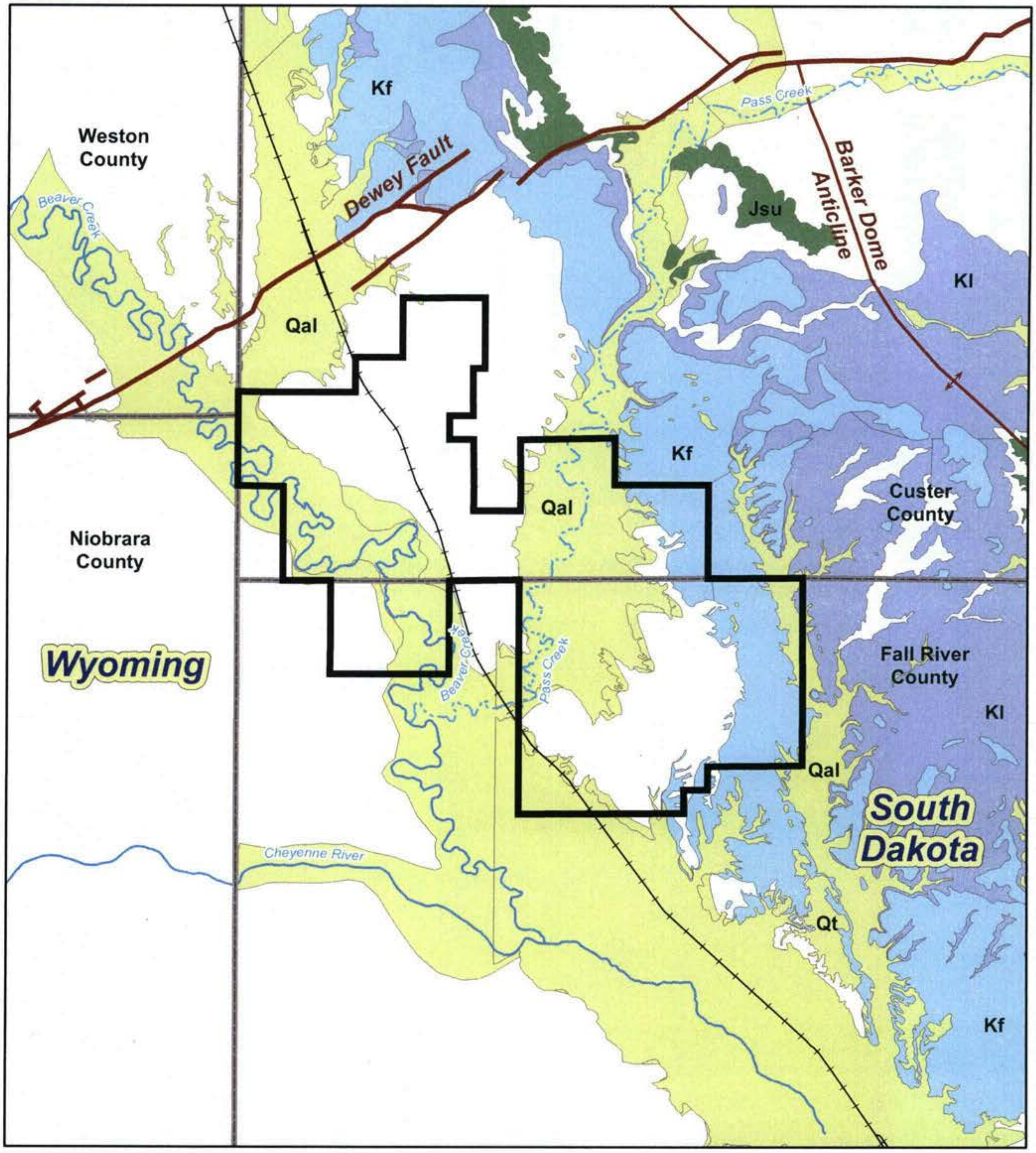

Figure 5.4

Recharge Areas for the Fall River and Lakota Formations

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FILENAME	RechargeAreas.mxd

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is discharging to the ground surface, presumably through unplugged or improperly plugged exploration drill holes. This area is discussed in Section 4.3.

The areas where the Fall River subcrops below the surface alluvium and crops out near the eastern edge of the project area are recharge areas for the Fall River sands. A similar area of recharge occurs north of the project area where Pass Creek alluvium crosses the subcrops of the Fall River and the Chilson. Recharge was observed during runoff events in 2011 where flowing streams disappeared into the Fall River and Chilson sandstones. Downgradient of the known recharge areas, there is no evidence of surface discharge from the Fall River via seeps or springs.

Refer to Section 3.2 for a discussion of the historical uranium mines within the AOR. The bottoms of the Darrow pits, with the exception of Pit #2, are above the Fall River potentiometric surface. These Darrow pits are usually dry but occasionally contain water that collects from runoff events. Darrow Pit #2, however, usually contains water suggesting that the base of the pit may be below the potentiometric surface of the Fall River. The pH of the water in Darrow Pit #2 is low (i.e., acidic) suggesting that surface drainage may be influencing the water chemistry in the pit. This implies that at least a portion of the water in Darrow Pit #2 is derived from surface runoff. The bottom of the Triangle Pit is below the potentiometric surface of the Fall River. The Triangle Pit is therefore hydraulically connected to the Fall River Formation.

5.2.2.4 Hydraulic Isolation of Aquifers

Regionally, the Inyan Kara Group is geologically confined. In the project area, the Graneros Group shale serves as the overlying confining unit above the Fall River in the western portion of the project area. There are no major aquifers above the Inyan Kara. Below the Inyan Kara, the Morrison Formation serves as a confining unit. In the project area, results from recent pump tests show that the Morrison effectively confines the underlying Unkpapa aquifer since no measureable drawdown in the Unkpapa was observed while pumping in the Inyan Kara. For a more detailed discussion on the regional and site hydrostratigraphic units see Sections 5.1.1 and 5.2.1.

As described in Section 10.5, the only area where the Fall River Formation is geologically unconfined is in the eastern part of the project area in the general vicinity of the Darrow pits. Powertech does not propose to conduct ISR operations in the Fall River in this area. The Chilson throughout the project area is physically and hydraulically isolated from the overlying Fall River Formation by the Fuson Shale.

Based on Powertech's borehole and geophysical logs for thousands of exploration holes, the Fuson Shale is continuous and no less than 20 feet thick throughout the entire project area. An isopach map showing the thickness and continuity of the Fuson Shale throughout the project area is presented as Plate 6.8. The pervasive occurrence and continuity of the Fuson Shale throughout the project area are shown on the geologic cross sections (Plates 6.13 through 6.22).

5.2.2.5 Partially Saturated Conditions

The uppermost portion of the Fall River Formation crops out in the eastern portion of the project area in the vicinity of the Darrow pits, and the full section crops out further east in Bennett Canyon. In these areas, the Fall River is geologically unconfined. As the Fall River rises to the east, it becomes partially saturated as the top of the formation rises above the groundwater table, as shown on Plate 6.13 (Cross Section A-A'). The approximate boundaries between fully saturated and partially saturated conditions in the Fall River and underlying Chilson are shown in Figures 5.5 and 5.6, respectively. As the Fall River dips basinward to the southwest, the potentiometric surface is above the top of the formation, as shown on Plate 6.13. Beneath the Beaver Creek and Pass Creek drainages, the potentiometric surface for the Fall River is above the ground surface.

Similarly, the Chilson Member rises in elevation to the northeast and subcrops beneath the alluvium in Bennett Canyon. The potentiometric surface elevation for the Chilson is projected to be below the top of the formation on the eastern edge of the project area. Only in this limited area, the Chilson, although geologically confined by the overlying Fuson Shale, is partially saturated (i.e., the water table is below the top of the formation).

Refer to Section 10.5 for a description of well field development with respect to partially saturated conditions. After license/permit issuance but prior to well field development, delineation drilling and well field pumping tests will be conducted to fully characterize the existing geologic and hydrogeologic conditions and to confirm sufficient head is available to perform normal ISR operations.

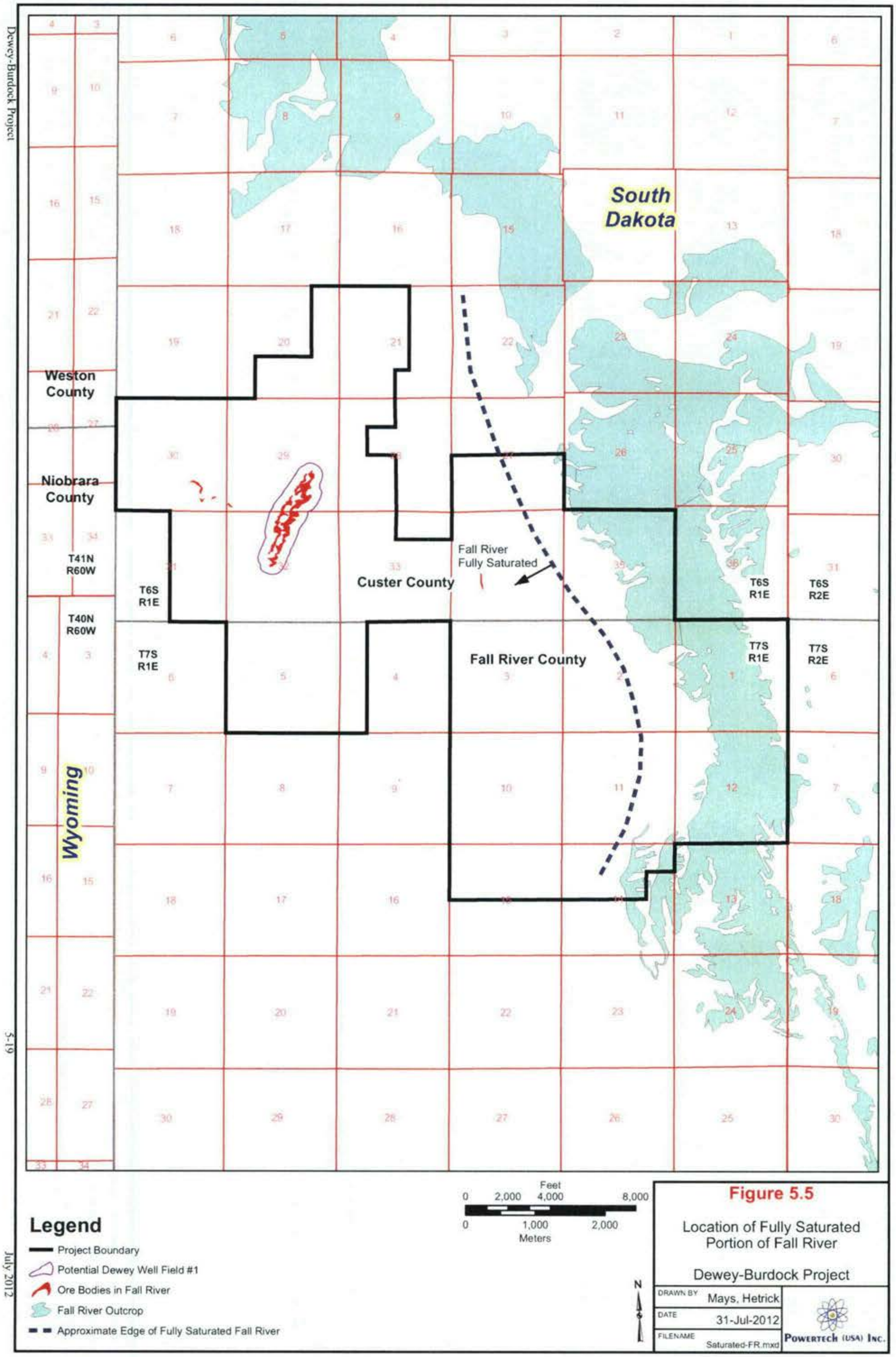

Figure 5.5

Location of Fully Saturated Portion of Fall River

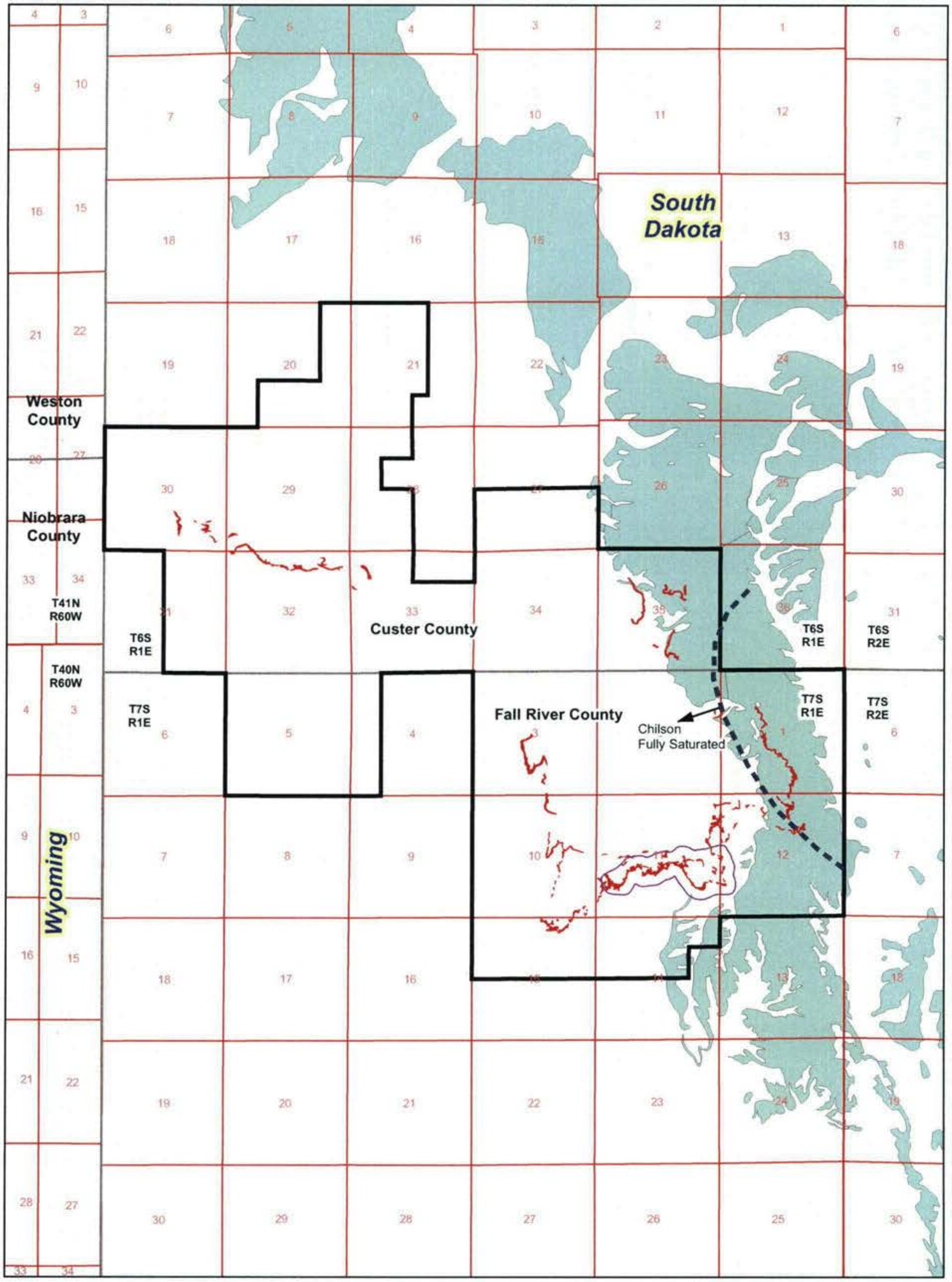

Figure 5.6

Location of Fully Saturated Portion of Chilson

Dewey-Burdock Project

DRAWN BY	Mays, Hetrick
DATE	31-Jul-2012
FILENAME	Saturated-Chil.mxd

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6.0 ATTACHMENT F - MAPS AND CROSS SECTIONS OF GEOLOGIC STRUCTURE OF AREA

This attachment includes maps and cross sections that show detailed geologic structure affecting local stratigraphy, lithology of injection intervals and lithology of confining intervals. Supporting information is provided in appendices.

6.1 Regional Geology

The Dewey-Burdock Project is located in the Great Plains Physiographic province on the southwestern flank of the Black Hills Uplift in southwestern South Dakota. To the west of the project area is the Powder River Basin of Wyoming. The regional geologic map of this region is shown on Figure 6.1.

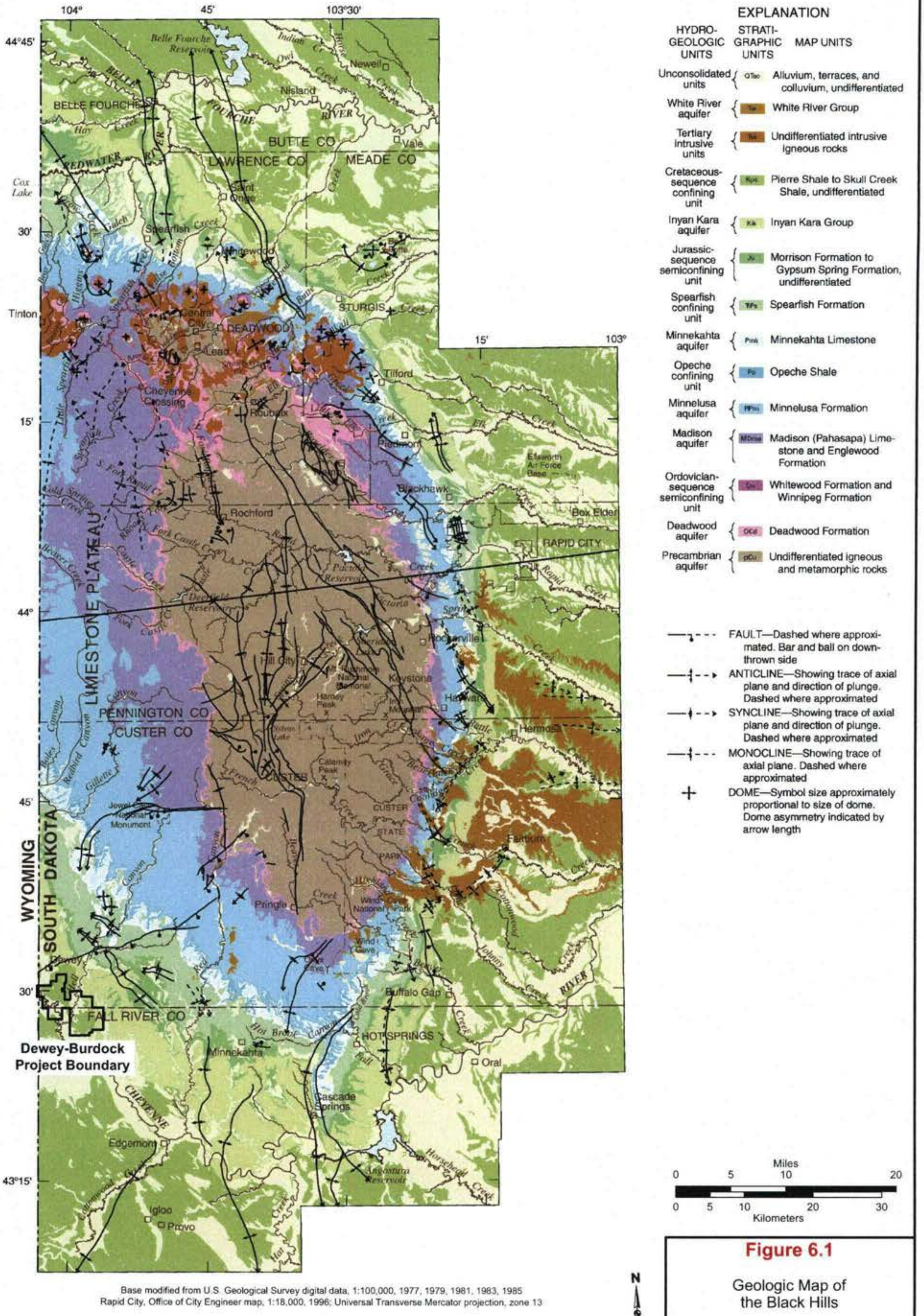
6.1.1 Regional Structure

The dominant structural feature in this region is the Black Hills Uplift. This uplift is of Laramide age (65 million years ago) and is an elongate northwest trending dome about 125 miles long and 60 miles wide. Igneous and metamorphic Precambrian-age rocks are exposed in the core of the uplift and are surrounded by outward-dipping Paleozoic and Mesozoic rocks that form cuestas and hogbacks around the core of the uplift. Folds constitute the major structural features in the Black Hills. During the early Cretaceous period, minor deformation along concealed northeast-trending remnant structures of the Precambrian age affected the courses of the northwest-flowing streams and their tributaries, thereby influencing the location of the fluvial sandstone deposits of the Inyan Kara Group.

6.1.2 Regional Stratigraphy

The oldest rocks in the region are Precambrian metamorphic rocks and granites. These form the core of the Black Hills Uplift and are exposed at the surface of this structural feature. Overlying these crystalline rocks as one moves radially outward from the core of the uplift are 2,000-3,000 feet of Paleozoic sediments. This sedimentary sequence contains several regional aquifers, including the Deadwood Formation of Cambrian age, the Mississippian Madison Limestone and the Pennsylvanian/Permian-age Minnelusa Formation.

Mesozoic sediments include the Triassic-age Spearfish Formation and the Sundance Formation, Unkpapa Sandstone, and Morrison Formation of Jurassic age. The Sundance Formation is a minor aquifer in the southern Black Hills region. A thick sequence of Cretaceous-age sediments completes the Mesozoic section.



Base modified from U.S. Geological Survey digital data, 1:100,000, 1977, 1979, 1981, 1983, 1985
Rapid City, Office of City Engineer map, 1:18,000, 1996; Universal Transverse Mercator projection, zone 13

Source: Carter et al. (2003)

Figure 6.1

Geologic Map of the Black Hills

Dewey-Burdock Project

DRAWN BY	Bonner, Hetrick
DATE	24-Jul-2012
FILENAME	BlackHillsGeoMap.dwg

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The Early Cretaceous sediments of the Inyan Kara Group consist of the Lakota and Fall River formations. The Inyan Kara Group is a transitional unit, exhibiting a change from terrestrial to marine deposition. The basal Lakota Formation (Chilson Member) is a fluvial sequence, which grades upward into marginal marine sediments where the Cretaceous Seaway inundated a stable land surface. Basal units of the Lakota Formation scour into clays of the underlying Morrison Formation and display the depositional nature of a large braided stream system, crossing a broad, flat coastal plain and flowing toward the northwest. Younger fluvial sand units of the Lakota become progressively thinner and less continuous and are separated by thin deposits of overbank and floodplain silts and clays. At the top of the Lakota is the Fuson Member. The Fuson consists of shale with minor beds of fine-grained sandstone and siltstone. The Fuson separates the underlying Lakota Formation from the overlying Fall River Formation. The Fall River consists of thick, widespread fluvial sands in the lower portion, grading to thinner, less continuous, marginal sands in the upper part. The Cretaceous Lakota and Fall River formations are hosts of the roll-front uranium mineralization in the Black Hills region.

Following deposition of the Fall River, the region was covered by the North American Cretaceous Seaway, which resulted in the accumulation of vast thicknesses of marine sediments (from 3,000-5,000 feet thick). These marine sediments are represented by the Skull Creek Shale, Newcastle Sandstone, Mowry Shale, Belle Fourche Shale, Greenhorn Formation, Carlile Shale, Niobrara Formation and Pierre Shale. In Late Cretaceous time, the modern Rocky Mountain Uplift began, forcing the retreat of the Cretaceous Seaway.

Unconformably overlying the Cretaceous sediments in the Black Hills region is the Tertiary-age (Oligocene) White River Group. This thick sequence is primarily composed of tuffaceous mudstones and siltstones, with minor amounts of fluvial, coarse sandstone, lacustrine limestone and gypsum, and tuff beds. The tuff beds were deposited from volcanic eruptions to the west (Larson and Evanoff, 1998). The majority of the White River sediments have been removed by erosion and the remainder can be found as erosional remnants. This unit is thought to be the source of the uranium deposits found in the Black Hills region and the Powder River Basin of Wyoming.

The most recent sediments in the region are Quaternary-age deposits consisting of local material derived as a result of post-Laramide-uplift erosion. Recent deposits include alluvium and floodplain terrace deposits.

A stratigraphic column of the Black Hills is illustrated in Figure 6.2.

Source: Driscoll et al. (2002)

§ Modified based on drill-hole data

ERATHEM	SYSTEM	ABBREVIATION FOR STRATIGRAPHIC INTERVAL	STRATIGRAPHIC UNIT	THICKNESS IN FEET	DESCRIPTION
CENOZOIC	QUATERNARY & TERTIARY (?)	QTac	UNDIFFERENTIATED ALLUVIUM AND COLLUVIUM	0 - 50	Sand, gravel. boulder and clay.
		Tw	WHITE RIVER GROUP	0 - 300	Light colored clays with sandstone channel fillings and local limestone lenses.
	TERTIARY	Tui	INTRUSIVE IGNEOUS ROCKS	--	Included rhyolite, latite, trachyte and phonolite.
MESOZOIC	CRETACEOUS	Kps	PIERRE SHALE	1,200 - 2,700	Principal horizon of limestone lenses giving teepee buttes. Dark-gray shale containing scattered concretions. Widely scattered limestone masses giving small teepee buttes. Black fissile shale with concretions.
			NIOBRARA FORMATION	80 - 300 §	Impure chalk and calcareous shale.
			CARLILE SHALE — Turner Sandy Member, Wall Creek Member	350 - 750 §	Light-gray shale with numerous large concretions and sandy layers. Dark-gray shale.
			GREENHORN FORMATION	225 - 380	Impure slabby limestone. Weathers buff. Dark-gray calcareous shale with thin Oman Lake limestone at base.
			GRANEROS GROUP: BELLE FOURCHE SHALE	150 - 850	Gray shale with scattered limestone concretions. Clay spur bentonite at base.
			GRANEROS GROUP: MOWRY SHALE	125 - 230	Light-gray siliceous shale. Fish scales and thin layers of bentonite.
			GRANEROS GROUP: MUDDY SANDSTONE / NEWCASTLE SANDSTONE	0 - 150	Brown to light-yellow and white sandstone.
			GRANEROS GROUP: SKULL CREEK SHALE	150 - 270	Dark-gray to black siliceous shale.
		Kik	INYAN KARA GROUP: FALL RIVER FORMATION	10 - 200	Massive to thin-bedded, brown to reddish-brown sandstone.
			INYAN KARA GROUP: LAKOTA FORMATION — Fuson Shale Minnewaste Limestone Chilson Member	10 - 190 0 - 25 25 - 485	Yellow, brown and reddish brown massive to thinly bedded sandstone, pebble conglomerate, siltstone and claystone. Local fine-grained limestone and coal.
	JURASSIC	Ju	MORRISON FORMATION	0 - 220	Green to maroon shale. Thin sandstone.
			UNKPAPA SANDSTONE	0 - 225	Massive fine-grained sandstone.
			SUNDANCE FORMATION — Redwater Member Lak Member Hulett Member Stockade Beaver Member Canyon Spr Member	250 - 450	Greenish-gray shale, thin limestone lenses. Glauconitic sandstone, red sandstone near middle.
			GYPSUM SPRING FORMATION	0 - 45	Red siltstone, gypsum and limestone.
	TRIASSIC	TRPs	SPEARFISH FORMATION — Goose Egg Equivalent	375 - 800	Red silty shale, soft red sandstone and siltstone with gypsum and thin limestone layers. Gypsum locally near the base.
PALEOZOIC	PERMIAN	Pmk	MINNEKAHTA LINESTONE	25 - 65 §	Thin to medium-bedded, fine-grained, purplish gray laminated limestone.
		Po	OPECHE SHALE	25 - 150 §	Red shale and sandstone.
	PENNSYLVANIAN	PIPm	MINNELUSA FORMATION	375 - 1,175 §	Yellow to red cross-bedded sandstone, limestone and anhydrite locally at top. Interbedded sandstone, limestone, dolomite, shale and anhydrite. Red shale with interbedded limestone and sandstone at base.
	MISSISSIPPIAN	MDme	MADISON (PAHASAPA) LIMESTONE	< 200 - 1,000 §	Massive light-colored limestone. Dolomite in part. Cavernous in upper part.
	DEVONIAN		ENGLEWOOD FORMATION	30 - 60	Pink to buff limestone. Shale locally at base.
	ORDOVIOAN	Ou	WHITEWOOD (RED RIVER) FORMATION	0 - 235 §	Buff dolomite and limestone.
			WINNIPEG FORMATION	0 - 150 §	Green shale with siltstone.
	CAMBRIAN	O€d	DEADWOOD FORMATION	0 - 500 §	Massive to thin-bedded buff to purple sandstone. Greenish glauconitic shale flaggy dolomite and flat-pebble limestone conglomerate. Sandstone with conglomerate locally at the base.
PRECAMBRIAN		p€u	UNDIFFERENTIATED IGNEOUS AND METAMORPHIC ROCKS		Schist, slate, quartzite and arkosic grit. Intruded by diorite, metamorphosed to amphibolite, and by granite and pegmatite.

Figure 6.2

Stratigraphic Column of the Black Hills Area

Dewey-Burdock Project

DRAWN BY Mays, Hetrick

DATE 24-Jul-2012

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6.2 Site Geology

The site surface geology is shown in Figure 6.3. The Fall River Formation crops out across the eastern part of the project area and the Skull Creek Shale, Mowry Shale and Belle Fourche Shale (collectively referred to as the Graneros Group) crop out across the western part of the project area. The formations dip west and southwest at 2 to 6 degrees.

The geology of the project area was developed through the interpretation of data gathered from thousands of exploration drill holes. For each drill hole a suite of down-hole electric logs was run to characterize natural radioactivity and the lithology of the sediments in the subsurface. Resistivity and self potential define the rock types encountered in the subsurface (sandstone, siltstone, shale, etc.). This is further enhanced by a geologist's description of the drill cuttings. Figure 6.4 is an example of a "type log" from the project area.

6.2.1 Site Structure

The structure across the project area is simple and shows sediments dipping gently 2 to 6 degrees to the southwest. This is illustrated by structure contour maps on the tops of the Unkpapa Sandstone (Plate 6.1), the Morrison Formation (Plate 6.2), the Chilson Member of the Lakota Formation (Plate 6.3), the Fuson Shale (Plate 6.4), and the Fall River Formation (Plate 6.5). Isopach maps also are provided for the Morrison Formation (Plate 6.6), Chilson Member (Plate 6.7), Fuson Shale (Plate 6.8), Fall River Formation (Plate 6.9), Graneros Group (Plate 6.10) and Alluvium (Plate 6.11).

The Dewey Fault, a northeast to southwest trending fault zone, is present approximately one mile north of the project area. The Dewey Fault is a steeply dipping to vertical normal fault with the north side uplifted approximately 500 feet by a combination of displacement and drag. The USGS considers the area 7 miles southeast of the project as the Long Mountain Structural Zone. This northeast-southwest trend contains several small, shallow surface faults in the Inyan Kara Group. No faults were identified along this trend on subsurface structure maps of the underlying Madison Limestone, Minnelusa Formation or the Deadwood Formation.

Despite the presence of faulting north and south of the site, there are no identified faults within the project area. There is some folding in the areas surrounding the project area. East of the project area is a northwest-southeast trending anticline that ends in a closed structure called the Barker Dome. To the west is the Fanny Peak Monocline. This monocline is the structural boundary between the Black Hills and the Powder River Basin.

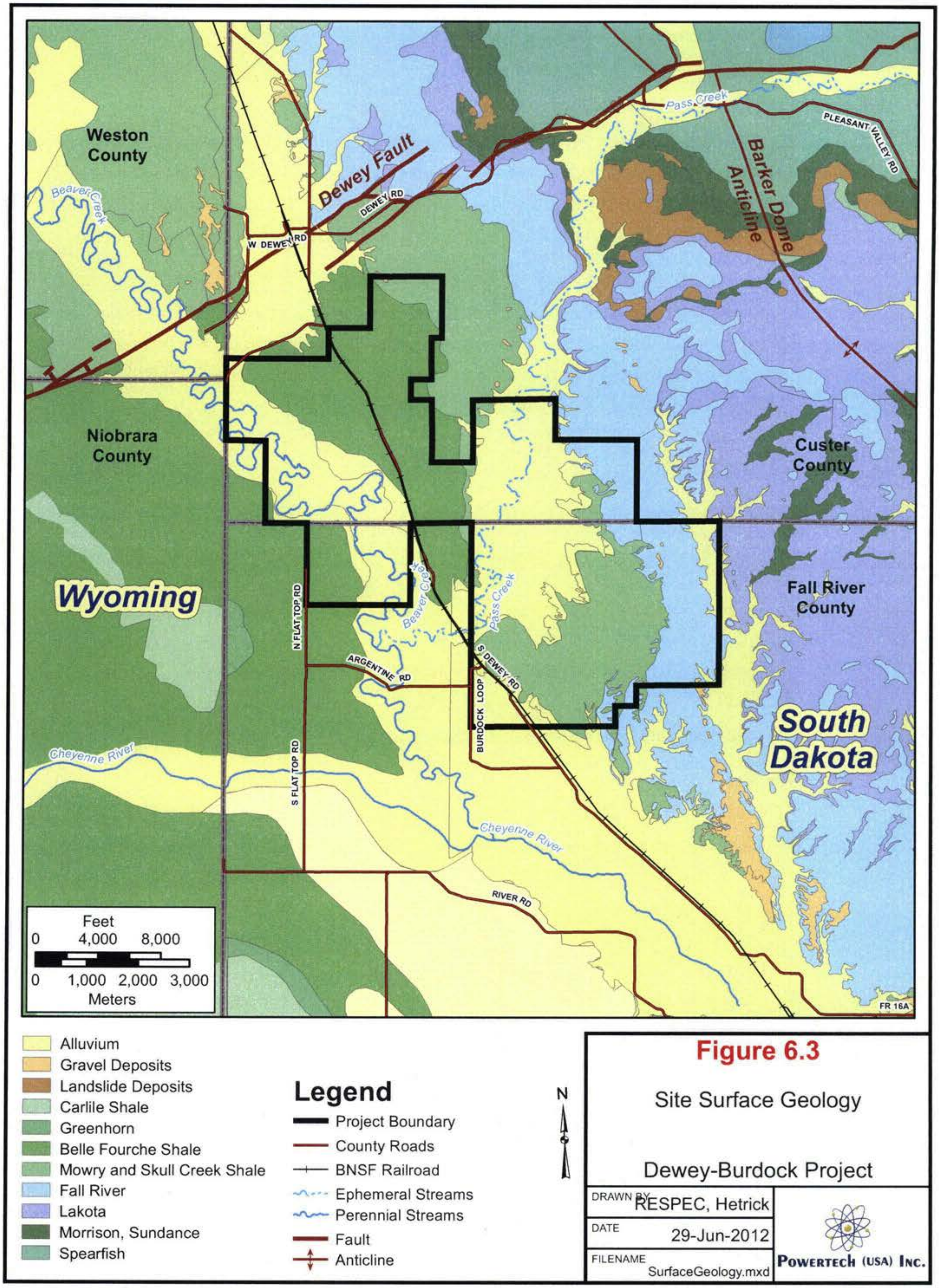

Figure 6.3

Site Surface Geology

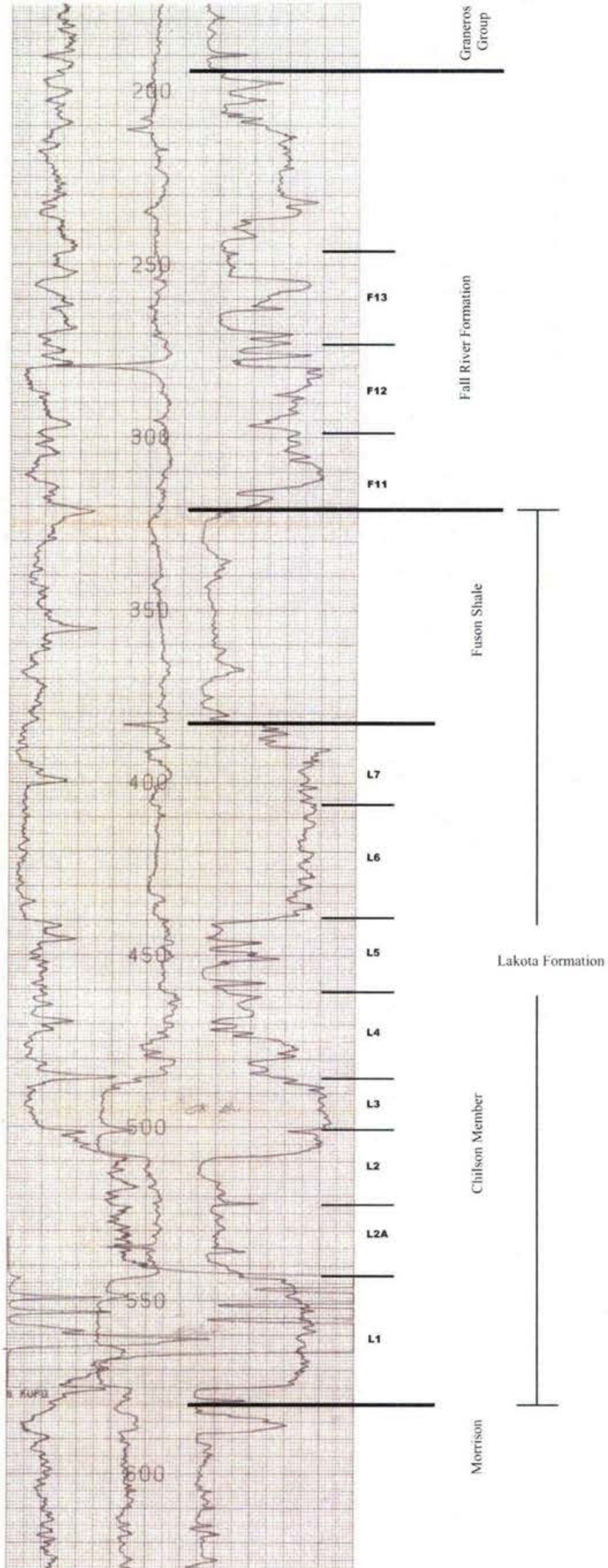

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Figure 6.4

Type Log

Dewey-Burdock Project

DRAWN BY	R. Lichnovsky
DATE	24-Jul-2012
FILENAME	TypTypeLog.dwg

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6.2.2 *Site Stratigraphy*

The sedimentary rocks that underlie the project area range in age from Upper Jurassic to Early Cretaceous. The Upper Jurassic Morrison Formation is the lowermost confining unit for ISR operations (see discussion below). The uranium mineralization is within the Inyan Kara Group (specifically within the Fall River Formation and Chilson Member of the Lakota Formation). The Graneros Group is the uppermost confining unit for ISR operations. Figure 6.4 is a type log for the project, illustrating the relationship between these sedimentary units. Figure 6.2 demonstrates the relationship between these sedimentary units and underlying rocks, ranging in age from Jurassic to Precambrian.

Plate 6.12 is a cross section index map for nine geologic cross sections (Plates 6.13 through 6.21) covering the project area. In addition to showing the scaled vertical location of each ore body proposed for uranium recovery, the nine cross sections also illustrate the continuity of the Graneros Group, the Fuson Shale and the Morrison Formation, the major confining units, across the entire project area:

1) The Graneros Group is the uppermost confining unit and overlies the Fall River Formation. This marine shale sequence has a maximum thickness of 550 feet in the project area. The Graneros Group is composed of several geologic formations including the Skull Creek, Newcastle (not present in the project area), Mowry and Belle Fourche.
2) The Fuson Member is the confining unit between the Fall River Formation and the Chilson Member of the Lakota Formation. The Fuson Shale is a low-permeability shale unit within the Fuson Member that ranges in thickness from 20 to 80 feet across the entire project area and crops out east of the project boundary.
3) The Morrison Formation is the lowermost confining unit and underlies the Chilson Member of the Lakota Formation. This low-permeability shale unit that ranges in thickness from 60 to 140 feet across the entire project area crops out east of the project boundary.

The nine cross sections presented in Plates 6.13 through 6.21 also provide detailed lithologic interpretations of the host sandstones within the Fall River Formation and the Chilson Member of the Lakota Formation. These interpretations show that interbedded clay beds are found locally within both the Fall River and Chilson sandstones and may be sufficiently continuous as to further subdivide the Fall River and Chilson into discrete, mappable fluvial sandstone packages (i.e., Upper Fall River, Lower Fall River, Upper Chilson, etc.). These interbedded clay beds may act as confining units within individual well fields. However, they cannot be considered as regional confining units because they are discontinuous. This will be confirmed through delineation drilling and aquifer pump tests. Potential use of these interbedded clay beds, as they relate to operational fluid control and monitoring, will be addressed in hydrogeologic packages prepared for each well field (refer to Section 8.2.4).

The three major confining units (Graneros Group, or uppermost confining unit, Fuson Shale, and Morrison Formation, or lowermost confining unit) are depicted on Figure 6.4 in their typical relationship to the host sands, which are in the Fall River and Lakota formations.

The following is a brief description of the formations of interest at the project area:

Sundance Formation and Unkpapa Sandstone - The Sundance Formation is composed primarily of shale and sandstone with an average thickness of 280 feet near the project area. Where present, the Unkpapa Sandstone is 50 to 80 feet of well sorted, fine-grained, eolian sandstone.

Morrison Formation - The Upper Jurassic Morrison Formation was deposited as floodplain deposits. It is composed of waxy, unctuous, calcareous, noncarbonaceous massive shale with numerous limestone lenses and a few thin fine grained sandstones. Below the site, this formation has an average thickness of approximately 100 feet and is the lowermost confining unit for ISR operations. The confining properties of the Morrison Formation are well documented. An article entitled "Clay Mineralogy of the Morrison Formation – Black Hills Area," published in the Bulletin of the American Association of Petroleum Geologists, Vol. 40, No. 5, by Ronald Warren Tank (1956), provides an excellent description of Morrison clays in this area. The Morrison Formation is an extensive, low-permeability, terrestrial clay unit, with illite being the dominant clay mineral. Illite is a stable clay mineral that is usually deposited in fairly stagnant waters in an alkaline pH. Analyses of Morrison Formation core samples by Powertech indicate very small vertical permeabilities ranging from 0.004 to 0.04 millidarcies. The continuity, thickness, and lithology of the Morrison Formation ensure hydraulic isolation of the overlying Chilson sandstones from any potential aquifers below the Morrison.

Exploration holes drilled to evaluate the economic geology of the Lakota Formation were generally not continued the additional 100 feet required to penetrate the entire Morrison Formation. Powertech drilled eight holes that penetrated through the Morrison Formation, and records indicate that 16 historical TVA exploration holes penetrated the entire Morrison Formation. Two electric logs from plugged and abandoned oil test holes in the project area are also available to assist with evaluation of the Morrison Formation. Table 6.1 provides a listing of these 26 identified Morrison Formation penetrations.

Table 6.1: Drill Holes Penetrating the Morrison Formation

	Hole No.	Easting (ft)	Northing (ft)	Elevation (ft amsl)
1.	CAT1	1028330	444666	3738
2.	DRJ90	1037602	438720	3762
3.	FBR31	1038131	433097	3800
4.	RONA81	1033459	429385	3688
5.	PM159	1032551	433100	3651
6.	DWT48	1025864	444053	3702
7.	DWT49	1025235	442634	3661
8.	ELT14	1017626	444849	3617
9.	DWT40	1022610	445875	3681
10.	DWW190	1032799	450521	3760
11.	DWW192	1033149	450479	3740
12.	DY12	1025946	450088	3820
13.	DY17	1027335	455821	3818
14.	DY308	1012901	445124	3616
15.	HDA1	1028537	448585	3780
16.	TRM38	1035605	441152	3749
17.	DB07-11-31	1038312	429998	3731
18.	DB07-11-16C	1035139	429992	3698
19.	DB08-11-18	1035133	429986	3700
20.	DB08-32-12	1022352	439368	3590
21.	DB08-32-11	1020339	443666	3627
22.	DB08-5-1	1017626	444849	3629
23.	DB08-1-7	1042271	434137	3913
24.	DB09-21-1	1028628	453319	3822
25.	API 40 047 05095	1038166	433840	3792
26.	API 40 047 05093	1032429	423452	3576

Note: Coordinate system is NAD 27 South Dakota State Plane South

Plate 6.2 is a structure contour map of the top of the Morrison Formation. This map was developed in response to an NRC staff request for information on holes that penetrated into the Morrison Formation. This structure map shows the Morrison Formation generally dipping 2½ degrees to the southwest – away from the southwestern flank of the Black Hills Uplift. The irregular contour lines on Plate 6.2 in the Dewey and Burdock areas may indicate some minor scouring into the top of the Morrison Formation and subsequent deposition of the Lower Chilson sands. This minor scouring has not cut deeply into the Morrison clays, and the overall 60- to 140-foot thickness of this formation has not been significantly affected.

A good understanding of the Morrison Formation is important to the Dewey-Burdock Project. For this reason, in addition to providing the structure contour map of the Morrison Formation, Plate 6.6 provides an isopach map of the Morrison Formation. This map was based on the

26 drill holes that fully penetrated the Morrison Formation and shows the thickness of the Morrison varying from approximately 60 to 140 feet beneath the project area. Also shown on this isopach map is the location of cross section A-A'-A", which is shown on Plate 6.22.

Cross section A-A'-A" depicts the surface to the base of the Morrison Formation based on 10 of the drill holes used in the development of the isopach map. The electric logs shown on this cross section illustrate a consistent thick sequence of Morrison clays across the project area. Copies of all electric logs from test holes that penetrate the Morrison Formation are contained in Appendix G. The A–A' portion of the cross section traverses the project in an "updip" direction through the initial proposed well field in the Dewey area. Due to the 2½ degree dip, the Fall River Formation is shown to rise from a depth of 550 feet below ground surface in the Dewey area and crop out along the eastern edge of the project area near A' (drill hole DB08-1-7). The A'-A" portion of the cross section proceeds in a "downdip" direction from the outcrop and continues through the initial proposed well field in the Burdock area.

Cross section A-A'-A" also illustrates the presence of the project's uppermost confining unit (the Graneros Group) and the Fuson Shale confining unit between the Fall River Formation and the Chilson Member of the Lakota Formation. The thickness of the Graneros Group ranges from 0 feet at its outcrop within the eastern portion of the project area to over 550 feet in the southwestern portion of the project area. The Fuson Shale ranges from 20 to 80 feet thick throughout the project area.

Inyan Kara Group – This Group consists of the Lakota Formation and the Fall River Formation. Sandstones within these two formations are hosts to all the uranium mineralization for the project.

Lakota Formation - The Lakota Formation regionally consists of three members: from lower to upper they are the Chilson Member, the Minnewaste Limestone Member and the Fuson Member.

The Chilson Member (commonly referred to as the Lakota Sandstone) is composed largely of fluvial deposits. These deposits consist of sandstone, shale, and siltstone. The member consists of a complex of channel sandstone deposits and their laterally fine-grained equivalents. The Chilson Member consists of two units: a basal carbonaceous black mudstone and an overlying unit of channel sandstones with laterally fine-grained equivalents and interbedded shales. The sandstones are very fine to medium-grained and well sorted and were deposited by a northwest flowing river system. The massive sandstone is made up of numerous individual sand filled channels, which contain the uranium deposits.

The isopach map of the Chilson Member of the Lakota Formation (Plate 6.7) shows the thickness of the channel sandstones and interbedded shales within the Chilson Member. Thicknesses vary from 100 to 240 feet. This isopach map may not adequately show the total thickness of the Chilson Member because drilling was usually stopped in the lower carbonaceous shale unit of the Chilson Member and did not reach the Morrison Formation.

The Minnewaste Limestone Member, although present in the region, is not present in the project area. Darton (1909) noted that the Minnewaste Limestone is some 20 feet thick at its type locality at the falls of the Cheyenne River (25 miles east of the project area, now under Angostura Reservoir). In USGS Professional Paper 763 (Gott et al., 1974), the Minnewaste Limestone is described in the type locality as being a pure limestone, but grading out laterally to a sandy limestone and to a calcareous sandstone at its margins. Gott et al. also state that it is discontinuous west and northwest of the type locality (toward the project area).

A review of all drill hole and geologic lithology logs confirms the Minnewaste Limestone does not occur within the project area. Geologic cross section E-E' (Plate 6.17), along the northeastern portion of the project area, illustrates the geologic section where, if present, the Minnewaste Limestone would occur. If present, this limestone unit would occur immediately beneath the Fuson Shale confining unit and above the Chilson Member of the Lakota Formation. A limestone would have a characteristically high (off-scale) response on the resistivity curve on the electric logs. As shown on cross section E-E' no limestone is present.

The Fuson Member is the uppermost member of the Lakota Formation. The shale-siltstone portion of the Fuson (Fuson Shale) has been used to divide the Lakota Formation from the Fall River Formation.

For clarification, the Fuson Shale is differentiated from the Fuson Member of the Lakota Formation by Powertech for the purpose of characterizing the site geology. The Fuson Shale has been mapped by Powertech and consists of 20 to 80 feet of low-permeability shales and clays, which generally occur at or near the base of the unit. The Fuson Member of the Lakota, in comparison, has been mapped based on outcrop by the USGS and others to be from 40 to 80 feet thick and consisting of interbedded fluvial shales, clays, mudstones, and sands.

The Fuson Member is described as having a lower discontinuous sandstone unit at its base and an upper discontinuous sandstone at the top of the member. If present the lower sandstone unit was mapped as Lakota sandstone. Similarly if the upper sandstone was present it was mapped as Fall River sandstone. The isopach map of the Fuson Shale shows the thickness of the shale-siltstone unit ranging from 20 to 80 feet (Plate 6.8). It shows thinning of the shale under the overlying channel sandstones of the Fall River Formation.

The shales and mudstones within the Fuson Shale are highly stratified. Due to this stratification, the vertical permeability is estimated to be several orders of magnitude smaller than the horizontal permeability. Measurements of vertical permeability from core samples and estimates from pumping tests are provided in Section 5.2.1.2.

The Fuson Member, being of fluvial origin, locally contains sand deposits (Schnabel and Charlesworth, 1963). The presence of the sand facies within the Fuson Member does not diminish the confining capacity of the Fuson Shale within the Fuson Member as defined and mapped by Powertech. The geologic map of the Burdock quadrangle (Schnabel and Charlesworth, 1963) indicates that the Fuson Shale may pinch out in some areas. In particular, the interpretive fence diagram presented by Schnabel and Charlesworth shows an area approximately 1½ miles east and northeast of the project area, across Bennett Canyon, in the E/2 Section 30, T6S, R2E, where the Fuson Member pinches out. However, based on available borehole logs the Fuson Shale is continuous and no less than 20 feet thick throughout the entire project area. The pervasive occurrence and continuity of the Fuson Shale throughout the project area is shown on the geologic cross sections (Plates 6.13 through 6.22).

Fall River Formation - The Fall River Formation is composed of carbonaceous interbedded siltstone and sandstone, channel sandstones, and a sequence of interbedded sandstone and shale. The lower part of the Fall River consists of dark carbonaceous siltstone interbedded with thin laminations of fine-grained sandstone. Channels were cut into this interbedded sequence by northwest-flowing rivers and fluvial sandstones were deposited. These channel sandstones occur across various parts of the project and generally contain the uranium deposits. Overlying the channel sandstones is another sequence of alternating sandstones and shales. The sandstones are cross-bedded to massive, fine to medium-grained, and well sorted.

The isopach map of the Fall River Formation (Plate 6.9) shows a range of thickness of 120 to 160 feet. The thickening of the formation indicates the presence of channel sandstones. Along the northeastern portion of the project area, this formation is exposed on the surface and erosion has taken place.

Graneros Group - The Cretaceous Graneros Group consists of several geologic units, including the Skull Creek Shale, Newcastle Sandstone (where present), Mowry Shale, and Belle Fourche Shale, which act as a single confining unit overlying the Inyan Kara. In the project area, the thickness of the Graneros Group ranges from zero at the outcrop of the Fall River to more than 500 feet (Plate 6.10). The members which comprise the Graneros Group and described in Section 5.2.1.3.

Terrace Deposits - Along the sides of drainages are relatively thin and flat-lying terrace deposits representing floodplains and former levels of streams. The terraces are primarily overbank deposits of clay and silt with gravel beds. Gravel deposits consist of boulders and pebbles of chert, sandstone, and limestone.

Alluvium - The most recent sedimentary units deposited within the project area are the Quaternary-age alluvium deposits. Alluvium is present in the major drainages and their tributaries. The alluvium consists of silt, clay, sand and gravel. An isopach of the alluvium is presented as Plate 6.11.

6.2.3 Clarification of Breccia Pipes

Powertech evaluated the potential for breccia pipes in and around the project area and concluded that there is no evidence of breccia pipes. The detailed evaluation is presented in Appendix E and summarized below.

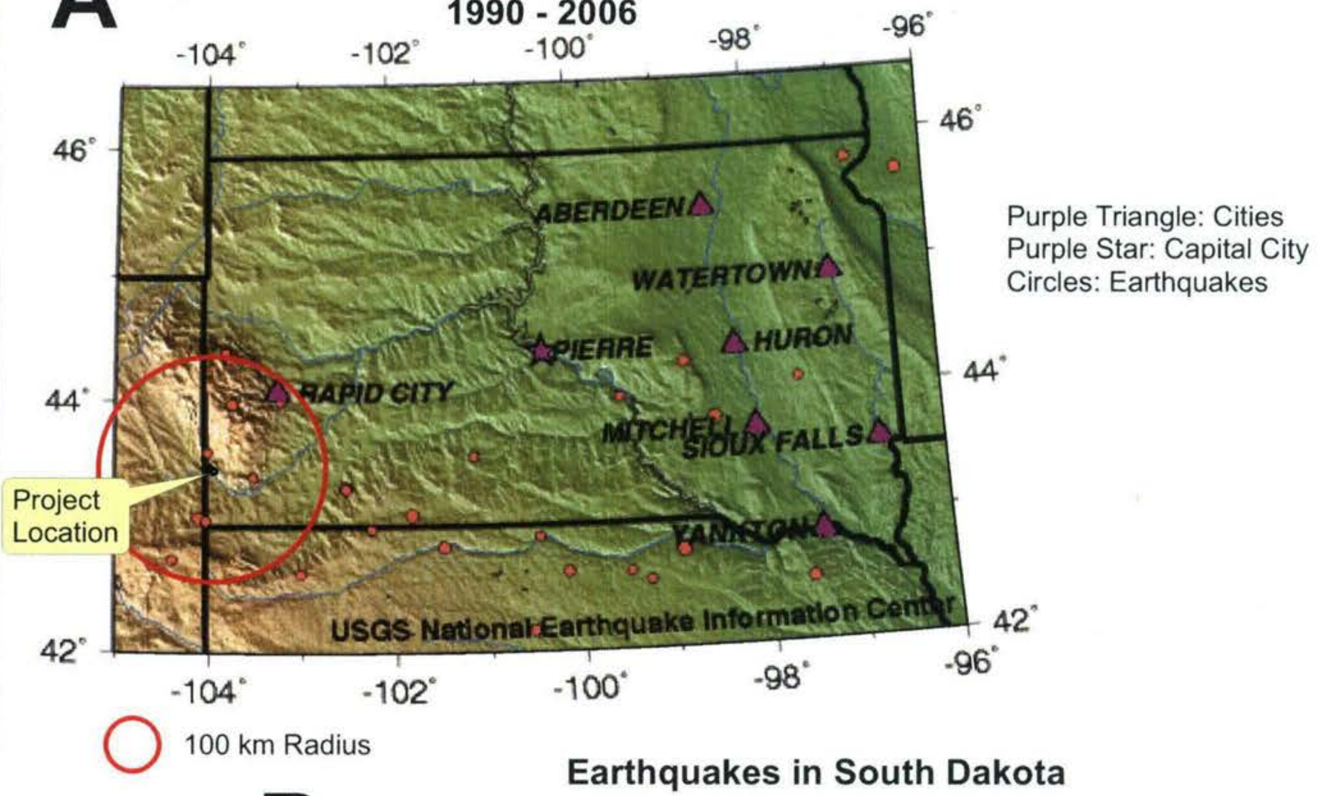
Breccia pipes have been studied and mapped in the southern Black Hills and are known to originate in anhydrite and gypsum sequences within the upper portion of the Minnelusa Formation. Dissolution of these evaporite sequences by underlying Minnelusa and/or Madison artesian water created solution cavities into which overlying Permian sediments collapsed. The aerial extent of dissolution is limited to a few miles downgradient from the Minnelusa outcrop. The probable maximum downgradient limit of dissolution, or dissolution front, has been mapped by the USGS and is more than 6 miles northeast of the project area. There is no evidence of dissolution of the Minnelusa in the project area based on evaluation of an electric log from an abandoned oil and gas test well within the project area. In areas where there has been no dissolution, there is no geologic foundation for the creation of breccia pipes in overlying sediments.

Further evidence against the presence of breccia pipes is presented in Appendix E and includes exploration drilling, field investigations for breccia pipes, an evaluation of Inyan Kara water temperatures, regional pumping tests, and evaluation of CIR imagery. Further, calibration of the groundwater model submitted to the NRC in February 2012 (Petrotek, 2012) does not support inflow to the Inyan Kara from deeper formations including through breccia pipes.

6.3 Seismology

The project area is located in an area of historically low seismic potential. There are no known capable faults within 100 km and a relatively low number of historical earthquakes. Seismic hazards at the project site include low to moderate ground shaking associated with regional and local earthquake sources. Figures 6.5 and 6.6 illustrate seismicity and peak ground acceleration (PGA) maps for the project area, and Appendix H provides a summary of the USGS database

A
Seismicity of South Dakota 1990 - 2006



B
Earthquakes in South Dakota (1872 - 2007)

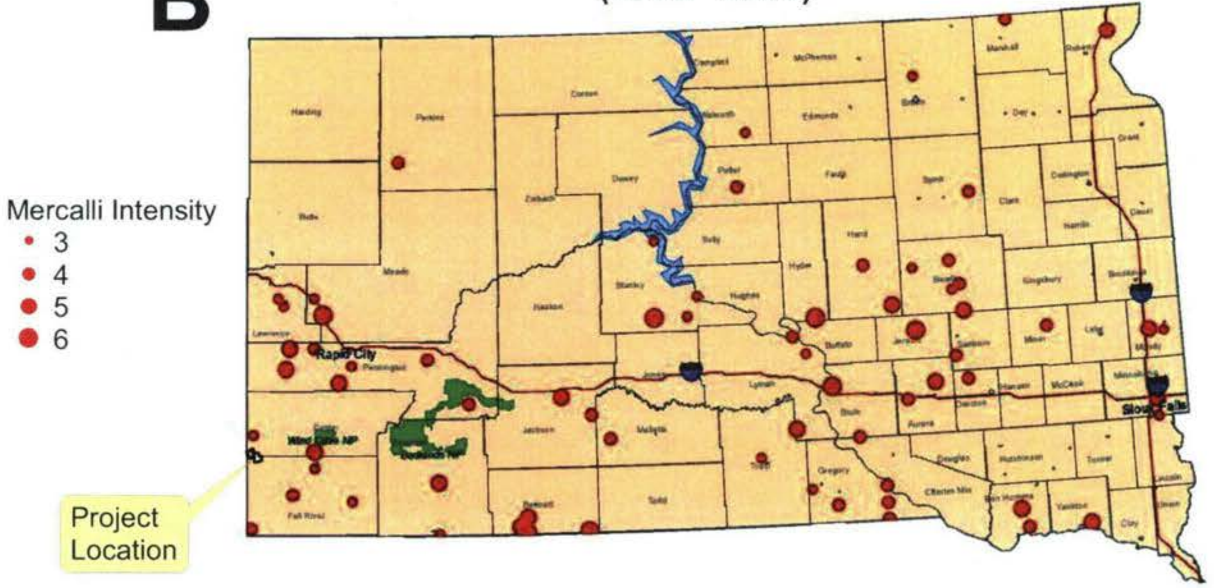


Figure 6.5
Seismicity of South Dakota 1990 - 2006 and Earthquakes in South Dakota 1872 - 2007
Dewey-Burdock Project

DRAWN BY	Mays, Hetrick
DATE	29-Jun-2012
FILENAME	SDQuakesSeismic.mxd

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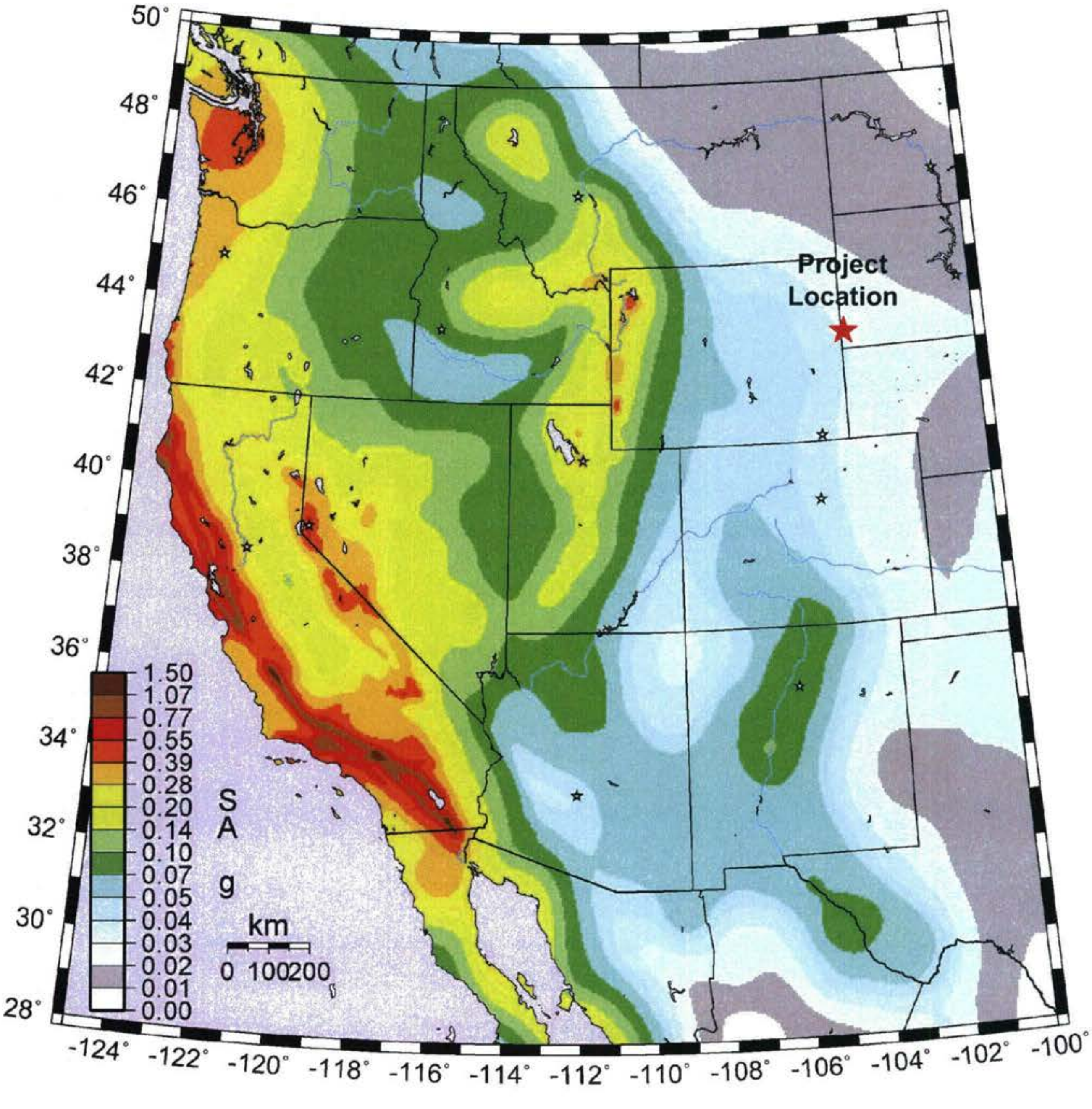
Source: USGS/DEIC PDE Catalog
Map A: USGS website:
http://earthquake.usgs.gov/regional/states/south_dakota/seismicity.php
Map B: USGS website:
http://www.sdgs.usd.edu/digitalpubmaps/quakemap.html



Source: USGS (2008)

Figure 6.6
Peak Ground Acceleration (PGA), Illustrating 10 Percent Probability of Exceedance in the Next 50 Years
Dewey-Burdock Project

DRAWN BY	S. Hetrick
DATE	24-Jul-2012
FILENAME	PGA10Pct50Yr.dwg

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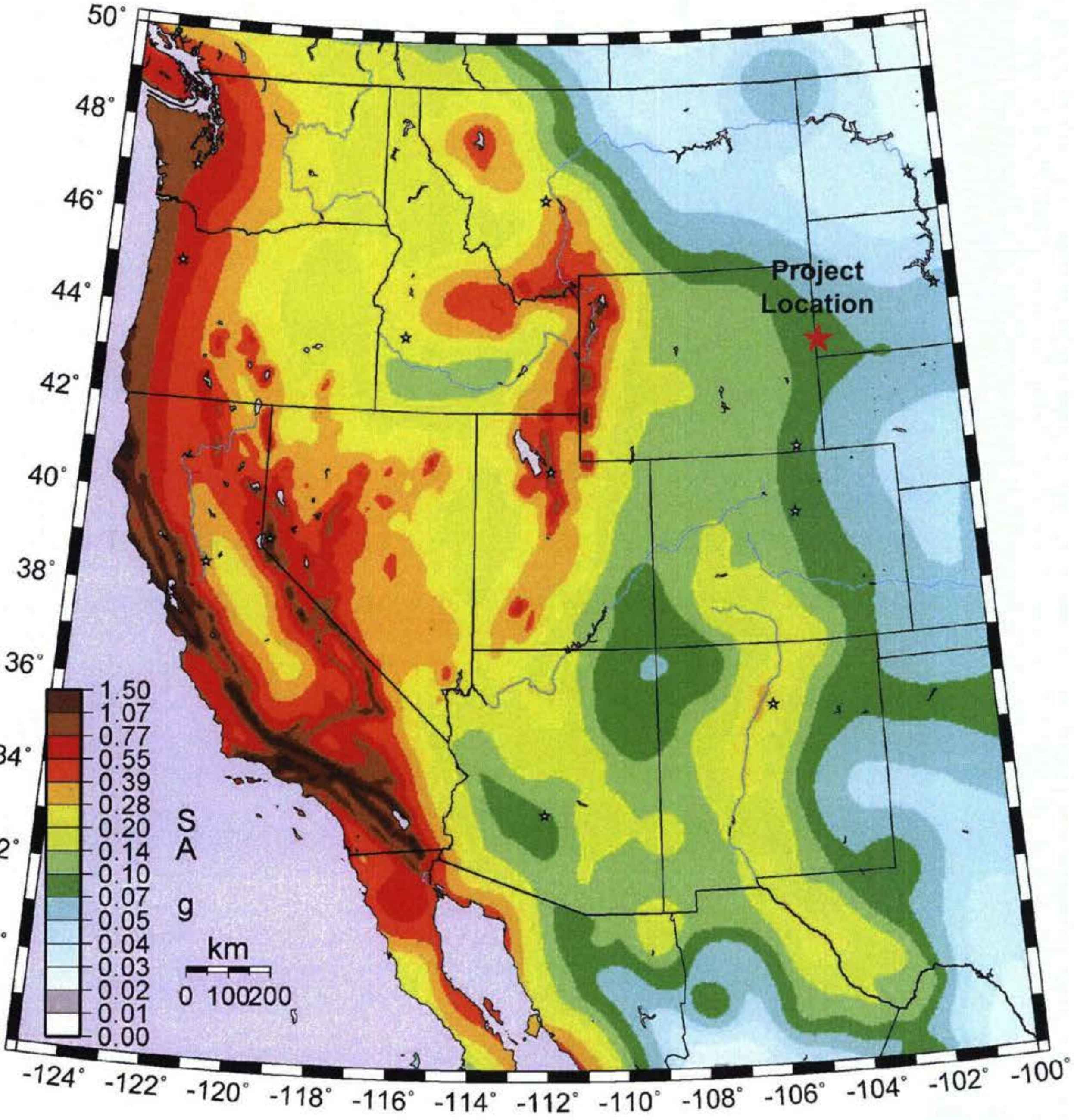
results for historical earthquakes recorded within 100 and 200 km from the project area since 1973.

There are no capable faults (as defined in 10 CFR Part 100, Appendix A, Section III(g)) known to be present within 100 km of the project area. The closest capable fault zone to the project area is located nearly 345 km (200 miles) west of the site in central Wyoming. Therefore, the most significant seismic hazard is considered to be the randomly occurring or "floating" earthquake. This is the maximum credible earthquake estimated for the project area based on available literature, geologic information of the surrounding area, and historical data. A magnitude $M_{max} = 6.1$ is estimated for this event.

According to the USGS 2008 Seismic Hazard Mapping Program, PGA derived from the probabilistic maximum bedrock acceleration with a 10 percent exceedance in 50 years (475-year return period) is 0.02 to 0.03g (Figure 6.6) for the southwestern part of South Dakota. The probabilistic maximum bedrock acceleration with a 2 percent chance of exceedance in 50 years (2,475-year return period) is 0.07 to 0.10g for the region (Figure 6.7). Both of these estimates reflect a low ground motion hazard.

As discussed further in Section 13.5.2, all buildings, structures, foundations, and equipment will be designed in accordance with recommendations in the latest versions of the International Building Code and ASCE-7 published by the American Society of Civil Engineers. Maps published in ASCE-7, and the latest version of the USGS Earthquake Ground Motion Tool, along with information regarding soil characteristics provided by the project professional geotechnical engineer, will be used to determine seismic loadings and design requirements.



Source: USGS (2008)

Figure 6.7
Peak Ground Acceleration (PGA), Illustrating 2 Percent Probability of Exceedance in the Next 50 Years
Dewey-Burdock Project

DRAWN BY	S. Hetrick
DATE	24-Jul-2012
FILENAME	PGA2Pct50Yr.dwg

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7.0 ATTACHMENT H - OPERATING DATA

This attachment discusses the operating data for the injection wells, including the typical and anticipated maximum injection rate, injection pressure range, and range in concentrations of the injected fluids.

7.1 Injection Flow Rate

The injection flow rates for individual Class III injection wells are anticipated to range from approximately 5 to 30 gpm. The project-wide injection flow rate will fluctuate depending on the number of well fields undergoing uranium recovery and aquifer restoration. The project-wide injection flow rate is expected to increase from the onset of uranium recovery in the first well field through the period of concurrent uranium recovery and aquifer restoration. Powertech estimates that individual well field uranium recovery times will be about 2 years, with multiple well fields typically in uranium recovery at any given time. Aquifer restoration will be completed following uranium recovery in each well field. Therefore, concurrent uranium recovery and aquifer restoration is anticipated to begin approximately 2 years after initial well field operation. Figure 10.2 in Section 10 depicts the anticipated project schedule.

Table 7.1 summarizes the typical project-wide flow rates during concurrent uranium recovery and aquifer restoration. The maximum gross pumping rate from producing well fields is anticipated to be 8,000 gpm. This will be limited by NRC license conditions. Although the NRC license application currently requests a maximum gross pumping rate of 4,000 gpm, Powertech anticipates submitting an amendment application to NRC to increase the maximum allowable gross pumping rate in order to provide operational flexibility. The production bleed is estimated to range from approximately 0.5% to 3%. At a maximum gross pumping rate of 8,000 gpm, the typical injection rate would therefore range from about 7,760 to 7,960 gpm. This demonstrates that the vast majority of water pumped from the production zone will be reinjected, such that the net withdrawal rate will be only a small fraction of the gross pumping rate. The maximum anticipated gross pumping rate from well fields undergoing aquifer restoration will be 500 gpm, with a typical restoration bleed of 1.0%. The typical injection rate for aquifer restoration therefore will be up to 495 gpm. The total estimated bleed during concurrent uranium recovery and aquifer restoration is estimated to be about 75 gpm, or about 0.88% of the maximum gross pumping rate of 8,500 gpm. The production and restoration bleed may vary, but the total injection rate is not anticipated to exceed 8,500 gpm or 12.24 mgd. This estimate of the maximum injection flow rate is provided for information purposes only; Powertech is not requesting that the proposed Class III UIC permit include flow limits.

Table 7.1: Typical Project-Wide Injection Flow Rates Corresponding to Maximum Anticipated Gross Pumping Rates

Operation Phase	Injection Flow Rate (gpm)	Production Flow Rate (gpm)	Bleed (gpm)	Bleed (%)
Uranium Recovery	7,930	8,000	70	0.875%
Aquifer Restoration	495	500	5	1.0%
Concurrent Uranium Recovery and Aquifer Restoration	8,425	8,500	75	0.88%

Figure 7.1 depicts the typical project-wide flow rates during concurrent uranium recovery and aquifer restoration. With respect to the Class III UIC permit application, the key streams are identified as C, E, L, and M on Figure 7.1. Streams C and L represent the primary injection streams into the Burdock and Dewey well fields, respectively. Streams E and M represent injection of makeup water from the Madison Limestone or another suitable aquifer. During uranium recovery, the sum of C and L is typically 7,930 gpm, which matches the project-wide value in Table 7.1. During aquifer restoration, the sum of C, E, L and M is typically 416 to 495 gpm. The lower value corresponds to the optional use of groundwater sweep, which is described in Section 10.8.2.1.3. The cumulative injection flow rate at the maximum gross pumping rate of 8,500 gpm, a typical production bleed rate of 0.875%, and no groundwater sweep, will be about 8,425 gpm, which matches the value shown in Table 7.1.

7.2 Injection Pressure

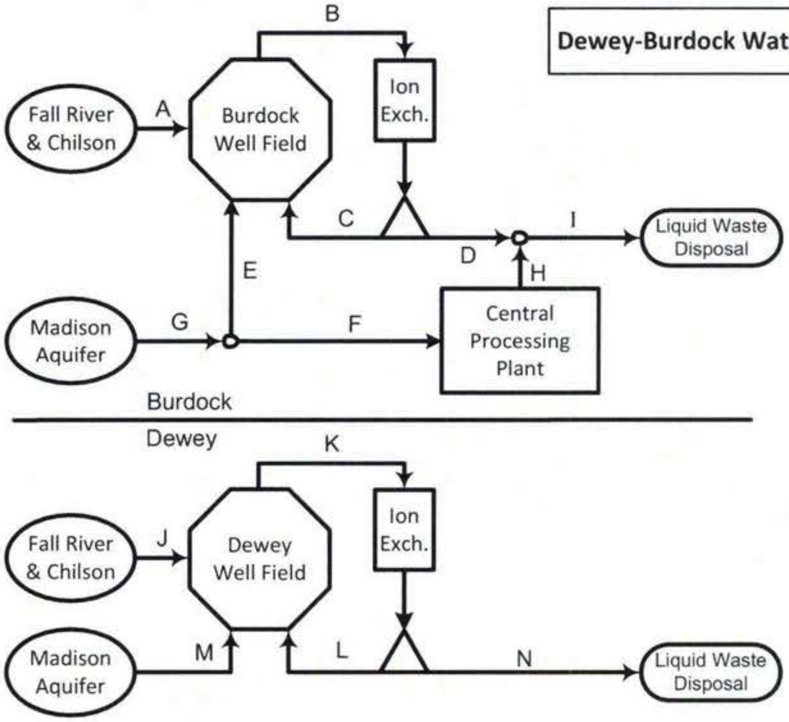
Powertech will specify the maximum injection pressure for each header house. The designated maximum pressure will be posted near the injection trunk line gauge used to monitor injection pressure. The maximum injection pressure will be calculated as the lowest value of the following:

- The lowest value of maximum allowable wellhead pressure for all injection wells connected to the header house based on fracture pressure calculations presented in Section 8.1.
- The manufacturer-specified maximum operating pressure for the well casing.
- The manufacturer-specified maximum operating pressure of the injection piping and fittings.

This pressure will not initiate new fractures or propagate existing fractures in the injection or confining zone or cause the migration of lixiviant into any USDW in accordance with 40 CFR § 144.28(f)(6)(i).

The anticipated range of injection pressures, measured at each header house, is 20 to 150 psig.

Dewey-Burdock Water Balance



Stream ID	Description
A	Burdock Aquifer Bleed
B	Burdock Extraction Composite
C	Burdock Reinjection
D	Burdock Well Field Bleed
E	Burdock Madison Make-up
F	Burdock Fresh Brine Make-up
G	Burdock Madison, Total
H	Burdock CPP Brine
I	Burdock Liquid Waste
J	Dewey Aquifer Bleed
K	Dewey Extraction Composite
L	Dewey Reinjection
M	Dewey Madison Make-up
N	Dewey Liquid Waste

Water Balance Flow Rates (gpm)											
Operation Phase	Aquifer Bleed Option	Disposal Option	Burdock								
			Stream ID								
			A	B	C	D	E	F	G	H	I
Recovery	0.875%	DDW	42	4800	4758	42	0	12	12	12	54
		LA	42	4800	4758	42	0	12	12	12	54
Restoration	Without Groundwater Sweep	DDW	2.5	250	175	75	73	0	73	0	75
		LA	2.5	250	0	250	247.5	0	247.5	0	250
	With Groundwater Sweep	DDW	42	250	175	75	33	0	33	0	75
		LA	42	250	0	250	208	0	208	0	250

Water Balance Flow Rates (gpm)							
Operation Phase	Aquifer Bleed Option	Disposal Option	Dewey				
			Stream ID				
			J	K	L	M	N
Recovery	0.875%	DDW	28	3200	3172	0	28
		LA	28	3200	3172	0	28
Restoration	Without Groundwater Sweep	DDW	2.5	250	175	73	75
		LA	2.5	250	0	247.5	250
	With Groundwater Sweep	DDW	42	250	175	33	75
		LA	42	250	0	208	250

Figure 7.1: Typical Project-wide Flow Rates during Uranium Recovery and Aquifer Restoration

7.3 Injection Fluid Composition

Two different types of fluid will be injected into the well fields. During uranium recovery, lixiviant consisting of production zone groundwater fortified with oxygen and carbon dioxide will be injected into the well fields. During aquifer restoration, permeate and/or clean makeup water from the Madison Limestone or another suitable aquifer will be injected into well fields. Table 7.2 describes the anticipated range of concentrations for various constituents in the lixiviant injected during uranium recovery. The lixiviant formulation is consistent with that used in typical U.S. ISR operations, will minimize potential groundwater quality impacts during uranium recovery, and will enable restoration goals to be achieved in a timely manner (NRC, 2003). The anticipated water quality of permeate and/or makeup water from the Madison Limestone or another suitable aquifer during restoration will be at the low end of the range of concentrations in Table 7.2.

Table 7.2: Typical Lixiviant Chemistry

Constituent	Units	Concentration Range	
		Minimum	Maximum
Sodium	mg/L	≤400	6,000
Calcium	mg/L	≤20	500
Magnesium	mg/L	≤3	100
Potassium	mg/L	≤15	300
Carbonate	mg/L	≤0.5	2,500
Bicarbonate	mg/L	≤400	5,000
Chloride	mg/L	≤200	5,000
Sulfate	mg/L	≤400	5,000
Uranium	mg/L	≤0.01	<2
Vanadium	mg/L	≤0.01	100
Total Dissolved Solids, TDS	mg/L	≤1,650	12,000
pH	std units	≤6.5	10.5

Source: Modified from NRC (2009) to reflect that uranium will be removed prior to injection.

8.0 ATTACHMENT I - FORMATION TESTING PROGRAM

This attachment provides a description of the formation testing program for the Dewey-Burdock Project. The formation testing program description includes information about geohydrologic properties of the ore zone and the confining zones from previous tests and information about the pump testing program that will be performed for each well field.

8.1 Fracture Pressure

Powertech will not use hydraulic fracturing as part of the ISR process, and no fracture pressure testing is planned. Fracture testing could increase the probability of creating a pathway for loss of fluid control in the immediate vicinity of the tested well. Powertech will operate its injection wells below the estimated fracture pressure of the injection zone. Maintaining the native hydraulic properties of the host sand is important to uranium recovery and control of well field solutions. Instead of fracture testing Powertech will rely on conservative and accepted methods of estimating fracture pressure as described below.

Fracture pressure varies with well depth, strength of formation rock and overburden pressure. Hydraulic pressure is the sum of the overburden pressure and the hydrostatic pressure of fluids within the wellbore. The hydrostatic pressure can be calculated based on the pressure gradient of the fluid multiplied by the fluid depth. The total hydraulic pressure or downhole pressure is calculated as follows:

total hydraulic pressure (psi) = overburden pressure (psi) +
[(fluid pressure gradient (psi/ft) x depth (ft)]

To prevent formation fracturing, the total hydraulic pressure or downhole pressure must not exceed the formation fracture pressure. Since the hydrostatic pressure is calculated as the fluid pressure gradient multiplied by the depth, the maximum surface pressure or maximum allowable well head pressure (max WHP) can be calculated as follows:

max WHP = formation fracture pressure (psi) – hydrostatic pressure (psi)

The formation fracture pressure can be calculated based on the fracture gradient multiplied by the depth.

Fracture gradient is defined by the EPA (2012) as follows:

> The fracture gradient is a measure of how the pressure required to fracture rock in the earth changes with depth. It is usually measured in units of "pounds per square inch per foot" (psi/ft) and varies with the type of rock and the stress history of the rock. The default value used by Region 5 in Michigan is 0.8 psi/ft. This means,

for example, that at a depth of 100 ft, a pressure of 80 psi would be required to fracture the rock, while at a depth of 500 ft, the required pressure would be 400 psi; at 1,000 ft, 800 psi.

To be conservative, Powertech will use a fracture gradient value of 0.7 psi/ft, which is used for Class V UIC permits in Wyoming. Therefore, the max WHP will be calculated based on the following equation, which uses a fluid pressure gradient of 0.433 psi/ft for the injected fluid:

max WHP = [0.7 psi/ft – 0.433 psi/ft] x [well depth or depth to open interval (ft)]

Based on a range of depths to the target mineralization of approximately 200 to 800 feet, the max WHP will range from approximately 53 to 214 psi. The maximum allowable WHP will be calculated on a well-by-well basis, and operational controls will be put in place to prevent exceeding designated pressures. The maximum injection pressure will be designated for each header house as described in Section 7.2. The designated maximum injection pressure will be posted near the injection trunk line gauge used to monitor injection pressure. This practice will ensure the formation fracture pressure is not exceeded according to 40 CFR § 144.28(f)(6)(i).

8.2 Pumping Tests

Appendices I and J provide reports documenting pumping tests that have been conducted at the project area. A summary of the reports in these appendices is provided below.

8.2.1 Summary of TVA Pumping Tests

TVA conducted groundwater pumping tests from 1977 through 1982 as part of its uranium mine development project near the towns of Edgemont and Dewey, South Dakota. The results of these tests are summarized in two reports provided in Appendix I: "Analysis of Aquifer Test Conducted at the Proposed Burdock Uranium Mine Site" (Boggs and Jenkins, 1980) and "Hydrogeologic Investigations at Proposed Uranium Mine near Dewey, South Dakota" (Boggs, 1983).

Two pumping tests conducted by TVA at the Burdock site in 1977 were unsuccessful. The results of these tests were considered inconclusive because of questionable discharge measurements, improperly constructed observation wells, and malfunctioning pressure gauges. No data from the 1977 tests are available.

TVA conducted two successful pumping tests in 1979 near the Burdock portion of the project area and one in 1982 about 2 miles north of the Dewey portion of the project area. The results of these tests are described below.

8.2.1.1 Burdock Area

The Burdock tests were conducted in 1979 near S. Dewey Road at the location shown on Figure 8.1. The Burdock tests consisted of separate pumping tests from the Lakota (Chilson) and Fall River in April and July of 1979. The tests used the same pumping well with packers to alternatively isolate screens open to the respective formations. Test durations were 73 hours for the Lakota (Chilson) test and 49 hours for the Fall River test. Pumping rates were about 200 gpm from the Lakota (Chilson) aquifer and 8.5 gpm from the Fall River. The reason for the unexpected low pumping rate from the Fall River aquifer was not specified in the TVA report.

Based on review of the testing results by Powertech, significant conclusions from the TVA testing indicate:

- Transmissivity of the Chilson based on the analysis of late time data averaged about 1,400 gpd/ft (190 ft^2/day) and storativity was determined to be approximately 1.8×10^{-4} (dimensionless).
- Transmissivity of the Fall River averaged about 400 gpd/ft (54 ft^2/day) and storativity approximately 1.4×10^{-5} (dimensionless).
- The vertical hydraulic conductivity of the Fuson aquitard calculated using the Neuman-Witherspoon ratio method (Neuman and Witherspoon, 1972) ranged from 1×10^{-3} to 1×10^{-4} ft/day; storativity was not determined, and specific storage was assumed to be about 10^{-6} ft^{-1}.
- The reported "leaky aquifer" response likely is related to (1) Well 668 that is completed in both the Chilson and Fall River and can provide a direct communication pathway, and/or (2) the presence of open boreholes that may provide communication between the Fall River and Lakota (Chilson) in a limited area near the Burdock test, or communication between the Fall River and land surface. The test results do not support a leaky confining zone (Fuson Shale).

8.2.1.2 Dewey Area

The Dewey test was conducted in 1982 northeast of S. Dewey Road at the location shown on Figure 8.1. The test consisted of pumping in the Lakota Formation (Chilson) at an average rate of 495 gpm for 11 days. The significant results are as follows:

- Transmissivity of the Chilson averaged about 4,400 gpd/ft (590 ft^2/day).
- Storativity of the Chilson was about 1.0×10^{-4} (dimensionless).
- The vertical hydraulic conductivity of the Fuson aquitard using the Neuman-Witherspoon ratio method (Neuman and Witherspoon, 1972) was 2×10^{-4} ft/day; storativity of the Fuson Shale was not determined and specific storage was about 7×10^{-7} ft^{-1}.

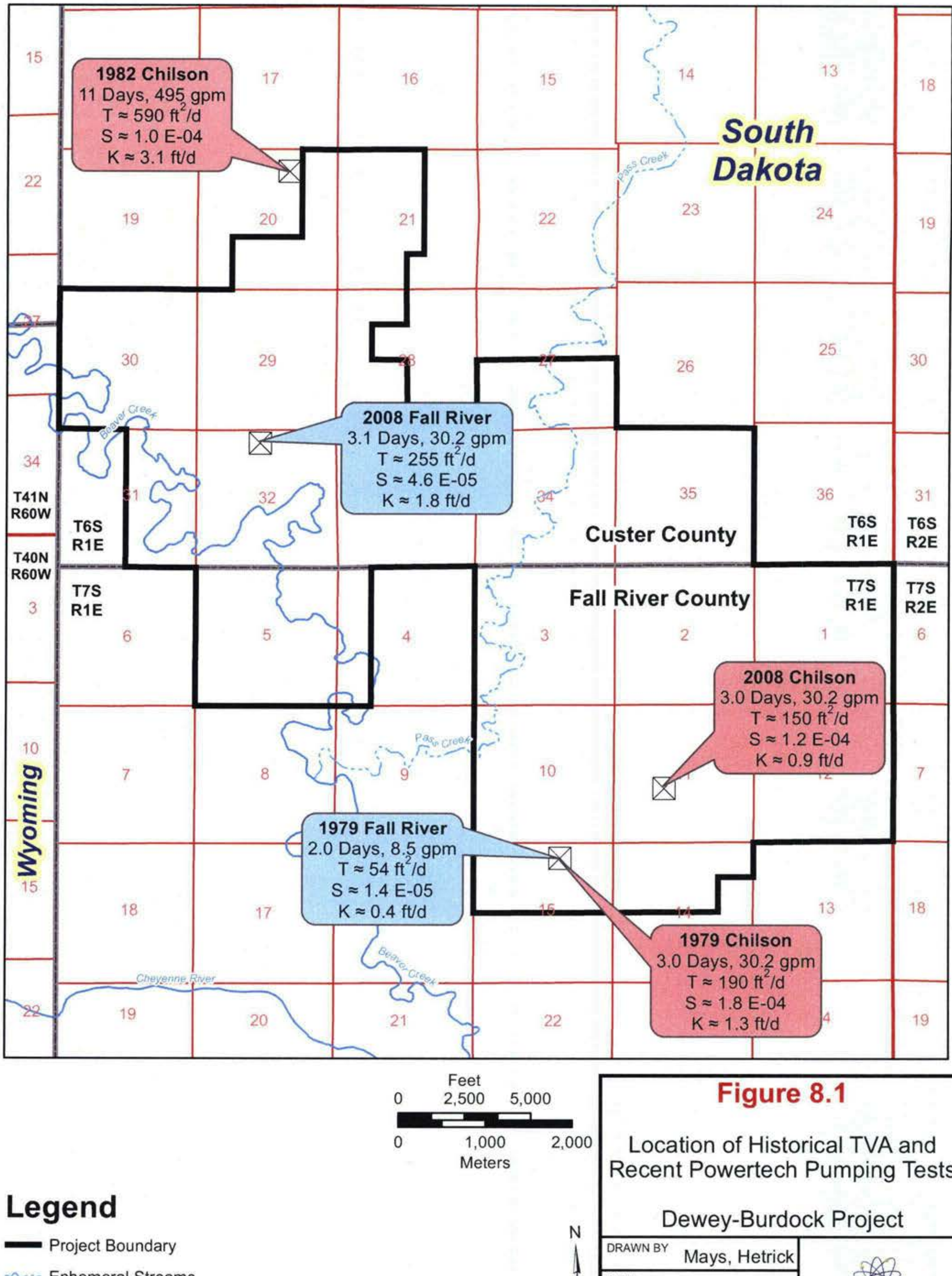


Figure 8.1

Location of Historical TVA and Recent Powertech Pumping Tests

Dewey-Burdock Project

DRAWN BY	Mays, Hetrick
DATE	12-Jul-2012
FILENAME	PumpTests.mxd

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- A barrier boundary or decrease in transmissivity due to lithologic changes with distance from the test site, or both, were observed; a possible geologic feature corresponding to a barrier was noted to be the Dewey Fault Zone, located about 1.5 miles north of the test site, where the Chilson and Fall River formations are structurally offset.

8.2.2 2008 Pumping Tests

In 2008 pumping tests were performed in the Dewey and Burdock portions of the project area (Figure 8.1), along with laboratory tests on related core samples, to assess aquifer properties. A work plan (Knight Piésold, 2008a) was prepared and distributed to interested representatives of state and federal agencies, including South Dakota DENR and the EPA.

A detailed description of the aquifer testing methodology and analysis of the results are contained in the aquifer test report (Knight Piésold, 2008b) (Appendix I). The report results are briefly summarized in the following sections.

8.2.2.1 Burdock Area

Summary of Burdock Pumping Test Results

Pump testing was conducted within the lower Lakota (Chilson) at pumping well DB07-11-11C. Three observation wells were monitored in the same horizon. An observation well was also monitored in the upper Chilson. Single observation wells were monitored in the overlying Fall River and underlying Unkpapa. The well was pumped at an average rate of 30.2 gpm for 4,320 minutes (3.0 days).

Drawdown at the pumping well was approximately 91 feet, and between 3.1 feet and 17.0 feet in the lower Lakota (Chilson) observation wells. The upper Lakota (Chilson) well response was delayed, but 3.4 ft of drawdown was observed in this well. Approximately 1 foot of drawdown was observed in the overlying Fall River well and no response was observed in the underlying Unkpapa well.

A summary of aquifer parameters for the 2008 Burdock pumping test (conducted in the Chilson Member of the Lakota Formation) and related laboratory core testing follows:

- Nine determinations of transmissivity (Table 8.1) ranged from 120 to 223 ft^2/day with the median value of 150 ft^2/day.
- Based on 170 feet of saturated thickness in the aquifer, hydraulic conductivities range from 0.7 ft/day to 1.3 ft/day, with a median value of 0.9 ft/day.
- Four storativity determinations (Table 8.1) ranged from 6.8×10^{-5} to 1.9×10^{-4} with a median value of 1.2×10^{-4}.
- The radius of influence of the pumping test determined by a distance-drawdown plot was 2,100 feet.

Table 8.1: Summary of Aquifer Hydraulic Characteristics for the Burdock Pumping Test

Well I.D.	Well Type	Radial Dist. (ft)	Interpretation Method	Transmissivity (ft^2/day)	u or u' (unitless)	Storativity (unitless)	Note
Ore zone (lower Chilson Sandstone)							
11-11C	Pumping	0.25 (0.33)	Theis DD(1)	145	-	2.9E-09(a)	-
			CJ DD (3)	150	<0.01	-	-
Pumping Well Efficiency = 65%(3)							
			CJ Recovery (3)	140	<0.01	-	-
15-Nov	Obs #1	243	Theis DD(1)	67	-	1.30E-03	-
			CJ Recovery (3)	100	<0.1	-	-
11-14C	Obs #2	250	Theis DD(1)	128	-	6.80E-05	-
			H-J DD(1)	120	-	6.90E-05	
			Theis Recovery(1)	174	<0.01	-	-
			CJ Recovery (3)	160	<0.01	-	-
2-Nov	Obs #3	1,292	Theis DD(1)	223	-	1.90E-04	-
			H-J DD(1)	185	-	1.70E-04	-
			CJ Recovery (3)	260	<0.15	-	-
Upper Chilson Sandstone							
19-Nov	Obs	50	Theis DD(2)	260	-	1.00E-01	-
			CJ Recovery (3)	190	<0.15	-	-
Fall River (lower sandstone layer)							
17-Nov	Obs	50	Noordbergum Effect and response cannot be interpreted analytically				
Unkpapa Sandstone							
18-Nov	Obs	35	No response during pumping test.				-
Distance Drawdown (11-14C, 11-15, 11-02)(2)				145	<0.08	2.20E-04	r^2 = 0.76 (3 point line)
Pumping Well Efficiency = 61% to 63%							
Summary:	Median			150		1.20E-04	
Average/Geometric Mean(5)				158		1.12E-04	
	TVA(4)			190		1.80E-04	

(1) Calculated by automated curve fitting in AquiferWin32™ software (ESI, 2003).
(2) Knight Piésold spreadsheet after methods in Driscoll (1986).
(3) Spreadsheet methods in U.S. Geol. Surv. Open File Rept. 02-197, Halford and Kuniansky (2002).
(4) Summary values from p. 17 in Boggs and Jenkins (1980).
(5) Average value calculated for Transmissivity, Geometric Mean value calculated for Storativity.
(a) Storativity not valid at pumping well.
(b) Based on 6 inch casing (8 inch borehole).

'158' = Accepted value based on conformance with theory discussed in the text

- Laboratory measurements of horizontal and vertical hydraulic conductivity (Table 8.2) were made on sandstone layers similar to that tested in the pump test; measured horizontal hydraulic conductivity ranged from 5.9 to 9.1 ft/day, the mean value was 7.4 ft/day and mean ratio of horizontal to vertical hydraulic conductivity in Burdock area sandstone was 2.47:1.
- Laboratory measurements of horizontal and vertical hydraulic conductivity (Table 8.2) were made on shale layers from two major confining units for the Lakota (Chilson) in the pump test area with the following results:
    - Fuson Shale: the laboratory core data indicated vertical permeabilities of about 2×10^{-7} to 1×10^{-8} cm/sec (average 2.7×10^{-4} ft/day) for shale samples from the Fuson Shale.
    - Morrison Shale: the laboratory core data for the shales in the underlying Morrison Formation indicated vertical permeabilities of 9×10^{-9} to 3×10^{-8} cm/sec (average 6.0×10^{-5} ft/day).

Burdock Pumping Test Conclusions

The Burdock pumping test in 2008 may be directly compared to the 1979 TVA test for the Lakota (Chilson) aquifer as the tests were nearly at the same location (Figure 8.1). The average transmissivity and storativity values determined from the TVA tests were 190 ft^2/day and 1.8×10^{-4} (see p. 17 in Boggs and Jenkins, 1980). Comparing the median transmissivity of 150 ft^2/day and storativity of 1.2×10^{-4} determined in the 2008 test to the TVA test, the new aquifer parameters for the lower Chilson are respectively about 80 and 70 percent of the 1979 results. Because transmissivity and storativity depend on aquifer thickness, comparison of the results suggests that there may be some scaling effect between the tests due to the different lengths of screened intervals.

The 1979 TVA test transmissivity of 190 ft^2/day is considered representative of the entire Chilson aquifer for a regional application (Table 8.1).

Previous conclusions and interpretations from this pump test submitted to NRC and EPA indicated that the Chilson behaved as a leaky aquifer system (e.g., a drawdown response was observed in the overlying Fall River observation well and the Chilson wells consistent with a leaky system based on a match of the data to the Hantush-Jacob solution). Further review of the site geology and hydrology suggest that those interpretations were not representative of site conditions.

The laboratory core data from samples collected within the project area indicate an average vertical permeability of 9.3×10^{-8} cm/s (2.7×10^{-4} ft/day) for shale samples from the Fuson Shale (Table 8.2). The shale core permeability values are about one to two orders of magnitude smaller than the pumping test values determined in the 1979 TVA test at Burdock, where the vertical

Table 8.2: Laboratory Core Analyses at Project Site

Sample Number	Depth (ft)	Confining Stress (psig)	Porosity (%)	Air Intrinsic Permeability(1) ka (mD)	Particle Density (g/cm^3)	Notes	Water Hydraulic Conductivity Kw(2)(3) (cm/s)	Core Kh (ft/day)	Core Kv (ft/day)
DB 07-11-11C Burdock									
1H	252.20	600	10.50	1.040	2.356	Fuson Shale	8.0073E-07		
1V	252.35	600	10.15	0.228	2.356	Fuson Shale	1.7555E-07		
4H	412.30	600	9.68	0.041	2.511	Fuson Shale	3.1567E-08		
4V	412.45	600	9.59	0.015	2.514	Fuson Shale	1.1549E-08		
DB 07-29-1C Dewey									
2H	480.70	600	8.90	0.078	2.613	Skull Creek shale	6.0055E-08		
2V	480.80	600	9.30	0.007	2.610	Skull Creek shale	5.3896E-09		
3H	609.10	600	12.26	0.073	2.603	Fuson Shale	5.6205E-08		
3V	609.10	600	10.84	0.008	2.793	Fuson Shale	6.1595E-09		
DB 07-11-14C Burdock									
5H	423.60	600	29.56	3,207	2.645	Lakota Sand	2.4692E-03	7.0	
5V	423.35	600	30.34	1,464	2.645	Lakota Sand	1.1272E-03		3.2
6H	430.20	600	31.90	4,161	2.640	Lakota Sand	3.2037E-03	9.1	
6V	430.35	600	30.16	939	2.646	Lakota Sand	7.2297E-04		2.1
7H	453.50	600	10.86	1.000	2.519	Morrison Shale	7.6994E-07		
7V	453.45	600	11.82	0.043	2.543	Morrison Shale	3.3107E-08		
DB-07-11-16C Burdock									
8H	420.40	600	30.50	2,697	2.643	Lakota Sand	2.0765E-03	5.9	
8V	420.10	600	30.17	1,750	2.651	Lakota Sand	1.3474E-03		3.8
9H	455.90	600	6.99	0.004	2.536	Morrison Shale	3.0797E-09		
9V	455.45	600	7.65	0.012	2.556	Morrison Shale	9.2392E-09		
10H	503.30	600	12.96	0.697	2.474	Morrison Shale	5.3665E-07		
10V	503.45	600	No data						
DB 07-32-4C Dewey									
11H	573.25	600	29.15	2,802	2.641	Fall River Sand	2.1574E-03	6.1	
11V	573.40	600	29.04	619	2.645	Fall River Sand	4.7659E-04		1.4
Summary									
Average Lakota Sand Kh, Kv								7.4	3.0

(1) Assumed air temperature = 70°F.
(2) Assumed water temperature = 52.8°F, water density = 0.999548 g/cm^3, and water dynamic viscosity = 0.012570 g/cm-s.
(3) $K_w = k_a \times (\rho_w g/\mu_w)$, and 1.0 mD = 0.987×10^{-11} cm^2

hydraulic conductivity of the Fuson aquitard was calculated using the Neuman-Witherspoon ratio method to be about 1 x 10^{-3} ft/day (see pg. [i] in Boggs and Jenkins, 1980).

For the Lakota (Chilson) sandstone, the laboratory core data within the project area indicate an average horizontal hydraulic conductivity of 2.5 x 10^{-3} cm/sec (7 ft/day) and a range as high as 3.2 x 10^{-3} cm/sec (9.1 ft/day) (Table 8.2). Pump test results indicate an average horizontal hydraulic conductivity of approximately 0.9 ft/day (3.2 x 10^{-4} cm/s).

Site-wide geologic data (logs, cross sections and isopach maps) clearly demonstrate the continuity of the Fuson Shale across the project area. Those data, combined with data from the pump tests and core results, indicate that the leaky behavior observed in the 2008 Chilson test likely is the result of (1) communication between the Chilson and Fall River via Well 668 that is completed in both sands, and/or (2) the presence of open boreholes that may provide communication between the Fall River and Lakota (Chilson) in a limited area near the Burdock test.

8.2.2.2 Dewey Area

Summary of Dewey Pumping Test Results

Pump testing was conducted in the lower sandstone interval of the Fall River at pumping well DB07-32-3C. This well was pumped at a rate of 30.2 gpm for 3.1 days (4,440 minutes). Three observation wells between 240 and 2,400 feet from the pumping well were monitored in the same horizon. An upper Fall River observation well was also monitored. Single observation wells were monitored in the underlying Lakota (Chilson) and Unkpapa aquifers.

Drawdown at the pumping well was 44.8 feet, and drawdown in the lower Fall River observation wells varied with distance from the pumping well to between 1.5 and 13 feet. Drawdown in the upper Fall River approximately 40 feet from the pumping well was approximately 4 feet. No drawdown response was observed in the underlying Lakota (Chilson) or Unkpapa aquifers.

A summary of aquifer parameters for the 2008 Dewey pumping test (conducted in the Fall River Formation) and related laboratory core testing is as follows:

- Ten determinations of transmissivity (Table 8.3) ranged from 180 to 330 ft^2/day with a median value of 255 ft^2/day.
- Based on 140 feet of saturated thickness in the Fall River, hydraulic conductivities range from 1.3 ft/day to 2.4 ft/day, with a median value of approximately 1.8 ft/day.
- Five storativity determinations (Table 8.3) ranged from 2.3 x 10^{-5} to 2.0 x 10^{-4} with a median value of 4.6 x 10^{-5}.

Table 8.3: Summary of Aquifer Hydraulic Characteristics for the Dewey Pumping Test

Well I.D.	Well Type	Radial Dist. (ft)	Interpretation Method	Transmissivity (ft^2/day)	u or u' (unitless)	Storativity (unitless)	Note
Ore zone (lower Fall River Sandstone)							
32-3C	Pumping	0.25 (0.33)	Theis DD(1)	250	-	1.2E-06(d)	-
			CJ DD (3)	250	<0.01	-	-
Pumping Well Efficiency = 80%(3)							
			CJ Recovery (3)	270	<0.01	-	-
32-5	Obs #1	243	Theis DD(1)	294	-	3.30E-05	--
			Theis Recovery(1)	260	<0.01	-	-
			CJ Recovery(3)	280	<0.01	-	-
32-4C	Obs #2	467	Theis DD(1)	333	-	5.60E-05	-
			CJ Recovery (3)	120(a)	<0.01	-	
29-7	Obs #3	2,400	Theis DD(2)	178	-	2.00E-04	
			CJ Recovery (3)	Insufficient recovery for analysis			-
Fall River Aquifer Stock Well (Screened in top half of Fall River)							
GW-49	Stock	1,400	Theis DD(1)	177	-	2.30E-05	-
			CJ Recovery (3)	110	<0.05	-	-
Upper Fall River Sandstone							
32-9C	Obs	41	Theis DD(1)	217	-	1.60E-02	-
			CJ Recovery (3)	150	<0.05	-	--
Chilson Sandstone Layer							
32-10	Obs	61	No response during pumping test.				--
Unkpapa Sandstone							
32-11	Obs	50	No response during pumping test.				-
Distance Drawdown (32-5, 32-4C, 29-7, GW-49)(2)				218	<0.05	4.60E-05	r^2 = 0.78 (4 point line)
Pumping Well Efficiency = 93% to 95%							
Summary:	Median			255		4.60E-05	
Average/Geometric Mean(4)				251		5.23E-05	

Notes/References: DD = drawdown, CJ = Cooper -Jacob, Obs = Observation Well
(1) Calculated by automated curve fitting in AquiferWin32™ software (ESI, 2003).
(2) Knight Piésold spreadsheet after methods in Driscoll (1986).
(3) Spreadsheet methods in U.S. Geol. Surv. Open File Rept. 02-197, Halford and Kuniansky (2002).
(4) Average value calculated for Transmissivity, Geometric Mean value calculated for Storativity.
(a) Only slope satisfying u 'criterion occurs after intersection with barrier boundary.
(b) Not accepted due to anomalous response at well, see text.

- The radius of influence of the pumping test determined by a distance-drawdown plot was 5,700 feet.
- Laboratory measurements of horizontal and vertical hydraulic conductivity (Table 8.2) were made on shale samples from the two major confining units overlying and underlying the pump test area with the following results:
  - Skull Creek Shale: laboratory core data for the shale sample from the overlying Skull Creek Shale (Graneros Group) indicate a vertical permeability of 5.4×10^{-9} cm/sec (1.5×10^{-5} ft/day).
  - Fuson Shale: laboratory core data for the shale sample from the underlying Fuson Shale indicate a vertical permeability of 6.2×10^{-9} cm/sec (1.8×10^{-5} ft/day).

Dewey Pumping Test Conclusions

The Dewey pumping test in 2008 in the Fall River aquifer is not directly comparable to the 1982 TVA test because the underlying Lakota (Chilson) aquifer was tested in 1982.

The 2008 test indicated that the lower and upper sandstone portions of the Fall River Formation behave as a single, confined aquifer with some form of lateral barrier due to changing lithology, such as a channel boundary. The TVA test in 1982 observed a barrier boundary in the underlying Lakota Formation, likely the result of the Dewey Fault Zone. Apparently, both the Chilson and Fall River Formation in the general Dewey area are highly transmissive and show barrier boundaries. These test results are more definitive than the 1982 TVA test concerning the effect of the barrier boundary, because the 2008 radius of influence was about one mile, or about one-half to one-third the distance to the fault zone.

Confinement provided by the Fuson Shale between the Fall River and underlying Chilson Member of the Lakota was demonstrated by the 2008 testing. The Chilson and Fall River aquifers at the Dewey test site are hydraulically isolated by the intervening Fuson Shale with nearly 40 feet of head difference between the two units. The laboratory core data indicate a very low vertical permeability of 6.2×10^{-9} cm/sec (1.8×10^{-5} ft/day) for a shale sample from the Fuson Shale within the project area (Table 8.2).

The laboratory core data for the shale sample from the Skull Creek Shale, which overlies the Fall River Formation, indicate a very low vertical permeability of 5.4×10^{-9} cm/sec (1.5×10^{-5} ft/day), which is representative of an effective aquitard or aquiclude (Table 8.2).

For the sandstone of the Fall River Formation, the laboratory core data indicate a horizontal hydraulic conductivity of 6.1 ft/day (2.2×10^{-3} cm/s) (Table 8.2). Based on pump test results, the average horizontal conductivity is approximately 1.8 ft/day (6.4×10^{-4} cm/s). Within the lower Fall River Formation, the test results indicate transmissive, rapid response (2 to 3 minutes) between pumping and observation wells up to 467 feet apart with nearly 10 feet of drawdown.

Response was nearly 9 feet of drawdown at 1,400 feet distance. This indicates that the aquifer was stressed to produce good quality analytical results.

8.2.3 Pre-Operational Pump Testing for Each Well Field

The following pump testing procedures will be used to establish that the production and injection wells are hydraulically connected to the perimeter production zone monitor wells, that the production and injection wells are hydraulically isolated from non-production zone vertical monitor wells, and to detect potentially improperly plugged wells or exploration holes. Pump testing results will be included in the well field hydrogeologic data packages described in Section 8.2.4 and the injection authorization data packages described in Section 8.2.5.

Pump Testing Design

An extensive pump test program will be designed and implemented prior to operation of each well field to evaluate the hydrogeology and assess the ability to operate the well field. Prior to pump testing several important well field development steps will be completed:

1) Delineation drilling at spacing sufficient to finalize well field design. As standard procedure, all delineation holes will be plugged and abandoned after drilling.
2) Detailed mapping of the ore bodies targeted for ISR operations and the lithology of overlying and underlying sand units and aquitards.
3) Revision of the conceptual geology and hydrogeology including definition of aquitards and sand units to be produced or monitored.
4) Design of the production and injection wells including well locations and screened intervals.
5) Design of the monitor well system based on production and injection well locations and refined conceptual geology and hydrogeology.
6) Specification of all monitor well locations and screened intervals.
7) Installation of all monitor wells and production wells to be used during pump testing.
8) Plugging and abandoning all water supply wells within ¼ mile of the well field or that have been determined through preliminary evaluation to be potentially impacted by ISR operations or to impact ISR operations.

Pump Testing Procedures

Appropriate wells as needed for characterization and regulatory purposes will be monitored during the pumping test, including but not necessarily limited to the following wells:

1) Pumping wells,
2) Monitor wells within the production zone,
3) Perimeter production zone monitor wells,

4) Monitor wells in the immediately overlying non-production zone sand unit,
5) Monitor wells in each subsequently overlying non-production zone sand unit,
6) Monitor wells in the alluvium, if present,
7) Monitor wells in the immediately underlying non-production zone sand unit, if the production zone does not occur immediately above the Morrison,
8) Any additional wells installed for investigating other hydrogeologic features, and
9) Any other wells within proximity to the well field that have been identified as having the potential to impact or be impacted by ISR operations.

In general, the monitoring system wells will be monitored using downhole data logging pressure transducers, which will be corrected for variations in barometric pressure. Some manual measurements with electronic meters also may be made.

Prior to testing, static potentiometric water levels will be measured in every well in the monitoring system. Where a sufficient number of data points exist, these data will be used to map the pre-operational potentiometric surface for each unit including alluvium, where present. Because of the high density of wells and artesian conditions at the site, any leakage across aquitards due to improperly plugged boreholes or wells typically will become apparent while preparing potentiometric surface maps. Water samples will be collected from selected monitor wells and analyzed for baseline parameters. The water quality will be evaluated to identify any potential areas of leakage across aquitards due to improperly plugged boreholes or wells.

Pump testing will involve inducing stress on the production zone sand unit by operating pumping wells. The goal of the test will be to demonstrate suitable conditions for ISR operations. This will be done by causing drawdown in the production zone extending to all perimeter monitor wells, creating a cone of depression across the well field area to test the confinement between the production zone and the overlying and underlying sand units and alluvium, if present, and addressing potential leakage through confining units via improperly sealed or unplugged exploration boreholes, or associated with naturally occurring geologic features. The presence or lack of response in vertical monitor wells will be used for evaluation of confinement between these units and for identification of leakage due to anomalies such as improperly plugged boreholes. If leakage is present, the relative responses in the overlying, underlying, and/or alluvial monitor wells will indicate the proximity and direction toward the source of leakage.

If saturated alluvium is present within the well field, alluvial monitor wells will be installed and monitored above the production zone and within an appropriate distance from the well field. The water level in the alluvium will be measured prior to testing and monitored during pump testing. If there are anomalous conditions that cause communication between the production zone and alluvium such as an improperly plugged borehole, these conditions will be identified through responses in the alluvial monitor wells.

The pumping test duration will be sufficient to create a suitable response in the perimeter monitor wells, typically a minimum drawdown of 1 foot. If hydrogeologic conditions dictate, less response may be adequate to show a direct cause and effect from pumping.

The flow rate of the pumping test will be based on well capacity and design requirements. More than one pumping well may be required to create drawdown in all perimeter wells.

Measurements during pump testing will include instantaneous and totalized flow, periodic pressure transducer measurements, barometric pressure, and time. A step rate test will be performed initially. There will be an initial stabilization phase with no flow, a stress period of constant flow, and a recovery period with no flow.

Pump Test Evaluation

Evaluation of pump test data will address the following:

1) Demonstration of hydraulic connection between the production and injection wells and all perimeter monitor wells and across the production zone.
2) Verification of the geologic conceptual model for the well field.
3) Evaluation of the vertical confinement and hydraulic isolation between the production zone and overlying and underlying units.
4) Calculation of the hydraulic conductivity, storativity, and transmissivity of the production zone sand unit.
5) Evaluation of anisotropy within the production zone sand unit.

8.2.4 Well Field Hydrogeologic Data Packages

Pump testing data and results will be included in the well field hydrogeologic data packages, which will be prepared in accordance with NRC license requirements. This section describes the contents and evaluation of the well field hydrogeologic data packages. These will be reviewed by the SERP and, as necessary, NRC. Refer to Section 8.2.5 for a description of the injection authorization data packages, which will be prepared and presented to EPA for each well field.

Upon completion of field data collection and laboratory analysis, the well field hydrogeologic data packages will be assembled and submitted for review by the SERP for evaluation. The SERP evaluation will determine whether the results of the hydrologic testing and the planned ISR operations are consistent with standard operating procedures and technical requirements stated in the NRC license. The evaluation will include review of the potential impacts to human health and environment. Relevant portions also will be included in the injection authorization data packages described in Section 8.2.5. If anomalous conditions are present or the SERP evaluation indicates potential to impact human health or the environment, the well field hydrogeologic data package will be submitted to NRC for review and approval. The well field hydrogeologic data package and written SERP evaluation will be maintained at the site and available for regulatory agency review.

Each well field hydrogeologic data package will contain the following:

1) A description of the proposed well field (location, extent, etc.).
2) Map(s) showing the proposed production and injection well patterns and locations of all monitor wells.
3) Geologic cross sections and cross section location maps.
4) Isopach maps of the production zone sand and overlying and underlying confining units.
5) Discussion of how pump testing was performed, including well completion reports.
6) Discussion of the results and conclusions of the pump testing, including pump testing raw data, drawdown match curves, potentiometric surface maps, water level graphs, drawdown maps and, when appropriate, directional transmissivity data and graphs.
7) Sufficient information to show that wells in the monitor well ring are in adequate communication with the production patterns.
8) Baseline water quality information including proposed UCLs for monitor wells and target restoration goals (TRGs).
9) Any other information pertinent to the proposed well field area tested will be included and discussed.

8.2.5 Injection Authorization Data Packages

Injection authorization data packages will be prepared and presented to EPA for each well field. Each injection authorization data package will contain the following:

1) A description of the proposed well field (location, extent, etc.).
2) Map(s) showing the proposed production and injection well patterns and locations of all monitor wells.
3) Geologic cross sections and cross section location maps.
4) Discussion of how pump testing was performed, including well completion reports and MIT results.
5) Discussion of the results and conclusions of the pump testing, including pump testing raw data, drawdown match curves, potentiometric surface maps, water level graphs, drawdown maps and, when appropriate, directional transmissivity data and graphs.
6) Sufficient information to show that wells in the monitor well ring are in adequate communication with the production patterns.

7) The calculated formation fracture pressure for each header house and the designated maximum injection pressure for each header house.

8) Commitment to completing MIT and preparing well completion reports for all injection wells prior to initiating injection into the well field.

9) Schedule for proceeding with operation of the well field.