POWERTECH (USA) INC.

APPENDIX F
PUMPING TESTS

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Powertech (USA) Inc.
Dewey-Burdock Project
2008 Pumping Tests:
Results and Analysis

November 2008

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Knight Piésold
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Powertech (USA) Inc.
Dewey-Burdock Project
2008 Pumping Tests:
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1.0 Introduction

Powertech Uranium Corp. (Powertech) is submitting an application to the United States Nuclear Regulatory Commission (USNRC) for the Radioactive Source Materials License to develop and operate the Dewey-Burdock Uranium Project using in-situ recovery (ISR) methods. The project is located near Edgemont, South Dakota in Custer and Fall River Counties and will consist of injection and production well fields and a central processing plant (ion exchange resin columns and yellowcake dryer) to recover the final uranium product.

Figure 1.1 shows the project location and license boundary. The Project is located approximately 12 miles north-northwest of Edgemont, South Dakota and spans northern Fall River and southern Custer Counties. The project boundary encompasses approximately 11,000 acres of private land on either side of County Road 6463. The Dewey-Burdock project will operate uranium ISR production facilities at both the Dewey and Burdock project areas, with a central processing plant located at the Burdock site. It is anticipated that the ISR well fields at each site will operate at an estimated flow rates of between 1500 gallons per minute (gpm) to 2000 gpm. Net withdrawal of groundwater during ISR leaching operations is expected to be 0.5 to 3 percent of total flow, or 10 to 60 gpm at each site. Total production from both sites is expected to produce approximately 1,000,000 pounds of U_3O_8 per year.

1.1 Objectives

USNRC NUREG 1569 Sections 2.7.2 and 2.7.3, Hydrology, Review Procedures (3) and Acceptance Criteria (3), describe the type of information and analyses that can fulfill the requirements for a description of Site hydrogeology. Consistent with the examples provided in the NUREG sections referenced above, the objective of this report is to provide the determinations of aquifer properties obtained with two pumping tests together with the results of laboratory tests Powertech conducted on related core samples. The pumping tests are interpreted in the context of geological and hydrogeological data that are summarized here and presented authoritatively in greater detail in NRC Technical Report Sections 2.6 and 2.7. The more detailed information presented outside this report consists of: (1) geologic cross-sections, including the underlying electric log data from test pumping wells, test observation wells and

nearby exploration boreholes; (2) isopach maps of the production zone, overlying confining units and aquifers and underlying confining units and aquifers; and (3) potentiometric surface maps of the major aquifers.

Other information prescribed in NUREG 1569 Section 2.7.1, Hydrology, Areas of Review (3), notably soil survey and baseline groundwater quality information, is presented in separate reports. It is noted that the pumping tests described here are not intended to replace well field-scale pumping tests that are proposed to be conducted prior to startup of each particular mine unit. The following information is included in this report:

- Site location maps
- A summary of previous pumping test results
- A synopsis of geologic and hydrogeologic information for the Project Area relevant to the interpretation of pumping tests, including detailed conceptual stratigraphic cross-sections illustrating the test layouts relative to ore-body features
- Presentation of the pumping test results, including raw test data (drawdown graphs) that provide overall response characteristics for all wells monitored during the tests
- Interpretation of aquifer parameters using type curve matches and other methods of parameter determinations
- Interpretation, based on the communication of pumping and observation wells that it is likely feasible to conduct ISR mining within limited portions of the major aquifers
- Interpretation, based on the pumping test data and laboratory core data, that there is likely additional vertical containment between major aquitards overlying and underlying the major aquifers

1.2 Report Organization

This report includes seven sections. Section 1 (this section) is the introduction. Section 2 describes site-specific geologic and hydrogeologic conditions followed by a summary of previous aquifer tests in the period 1979 to 1982. Section 3 describes the general procedures for well installation, test equipment used, background measurements, and data processing procedures for the pumping tests. Details of the background monitoring and analysis are provided in Appendix A-1, and Appendix A-2 provides an overview of pumping test interpretation methods, theoretical considerations, and spreadsheet tools used for test analysis. Section 4 describes the results and analysis of the pumping test at the Dewey test location; Appendix B provides backup data for the Dewey Pumping Test including well completion

diagrams, processed time-drawdown data used to perform the test analysis, and the determinations of aquifer parameters with graphical methods not directly presented in the text. Similarly, Section 5 describes the results and analysis at the Burdock test location and Appendix C provides the related data for the Burdock test. Section 6 is a summary of laboratory core testing information and Appendix D provides the laboratory data report for the core testing. Section 7 is a summary describing major conclusions from the testing. Appendix E is a CD-ROM that contains the raw digital pressure transducer data in binary files.

1.3 Limitations and Disclaimer

This report entitled "Powertech (USA) Inc., Dewey-Burdock Project, 2008 Pumping Tests: Results and Analysis" has been prepared by Knight Piésold and Co. for the exclusive use of Powertech (USA) Inc. No other party is an intended beneficiary of this report or the information, opinions, and conclusions contained herein. Any use by any party other than Powertech (USA) Inc. of any of the information, opinions, or conclusions is the sole responsibility of said party. The use of this report shall be at the sole risk of the user regardless of any fault or negligence of Powertech (USA) Inc. or Knight Piésold and Co.

The information and analyses contained herein have been completed to a level of detail commensurate with the objectives of the assignment. This report and its supporting documentation have been reviewed and/or checked for conformance with industry-accepted norms and applicable government regulations. Calculations and computer simulations have been checked and verified for reasonableness, and the content of the report has been reviewed for completeness, accuracy, and appropriateness of conclusions. To the best of the information and belief of Knight Piésold and Co. the information presented in this report is accurate to within the limitations specified herein.

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2.0 Site Characterization

This section presents a synopsis of geologic and hydrogeologic information. Section 2.1 presents geologic information (see Figure 2.2) taken from Section 2.6 of the USNRC Technical Report. Section 2.2 presents hydrogeologic information presented in Section 2.7 of the Technical Report. Section 2.3 describes the history of previous aquifer testing in relation to uranium exploration and development.

2.1 Stratigraphy

The sedimentary rocks of interest that underlie the Dewey-Burdock Project range in age from Upper Jurassic to Early Cretaceous. These are the Upper Jurassic Sundance Formation, the Unkpapa Formation, and the Morrison Formation. The Early Cretaceous Lakota Formation, the Fall River Formation, the Skull Creek Shale Formation and the Mowry Shale Formation. Figure 2.1.

Underlying these, are rocks that range in age from Cambrian to Pennsylvanian in age. The sediments exposed at the Dewey-Burdock Project are of Early Cretaceous age.

2.1.1 Overlying Unit: Skull Creek Formation Shales

The combined Skull Creek Shale – Mowry Shale reaches a thickness of 400 ft (ft) in the western part of the Dewey-Burdock project.

Mowry Shale

The Mowry Shale consists of light gray marine shale with minor amounts of siltstone, fine grained sandstone, and a few thin beds of bentonite.

Newcastle Sandstone Formation

The Newcastle Sandstone, normally occurring between the Skull Creek Shale and the Mowry Shale, is composed of fine-grained sandstone interbedded with siltstones. This formation is discontinuous across the region and is absent across the project area. At the Dewey-Burdock Project the Skull Creek Shale is directly overlain by the Mowry shale.

Skull Creek Shale Formation

The Skull Creek Shale is a sequence of dark-gray to black marine shales. The Skull Creek shale consists of black shale, organic material, and some silt sized quartz grains. The Skull Creek

Shale has a thickness of approximately 200 ft. The Skull Creek Shale is eroded from the eastern parts of the project.

2.1.2 Inyan Kara Group: Fall River Formation and Lakota Formation Sandstones

Inyan Kara Group

The Early Cretaceous Inyan Kara Group consists of two formations, the Lakota and the Fall River. The Inyan Kara is composed of interbedded sandstone siltstone and shale. The depositional environment of the Inyan Kara is fluvial to marginal marine.

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 Dewey-Burdock Project and generally contain the uranium deposits. Overlying the channel sandstones is another sequence of alternating sandstone and shales.

Lakota Formation

The Lakota Formation consists of three members, from lower to upper is the **Chilson** Member, the **Minnewasta Limestone** Member and the **Fuson** Member.

The **Minnewasta Limestone** Member is not present in the Dewey-Burdock Project area.

The **Chilson** Member is composed largely of fluvial deposits. These deposits consist of sandstone, shale, siltstone, and shale. The unit consists of a complex of channel sandstone deposits and their fine-grained equivalents. The unit contains uranium deposits.

The **Fuson** Member is the upper most member of the Lakota Formation and the shale-siltstone portion of the Fuson has been used to divide the Lakota Formation from the Fall River Formation.

The Fuson 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 a Lakota sandstone. Similarly if the upper sandstone was present it was mapped as a Fall River sandstone. The Lakota was deposited by a northwest flowing river system.

2.1.3 Underlying Units: Morrison Formation Shale and Unkpapa/Sundance Formation Sandstone

Morrison Formation

The Upper Jurassic Morrison Formation was deposited as flood plain deposits. It is composed of waxy, unctuous, calcareous, noncarbonaceous massive shale with numerous limestone lenses and a few thin fine grained sandstones.

Unkpapa Formation

Overlying the Sundance Formation is a sandstone unit that has been called the Unkpapa formation. The Unkpapa is a massive fine grained sandstone that was deposited as sand dunes.

Sundance Formation

The Sundance Formation of Upper Jurassic age consists of marine rocks composed of red shales and sandstones. The Sundance has been subdivided into five members. In ascending order they are the **Canyon Springs** sandstone member, the **Stockade Beaver** shale member, the **Hulett** sandstone member, the **Lak** member, and the **Redwater** shale member.

2.2 Hydrogeologic Conditions: Potentiometric Surface and Hydraulic Gradient

Groundwaters within the Inyan Kara formations are under artesian conditions in much of the Dewey-Burdock area. Some wells are known to have flowed for years. Figure 2.3 is a potentiometric surface map of the Fall River Formation aquifer within the Inyan Kara group. The map is based on measurements made in 2008. Based on Figure 2.3, groundwater flow direction in the Fall River aquifer is generally to the southwest, consistent with the topography of the broad Black Hills domal uplift, with significant components either more southerly or more westerly as reflected by the curvature of the potentiometric surface equipotential lines.

Groundwater gradient in the Fall River aquifer varies significantly throughout the project area. Near the outcrop areas upgradient of both the Dewey and Burdock project portions of the Site, the gradient is about 20 to 25 ft per mile (0.0038 to 0.0047 feet per foot [ft/ft]). At the Burdock portion of the Site, the Fall River aquifer gradient flattens to about 14 ft per mile (0.0026 ft/ft) extending downgradient to the southwestern project boundary. At the Dewey portion of the Site,

however, the groundwater gradient in the Fall River aquifer increases sharply to as much as about 52 ft per mile [0.01 ft/ft] within the central portion of the project area.

Figure 2.4 is a potentiometric surface map of the Lakota Formation aquifer below the Fall River aquifer within the Inyan Kara Group, based on measurements made in 2008. Groundwater flow direction is generally to the southwest with locally more southerly component. At the Burdock portion of the site, the groundwater gradient is relatively uniform from the outcrop area to the project boundary, about 18 ft per mile (about 0.0034 ft/ft). At the Dewey portion of the site Figure 2.4 indicates a somewhat flatter overall gradient, about 16 ft per mile (0.003 ft/ft). However, within the central portion of the Dewey project area there a broad area where the potentiometric surface elevations in the Lakota are between 3,680 and 3,690 ft above mean sea level (amsl).

The variations in the potentiometric surfaces in both Inyan Kara formations produce variations in the direction of vertical gradients throughout the project area. At the Burdock portion of the Site, the potentiometric surface in the Fall River aquifer is generally close to that in underlying Lakota (Chilson) aquifer; where there are differences, the Fall River appears to be slightly higher in elevation by a few (less than five) feet. This indicates minimal overall vertical gradients with possible downward flow direction between the two formations through the intervening Fuson Member of the Lakota Formation.

By contrast, at the Dewey portion of the Site there are areas where the potentiometric surface in the Lakota Formation is 20 to 30 ft higher than in the overlying Fall River Formation, indicating a vertically upward gradient. This is consistent with the character of the intervening Fuson Member in previous pumping tests, described in Section 2.6 below, where the Fuson was described as leaky in the Burdock area but a more effective aquitard in the Dewey area. This was also noted in earlier investigations (Keene, 1973, p. 26), which stated that “pressures in the Lakota Formation appear greater than those of the Fall River aquifer in the northwestern townships of the [Fall River] county. This is reasonable when one considers the higher intake elevation of the Lakota Formation, the greater thickness of the Chilson Member than the Fall River sands, and the smaller production from the Lakota aquifer.”

Figure 2.5 is a potentiometric surface map of the Unkpapa aquifer below the Inyan Kara group, based on measurements made in 2008 at four locations. The potentiometric surface in the Unkpapa Formation indicates groundwater flow direction to the southwest with locally more southerly components. Overall gradient is about 100 ft per 3 miles, which corresponds to an

average gradient of about 0.006 ft/ft. The potentiometric surface elevation is generally about 50 to 100 ft higher in both the overlying Lakota and Fall River Formation aquifers. This indicates vertical upward gradients between the Unkpapa Formation, the intervening Morrison Formation and the Inyan Kara Group. The Morrison Formation thus appears to function as an effective aquitard throughout the project area.

2.3 Summary of Previous Aquifer Testing Results

The Tennessee Valley Authority (TVA) conducted groundwater pumping tests from 1977 through 1982 as part of a uranium mine development project near the towns of Edgemont and Dewey, South Dakota. TVA produced two summary pumping test reports, "Analysis of Aquifer Tests 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). In addition, TVA prepared a draft Environmental Impact Statement for the proposed Edgemont Uranium Mine in 1979.

TVA first conducted two unsuccessful tests in 1977 at the Burdock test site. The results of the 1977 tests were considered inconclusive because of various problems including questionable discharge measurements, some observation wells improperly constructed, and some pressure gauges malfunctioned. No data from the 1977 tests are currently available.

TVA conducted three successful pumping tests, two in 1979 near the current Burdock Project Area, and one in 1982 about two miles north of the current Dewey Project Area. The results of these successful tests are described in separate sections below. However, no data for these tests, in particular electronic records of drawdown, are available, other than information contained in the reports.

2.3.1 Dewey Project Area

The Dewey test was conducted in 1982 northeast of the Dewey Road at the location shown on Figure 1.1. The test consisted of pumping in the Lakota formation for 11 days at an average rate of 495 gpm. The test developed the following information:

- Transmissivity of the Lakota averaged about 4,400 gallons per day per foot (gpd/ft) which is equivalent to 590 ft squared per day (ft^2/day).
- Storativity of the Lakota was about 1.0×10^{-4} (dimensionless).

- There was response between the Fall River and Lakota formations through the intervening Fuson shale-siltstone member that was manifested at relatively late time (3000 to 10000 minutes).

- The vertical hydraulic conductivity of the Fuson aquitard using the Neuman-Witherspoon ratio method (Neuman and Witherspoon, 1973) was 2 x 10^{-4} ft/day; storativity of the Fuson Member was not determined and specific storage was about 7 x 10^{-7} ft^{-1}.

- A barrier boundary, or a 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 Lakota and Fall River formations are structurally offset.

2.3.2 Burdock Project Area

The Burdock tests were conducted in 1979 near the Dewey road at the location shown on Figure 1.1. The Burdock tests consisted of separate pumping tests from the Lakota (Chilson) and Fall River Aquifer, respectively in April and July of 1979. The tests used the same pumping well with packers to alternately isolate screens open to the respective formations. Test durations were 73 hours for the Lakota test and 49 hours for the Fall River test. Pumping rates were about 200 gpm from the Lakota 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.

The tests developed the following information:

- Interpreted transmissivity of the Lakota was based on analysis of later time data and inferred decreasing transmissivity with distance from the test site due to changes in lithology; overall transmissivity averaged about 1,400 gpd/ft (190 ft^2/day) and storativity about 1.8 x 10^{-4} (dimensionless); maximum transmissivity from early time data was about 2,300 gpd/ft (310 ft^2/day).

- Transmissivity of the Fall River averaged about 400 gpd/ft (54 ft^2/day) and storativity about 1.4 x 10^{-5} (dimensionless).

- There was communication between the Fall River and Lakota formations through the intervening Fuson shale-siltstone member; leaky behavior was observed in the Fall River Formation and believed to exist in the Lakota although “leakage effects in the Lakota drawdown data are masked by the conflicting effect of a decreasing transmissivity in site vicinity” (p. 16 in Boggs and Jenkins, 1980).

- The vertical hydraulic conductivity of the Fuson aquitard determined with the Neuman-Witherspoon ratio method (Neuman and Witherspoon, 1973) ranged from

10^{-3} to 10^{-4} ft/day; storativity was not determined, and specific storage was assumed to be about 10^{-6} ft^{-1}.

3.0 2008 Pumping Tests: Design and Procedures

In 2008 pumping tests were performed at both the Dewey and Burdock project areas. A work plan (Knight Piésold, 2008) was prepared and distributed to interested representatives of State and Federal agencies, including the South Dakota DENR and the USEPA. Individual production zones within the Inyan Kara Group will likely be on the order of 10 to 15 ft thick to target ore horizons in both the Fall River and Lakota aquifers. Uranium ore is often located at different horizons in both aquifers at the same spatial locations (Drawings 4.1, 4.2, 5.1, 5.2 and 5.3).

Powertech performed geologic interpretations, well design, well installation and mechanical integrity testing. Well completions are described in detail for the test layout at each of the Dewey and Burdock project areas (Sections 4 and 5). Field activities for the Dewey and Burdock pumping tests were jointly performed by Powertech and Knight Piésold personnel. Aquifer test analyses were performed and this aquifer testing report was written by Knight Piésold.

3.1 Well Installation, Completion and Mechanical Integrity Testing

Well bores are drilled to diameters specified in SDDENR regulations. New casing is set and 15.2 pounds per gallon (lb/gal) cement is positively displaced into the annulus. After a cement cure time not less than 24 hours, the well is pressured up with air for a minimum of 1 hour. After the mechanical integrity test has passed, the well is developed until the water runs clear, and the screen is then pushed into place. The casing is cut off to 2.5 ft above ground surface and capped. Applicable reports are filed with the State. Wells are not used under conditions that do not meet manufacturer's recommendations and specifications for its type (SDA74:02:04:42).

3.2 Pumping Test Equipment and Facilities

Powertech personnel installed the pumping and monitoring equipment prior to testing. Knight Piésold verified the performance of the pumping test equipment by conducting step-drawdown tests at each site. Thereafter, Knight Piésold performed or supervised pump operations throughout the constant rate tests together with the datalogger programming and day-to-day downloads of data.

The tests were performed using a 5-horsepower (Hp) electrical submersible pump powered by a portable generator. At each site the pump was set at 300 ft with 2-inch diameter drop pipe. Surface flow monitoring equipment were Cameron 1-inch NUFLO™ flowmeters and MP-III™ digital flow analyzer with readout of instantaneous flow and totalizer of flow. In accordance

with the temporary discharge permit received from South Dakota DENR, the pump discharge water was piped to temporary holding ponds via 1 1/4-inch diameter high density polyethylene plastic pipe. Throughout the tests, a portion of the discharge water was routed through a YSI™ flow-through cell with multi-parameter probe that read field parameters (temperature, pH, conductivity, dissolved oxygen and turbidity) that were recorded twice daily through pumping phases of the tests.

Water levels in each well were measured and recorded with vented In-Situ™ Level TROLL™ pressure transducers with built in data loggers. The pressure ratings for the transducers range from 100 to 300 pounds per square inch (psi). Transducer accuracy (in comparison to known pressure or other pressure reading devices) is stated by the manufacturer to be ±0.1 percent of full-scale reading (i.e., 100 to 300 psi), so the limit of accuracy varies from 0.1 to 0.3 psi, or about 0.2 to 0.7 ft. Transducer sensitivity is stated to be ±0.01 percent of full-scale, resulting in sensitivity limits of about 0.01 to 0.03 psi, or 0.02 to 0.07 ft.

The sequence of events before and during the 2008 pumping tests is summarized in Figures 3.1 and 3.2. Figure 3.1 illustrates background pressure transducer and site barometer measurements that are described in Section 3.3, below. Evaluation of the background monitoring data produced several methods for correcting water levels; however, after these were applied on a test data set it was concluded that necessary corrections to water level data were minimal and that the test interpretations could equally well rely on uncorrected time-drawdown data.

Figure 3.2 displays output from the discharge flow data logger that is described in Section 3.4, below.

3.3 Background Monitoring and Water Level Corrections

Pressure transducers were installed in wells at both sites by April 2, 2008 in order to obtain background groundwater level measurements. At the Burdock test site, a transducer was installed in the designated pumping well (DB07-11-11C) in the lower Lakota Formation. At the Dewey test site, a transducer was installed in observation well (DB07-32-4C), screened in the same zone as the pumping well in the lower Fall River Formation. The right hand axis of Figure 3.1 graphs hourly barometric pressure measurements in millibars obtained from the meteorological station installed at the site. The site station is maintained by South Dakota State University (SDSU) and data are available at the following URL: “http://climate.sdstate.edu/awdn/edgemont/archive3.asp”.

One month of background measurements were obtained from April 8 to May 9, 2008 (Figure 3.1). Background measurements shown on Figure 3.1 fluctuate over a range of about 0.4 psi with the expected inverse relationship between site barometer readings and increases/decreases in groundwater levels. There are also smaller cyclic sinusoidal variations that occur twice daily and are attributable to Earth tide cycles. A period of two weeks (April 23 to May 8, 2008) after pump installation and initial testing produced undisturbed background water level data.

Three types of water level correction procedures were evaluated using the background monitoring data. The first procedure was manually correcting the transducer psi values with a constant barometric efficiency (BE) determined for each major aquifer (e.g., Kruseman and de Ridder, 1991). The BE is defined as the change in water level in a well versus a related change in atmospheric pressure. Gontheir (2007) describes the historical methods of determining BE, which by convention is dimensionless and ranges from zero to one.

The second type of correction that was evaluated considers additional factors, chiefly long-term seasonal trends and Earth tides (Gontheir, 2007). A spreadsheet distributed by the USGS as an open-file report (Halford, 2006) has programming that empirically factors the overall water level response into multiple synthetically generated time series with adjustments to both phase and amplitude of each component (see Appendix A.1, Figures A.1-3 and A.1-4). The USGS spreadsheet was used to determine that the Dewey background water level data from April 23 to May 8, 2008, could be closely matched as a series of four components: (1) water level increase at a linear rate [i.e., slope], (2) variation in air pressure measured with the site barometer, (3 and 4) two Earth tide components.

The third type of correction procedure evaluated was a computer method known as BETCO (Sandia Corporation, 2005; Toll and Rasmussen, 2006). This software is available at "http://www.sandia.gov/betco/". To correct data, water level, time and barometric pressure are input and BETCO calculates corrected water level values. Compared with the manual BE correction, the corrected water levels calculated in BETCO yielded similar results, generally within about ± 0.01 psi.

The manual BE method was judged to be better than the BETCO computer method for the background calibration period examined (Appendix A). Moreover, both the BETCO and USGS methods were difficult to apply with confidence to the drawdown data after the background monitoring period because wells with similar construction to the pumping test wells, but outside

the area of test influence, are not available to validate the corrections. A further difficulty with the BETCO and USGS computer methods is that they do not accommodate logarithmic measurement times as input data.

To examine the possible importance of BE corrections on water levels, the drawdown phase of the Dewey test was manually corrected with a BE of 0.48 (see Figure A.1-1 in Appendix A) relative to the site barometer over the test period. The maximum effect of the BE correction was to add about 0.2 ft to the water levels at the end of the drawdown phase due to an overall barometric pressure decline of about 15 millibars (i.e., from about 1,030 to 1,015 millibars, Figure 3.1). Test interpretations (Theis drawdown) were made with and without the BE corrections for the Dewey test. The corrections were found to have no discernable effect on the visual fits to type curves. Because the changes in barometric pressure during the 3-day constant rate tests at Burdock and Dewey were similar (Figure 3.1), the analysis determined that BE corrections would be no greater for the Burdock test compared to the Dewey test. Therefore, corrections to water level data were not further performed and the test interpretations rely on uncorrected time-drawdown data.

3.4 Test Procedures, Data Collection, Data Processing

The discharge flow data logger was set to record at hourly intervals and was downloaded at the end of the tests (Figure 3.2). The discharge flow rate was adjusted with a manual gate valve. Step-drawdown tests were performed on May 12 and 13, 2008 (Figures 3.1 and 3.2). The step-drawdown tests consisted of four steps at 10 gpm, 20 gpm, 25 gpm, and 30 gpm for a minimum of 90 minutes at each step. The step-drawdown data indicated successful performance of all equipment at both test sites. Subsequent analysis of the step-drawdown data was not performed due to the better quality (i.e., much longer time) data obtained from the constant rate tests for determining both aquifer parameters and well efficiencies.

Constant rate tests were performed on May 15 to May 18, 2008 at Dewey and from May 18 to May 21, 2008 at Burdock (Figures 3.1 and 3.2) after recovery from the step-rate tests. At both test sites the recorded hourly flow rates during the constant rate tests varied no more than 2 percent (between 30.0 and 30.7 gpm) throughout the tests and the pumping rates for the entire 3-day tests at each site averaged 30.2 gpm.

The data loggers in all wells were synchronized to the same clock-time immediately prior to start-up. To collect closely-spaced measurements during the start-up of the drawdown phase of the test, the transducers were programmed to record temperature and psi measurements at

one-second intervals for two hours, then at ten second-intervals for 70 to 72 hours. For recovery, the data loggers returned to a measurement frequency of one-second for two hours, during which time the pump was shut off, followed by ten-second measurement intervals thereafter.

The time-drawdown data output from the data loggers consisted of two hours of data at one-second intervals followed by 72 or 74 hours of data collected at ten-second intervals, with the sequence repeated for the recovery phase. The WinSitu™ software produced drawdown graphs that are reproduced in Sections 4 and 5. The software exported records to text ".csv" files with approximately 60,000 to 70,000 records for each well. The time-drawdown data were processed using a custom FORTRAN program that wrote data records to an output file based on a template file specifying which date-time records would be written. The template file was prepared to produce logarithmically spaced data with 30 records per log cycle (in seconds). Due to slight variations in transducer output and the precision of the Microsoft Excel date-time format, there are some ± one-second variations in the sequences of records from well to well.

The FORTRAN program also converted transducer psi to drawdown in ft using formulas described in Appendix A. The reference value for zero drawdown was set as the average of psi readings from the start of the data log to the time just prior to test startup. Separate time-drawdown files were prepared for both drawdown and recovery phases of the tests. Tables of the processed time-drawdown data used for test interpretations are provided in Appendices B and C. Complete binary files with the raw data for each well in Win-Situ™ format are also provided on a CD-ROM in Appendix E.

4.0 Dewey Project Area Pumping Test

4.1 Test Layout and Initial Potentiometric Surface Measurements

The Dewey pumping test well is located in NE ¼ NW ¼ Sec. 32, T.6S, R.1E, Custer County, South Dakota (Figure 4.1, Table 4.1). Powertech completed the pumping well (DB07-32-3C) with a fifteen-ft screen within the lower sandstone layer in the Fall River Formation near the roll front ore zones (Drawings 4.1 and 4.2). Three new observation wells were similarly screened at the same stratigraphic horizon within the lower Fall River Formation, located at radial distances of 265, 467 and 2,400 ft away from the pumped well (Figure 4.1 Table 4.1). A pre-existing stock watering well (GW-49) was also monitored. The stock well is located approximately 1,400 ft west of the pumped well and is believed (based on a recent electric log) to be an open hole for about 70 ft corresponding to about the top half of the Fall River formation.

Additional information on the design of the pumping test well layout and objectives for test analysis are provided in Appendix A.2. Well Construction diagrams and borehole electric logs for the Dewey test wells are provided, respectively, in Appendices B.1 and B.2.

Within a fifty-ft radius around the pumping well, additional observation wells were completed in a vertical nest in order to provide hydraulic data for the degree of confinement of both the test sandstone horizon and the entire Fall River Formation aquifer. Observation well DB-07-32-9C was screened in the upper Fall River aquifer at 41 ft lateral distance and 95 ft vertically above the screen in pumping well 32-3C. Observation well DB-07-32-10 was located within the underlying Lakota Formation 61 ft laterally and 130 ft vertically below the screen in the pumping well. Observation well DB-07-32-11 was located in the underlying Unkpapa Formation aquifer 50 ft laterally and 325 ft vertically below the screen in pumping well 32-3C.

Piezometric measurements (Eric Krantz, RESPEC, personal communication, May 2008) and well survey data provided by Powertech were used to calculate potentiometric surface elevations in ft above mean sea level with an estimated accuracy of ± 3 ft (Table 4.2). The potentiometric surface elevations for the Unkpapa, Lakota, and Fall River aquifers at the wells in the vertical well nest at the Dewey test site indicate artesian conditions. The three major geologic formations appear to be locally hydraulically isolated with upward vertical gradients, as follows:

- nearly 80 ft head difference upward (Table 4.2) between the Unkpapa and lower Lakota aquifers

- nearly 40 ft head difference upward between the lower Lakota and lower Fall River aquifers
- nearly 20 ft head difference upward between the wells screened in the lower Fall River and upper Fall River formation

4.2 Pumping Rate and Duration

The pumping phase of the constant-rate test at the Dewey area was started at 10:30:09 AM on May 15, 2008 and the pump was shut down at 12:30:59 PM on May 18, 2006, for a total duration of 4,440 minutes or 3.08 days (Figure 3.2). Because of the artesian condition in the pumping zone, the pumping well (32-3C) was shut-in, the pump turned on at 10:29:54 AM and the shut-in valve opened at 10:30:09 AM, the designated starting time of the test. The artesian observation wells had been left open for at least a day prior to startup to test for leakage from gaskets surrounding the transducer cables. Leakage during the constant rate test was not observed at any well except observation well 32-11 in the Unkpapa Formation, as described in Section 4.6, below.

The average pumping rate for the 3.08 day test was 30.2 gpm (Figure 3.2). During drawdown, there was a major flow rate adjustment where the gate valve was opened and throttled back; this occurred from 0.4 to 1.2 minutes and produces a discontinuity on logarithmically displayed time-drawdown data at the pumping well (Figure 4.7). Minor flow rate adjustments were also made at 21, 125, and 2777 minutes into the test that can also be seen on time-drawdown data for the pumping well (Figure 4.7). During recovery, the pumping well was initially left open to discharge water in piping and then shut-in when it was determined that the well was discharging due to artesian flow; this produces a discontinuity shown on the recovery plot for the well (Figure 4.7).

4.3 Responses at Pumping and Observation Wells

Table 4.2 summarizes the responses to pumping for the Dewey test. Figures 4.2, 4.3 and 4.4 display the transducer responses. Drawdown throughout the lower Fall River aquifer was 44.8 ft at the pumping well and ranged from 13.0 to 1.5 ft at the observation wells. Response to pumping varied progressively with distance from the pumping well throughout the lower Fall River: within 3 minutes at the two observation wells at 265 and 467 ft, and response was at 140 minutes at 2,400 ft distance. Similarly, the upper Fall River stock well (GW-49) responded at 40 minutes at 1,400 ft distance (Table 4.2).

However, it took 10.6 minutes for upper Fall River well (32-9C) to respond at 41 ft radial distance and 95 ft vertical distance (Table 4.2. The delayed response at the upper Fall River well is attributed to vertical anisotropy due to shale interbeds overlying the lower sandstone layer (Drawings 4.1 and 4.2).

The pumping and observation wells generally had symmetrical patterns of drawdown response and recovery response, except at the distant observation well 29-7 (Figure 4.3). There, the drawdown began at 140 minutes into the test, and drawdown continued to a maximum of 2.1 ft at about two days after the pump was shut down (Table 4.2). Therefore, the recovery response at well 29-7 was not further analyzed.

4.4 Determination of Aquifer Parameters

Aquifer parameters determined with the Theis drawdown, Theis recovery, Cooper-Jacob drawdown, Theis-Cooper-Jacob recovery, and distance drawdown methods are summarized in Table 4.3. Appendix A provides a definition of the well function parameters (u, u'), a complete description of the methods used, and corresponding assumptions for aquifer parameter determinations. For the straight-line methods, analyses with u or u' > 0.01 are reported but are not considered acceptable, as indicated in the table. Appendix B provides the graphical analyses that determined aquifer parameters at each well listed in Table 4.3.

The following discussion and Figures 4.5 through 4.8 illustrate the overall analysis of the pumping test and exemplify the determination of aquifer parameters with figures illustrating each of the major graphical analysis methods used. The observation well exhibiting the most diagnostic response is discussed first, followed by the drawdown at all observation wells, the drawdown at the pumping well, and finally the recovery at all wells.

4.4.1 Theis Drawdown and Recovery Analysis

Figure 4.5 displays time drawdown data and analysis on the log-log Theis plot for the closest observation well (32-5 at 265 ft distance). The data indicate a confined aquifer response fitting the Theis type curve until latest time, where there is a barrier boundary, where the drawdown increased above the theoretical rate of drawdown. The boundary was encountered at a time of about 0.6 days into the test (Table 4.2). The data at the next closest observation wells (32-4C and the stock well GW-49) also suggest a barrier boundary at times ranging from about 0.7 to 1.9 days into the test (Table 4.2).

Drawdown analyses using the Theis method for all applicable wells (i.e., 32-3C, 32-5, 32-4C, 29-7, and GW-49) are given in Appendix B.4 (Figures B.4-1 through Figure B.4-5) and summarized in Table 4.3. The Theis analyses in Appendix B use test analysis software (AquiferWin32™ ESI, 2003). Input data is weighted to ignore the late-time barrier boundary using an automated curve matching procedure. The weighting for all samples is the same, as follows: time-drawdown data before the first response are ignored, and data after the earliest occurrence of the barrier boundary at any of the wells (0.6 days) are ignored. The aquifer parameters transmissivity and storativity determined with Theis analyses are summarized in Table 4.3.

Figure B.4-6 in Appendix B shows the data at observation well 32-9C, completed in the upper Fall River 41 ft radially and 95 ft vertically from the screened interval in the pumping well. Samples are weighted as described above. This data cannot be interpreted successfully with the Theis analysis because only the middle-time portion of the drawdown closely follows the type curve. The poor fit to the Theis curve for well 32-9C yields a transmissivity of 217 ft^2/d, a value within the range of other observation wells, but a high storativity value of 0.016, which is inappropriate for a confined aquifer (e.g., Freeze and Cherry, 1979, Halford and Kuniansky, 2002). The artificially high storativity is attributed to the time-delay in response. The time-delay is attributed to vertical anisotropy as described in Section 4.3, above. Therefore, aquifer parameters from this well are reported in Table 4.3 but are not considered reliable determinations and are not used in determining the overall average aquifer parameters for the test.

4.4.2 Theis-Cooper-Jacob Straight-line Analysis

Figure 4.6 displays the Theis recovery analysis at the closest observation well 32-5 using automated straight-line fitting in AquiferWin32™ software. Appendix A.2 provides an overview of the theoretical basis for straight-line test analysis and definitions for the terms u', t and t'. Samples are weighted according to (1) the theoretical criterion that u' be < 0.01, which restricts the data to later-time (to the left on the t/t' axis); and (2) the portion of the recovery before the change in slope due the barrier boundary. The sample weighting restricts the matched straight-line portion of the recovery plot to the line-segment shown in Figure 4.6 and a value for the transmissivity, but not storativity, is obtained (Table 4.3).

Figure 4.7 (top) shows a Cooper-Jacob straight-line drawdown plot for the Dewey pumping well 32-3C. This USGS graphical-analysis tool is a spreadsheet that allows manual fitting of the straight-line (Halford and Kuniansky, 2002). The portion of the plot corresponding to later time

where is indicated, and this slope is used to determine transmissivity of 250 ft^2/d and well efficiency of 81 percent (Table 4.3).

The bottom portion of Figure 4.7 shows the USGS spreadsheet implementation of the Theis recovery analysis for the pumping well 32-3C, referred to as the Theis-Cooper-Jacob method (Halford and Kuniansky, 2002). Similar to Figure 4.6, the portion of the plot corresponding to later time is indicated to the left on the t/t' axis, and this slope is used to determine transmissivity of 270 ft^2/d (Table 4.3). The recovery plot at the pumping well also shows the change in slope with an increase in rate of drawdown at the latest times which is ignored in the manual fit of the straight-line.

4.4.3 Distance-Drawdown Analysis

Figure 4.8 is distance-drawdown analysis plot that determines transmissivity, storativity, and pumping well efficiency by considering all observation wells at once. The pumping well efficiency of 93 to 95 percent is determined by extending the straight line to the assumed diameter of the pumping well (0.25 ft for the 6-inch diameter well casing or possibly 0.33 ft for the 8-inch diameter borehole) relative to the actual drawdown observed at the pumping well. The aquifer parameters and the high efficiency are somewhat questionable given the relatively poor (r^2 = 0.7) straight-line fit through all data points. However, transmissivity and storativity values obtained are reasonable and the distance drawdown results are included in the overall average aquifer parameters for the test (Table 4.3).

The distance-drawdown analysis also gives the maximum radius of influence of the test. Based on Figure 4.8, the radius of influence was about 5,700 ft, about twice the radial distance to the most distant responding well (i.e., 29-7 at 2,400 ft). The radius of influence may be compared to the dimensions of prospective well fields in the area to evaluate whether aquifer parameters have been adequately characterized.

4.4.4 Summary of Dewey Test – Lower Fall River Formation Aquifer Parameters

The aquifer parameters determined by the techniques described above are summarized in Table 5.3. Ten accepted determinations of transmissivity (outlined) range from 180 to 330 ft^2/day and the mean and median are close at 251 to 255 ft^2/day. The five accepted storativity determinations ranged from 2.3×10^{-5} to 2.0×10^{-4}. The geometric mean and median storativity values are respectively 5.2 to 4.6×10^{-5}. The median transmissivity of 255 ft^2/day and median storativity of 4.6×10^{-5} are considered the best measures of the central tendency of the test results.

4.5 Underlying Lakota Aquifer Test Results

Observation well (DB-07-32-10, Figure 4.1, Drawing 4.2) was located within the underlying Lakota Formation 61 ft laterally and 130 ft vertically below the screen in pumping well 32-3C. Figure 4.4 illustrates that there was no response of observation well 32-10 to the drawdown or recovery phases at the pumping well 32-3C. Therefore, there was no further analysis of this observation well.

4.6 Underlying Unkpapa Aquifer Test Results

Observation well DB-07-32-11 is screened in the underlying Unkpapa Formation aquifer 50 ft radially and 325 ft vertically below the screen in pumping well 32-3C (Table 4.1). Figure 4.4 depicts a generally rising trend in transducer response with sinusoidal variations associated with Earth tides indicating the aquifer remained undisturbed when the pump was turned on and turned off. Mid-way through the recovery, a shift in the pressure response on May 20, 2008 was noted similar to when leaks in the gasket-seal were observed previously. The threaded cap and gasket were checked on May 21, 2008 and found to be moist suggesting that a temporary leak may have occurred.

Figure 4.4 illustrates that there was no response of observation well 32-11 to the drawdown or recovery phases at the pumping well 32-3C. Therefore, there was no further analysis of this observation well.

5.0 Burdock Project Area Pumping Test

5.1 Test Layout and Initial Potentiometric Surface Measurements

The Burdock pumping test well is located in NE ¼ SW ¼ Sec. 11, T.7S, R.1E, Fall River County, South Dakota (Figure 5.1, Table 5.1). Powertech completed the pumping well (DB07-11-11C) with a ten-ft screen within a lower sandstone layer in the Lakota (Chilson) formation. Hereafter, the term Lakota is used to refer to the Chilson member of the Lakota formation. The ten-ft screen was set near the horizon of the lower Lakota ore zone(s), indicated by the roll fronts on Drawings 5.1 through 5.3. Three new observation wells were similarly screened at the same stratigraphic horizon within the lower Lakota Formation, located at radial distances of 243, 250 and 1,292 ft away from the pumped well (Figure 5.1, Table 5.1).

Additional information on the design of the pumping test well layout and objectives for test analysis are provided in Appendix A.2. Well Construction diagrams and borehole electric logs for the Burdock test pumping and observation wells are provided respectively, in Appendices C.1 and C.2.

Within a fifty-ft radius around the pumping well, additional observation wells were completed in a vertical nest in order to provide hydraulic data for the degree of confinement of both the test sandstone horizon and the entire Lakota formation aquifer. Observation well DB-07-11-19 was screened in the upper Lakota aquifer at 50 ft lateral distance and 100 ft vertical distance above the screen in pumping well 11-11C. Observation well DB-07-11-19 was located within the overlying Fall River Formation 61 ft laterally and 180 ft vertically above the screen in the pumping well. Observation well DB-07-11-18 was located in the underlying Unkpapa Formation aquifer 50 ft radially and 195 ft vertically below the screen in the pumping well.

Piezometric measurements (Eric Krantz, RESPEC, personal communication, May 2008) and well survey data provided by Powertech were used to calculate potentiometric surface elevations in ft msl with an estimated accuracy of ±3 ft (Table 5.2). The potentiometric surfaces of the Lakota and Fall River aquifers at the wells in the vertical well nest at the Burdock site indicate confined and non-artesian conditions. The two major aquifers (Fall River and Lakota) appear to be locally hydraulically connected through the intervening Fuson Member with minimal vertical gradients because the water levels are similar within ± 2-3 ft (Table 5.2).

Piezometric surface information for the Unkpapa and Lakota/Fall River aquifers indicate that the Unkpapa formation aquifer is artesian and hydraulically isolated with a nearly 70 ft head difference directed vertically upward (Table 5.2).

5.2 Pumping Rate and Duration

The pumping phase of the constant-rate test at the Burdock area was started at 2:20:36 PM on May 18, 2008 and the pump was shut down at 2:30:37 PM on May 21, 2008, for a total duration of 4,320 minutes or 3.0 days. The average pumping rate was 30.2 gpm. A flow rate adjustment was made at 160 minutes into the test that can be seen on logarithmic time-drawdown data for the pumping well (Figure 5.7). The average pumping rate for the 3.0 day test was 30.2 gpm (Figure 3.2).

5.3 Responses at Pumping and Observation Wells

Table 5.2 summarizes the responses to pumping for the Burdock test. Figures 5.2, 5.3 and 5.4 display the transducer responses. Drawdown throughout the lower Lakota aquifer was 91.1 ft at the pumping well and ranged from 17.0 to 3.1 ft at the observation wells. Response to pumping varied with distance from the pumping well in the Lakota aquifer in a non-systematic manner indicating significant lateral and vertical anisotropy, as follows:

- Response was within 3.6 minutes at the observation well (11-14C) at 250 ft distance with 17 ft of ultimate drawdown (Table 5.2).
- But the other lower Lakota observation well at 243 ft distance (11-15) took 140 minutes to respond, with 10 ft of ultimate drawdown.
- Upper Lakota observation well 11-19 took 160 minutes to respond with 3.4 ft ultimate drawdown at 50 ft radial distance and 100 ft vertical distance.
- First response was at 280 minutes at the most distant well (11-2) at 1,292 ft distance.

The responses of close-in well 11-14C and the distant well 11-2 are interpreted as a typical sequence of response to pumping well in a confined aquifer with similar transmissivity connecting all three wells. The delayed response at the upper Lakota well 11-19 is attributable to vertical anisotropy due to shale interbeds overlying the lower sandstone layer (Drawings 5.1 through 5.3). The delayed response of the closest observation well 11-15 requires an explanation in addition to lateral anisotropy. Powertech geologists were contacted and have subsequently indicated that there may have been problems with the installation of well 11-15 because it was subjected to intensive efforts during development.

Figures 5.2 through 5.4 indicate symmetrical patterns of drawdown response and recovery response, such that if the drawdown response was delayed there was a generally similar time before the recovery response (e.g., wells 11-2, and 11-19 on Figure 5.3). The anomalous recovery response at observation well 11-17, screened in the overlying Fall River aquifer, is discussed in Section 5.5, below.

5.4 Determination of Aquifer Parameters

Aquifer parameters determined with the Theis drawdown, Hantush-Jacob drawdown, Cooper-Jacob drawdown, Theis-Cooper-Jacob recovery and distance drawdown methods are summarized in Table 5.3. For the straight-line methods, analyses with u or u' > 0.01 are reported but are not considered acceptable, as indicated in the table. Appendix A provides a complete description of the methods used and corresponding assumptions for aquifer parameter determinations. Appendix C provides the graphical analyses that determined aquifer parameters at each well listed in Table 5.3.

The following discussion and Figures 5.5 through 5.8 illustrate the overall analysis of the pumping test and exemplify the determination of aquifer parameters with figures illustrating each of the major graphical analysis methods used. The observation well exhibiting the most diagnostic response is discussed first, followed by the drawdown at all observation wells, the drawdown at the pumping well, and finally the recovery at all wells.

5.4.1 Theis Drawdown Analysis

Figure 5.5 displays time-drawdown data and analysis on the log-log Theis plot for close-in observation well 11-14C at 250 ft distance. The data indicate confined aquifer response fitting the Theis type curve for the first 1.1 days of the test. After 1.1 days, the drawdown indicates a recharge boundary or vertical leakage from an adjacent confining layer where the actual rate of drawdown is less than the theoretical rate of drawdown. The drawdown at the most distant observation well (11-2 at 1,292 ft distance) also fits the Theis type curve for the first 1.8 days of the test (see Appendix C, Figure C.4-5) at which time a recharge boundary is encountered. Boundary responses are summarized in Table 5.2.

Drawdown analyses using the Theis method for all applicable wells (i.e., 11-11C, 11-15, 11-14C and 11-29) are given in Appendix C.4 (Figures C.4-1 through Figure C.4-5) and summarized in Table 5.3. The Theis analyses in Appendix C use test analysis software (AquiferWin32^{TM} ESI, 2003). Input data is weighted to ignore the late-time recharge boundary using an automated curve matching procedure. The weighting for all samples is the same, as follows:

time-drawdown data before the first response are ignored, and data after the earliest occurrence of the recharge boundary at any of the wells (1.1 days) are ignored. The aquifer parameters transmissivity and storativity determined with Theis analyses are summarized in Table 5.3.

The data at the close-in Lakota observation well 11-15 at 243 ft distance are successfully fitted with the Theis curve and recharge boundary (see Appendix C, Figure C.4-2). A trial analysis of the best fit yields a transmissivity value lower than the range of other observation wells and a relatively high storativity value of 0.0013. Because this storativity value is high compared to confined aquifers in general (e.g., Freeze and Cherry, 1979, Halford and Kuniansky, 2002) and also the other Burdock test wells (Table 5.3), aquifer parameters from this well were not further considered. The high storativity is attributable to the delayed response time (140 minutes at 243 ft distance), and the cause of the delay is attributed to problems with well construction.

At observation well 11-19, completed in the upper Lakota 50 ft radially and 130 ft vertically from the screened interval in the pumping well, the drawdown data appear to be interpretable with the Theis analysis and yield a transmissivity value within the range of other observation wells (see Appendix C, Figure C.4-7). However, the very high storativity value of 0.10 is inappropriate for a confined aquifer. As described in Appendix A.2, there are a number of violations of the Theis test conditions when attempting to analyze drawdown due to pumping between partially penetrating well screens set apart 130 ft vertically. The artificially high storativity is attributed to the time-delay in response (160 minutes). The time-delay is attributed to vertical anisotropy as described in Section 5.3, above. Therefore, aquifer parameters from this well were not further considered.

5.4.2 Hantush-Jacob Drawdown Analysis

The AquiferWin32™ software implements the Hantush-Jacob (Hantush and Jacob, 1955) analytical model for drawdown analysis that follows the Theis curve in early-time and calculates a flattening recharge boundary due to vertical leakage from an assumed overlying leaky confining layer. The vertical leakage is described in the term r/B, which is implemented in this analysis as follows:

- $r/B = r/((T\ b')/K')^{0.5}$
- T transmissivity of confined Lakota aquifer (assume provisional value of 145 ft^2/day)
- b' thickness of Fuson member aquitard/confining layer (35 ft, based on Drawing 5.3)

- K' vertical hydraulic conductivity of Fuson (10^{-3} ft/day from the TVA test, Section 2.3.2)
- radial distance (r = 250 ft to well 11-14C and 1,292 ft to well 11-2)
- r/B well 11-14C = 0.11; r/b well 11-2 = 0.57

Figure 5.6 shows the Hantush-Jacob analysis at observation well 11-14C where r/B is input as fixed and all data after initial response are equally weighted. It is noted that automated curve-fitting in the AquiferWin32™ software can also be set to optimize to r/B, and a value of 0.11 is also obtained, indicating that this is a good match. For distant observation well 11-2 the software optimized to an r/B value of 0.77, so the calculated value of 0.57 was fixed (see Figure C.4-6 in Appendix C). Transmissivity and storativity values obtained through the curve matching at the two observation wells are entered in Table 5.3.

5.4.3 Theis-Cooper-Jacob Straight-line Analysis

Figure 5.7 (top) shows a Cooper-Jacob drawdown plot for the Burdock pumping well 11-11C. This USGS graphical-analysis tool is a spreadsheet that allows manual fitting of the straight-line (Halford and Kuniansky, 2002). Appendix A.2 provides an overview of the theoretical basis for straight-line test analysis and definitions for the terms u, u', t and t'. The portion of the plot corresponding to later time where u < 0.01 is indicated, and this slope is used to determine transmissivity of 150 ft^2/day and well efficiency of 65 percent (Table 5.3).

The bottom portion of Figure 5.7 shows the USGS spreadsheet implementation of the Theis recovery analysis for the pumping well 11-11C, referred to as the Theis-Cooper-Jacob method (Halford and Kuniansky, 2002). The portion of the plot corresponding to later time where u' < 0.01 is indicated to the left on the t/t' axis, and this slope is used to determine transmissivity of 140 ft^2/d (Table 5.3). A definite change in slope indicating a late time leakage/recharge boundary is not apparent at the pumping well, but the late-time data has a slight upward concavity indicating reduction in the rate of drawdown.

The results of Theis recovery analyses for all wells are summarized in Table 5.3, together the u' criteria on which each transmissivity determination is based. Analyses with u' > 0.01 are tabulated but are not considered acceptable, as indicated in the table.

5.4.4 Distance-Drawdown Analysis

Figure 5.8 is distance-drawdown analysis plot that determines transmissivity, storativity, and pumping well efficiency by considering all observation wells at once. As shown on Figure 5.8,

fitting a straight line to incorporate the close-in observation wells 11-14C and 11-15 simultaneously is not ideal because it averages the clearly anisotropic response between the close-in wells. On the other hand, convention (Driscoll, 1986 and numerous other references) dictates that a distance-drawdown analysis should be based on a minimum of three observation wells. It is noted that if a two-well solution is used ignoring the anisotropic response at well 11-14C, transmissivity is 108 ft^2/day and storativity is 2.8 x 10^{-5}. Nevertheless, the three-well solution with greater transmissivity and storativity is accepted as indicated on the figure and in Table 5.3.

The pumping well efficiency of 61 to 63 percent is determined with the three-well distance-drawdown solution by extending the straight line to the assumed diameters of the pumping well. These efficiencies agree with the 65 percent determined in the USGS spreadsheet (Table 5.3). The aquifer parameters are somewhat questionable given the relatively poor (r^2 = 0.7) straight-line fit through all data points. Based on the large u criterion (0.08) at one of the wells (11-15), the transmissivity and storativity values obtained are not included in the overall average aquifer parameters for the test (Table 5.3).

The distance-drawdown analysis also gives the maximum radius of influence of the test. Based on Figure 5.8, the radius of influence was about 2,100 ft, somewhat greater than the radial distance to the most distant responding well (i.e., 11-2 at 1,292 ft). The radius of influence may be compared to the dimensions of prospective well fields in the area to evaluate whether aquifer parameters have been adequately characterized.

5.4.5 Summary of Burdock Test – Lower Lakota (Chilson) Formation Aquifer Parameters

The aquifer parameters determined by the techniques described above are summarized in Table 5.3. Nine accepted determinations of transmissivity (outlined) range from 120 to 223 ft^2/day and the mean and median are close at 150 and 158 ft^2/day. Four accepted storativity determinations ranged from 6.8 x 10^{-5} to 1.9 x 10^{-4}. The geometric mean and median storativity values are 1.1 x 10^{-4} and 1.2 x 10^{-4}. The median transmissivity of 150 ft^2/day and median storativity of 1.2 x 10^{-4} are considered the best measures of the central tendency of the test results.

Only two wells were used to contribute to the overall storativity results because of the large anisotropy in responses exhibited between wells 11-15 and 11-14C and the anomalous results at

11-15 described above. Powertech geologists have noted that there were problems with the installation of well 11-15.

5.5 Overlying Fall River Aquifer Test Results

Observation well 11-17 is screened in the lower Fall River 50 ft laterally and about 185 ft vertically above the screen in pumping well 11-11C (Table 5.2, Drawing 5.3). Piezometric surface information for the Lakota aquifer indicates the two wells are locally hydraulically connected with similar water levels within ± 2 ft (Table 5.2).

Figure 5.3 illustrates response of observation well 11-17 to the drawdown phase of the Burdock well 11-11C pumping in the Lakota Formation. The first response was a very slight increase in pressure over a period of about 600 minutes, corresponding to a water level increase of about 0.12 ft (3.5 centimeter [cm]). The water level stopped increasing then underwent 1.1 ft of drawdown to time of pump shut-down (2:00 PM) on May 21, 2008. Drawdown continued for about a day to a maximum of 1.4 ft, then remained flat with erratic fluctuations for another 24 hours, until the evening of May 23, 2008 where a partial and sharply "spiked" recovery started.

The response of a "reverse" drawdown monitored in a zone above (or below) the pumping zone is known as the Noordbergum effect (Ohio EPA, 2006). There is uncertainty whether the water level increase at Burdock well 11-17 is the Noordbergum effect or alternatively a barometric response. In any case, the Noordbergum effect was observed in the 1979 TVA Lakota aquifer pumping test at Burdock pumping at 200 gpm where increases in water levels were monitored in the Fall River aquifer and Fuson Member observation wells for 30 to 90 minutes after the start of the test. Judging from the water level plot figures (Boggs and Jenkins, 1980), the increases were a fraction of a ft in the Fall River and up to about 1.5 ft in the Fuson.

In a 1985 pumping test in the Eastern Black Hills near Wall, South Dakota, pumping at 125 gpm, a water level rise of about 1.7 ft just after pumping started, eventually declining in an "erratic manner", was attributed to the Noordbergum effect (Rahn, 1992). There the well (Kelly Well) with the anomalous response was open to an unknown portion of the Inyan Kara aquifer; however it was considered to be somewhat hydraulically isolated from the pumping and other observation wells based on differing background water levels.

The fact that substantial Noordbergum effects were observed in pumping tests in the Fuson/Fall River and Inyan Kara (undifferentiated) monitoring wells at widely spaced locations in the Black

Hills uplift (i.e., the TVA and Wall tests) suggests the effect is a characteristic of the Inyan Kara Group. A small magnitude Noordbergum effect response observed in the 2008 test at Burdock is attributable to the much lower pumping rate and relatively short, 10-ft screened intervals of both pumping and observation wells. The Noordbergum effect of a 10 cm rise in water levels has been simulated with numerical models by the USGS (Hsieh, 1997), where three-dimensional deformation caused by groundwater withdrawal from a confined aquifer can induce positive hydraulic head changes in adjacent aquitards (and presumably in an aquifer overlying an aquitard).

An alternative explanation for the slight rise in water level in the Fall River (Burdock 11-17) is found in similar patterns of water level changes seen in the Unkpapa Formation (Burdock 11-18), underlying the Lakota Formation, at about the same time and magnitude. This will be described further in Section 5.6 below.

Referring again to Figure 5.3, an explanation for the drawdown in the Fall River aquifer at Burdock continuing for about a day past the pump shut-down and then stabilizing for another day is not apparent. It is most similar to the 1.5 days of extended drawdown and poor recovery observed at well 29-7 at the Dewey pumping test. These anomalous responses are attributed to the observation wells having been located away from the sandstone layer with the pumping well; it is possible the observation wells are monitoring localized effects in sedimentary facies separated from the pumping well by numerous shale layers,

5.6 Underlying Unkpapa Aquifer Test Results

As discussed in Section 3, observation well 11-18 is screened in the Unkpapa aquifer 35 ft laterally and 195 ft vertically below the screen in pumping well 11-11C (Table 5.1). Piezometric surface information for the Unkpapa and Lakota aquifers indicate the two wells are locally hydraulically isolated, with a nearly 70 ft head difference directed vertically upward (Table 5.1).

Figure 5.4 illustrates that there was no response of observation well 11-18 to the drawdown or recovery phases at the pumping well 11-11C. However, comparison with the Fall River observation well (Burdock 11-17, Figure 5.3) finds a similar pattern, timing and magnitude of several water level changes. In addition to the early time rise in water levels (i.e. possible Noordbergum effect described above) starting at about 2:00 PM on 5/18/08 (i.e., the time of pump shut-down and start of recovery), there are the following similarities:

- the erratic transducer readings starting at about 3:00 PM on 5/22/08

- the upward spike in transducer readings at about 7:00 PM on 5/23/08

The barometer readings for the site (Figure 3.1) were examined in detail, and there is a possible correlation with barometric fluctuations where the water level increases start at the times of temporary declines (troughs) in barometric pressure throughout an overall period of increasing atmospheric pressure (i.e., going forward in time from the start of Burdock Recovery on Figure 3.1). However, throughout several days there were equally large fluctuations in barometric pressure with no similar corresponding changes in water levels.

An explanation for the water level variations simultaneously in both wells is that the Unkpapa monitoring well 11-18 (Figure 5.4) records a barometric and tidal response while the Fall River monitoring well 11-17 (Figure 5.3) records a combination of both drawdown (without recovery) and barometric response. As noted above, the existence of the Noordbergum effect at the Fall River monitoring well is possible but uncertain.

6.0 Laboratory Core Data

6.1 Background

Selected core samples were sent to Core Laboratories by Powertech (Personal Communication, Frank Lichnovsky, February 1, 2008) for measurement of intrinsic permeability to assess the differences in the less permeable Skull Creek shale, Fuson shale, Morrison shale, and interbed units of the Dewey (Fall River) and Burdock (Lakota) sandstone units. The intrinsic permeability data were converted to hydraulic conductivity values as shown in Table 6.1.

6.2 Conversion from Intrinsic Permeability to Hydraulic Conductivity

Intrinsic permeability is a property of the core material (rock) only and does not include any fluid properties. The core intrinsic permeability was measured by moving air through the core under confining pressure in the laboratory which resulted in the measurement of both porosity (from the bulk density and particle density of the core) and intrinsic permeability in milliDarcys (mD) as shown in Table 6.1. The footnotes at the bottom of Table 6.1 show the constants assumed for the conversion from intrinsic permeability to hydraulic conductivity at the prevailing temperatures of the laboratory, assumed to be 70 ^{o}F, and the site groundwater (average of 52.8 ^{o}F from field measurements by RESPEC (Personal Communication, Crystal M. Hocking, February 4, 2008).

It is well known that the units of intrinsic permeability can be changed from mD to cm^2 by using equations shown in Table 6.1. The intrinsic permeability is multiplied by the fluid properties of water density times the gravitational constant divided by the dynamic viscosity (both temperature dependent) of the site groundwater to obtain the hydraulic conductivity.

Analyses of core data in Table 6.1 indicate that the horizontal hydraulic conductivity of the Skull Creek shale is approximately 6.0 x 10^{-8} centimeters per second (cm/s). The horizontal hydraulic conductivity of the Fuson Shale ranges from 8.0 x 10^{-7} to 3.2 x 10^{-8} cm/s, and for the Morrison between 7.7 x 10^{-7} and 3.1 x 10^{-9} cm/s. Vertical hydraulic conductivities of the Skull Creek and Morrison shales, and the Fuson shale from the Dewey project area, are typically one-tenth to one-twentieth the horizontal values. In terms of ft per day (ft/day) vertical hydraulic conductivities for all the above shale units range from about 2 to 6 x 10^{-5} ft/day.

The average vertical hydraulic conductivity for the two core samples from the Fuson shale from the Burdock project area is considerably more permeable (9.8 x 10^{-8} cm/sec), at roughly 25 percent the horizontal value. In terms of ft/day, vertical hydraulic conductivities for the

Burdock Fuson shale units are about 3 x 10^{-4} ft/day, about one order of magnitude less than the Fuson shale sample at the Dewey project area (2 x 10^{-5} ft/day) and also all the Skull Creek and Morrison shale samples.

In contrast, the core units of the Burdock Lakota sandstone unit have an average horizontal hydraulic conductivity of 2.6 x 10^{-3} cm/s (7.4 ft/day), ranging from 2.1 x 10^{-3} to 3.2 x 10^{-3} cm/s. Core from the Dewey Fall River sandstone unit has a horizontal hydraulic conductivity of 2.2 x 10^{-3} cm/s (6.1 ft/day). The ratio of horizontal to vertical hydraulic conductivity (K_h:K_v) for the Burdock sandstone units is 2.4:1, and for the Dewey sandstone unit it is 4.5:1, based on the core data shown in Table 6.1.

6.3 Interpretations of the Laboratory Core Data

Comparison of horizontal hydraulic conductivity of the Dewey and Burdock sandstone samples in Table 6.1 with the conductivity calculated from pumping test transmissivity (Tables 4.3 and 5.3) can be made as follows:

- Dewey Transmissivity 255 ft^2/d divided by 15 ft screen length = 17 ft/day
- Dewey Transmissivity 255 ft^2/d divided by 165 ft formation thickness = 1.5 ft/day
- Burdock Transmissivity 150 ft^2/d divided by 10 ft screen length = 15.0 ft/day
- Burdock Transmissivity 150 ft^2/d divided by 170 ft formation thickness = 0.9 ft/day

The most commonly used procedure when converting test results is to use the screen length of the pumping well as the divisor. The above analysis indicates that the pumping test data may be interpreted to yield up to two to three times greater higher hydraulic conductivity than core data.

However, the above analysis also indicates that the hydraulic conductivities calculated from the pumping test transmissivities and the overall formation thicknesses bracket the core data at the lower end of ranges in hydraulic conductivity, with the core falling in the middle of the range. The core data can be considered to be generally consistent with, and therefore independently confirming, the pumping test results. Generally, the above ranges in calculated hydraulic conductivity also indicate order-of-magnitude uncertainty (generally, about one to 17 ft/day),

Powertech reports that the laboratory would not take samples containing uranium, so sandstone core samples from outside of the ore zone were submitted. The electric logs and boring lithologic logs indicate that the core samples were taken from sandstone layers which may have

had slightly different, possibly less permeable, ideologies than the screened intervals used for the pumping tests in the ore zones.

6.4 Conclusions

The first conclusion from the core analyses is that the major shale aquitards (Fuson, Skull Creek, Morrison formations) have hydraulic conductivities several orders of magnitude lower than hydraulic conductivities of either the Fall River or Lakota sandstone units. Using the vertical hydraulic conductivities as a measure of degree of confinement, at the Burdock project area Table 6.1 indicates that the shales in the Fuson overlying the Lakota formation (K_h = 7.4 ft/day) have an average vertical permeability of about 2.7 x 10^{-4} ft/day and the underlying Morrison formation 6.0 x 10^{-5} ft/day. At the Dewey project area, shales in the Fuson formation underlying the Fall River formation (Kh = 6.6 ft/day) have an average vertical permeability of 1.8 x 10^{-5} ft/day, and shale in the single sample of overlying Skull Creek shale has a vertical permeability of 1.5 x 10^{-5} ft/day.

The second conclusion is that core data from the sandstones are within the range of hydraulic conductivities determinable from test transmissivities, specifically 1.5 to 17 ft/day at the Dewey project area and 0.9 to 15 ft/day at the Burdock project area. This is also an appropriate range of uncertainty for converting the test results to hydraulic conductivity. Using the usual procedure for determining hydraulic conductivity from pumping test transmissivity, the sandstone core results may have two to three times smaller hydraulic conductivities than those estimated from the pumping tests, perhaps due to slightly different lithologies between the core and screened intervals. Overall, there is reasonable agreement between the laboratory and field hydraulic tests considering typically order-of-magnitude differences in hydraulic conductivity determinations.

7.0 Summary and Conclusions

The following sections first summarize new facts about the Dewey and Burdock project areas based on the 2008 tests and related information. A discussion of the results in comparison to the 1979 to 1982 TVA pumping tests follows. The Burdock site is discussed first because comparison with the TVA tests is most straightforward.

7.1 Burdock Project Area

7.1.1 Summary

A summary of aquifer parameters for the 2008 Burdock pumping test and related laboratory core testing is as follows:

- Nine determinations of transmissivity (Table 5.3) ranged from 120 to 223 ft^2/day with the median value of 150 ft^2/day.
- Four storativity determinations (Table 5.3) ranged from 6.8×10^{-5} to 1.9×10^{-4} with the median value of 1.2×10^{-4}.
- The radius of influence of the pumping test determined by a distance-drawdown plot was 2,100 ft (Section 5.3.3).
- The pumping well in the lower Lakota formation was determined to be moderately efficient: 80 to 83 percent by the empirical distance-drawdown method and 65 percent the USGS (Halford and Kuniansky, 2002) theoretical method.
- Laboratory measurements of horizontal and vertical hydraulic conductivity (Table 6.1) were made on sandstone layers similar to that tested in the pumping test; measured horizontal hydraulic conductivity ranged from 5.9 to 9.1 ft/day, the mean value was 7.4 ft/day and the 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 6.1) were made on shale layers from the two major confining units for the Lakota formation in the pumping test area with the following results:
  - Fuson Shale: the laboratory core data indicate vertical permeabilities of about 2×10^{-7} to 1×10^{-8} cm/sec (average 2.7×10^{-4} ft/day) for shale samples from within the Fuson member overlying the Lakota formation.
  - Morrison Shale: the laboratory core data for the shales in the underlying Morrison formation indicate vertical permeabilities of 9×10^{-9} to 3×10^{-8} cm/sec (average 6.0×10^{-5} ft/day).

- The range of hydraulic conductivities determinable from test transmissivities (Section 6.3) was 0.9 to 15.0 ft/day, which is considered an appropriate range that is also verified by the sandstone core sample results falling in the middle of the range; it is noted that the lower end of the hydraulic conductivity range is probably appropriate for use with the entire formation thickness (shale layers included) and the upper end represents the most permeable sandstone layers such as the ore zone areas tested in the pumping test.

7.1.2 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 1.1). The average transmissivity and storativity values determined from the TVA tests were 190 ft^2/d and 1.8×10^{-4} (Section 2.3, see p. 17 in Boggs and Jenkins, 1980). Comparing median transmissivity of 150 ft^2/d and storativity of 1.2×10^{-4}determined in the 2008 test (Section 5.4.4) to the TVA test, the new aquifer parameters for the lower Lakota are respectively about 80 and 70 percent of the 1979 results. Because transmissivity and storativity depend on aquifer thickness, comparing the results suggests that there may be some scaling effect between the tests due to the differing lengths of screened intervals.

Therefore, the 1979 TVA test is transmissivity of 190 ft^2/d is considered representative of the entire Lakota aquifer for a regional application, such as groundwater flow model where an average hydraulic conductivity of about 1 ft/day over a thickness of 170 ft could be specified. The 2008 test provides specific data at the operational-scale of a prospective ISR well field where local hydraulic conductivities of up to 15 ft/day could be specified for the most permeable ore zones horizons.

Within the Lakota formation, vertical communication throughout the entire formation is indicated by the delayed response at the upper Lakota observation well (11-19). The 160-minute delay in response at the upper Lakota observation well 11-19 is attributed to lateral and vertical anisotropy due to the shale interbeds seen on the conceptual stratigraphic cross-sections for the pumping test site (Drawings 5.1, 5.2 and 5.3). The extent and continuity of the shale interbeds are unknown. Whether the shale interbeds in the Lakota aquifer are sufficiently thick and continuous to serve as vertical confinement for ISR operations will probably need to be evaluated by analyzing cores from borings as well fields are drilled.

The 2008 test indicates that the lower and upper portions of the Lakota formation behave as a single, confined, leaky aquifer. Confinement and leakage from the overlying Fuson member is

evident in the matches to the Hantush-Jacob type curves seen most clearly at observation wells 11-14C and 11-2. These results are more definitive than the 1979 TVA test where confined, leaky behavior for the Lakota was predicted but not demonstrated with curve match results. Hydraulic communication through the Fuson member between the Lakota and Fall River aquifers is evidenced by the drawdown at the Fall River observation well 11-17, indicating that leakage was established through underlying the Fuson formation.

The laboratory core data indicate an average vertical permeability of 9.3×10^{-8} (2.7×10^{-4} ft/day) for shale samples from within the Fuson member. The shale core permeability values are about one to two orders of magnitude less permeable than pumping test values determined in the 1979 TVA test at Burdock, where the vertical hydraulic conductivity of the Fuson aquitard was calculated using the Neuman-Witherspoon ratio method to be about 10^{-3} ft/day (see page i in Boggs and Jenkins, 1980).

As described in Section 5.1, the potentiometric surface in the Fall River aquifer is close to that in the Lakota aquifer at the Burdock pumping test site, indicating some local connection between the two formations through the intervening Fuson member. In other locations in the Inyan Kara, the Fuson member is known to have sandstone layers that are downcut into the Lakota member (Gott et al., 1974). Therefore, determining the degree of vertical confinement for ISR operations by the Fuson will probably need to be evaluated by analyzing cores from borings as well fields are drilled, and with well field-scale pumping tests that are proposed to be conducted prior to startup of each particular mine unit.

The aquifer tests in 1979 and 2008 indicate that the Lakota Formation is a confined aquifer with a leaky confining layer, which is demonstrably the Fuson member. The laboratory core data for the shales in the underlying Morrison formation indicate an average vertical permeability of 2.1×10^{-8} cm/sec (6×10^{-5} ft/day). Together with the pumping test data, the core data indicate that the underlying Morrison formation and overlying Fuson member can serve as aquitards for ISR operations.

For the Lakota sandstone, the laboratory core data indicate an average horizontal hydraulic conductivity of 7 ft/day, and as high as 9.1 ft/day. Interpretation of the test results calculates that horizontal permeability may be as great as 15 ft/day throughout one of the ore zones. Within the lower Lakota formation, the test results indicate transmissive response between pumping and observation wells up to 250 ft apart with 17 ft of drawdown. Response was nearly 3 ft of

drawdown at 1,290 ft distance. This indicates the aquifer was stressed to produce good quality analytical results.

7.2 Dewey Project Area

7.2.1 Summary

A summary of aquifer parameters for the 2008 Dewey pumping test and related laboratory core testing is as follows:

- Ten determinations of transmissivity (Table 4.3) ranged from 180 to 330 ft^2/day with the median value of 255 ft^2/day.
- Five storativity determinations (Table 4.3) ranged from 2.3×10^{-5} to 2.0×10^{-4} with the median value of 4.6×10^{-5}.
- The radius of influence of the pumping test determined by a distance-drawdown plot was 5,700 ft (Section 4.4.3).
- The pumping well in the Fall River formation was determined to be highly efficient: 93 to 95 percent by the empirical distance-drawdown method and 81 percent the USGS (Halford and Kuniansky, 2002) theoretical method.
- Laboratory measurements of horizontal and vertical hydraulic conductivity (Table 6.1) were made in a core sample from the sandstone layer similar to that tested in the pumping test; measured horizontal hydraulic conductivity was 6.1 ft/day, and the ratio of horizontal to vertical hydraulic conductivity was 4.5:1.
- Laboratory measurements of horizontal and vertical hydraulic conductivity (Table 6.1) were made on shale samples from the two major confining units overlying and underlying the pumping test area with the following results:
  - Skull Creek shale: laboratory core data for the shale sample from the overlying Skull Creek formation indicate a vertical permeability of 5.4×10^{-9} cm/sec (1.5×10^{-5} ft/day).
  - Fuson Formation: laboratory core data for the shale sample from the underlying Fuson formation indicate a vertical permeability of 6.2×10^{-9} cm/sec (1.8×10^{-5} ft/day).

7.2.2 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 aquifer was tested in 1982. As demonstrated above for the Lakota aquifer (Section 7.1), a scaling effect may be assumed between total formation transmissivity and storativity (i.e., regional-scale) and the 2008 operational-scale test.

However, there are several lines of evidence that the 2008 test transmissivity and storativity results are representative of the entire Fall River aquifer at the Dewey test site, as follows:

1. Thickness of the sandstone layer screened by the pumping well is about one-half the total formation thickness as shown in Drawings 4.1 and 4.2.

2. Response at the stock tank well (GW-49 at 1,400 ft distance) was within the acceptable range for a confined aquifer; this is interpreted to indicate that the effects of partial penetration (due to elevation differences between the pumping well screen and the observation well open to the upper half of the aquifer) were diminished at the 1,400 ft distance and 40 minute response time.

3. The delay in response at the upper Fall River observation well 32-9C was a relatively brief 11 minutes (Table 4.2), compared to 160 minutes in the Burdock test; together with (2) above, these responses suggest that the vertical anisotropy due to shale interbeds overlying the lower sandstone layer does not extend laterally for more than about 1,400 ft.

The 2008 test indicates 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 changing lithology, such as a channel boundary. The TVA test in 1982 observed a barrier boundary in the underlying Lakota formation which was attributed to either a change in lithology or the Dewey Fault zone. Apparently, both the Lakota and Fall River formations in the general Dewey project area are highly transmissive and show barrier boundaries. These test results are more definitive than the 1982 TVA test concerning the proximity of the barrier boundary, because the 2008 radius of influence was about one mile compared to greater than two to three miles distance to the fault zone.

Vertical communication throughout the entire Fall River formation is indicated by the delayed response at the upper Fall River observation well (32-9C). Within the Fall River formation, the 11-minute delay in response at the upper observation well is attributed to lateral and vertical anisotropy due to the shale interbeds seen on the conceptual stratigraphic cross-sections for the pumping test site (Drawings 4.1 and 4.2). The extent and continuity of the shale interbeds are not known. Whether the shale interbeds in the Fall River aquifer are sufficiently thick and continuous to serve as vertical confinement for ISR operations will need to be evaluated by analyzing cores from borings as well fields are drilled.

Leakage from a confining layer, presumably the Fuson member, was observed in the 1982 TVA test of the Lakota formation. However, the leakage was observed only relatively late in the TVA tests, at 3,000 to 10,000 minutes, with a much greater pumping rate (495 gpm) and radius of influence. The large-scale vertical hydraulic conductivity value of 2 x 10^{-4} ft/day (7.1 x 10^{-8} cm/sec) determined in the 1982 TVA regional test at Dewey using the Neuman-Witherspoon ratio method is sufficiently impermeable to be considered an aquitard or aquiclude.

Hydraulic communication through the Fuson member between the Fall River and underlying Lakota aquifers is not indicated by the 2008 response at observation well 32-10. The 2008 test demonstrates that vertical leakage through the Fuson may not occur over a mile-wide radius. As described in Section 4.1, the Lakota and Fall River aquifers at the Dewey test site appear to be locally hydraulically isolated by the intervening Fuson member with nearly 40 ft head difference. The laboratory core data indicate a very low vertical permeability of 6.2 x 10^{-9} cm/sec (1.8 x 10^{-5} ft/day) for the shale sample from within the Fuson shale member.

The laboratory core data for the shale sample from the Skull Creek formation, overlying the Fall River formation, indicate a very low vertical permeability of 5.4 x 10^{-9} cm/sec (1.5 x 10^{-5} ft/day), also appropriate for an aquitard or aquiclude.

For the Fall River sandstone, the laboratory core data indicate a horizontal hydraulic conductivity of 6.1 ft/day, and interpretation of the test results calculates that horizontal permeability may be as great as 17 ft/day throughout one of the ore zones. Within the lower Fall River formation, the test results indicate transmissive, rapid response (two to three minutes) between pumping and observation wells up to 467 ft apart with nearly 10 ft of drawdown. Response was nearly 9 ft of drawdown at 1,400 ft distance. This indicates the aquifer was stressed to produce good quality analytical results.

Knight Piésold
CONSULTING

8.0 Certification

This report "Powertech (USA) Inc., Dewey-Burdock Project, 2008 Pumping Tests: Results and Analysis" has been prepared for Powertech (USA) Inc. by Knight Piésold and Co. The material in it reflects the best judgment of Knight Piésold and Co. in light of the information available to both firms at the time of the report preparation. Any use which a third party makes of this report, or any reliance on or decisions made based on it, are the responsibility of such third parties. Knight Piésold and Co. and Powertech (USA), Inc. accept no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this report.

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Tables

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Table 4.1
Powertech (USA) Inc.
Dewey-Burdock Project
2008 Pumping Tests: Results and Analysis

Dewey Pumping Test Completion Information

Well ID and Stratigraphic Interval	Well Type	Location	Radial Distance from pumping Well (ft)	Depth to top of Screen (ft bgs)	Depth to bottom of Screen (ft bgs)	Note
Ore Zone (lower Fall River Sandstone)						
DB 07-32-3C	Pumping Well	NWQ Sec. 32	0	585	600	
DB 07-32-05	Obs. Well #1	NWQ Sec. 32	265	593	608	
DB 07-32-4C	Obs. Well #2	NWQ Sec. 32	467	580	595	
DB 07-29-7	Obs. Well #3	SEQ Sec. 29	2,400	635	650	
Upper Fall River Sandstone						
DB 08-32-9C	Obs. Well	NWQ Sec. 32	41	490	505	
Lakota Sandstone Layer						
DB 08-32-10	Obs. Well	NWQ Sec. 32	61	715	730	
Unkpapa Formation						
DB 07-32-11	Obs Well	NWQ Sec. 32	50	910	930	
Additional Wells						
GW-49	Upper Fall River 70 ft	NEQ Sec. 29	1,433	475	540	Stock Well

Notes: Screen completion information from diagrams prepared by Powertech, Appendix B
Radial distance information provided by Powertech.

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Table 4.2
Powertech (USA) Inc.
Dewey-Burdock Project
2008 Pumping Tests: Results and Analysis

Dewey Pumping Test Drawdown and Response Summary

Well ID and Stratigraphic Interval	Well Type	Radial Distance from pumping Well (ft)	Approximate Ground Surface Elevation (ft amsl)[1]	Approximate Groundwater Elevation (ft amsl)[2]	Note	Maximum Drawdown at 3.08 days (ft)[3]	Note	Time of First Drawdown Response (min)	Minimum Pumping Groundwater Elevation (ft amsl)	Boundary Type (days)[4]
Ore Zone (lower Fall River Sandstone)										
DB 07-32-3C	Pumping Well	0	3626.3	3643.9	A	44.8		0.0	3599.1	
DB 07-32-05	Obs. Well #1	265	3622.2	3641.0	A	13.0		1.6 to 2.4	3628.0	Barrier (0.7)
DB 07-32-4C	Obs. Well #2	467	3626.3	3644.0	A	9.8		2.8	3634.2	Barrier (0.6)
DB 07-29-7	Obs. Well #3	2,400	3662.5	3659.3		1.5	a	140 to 850	3657.8	
Upper Fall River Sandstone										
DB 08-32-9C	Obs. Well	41	3625.9	3626.3	A	10.6		11.5	3615.7	
Lakota Sandstone Layer										
DB 08-32-10	Obs. Well	61	3625.2	3682.8	A	-0.1	N	No Response	NA	
Unkpapa Formation										
DB 07-32-11	Obs Well	50	3625.2	3761.0	A	-2.0	N	No Response	NA	
Additional Wells										
GW-49	Stock Well	1,433	3628	3652	A	9.0		40	3643.0	Barrier (1.9)

Notes: Screen completion information from diagrams prepared by Powertech, Appendix A
Radial distance informationprovided by Powertech.

[1] Ground Surface Elevations from Powertech

[2] Pressure or depth to water measurements relative to ground surface, Eric Krantz, RESPEC, personal communication.

[3] From table of processed drawdown data in Appendix B, or calculated visually from WinSituTM graph and table of data in non-responding wells.

[4] Boundary time estimated based on time of deviation from Theis type curve; 0.7 days used for weighting calculations.

A Artesian pressure surface above ground level.

N N response to pumping, water level rose slightly through drawdown phase of test

[a] Drawdown continued for about 1.5 days past pump shut-down to a maximum of 2.1 ft at about 3:00 AM on May 20, 2008.

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Table 4.3
Powertech (USA) Inc.
Dewey-Burdock Project
2008 Pumping Tests: Results and Analysis

Summary of Aquifer Hydraulic Characteristics for the Dewey Pumping Test

Dewey Test Site Pumping Test Interpretations

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	--	3.3E-05	--
			Theis Recovery[1]	260	<0.01	--	--
			CJ Recovery[3]	280	<0.01	--	--
32-4C	Obs #2	467	Theis DD[1]	333	--	5.6E-05	--
			CJ Recovery [3]	120[a]	<0.01	--	
29-7	Obs #3	2,400	Theis DD[2]	178	--	2.0E-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	--	2.3E-05	--
			CJ Recovery [3]	110	<0.05	--	--
Upper Fall River Sandstone							
32-9C	Obs	41	Theis DD[1]	217	--	1.6E-02	--
			CJ Recovery [3]	150	<0.05	--	--

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Table 4.3
Powertech (USA) Inc.
Dewey-Burdock Project
2008 Pumping Tests: Results and Analysis

Summary of Aquifer Hydraulic Characteristics for the Dewey Pumping Test

Dewey Test Site Pumping Test Interpretations

Well I.D.	Well Type	Radial Dist. (ft)	Interpretation Method	Transmissivity (ft^2/day)	u or u' (unitless)	Storativity (unitless)	Note
Lakota Sandstone Layer							
32-10	Obs	61	No response during pumping test.				--
Unkpapa Formation							
32-11	Obs	50	No response during pumping test.				--
Distance Drawdown (32-5, 32-4C, 29-7, GW-49)[2]				218	<0.05	4.6E-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 Piesold 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 valculated for Transmissivity, Geometric Mean value calculated for Storativity.

(a) only slope satisfying u 'critereon occurs after intersection with barrier boundary.

(b) not accepted due to anomalous response at well, see text.

(d) storativity not valid at pumping well.

[ ] = accepted value based on conformance with theory discussed in the text.

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Table 5.1
Powertech (USA) Inc.
Dewey-Burdock Project
2008 Pumping Tests: Results and Analysis

Burdock Pumping Test Completion Information

Well ID and Stratigraphic Interval	Well Type	Location	Radial Distance from pumping Well (ft)	Depth to top of Screen (ft bgs)	Depth to bottom of Screen (ft bgs)	Note
Ore Zone (lower Lakota Sandstone)						
DB 07-11-11C	Pumping Well	SWQ Sec. 11	0	426	436	
DB 07-11-15	Obs. Well #1	SWQ Sec. 11	243	418	428	
DB 07-11-14C	Obs. Well #2	SWQ Sec. 11	250	413	423	
DB 07-11-02	Obs. Well #3	NWQ Sec. 11	1,292	450	460	
Upper Lakota Sandstone						
DB 07-11-19	Obs. Well	SWQ Sec. 11	50	325	335	
Fall River (lower Sandstone layer)						
DB 07-11-17	Obs. Well	SWQ Sec. 11	50	245	255	
Unkpapa Formation						
DB07-11-18	Obs Well	SWQ Sec. 11	<100	621	631	
Additional Distant Wells						
	None					

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Table 5.2
Powertech (USA) Inc.
Dewey-Burdock Project
2008 Pumping Tests: Results and Analysis

Burdock Pumping Test Drawdown and Response Summary

Well ID and Stratigraphic Interval	Well Type	Radial Distance from pumping Well (ft)	Approximate Ground Surface Elevation (ft amsl)[1]	Approximate Groundwater Elevation (ft amsl)[2]	Note	Maximum Drawdown at 3.0 days (ft)[3]	Note	Time of First Drawdown Response (min)	Minimum Pumping Groundwater Elevation (ft amsl)	Boundary Type (days)[4]
Ore Zone (lower Lakota Sandstone)										
DB 07-11-11C	Pumping Well	0	3700.5	NA		91.1		0.0	3529	
DB 07-11-15	Obs. Well #1	243	3691.5	3660.2		10.4		140.2	3649.8	
DB 07-11-14C	Obs. Well #2	250	3688.4	3660.9		17.0		3.6	3643.9	Recharge (1.1)
DB 07-11-02	Obs. Well #3	1,292	3717.9	3664.8		3.1		280	3661.7	Recharge (1.8)
Upper Lakota Sandstone										
DB 07-11-19	Obs. Well	50	3701.7	3662.1		3.4		160	3658.7	
Fall River (lower Sandstone layer)										
DB 07-11-17	Obs. Well	50	3700.1	3660.3		2.1	a	see note b	3657.2	
Unkpapa Formation										
DB07-11-18	Obs Well	35	3699.2	3728.4	A	-0.5	N	No Response	NA	
Additional Wells										
None										

Notes: Radial distance information from Autocad drawing provided by Powertech.

[1] Ground Surface Elevations from Powertech
[2] Pressure or depth to water measurements relative to ground surface, Eric Krantz, RESPEC, personal communication.
[3] From table of processed drawdown data in Appendix B, or calculated from WinSitu™ graph and table of data in non-responding wells.
[4] Boundary time estimated based on time of deviation from Theis type curve; shortest time used for weighting calculations.
A Artesian pressure surface above ground level.
N N response to pumping, water level rose slightly through drawdown phase of test
(a)Drawdown continued for about 1 day past pump shut-down to a maximum of 3.1 ft at about 5:00 PM, May 22, 2008.
(b)First response was a 0.23 ft rise in water levels peaking at about 12:00 AM on May 19, 2008, interpreted as a possible Noordbergum effect.

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Table 5.3
Powertech (USA) Inc.
Dewey-Burdock Project
2008 Pumping Tests: Results and Analysis

Summary of Aquifer Hydraulic Characteristics for the Burdock Pumping Test

Burdock Project Pumping Test Interpretations

Well I.D.	Well Type	Radial Dist. (ft)	Interpretation Method	Transmissivity (ft^2/day)	u or u' (unitless)	Storativity (unitless)	Note
Ore zone (lower Lakota 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	--	--
11-15	Obs #1	243	Theis DD[1]	67	--	1.3E-03	--
			CJ Recovery [3]	100	<0.1	--	--
11-14C	Obs #2	250	Theis DD[1]	128	--	6.8E-05	--
			H-J DD[1]	120	--	6.9E-05	--
			Theis Recovery[1]	174	<0.01	--	--
			CJ Recovery [3]	160	<0.01	--	--
11-02	Obs #3	1,292	Theis DD[1]	223	--	1.9E-04	--
			H-J DD[1]	185	--	1.7E-04	--
			CJ Recovery [3]	260	<0.15	--	--
Upper Lakota Sandstone							
11-19	Obs	50	Theis DD[2]	260	--	1.0E-01	--
			CJ Recovery [3]	190	<0.15	--	--
Fall River (lower sandstone layer)							
11-17	Obs	50	Noordbergum Effect and response cannot be interpreted analytically				

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Table 5.3
Powertech (USA) Inc.
Dewey-Burdock Project
2008 Pumping Tests: Results and Analysis

Summary of Aquifer Hydraulic Characteristics for the Burdock Pumping Test

Burdock Project Pumping Test Interpretations

Well I.D.	Well Type	Radial Dist. (ft)	Interpretation Method	Transmissivity (ft^2/day)	u or u' (unitless)	Storativity (unitless)	Note
Unkpapa Formation							
11-18	Obs	35	No response during pumping test.				--
Distance Drawdown (11-14C, 11-15, 11-02)[2]				145	<0.08	2.2E-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		1.8E-04	

Notes/References: DD = drawdown, CJ = Cooper-Jacob, HJ = Hantush-Jacob, Obs = Observation Well

[1] Calculated by automated curve fitting in AquiferWin32™ software (ESI, 2003).

[2] Knight Piesold 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 valculated for Transmissivity, Geometric Mean value calculated for Storativity.

(a) storativity not valid at pumping well.

(b) based on 6 inch casing (8 inch borehole).

[ ] = accepted value based on conformance with theory discussed in the text.

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Table 6.1
Powertech (USA) Inc.
Dewey-Burdock Project
2008 Pumping Tests: Results and Analysis

Laboratory Core Analyses for Powertech USA Inc. at Dewey-Burdock Site

Sample Number	Depth (ft)	Confining Stress (psig)	Porosity (%)	Air Intrinsic Permeability[1] k_a (mD)	Particle Density (g/cm^3)	Notes	Water Hydraulic Conductivity[2][3] K_w (cm/s)	Core K_h (ft/day)	Core K_v (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		

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Table 6.1
Powertech (USA) Inc.
Dewey-Burdock Project
2008 Pumping Tests: Results and Analysis

Laboratory Core Analyses for Powertech USA Inc. at Dewey-Burdock Site

Sample Number	Depth (ft)	Confining Stress (psig)	Porosity (%)	Air Intrinsic Permeability[1] k_a (mD)	Particle Density (g/cm^3)	Notes	Water Hydraulic Conductivity[2][3] K_w (cm/s)	Core K_h (ft/day)	Core K_v (ft/day)
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 K_h, K_v								7.4	3.0
Average Lakota Sand K_h/K_v								2.42	
Fall River Sand K_h, K_v								6.1	1.4
Fall River Sand K_h/K_v								4.53	
Dewey Skull Creek Shale K_h							6.01E-08	1.71E-04	
Dewey Skull Creek Shale K_v							5.39E-09		1.54E-05
Dewey Skull Creek Shale K_h/K_v							11.14		

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Table 6.1
Powertech (USA) Inc.
Dewey-Burdock Project
2008 Pumping Tests: Results and Analysis

Laboratory Core Analyses for Powertech USA Inc. at Dewey-Burdock Site

Sample Number	Depth (ft)	Confining Stress (psig)	Porosity (%)	Air Intrinsic Permeability[1] k_a (mD)	Particle Density (g/cm^3)	Notes	Water Hydraulic Conductivity[2][3] K_w (cm/s)	Core K_h (ft/day)	Core K_v (ft/day)
Average Burdock Fuson Shale K_h							4.16E-07	1.19E-03	
Average Burdock Fuson Shale K_v							9.35E-08		2.67E-04
Average Burdock Fuson Shale K_h/K_v							4.45		
Dewey Fuson Shale K_h							5.62E-08	1.60E-04	
Dewey Fuson Shale K_v							6.16E-09		1.76E-05
Dewey Fuson Shale K_h/K_v							9.13		
Average Burdock Morrison Shale K_h							4.37E-07	1.24E-03	
Average Burdock Morrison Shale K_v							2.12E-08		6.03E-05
Average Burdock Morrison Shale K_h/K_v							20.62		

Notes:

(1) Assumed air temperature = 70°F.

(2) Assumed water temperature = 52.8^{o}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 x 10^{-11} cm^2

Constants: At 52.8 ^{o}F Water (11.5 ^{o}C)

Density = 0.999548 g/cm^3

Dynamic Viscosity = '0.01257 g/cm-s

1 mD = 9.87E-12 cm^2

gravity = 981 cm/s^2