POWERTECH (USA) INC.

Dewey-Burdock Project
Report to Accompany Madison Water Right Permit Application
Custer and Fall River Counties, South Dakota

Prepared for:

South Dakota Department of Environment and Natural Resources
Water Rights Program
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EXECUTIVE SUMMARY

This report accompanies an Application for Permit to Appropriate Water from the Madison aquifer within the State of South Dakota, Form 2, submitted by Powertech (USA) to DENR. The permit to appropriate water from the Madison aquifer is one of several permits required for Powertech (USA) to recover uranium in the Dewey-Burdock Project, which is located about 13 miles north-northwest of Edgemont, SD.

Powertech (USA) proposes to recover uranium by a method known as *in situ* recovery, or ISR, in which groundwater from the formation containing uranium (the Inyan Kara Group) is pumped to the surface from a field of wells, fortified with oxygen and carbon dioxide, and recirculated through the formation. The oxidized groundwater changes the uranium to a soluble form and is pumped to the surface, where the uranium is removed from solution and processed into yellowcake. The yellowcake will be shipped off site for further processing into fuel for electric energy production. After the uranium is removed, the groundwater is refortified with oxygen and carbon dioxide and recirculated through the well fields; the process is repeated until the economic reserves of uranium are fully removed from that particular well field. Then the process moves to another well field, and the depleted well field is restored by continuing to circulate clean water through the wells until the water is similar in quality to the water that existed in the formation prior to the ISR operations.

Because most of the water removed during the ISR process is recirculated through the well field, the net consumptive use of water is a small portion of the gross withdrawal rate. A small amount of water is “bled off” during the process in order to maintain flow gradients toward the center of the well field and help control the flow of the recovery solutions. The “bleed stream” is treated to remove uranium and uranium decay products and disposed in deep disposal wells or by land application. The disposal method has not yet been finalized; Powertech’s preferred disposal method will be deep disposal wells. A separate permitting action with EPA is ongoing, and once the necessary permits are received the testing can be undertaken to determine the feasibility of constructing deep disposal wells in this area. If deep disposal wells are not feasible in this area, the land application method will be used. Another permitting action is underway with DENR to authorize the land application. It is possible that a combination of methods will be necessary.

Most of the water used in the ISR operations will be obtained from the Inyan Kara Group as an integral part of the ISR process. Powertech (USA) plans to use water from the Madison aquifer to make up for the small amount of water that is not provided from the ISR process. The amount of “make-up” water from the Madison will depend upon the water disposal method as follows:

- Deep disposal wells: If deep disposal wells are proven feasible, the primary method of aquifer restoration will be to treat the water recovered from the ISR process using reverse osmosis (RO). About 70 percent of the water treated by RO (the permeate) is nearly pure water and will be recirculated through the well field to restore the water quality of the aquifer. About 30 percent of the water treated by RO is brine (too high in dissolved solids for reinjection into the aquifer) and will be disposed in the deep disposal wells, which naturally contain saline water. Water from the Madison will be mixed with the permeate to make up for the removal of the brine.
- Land application: If deep disposal wells are not feasible, the water that is bled off during the ISR process will be disposed of by seasonal land application (i.e., evaporation). The water will be stored in retention ponds during the winter when evaporation rates are low. In this process RO will not be used because there will be no way to dispose of the brine, which is too salty for land application. All of the water withdrawn from the ore zone aquifer during restoration will be disposed by evaporation, and Madison water will be circulated through the aquifer until the restoration process is complete.

Under the land application scenario, a maximum of 508 gpm will be required from the Madison wells. To allow for contingencies and uncertainties, Powertech (USA) is applying for a maximum rate of 551 gpm (equivalent to 1.228 cfs or 888.8 ac-ft per year). If deep disposal wells prove feasible, only up to about 160 gpm will be required from the Madison.

There are no records of Madison wells within or within 5 miles of the Dewey-Burdock project area. Therefore, it is not known if the required yield can be obtained from one well or if several wells will be required. For the purposes of this application, Powertech (USA) has listed two potential well locations on the permit application form, one in the Dewey portion of the project area and one in the Burdock portion. The final decision as to number and location of wells will depend upon water requirements, well yield, water quality and economic factors (e.g., whether it is more economical to complete one well and pipe the water to the points of use or more wells closer to the points of use).

SDCL 46-2A-9 states that, “A permit to appropriate water may be issued only if there is reasonable probability that there is unappropriated water available for the applicant's proposed use, that the proposed diversion can be developed without unlawful impairment of existing rights and that the proposed use is a beneficial use and in the public interest.” Each of these conditions is addressed in this report. A considerable amount of regional information, primarily from the USGS and DENR, was compiled and analyzed to describe the hydrologic and hydraulic characteristics of the Madison Limestone in and near the project area. A flow net was used to demonstrate that recharge to and flow within the Madison aquifer in the vicinity of the Dewey-Burdock Project area is more than three times the amount requested in this appropriation, and an estimate of the amount of water in storage in the vicinity of the project area using the same methods as those used by the USGS shows that the maximum anticipated usage will be less than 1 percent of the available water in storage in close proximity to the project area. This indicates a "reasonable probability that there is unappropriated water available for the applicant's proposed use" (SDCL 46-2A-9).

An analytical procedure based on the well-known Theis method was used to show that drawdown under this appropriation would be less than 8 feet at a distance of 5 miles from the well after continuously pumping for 10 years (Powertech (USA's) proposed schedule calls for a pumping period of 7-20 years). Even if the pumping were continued for a 20-year period, the drawdown at a distance of 5 miles from the pumped well would only be about 8.5 feet. This example assumes that the entire 551 gpm is obtained from a single well. Considering that the top of the Madison is expected to be 2,700 to 3,400 feet below the surface in the project area and the water level might be at or even above the ground surface, 8.5 feet of drawdown would comprise only a small portion of available drawdown. The drawdown would be less than 8.5 feet as distance from the well increased, but cannot be accurately predicted due to lack of data on the Madison aquifer in the vicinity of the project area. The nearest Madison wells are at Edgemont (about 15 miles southeast of the proposed well locations within the project area) and a suburban housing development about 13 miles to the northeast. These wells will not be adversely impacted since the drawdown, if it reaches these locations, will likely be much less than the 8.5 feet of drawdown that would be the maximum achieved at a distance of 5 miles from the proposed wells. Other Madison wells in the region are separated from the project area by structures such as the Dewey Fault and the Long Mountain Structural Zone, which may isolate these areas from any effects of the proposed water withdrawals.

Powertech (USA) is aware that there are several caves and springs in the region and is sensitive to the fact that there may be concerns about any effects on these features. These have been addressed in this report with the following conclusions:

- Jewel Cave, about 18 miles northeast of the project area, will not be affected because it is above the water table and is separated from the project area by the Dewey Fault and several other geologic structures.
- Wind Cave is about 26 miles east of the project area and is on the southeast flank of the Black Hills Uplift, while the project area is on the southwest flank. Groundwater flow in the Madison has repeatedly been determined by the USGS and others to be generally radially outward from the core of the Black Hills Uplift. A geologic cross section included in this report shows that there is a groundwater and structural divide between the project area and Wind Cave where the Madison is only partially saturated at best and may be entirely above the water table, effectively separating Wind Cave from the project area.

- More than 22 miles and several geologic structures separate the project area from the major springs in the area (Cascade Springs, Hot Springs and Beaver Creek Springs). These springs are on the southern or southeastern flank of the Black Hills Uplift and are unlikely to see any effect from Powertech (USA)'s proposed Madison wells.

Based on these findings, Powertech (USA) believes that proposed diversion can be developed without unlawful impairment of existing rights, as required by SDCL 46-2A-9, and without impairing other important water resource features in the general vicinity.

SDCL 46-1-6(3) defines beneficial use as "any use of water within or outside the state, that is reasonable and useful and beneficial to the appropriator, and at the same time is consistent with the interests of the public of this state in the best utilization of water supplies." SDCL 46-1-8 defines beneficial use as "the basis, measure and limit of the right to the use of the waters [of the state]." The amount of water requested in this appropriation has been carefully determined by engineering analysis as the amount necessary to recover the uranium and restore the aquifer water quality while protecting water resources outside the area. Additional support for uranium ISR to be considered a beneficial use is found in SDCL 45-6B, which states, "Every effort should be used to promote and encourage the development of mining as an industry, but to prevent the waste and spoilage of the land and the improper disposal of tailings which would deny its use and productivity" and SDCL 45-6B-3(11), which includes *in situ* mining in the definition of "mining operation."

The Dewey-Burdock Project will provide public benefits in the form of employment opportunities (250 jobs during construction and 150 new jobs during operation) and state and local tax revenues. Another public benefit from this appropriation is the information it can provide on the Madison aquifer in this location, including depth, potentiometric surface elevation, well yield, permeability and water quality. With approval of DENR, the wells could be used for domestic, stock and other uses after the relatively short-term ISR project is completed.

1.0 INTRODUCTION

Powertech (USA), Inc. (Powertech (USA)) is submitting an application for a water right permit within the State of South Dakota for the Madison aquifer. The permit application and this accompanying report have been prepared in accordance with the requirements of SDCL Title 46. Powertech (USA) is a U.S.-based corporation incorporated in South Dakota and a wholly owned subsidiary of Powertech Uranium Corporation, a Canadian company. In addition to the Dewey-Burdock Project, Powertech (USA) has one exploration permit in Colorado (Centennial Project) and two exploration permits in Wyoming (Dewey Terrace and Aladdin projects).

The Dewey-Burdock Project is a proposed uranium *in situ* recovery (ISR) project located approximately 13 miles north-northwest of Edgemont, South Dakota, in an area encompassing portions of Fall River and Custer counties. The Dewey-Burdock Project area (project area) encompasses approximately 10,580 acres of mostly private land on both sides of S. Dewey Road (County Road 6463) and includes portions of Sections 1-5, 10-12, and 14-15, Township 7 South, Range 1 East and Sections 20-21 and 27-35, Township 6 South, Range 1 East, Black Hills Meridian. Approximately 240 acres are under control of the Bureau of Land Management (BLM) in portions of Sections 3 and 10-12. The Dewey-Burdock Project location is shown on Figure 1-1. Table 1-1 shows the surface and mineral ownership within the project area. Through various mineral claims, leases, and other agreements, Powertech (USA) has acquired the legal right to conduct ISR operations within the project area.

The permit application proposes a permitted 888.8 ac-ft annual total appropriation of groundwater (551 gpm) from the Madison aquifer, to provide water for uranium ISR and aquifer restoration at the Dewey-Burdock Project. As demonstrated in this report other users of water from the Madison aquifer will not be adversely affected by this appropriation due to their distance from the project area, the presence of geologic and hydrologic barriers and boundaries, and the fact that the aquifer has adequate recharge and storage capacity to satisfy the requested appropriation.

This application is organized into six sections including this introduction. The requested appropriation volume and well design plans are discussed in Section 2. Section 3 summarizes the hydrogeologic setting, including a brief summary of water quality data. Section 4 provides a discussion of drawdown estimates. Section 5 presents a flow net-type analysis to demonstrate that there is a "reasonable probability that there is unappropriated water available for the applicant's proposed use," as required by SDCL 46-2A-9. Sections 4 and 5 of this report provide a demonstration, using hydrogeologic data provided in Section 3 and standard analytical

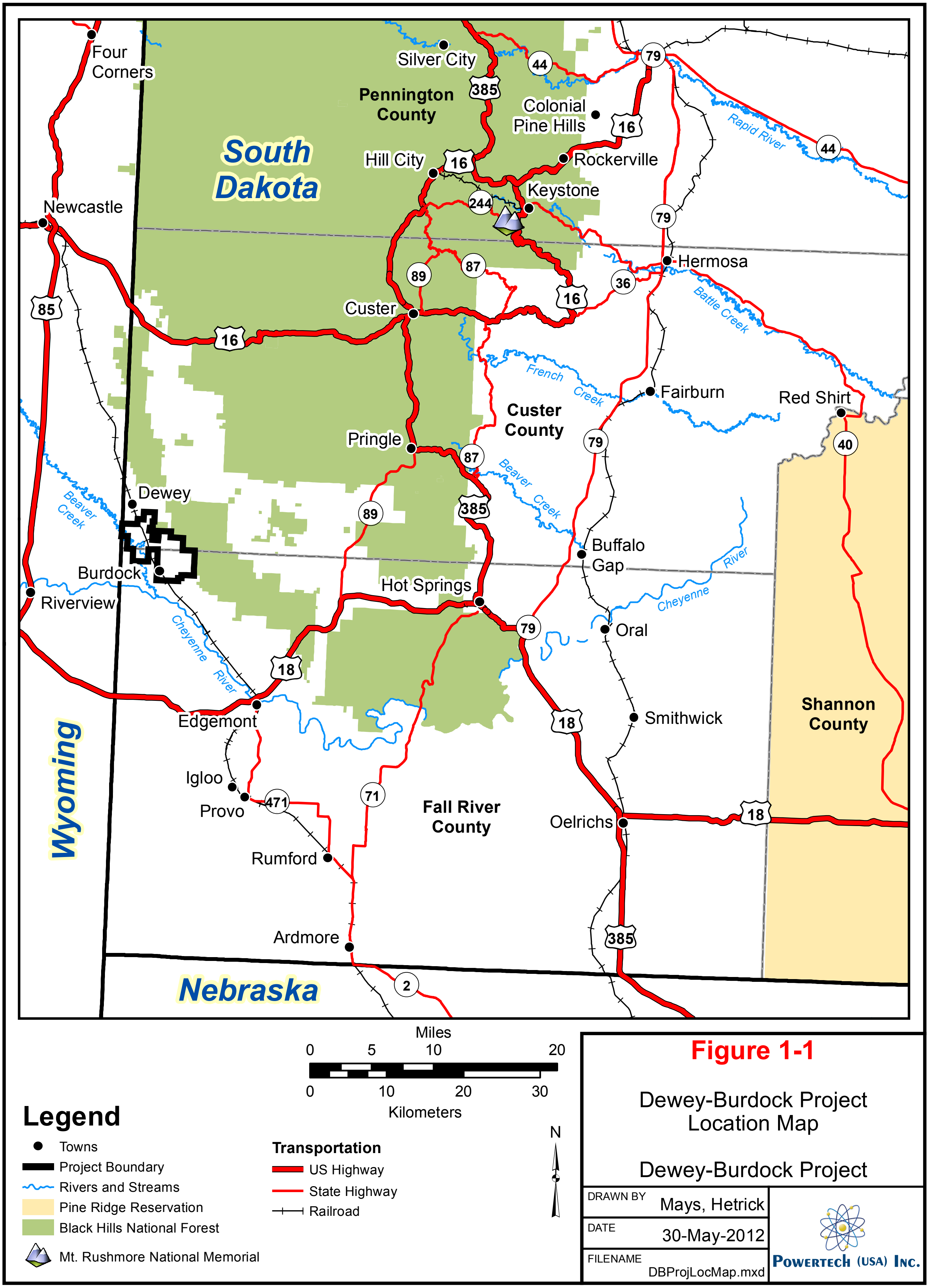


Figure 1-1

Dewey-Burdock Project
Location Map

Dewey-Burdock Project

Table 1-1. Surface and Mineral Ownership, Dewey-Burdock Project Area

Township 6S, Range 1E, Custer County, SD
Black Hills Meridian

Legal Description		Area (acres)	**Surface Owner(s)**	**Mineral Owner(s)**
Section 20	E½NE¼; E½SE¼; SW¼SE¼; S½NW¼SE¼; SE¼SW¼; S½NE¼SW¼	280	GCC Dacotah, Inc.	BLM Minerals
Section 21	W½; W½SW¼NE¼; W½NW¼SE¼	360	GCC Dacotah, Inc.	BLM Minerals
	W½NW¼NE¼	20	Donald L. Spencer	BLM Minerals
Section 27	W½SW¼; E½SE¼	160	Clayton Sander	BLM Minerals
	E½SW¼; W½SE¼	160	Clayton Sander	Clayton Sander
Section 28	N½NW¼; SW¼NW¼	120	GCC Dacotah, Inc.	BLM Minerals
	SW¼	160	Putnam & Putnam, LLP	BLM Minerals
Section 29	SW¼NE¼; N½NW¼; W½SE¼	200	GCC Dacotah, Inc.	Richard E. Elston; Elston Bros. Realty Co., LLC
	N½NE¼; SE¼NE¼; S½NW¼; SW¼; E½SE¼	440	GCC Dacotah, Inc.	BLM Minerals
Section 30	NE¼; W½	480	GCC Dacotah, Inc.	Francis A. and Phyllis Jozwik Paul and Janet Jozwik Robert and Alice Barnard (Barnard & Lowham, LLC) William and Joyce Barnard (Barnard & Lowham, LLC) Paul Lowham (Barnard & Lowham, LLC)
	SE¼	160	GCC Dacotah, Inc.	Richard E. Elston; Elston Bros. Realty Co., LLC
Section 31	E½	320	Bakewell-Andis Ranch, LLP	Bakewell-Andis Ranch, LLP
Section 32	NE¼NE¼; N½NW¼	120	GCC Dacotah, Inc.	BLM Minerals
	NW¼NE¼; S½NE¼; S½NW¼	200	GCC Dacotah, Inc.	Richard E. Elston; Elston Bros. Realty Co., LLC
	S½	320	Putnam & Putnam, LLP	Putnam & Putnam, LLP
Section 33	S½NE¼; SE¼	240	Donald and Pat Spencer	BLM Minerals
	W½	320	Putnam & Putnam, LLP	BLM Minerals
Section 34	NE¼NE¼	40	Donald and Pat Spencer	BLM Minerals
	W½NE¼; SE¼NE¼; W½; SE¼	600	Donald and Pat Spencer	Donald and Pat Spencer
Section 35	NE¼; E½NW¼; NW¼NW¼; NE¼SW¼; N½SE¼	400	Donald and Pat Spencer	BLM Minerals
	SW¼NW¼; NW¼SW¼	80	Donald and Pat Spencer	Donald and Pat Spencer
	S½SW¼; S½SE¼	160	Chris and Amy Daniel	Chris and Amy Daniel

Table 1-1. Surface and Mineral Ownership, Dewey-Burdock Project Area (Continued)

Township 7S, Range 1E, Fall River County, SD
Black Hills Meridian

Legal Description		Area (acres)	Surface Owner(s)	Mineral Owner(s)
Section 1	All	640	Daniel Properties, LLC	BLM Minerals
Section 2	All	640	Daniel Properties, LLC	Daniel Properties, LLC
Section 3	N½; SW¼; N½SE¼; SW¼SE¼	600	Donald and Pat Spencer	Donald and Pat Spencer
	SE¼SE¼	40	BLM	BLM Minerals
Section 4	W½W½	160	Putnam & Putnam, LLP	Putnam & Putnam, LLP
Section 5	All	640	Putnam & Putnam, LLP	Putnam & Putnam, LLP
Section 10	NE¼; W½SE¼; E½SW¼; SW¼NW¼SW¼; SW¼SW¼ minus 3.97 ac in NE portion	366.03	Peterson & Son, Inc.	Peterson & Son, Inc. Black Stone Minerals Company, LP Jean Swirczynski Roy Guess
	NW¼NW¼SW¼	10	TerraTecTonics Corporation	TerraTecTonics Corporation
	E½NW¼SW¼ minus lots in southern portion (1.44 ac)	18.56	Donald and Lynda Andersen	Donald and Lynda Andersen
	14 lots in southern portion of E½NW¼SW¼; 3.97 ac in NE portion of SW¼SW¼	5.1	Kathleen Klausen	Kathleen Klausen
	4 lots in southern portion of E½NW¼SW¼	0.31	Clifford James Lovell and Patricia C. Johnson	Clifford James Lovell and Patricia C. Johnson
	N½NW¼	80	Donald and Pat Spencer	Steven and Elizabeth Laesch Roger C. and Jeanette R. Laesch Christopher and Kelly Ann Viel Rev. Norman and Joyce Laesch Carol A. Laesch Barbara Jacqueline S. Laesch Ellison Frederick and Marilyn Laesch Helen L. and Carl Leroy Kellberg Rev. Richard and Irene L. Mueller William J. Laesch Allen G. and Barbara B. Wilson
	S½NW¼	80	Donald and Pat Spencer	Donald and Pat Spencer
	NE¼SE¼	40	BLM	BLM Minerals

Table 1-1. Surface and Mineral Ownership, Dewey-Burdock Project Area (Continued)

Township 7S, Range 1E, Fall River County, SD
Black Hills Meridian

Legal Description		Area (acres)	Surface Owner(s)	Mineral Owner(s)
Section 10	SE¼SE¼	40	Peterson & Son, Inc.	Agnes Medsker Irene R. Andersen Clint Andersen
Section 11	NE¼; SE¼NW¼; NE¼SW¼; N½SE¼	320	Daniel Properties, LLC	BLM Minerals
	NE¼NW¼	40	Daniel Properties, LLC	Daniel Properties, LLC
	W½NW¼; NW¼SW¼	120	BLM	BLM Minerals
	SW¼SW¼	40	Peterson & Son, Inc.	Agnes Medsker Irene R. Andersen Clint Andersen
	SE¼SW¼; S½SE¼	120	Peterson & Son, Inc.	Peterson & Son, Inc. Black Stone Minerals Company, LP Jean Swirczynski Roy Guess
Section 12	N½; NW¼SW¼	360	Carolyn Fines	BLM Minerals
	NE¼SW¼	40	BLM	BLM Minerals
	S½SW¼; SE¼	240	Everett and Dawn Englebert	BLM Minerals
Section 14	NE¼NE¼; S½NW¼NE¼; SW¼NE¼; S½NE¼NW¼; S½NW¼	200	Peterson & Son, Inc.	Peterson & Son, Inc.
	N½NW¼NE¼; N½NE¼NW¼	40	Peterson & Son, Inc.	Peterson & Son, Inc. Jean Swirczynski Roy Guess
	NW¼NW¼	40	Peterson & Son, Inc.	Agnes Medsker Irene R. Andersen Clint Andersen
Section 15	NE¼NE¼	40	Peterson & Son, Inc.	Agnes Medsker Irene R. Andersen Clint Andersen
	NW¼NE¼; S½NE¼; NW¼	280	Peterson & Son, Inc.	Peterson & Son, Inc. Black Stone Minerals Company, LP Jean Swirczynski Roy Guess

techniques, that the "proposed diversion can be developed without unlawful impairment of existing rights," also as required by SDCL 46-2A-9. The final two requirements in SDCL 46-2A-9, that the proposed use is a beneficial use and in the public interest, are addressed in Section 2.1. A list of references is contained in Section 6. Supporting documentation is provided in appendices.

1.1 Applicant Information

The Madison water right application is submitted by Powertech (USA), which is the U.S.-based wholly owned subsidiary of Powertech Uranium Corporation, a corporation registered in British Columbia. Powertech Uranium Corporation shares are publicly traded on the Toronto Stock Exchange (TSX) as PWE and the Frankfurt Stock Exchange as P8A. The corporate office of Powertech Uranium Corporation is located in Vancouver, British Columbia. Powertech (USA) is a U.S.-based corporation incorporated in the state of South Dakota.

The addresses and telephone numbers for the general office (Colorado) and the local office (South Dakota) of the applicant are listed as follows:

Name and address of applicant:

Company:	Powertech (USA) Inc.
Signatory:	Richard Blubaugh
Title:	Vice President, Environmental Health & Safety Resources
Address:	5575 DTC Parkway, Suite #140 Greenwood Village, CO 80111
Telephone:	(303) 790-7528

Local representative or contact person:

Name:	Mark Hollenbeck, P.E.
Title:	Project Manager
Address:	Powertech (USA) Inc. 310 2nd Avenue P.O. Box 812 Edgemont, SD 57735
Telephone:	(605) 662-8308

2.0 REQUESTED WATER APPROPRIATION

This section describes the purpose and need for the proposed water appropriation, the project overview, well locations, proposed water usage, well design, and term limitations.

2.1 Purpose and Need for Water Appropriation

The purpose of the water right application is to appropriate water from the Madison aquifer to be used beneficially for uranium mining using the ISR process. SDCL 46-2A-9 states the only conditions under which a permit to appropriate water may be issued:

> Appropriation of water--When permit may be issued. A permit to appropriate water may be issued only if there is reasonable probability that there is unappropriated water available for the applicant's proposed use, that the proposed diversion can be developed without unlawful impairment of existing rights and that the proposed use is a beneficial use and in the public interest.

The first two parts of SDCL 46-2A-9 are addressed in Sections 4 and 5 of this report. Section 4 shows that drawdown from withdrawal of up to 551 gpm from the Madison aquifer at the Dewey-Burdock Project will be small and will comprise only a minor portion of the available static head in the Madison aquifer in the vicinity of the project area. By the use of a conceptual model developed from available regional information and a standard flow net analysis, Section 5 demonstrates there is a very reasonable probability sufficient unappropriated water exists in the Madison aquifer to supply the 551 gpm requested by Powertech (USA) to support the proposed Dewey-Burdock Project needs and this proposed diversion can be developed without unlawful impairment of existing rights.

ISR mining including groundwater restoration as a beneficial use of water is supported by SDCL 45-6B, which states, “Every effort should be used to promote and encourage the development of mining as an industry, but to prevent the waste and spoilage of the land and the improper disposal of tailings which would deny its future use and productivity.” SDCL 46-1-6(3) defines beneficial use as “any use of water within or outside the state, that is reasonable and useful and beneficial to the appropriator, and at the same time is consistent with the interests of the public of this state in the best utilization of water supplies.” SDCL 46-1-8 defines beneficial use as “the basis, measure and limit of the right to the use of the waters [of the state].” The amount of water requested in this appropriation has been carefully determined by engineering analysis as the amount necessary to support uranium recovery, aquifer restoration, and potential domestic and livestock use while protecting water resources outside the project area. Additional support for uranium ISR to be considered a mining beneficial use is found in SDCL 45-6B-3(11), which includes *in situ* mining in the definition of “mining operation.”

Powertech (USA)'s commitment to adhering to best professional practices, U.S. Nuclear Regulatory Commission (NRC) license conditions and EPA and DENR permit conditions will ensure that facility construction, operation, decommissioning and reclamation will protect DENR-approved postmining land use(s). As required by the NRC license, LSM permit and EPA Class III and V Underground Injection Control permits, Powertech (USA) will be required to post financial assurance for all aspects of the Dewey-Burdock Project. This will ensure that resources will be available for decommissioning and reclamation such that the site will be released for unrestricted use.

The Dewey-Burdock Project NRC license application (Powertech, 2009) describes how the project benefits include its potential to create approximately 250 new jobs during construction and approximately 150 new jobs during operation, which will contribute direct and indirect benefits to the local economy. In addition, Powertech (USA) estimates that the project will generate some $35 million in state and local tax revenue and approximately $187 million in value added benefits over the life of the project.

There are anticipated to be three local public interest issues associated with developing Madison wells in the southern Black Hills: (1) the possibility of affecting water resources at Wind Cave National Park, (2) the possibility of affecting artesian spring discharge, and (3) the possibility of affecting water levels at the city of Edgemont. These issues may be considered by the Water Management Board as public interest issues. Potential impacts to these sites of public interest are described in Sections 4 and 5 of this report and are predicted to be small. Another public interest that will be served by this appropriation is the opportunity it will provide to obtain factual data on the Madison aquifer in this location. Information will include data on structure, hydraulic characteristics and water quality of the Madison aquifer. Because the proposed industrial use for the water has a finite term, as opposed to a municipal supply, the resource which will eventually be available for future uses will be well defined through the operation of this project. This will help assess water availability for future projects in the region.

2.2 Project Overview

The Dewey-Burdock Project is a proposed uranium ISR project. The uranium will be recovered by injecting groundwater fortified with oxidizing and complexing agents (oxygen and carbon dioxide) into a series of injection wells. The oxidized water will dissolve uranium and will be pumped by submersible pumps to the surface, where the uranium will be recovered via ion exchange and processed into the final product (yellowcake). After the uranium is removed, the groundwater will be refortified with oxygen and carbon dioxide and recirculated through the well fields. The uranium mineralization targeted for production is contained within the Inyan Kara Group, specifically within the Fall River Formation and Chilson Member of the Lakota Formation.

The eastern portion of the project area is called the Burdock area. It will include a series of ISR well fields and a central processing plant (CPP), which will be used to recover uranium from the Burdock well fields using ion exchange and to process the uranium-loaded ion exchange resin. The western portion of the project area is called the Dewey area. It will include a series of ISR well fields and a satellite plant, which will be used to recover uranium from the Dewey well fields using ion exchange. The uranium-loaded ion exchange resin will be transported from the satellite facility to the CPP for processing. Processing will include stripping the uranium from the loaded resin using a saltwater solution (elution), precipitating the dissolved uranium to form an insoluble uranium oxide (precipitation), and filtering, washing, drying, and packaging the dried uranium oxide product (yellowcake) into sealed containers.

Each ISR well field will be operated until uranium recovery is no longer economical. Powertech (USA) estimates that individual well field operating lives will be about 2 years, with multiple well fields typically in operation at any given time. Aquifer restoration will be completed following uranium recovery in each well field. During aquifer restoration, the groundwater in the well field will be restored in accordance with NRC requirements. The primary goal of aquifer restoration will be to restore the groundwater to baseline (background) or a maximum containment level (MCL), whichever is higher.

The primary need for Madison water will be during aquifer restoration. The quantity of Madison water used will depend on the aquifer restoration method, which in turn will depend on the liquid waste disposal option. Smaller quantities of Madison water also will be used in uranium processing in the CPP. Madison water also may be used as the general facility water supply for restrooms and other domestic use and may be provided for domestic and livestock use to local ranchers as a temporary replacement of their wells in the vicinity of ISR operations.

2.3 Appropriation Volume

Powertech (USA) is requesting a permit to appropriate up to 888.8 ac-ft of water annually, or 551 gpm, from the Madison aquifer. This is approximately equal to 1.228 cfs. Powertech (USA) proposes to construct up to two Madison wells within the project area. Depending on well yield and water demand, one well may be used to provide the necessary Madison water for the entire Dewey-Burdock Project, in which case Powertech (USA) would construct a pipeline between the Dewey satellite facility and Burdock CPP to convey Madison water. Alternately, one well may be constructed at each of the Dewey and Burdock areas. If necessary due to low well yield, Powertech (USA) may apply for a modification to the water permit to allow the construction of additional Madison wells. Powertech (USA) does not anticipate requesting an increase in the total appropriation amount for the Dewey-Burdock Project, which is approximately 9 percent higher than the maximum estimated usage. Maximum estimated water usage and the proposed appropriation amount are shown in Table 2-1.

Table 2-1. Maximum Estimated Madison Usage and Requested Appropriation Volume

Usage	Amount
Burdock Area Madison Usage	
Aquifer Restoration, gpm	248
Central Processing Plant, gpm	12
Total Burdock	**260**
Dewey Area Madison Usage	
Aquifer Restoration	248
Total Dewey	**248**
Maximum Anticipated Madison Usage, gpm	**508**
Proposed Appropriation Amount, gpm	**551**
Proposed Appropriation Amount, ac-ft/yr	**888.8**

Aquifer restoration will begin as soon as each well field has been depleted of commercial uranium, beginning approximately 2 years after the start of uranium production. The technology selected for aquifer restoration will depend on the liquid waste disposal option. Powertech (USA) is considering two options for disposal of liquid waste at the Dewey-Burdock Project: (1) injection of treated liquid waste in non-hazardous Class V deep disposal wells (DDWs), and/or (2) land application of treated liquid waste using center pivots. In the DDW liquid waste disposal option, the primary method of aquifer restoration will be reverse osmosis (RO) treatment with permeate injection. In this method, water will be pumped from one or more well fields to the CPP or satellite facility for treatment. The RO treatment systems will operate at a recovery rate of approximately 70 percent, with the resulting permeate circulated through the well field to restore the aquifer. Madison water will be injected along with permeate to make up for the approximately 30 percent of the treatment system influent that is disposed in the DDWs as RO brine. In the land application option, RO will not be used, since the resultant brine would be too high in dissolved solids for land application. Instead, all of the water withdrawn from the well field during aquifer restoration will be treated and disposed in an appropriately permitted land application system. Madison water will be circulated through the well field to accomplish aquifer restoration.

The maximum estimated project water usage values shown in Table 2-1 represent the Madison usage in the land application option. The estimated usage is 248 gpm for each of the Dewey and Burdock area well fields plus approximately 12 gpm usage at the CPP. The total requested appropriation amount is 551 gpm (888.8 ac-ft/yr), which is approximately 9 percent higher than the maximum estimated usage in order to provide operational flexibility and provide water for domestic and livestock use if needed. If Class V DDWs are used, the Madison usage will be much less. Powertech (USA) anticipates that the maximum Madison usage will be 160 gpm if Class V DDWs are used as the sole liquid waste disposal option.

2.4 Well Locations and Points of Use

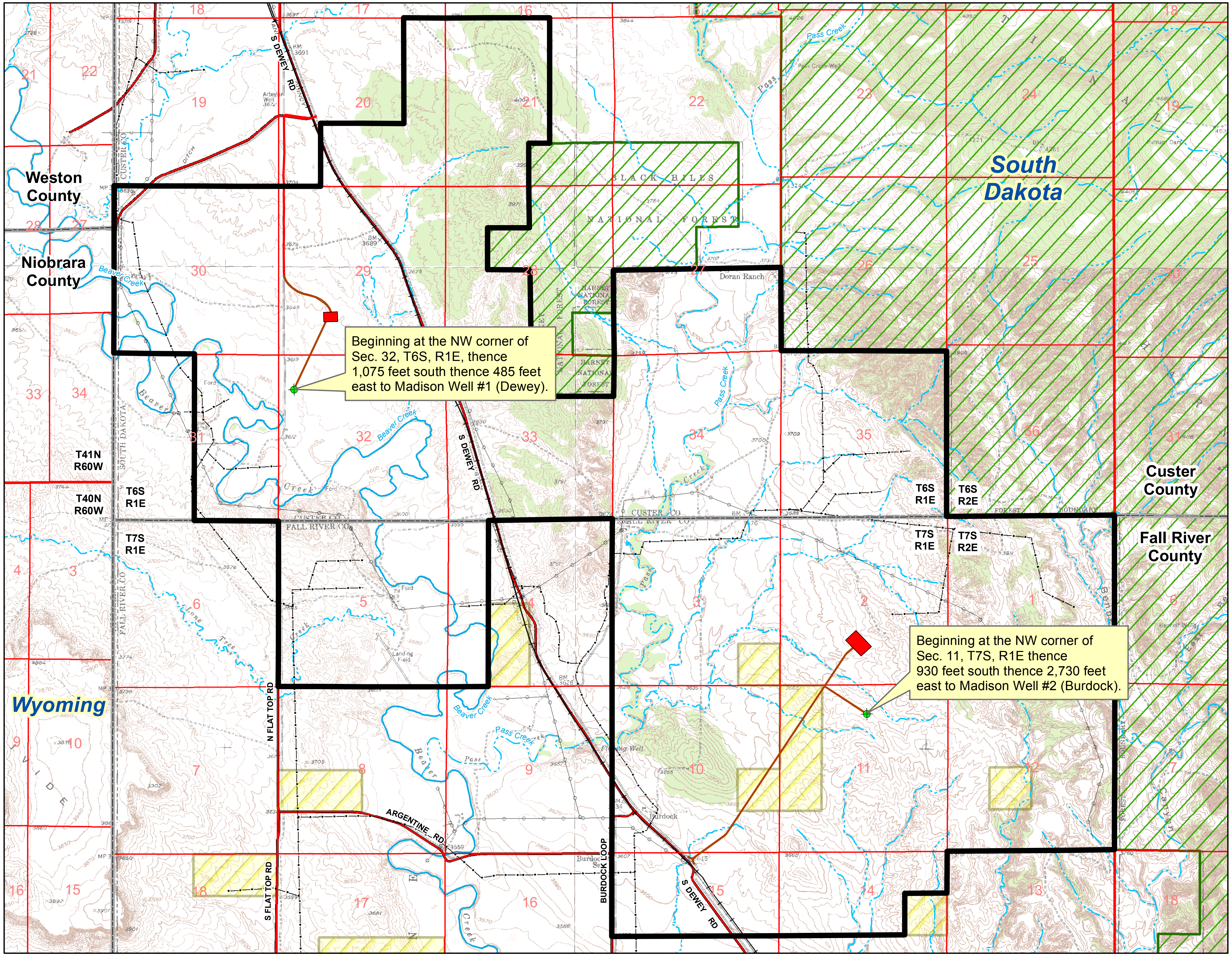
Two points of diversion (Madison wells) are proposed within the project area. One is proposed near the Dewey satellite facility and one near the Burdock CPP (see Figure 2-1). If sufficient yield is available in one well, Powertech (USA) may construct a pipeline between the satellite facility and CPP and use one well to supply the entire project area. Powertech (USA) alternately may apply for additional points of diversion if needed as described previously.

Table 2-2 and Figure 2-1 present the proposed points of diversion. One well is proposed near the Dewey satellite facility and one near the Burdock CPP. There is a possibility that Powertech (USA) will file a future request to relocate one or both wells pending more detailed well siting analysis.

Table 2-2. Points of Water Diversion

I.D.	Legal Location
Proposed Madison Well #1 (Dewey)	NW ¼ NW ¼, Sec. 32, T6S, R1E
Proposed Madison Well #2 (Burdock)	NW ¼ NE ¼, Sec. 11, T7S, R1E

Powertech (USA) proposes to include the entire area shown within the project boundary on Figure 2-1 as the designated industrial use area. Water from the Madison aquifer will be used throughout this area to restore ISR well fields and at the processing facilities to recover and process uranium into yellowcake. For water from the Madison aquifer potentially provided to local ranchers for livestock and domestic use, Powertech (USA) proposes to include the entire



Beginning at the NW corner of Sec. 32, T6S, R1E, thence 1,075 feet south thence 485 feet east to Madison Well #1 (Dewey).

Beginning at the NW corner of Sec. 11, T7S, R1E thence 930 feet south thence 2,730 feet east to Madison Well #2 (Burdock).

Legend

- Madison Well
- 🟥 Processing Plants
- BLM Land
- Black Hills National Forest
- Permit Boundary
- Ephemeral Streams
- Perennial Streams
- Existing BHEC Powerlines
- Existing Golden West Telephone Lines
- BNSF Railroad
- County Roads
- Existing Roads Used for Access
- Access Roads

This document originally issued and sealed by John M. Mays, Vice President - Engineering, South Dakota Registered Professional Engineer Reg. No. 11295, on June 8, 2012. This media should not be considered a certified document

Note:
This drawing is provided to fulfill the requirements of ARSD 74:02:01:07.

Figure 2-1

Proposed Well Locations

Dewey-Burdock Project

DRAWN BY	Mays, Hetrick
DATE	5-Jun-2012
FILENAME	MadWellLocs.mxd

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areas of Custer and Fall River counties. This will allow Powertech (USA) to provide Madison water as needed during ISR operations to landowners inside and near the project area.

2.5 Term Limitation

SDCL 46-2A-20 requires that:

> Notwithstanding §§ 46-1-14 and 46-2A-7, no water permit for construction of works to withdraw water from the Madison formation in Butte, Fall River, Custer, Lawrence, Meade and Pennington counties may be issued for a term of more than twenty years, unless the Water Management Board determines, based upon the evidence presented at a hearing that:
>
> (1) Sufficient information is available to determine whether any significant adverse hydrologic effects on the supply of water in the Madison formation would result if the proposed withdrawal were approved; and
>
> (2) The information, whether provided by the applicant or by other means, shows that there is a reasonable probability that issuance of the proposed permit would not have a significant adverse effect on nearby Madison formation wells and springs.

The proposed water right permit for the Dewey-Burdock Project constitutes a permit for the construction of works to withdraw water from the Madison in Custer and Fall River counties; therefore, SDCL 46-2A-20 is applicable. Current development plans for the Dewey-Burdock Project include a total estimated duration of uranium recovery operations of 7 to 20 years. Additional information is presented in the report accompanying the Inyan Kara water right application for the Dewey-Burdock Project. Evidence is not available to justify issuing this permit without a term limitation of 20 years. However, once the wells are drilled and tested, it may be possible for Powertech (USA) to demonstrate, through modeling or other means, that producing for a period in excess of 20 years will have no significant adverse hydrologic effects. This would be addressed through a request for permit modification or application for a new permit.

2.6 Madison Well Design

All wells drilled into the Madison aquifer by Powertech (USA) for aquifer restoration and other uses will be constructed in a similar manner and in accordance with South Dakota well construction standards (ARSD 74:02:04).

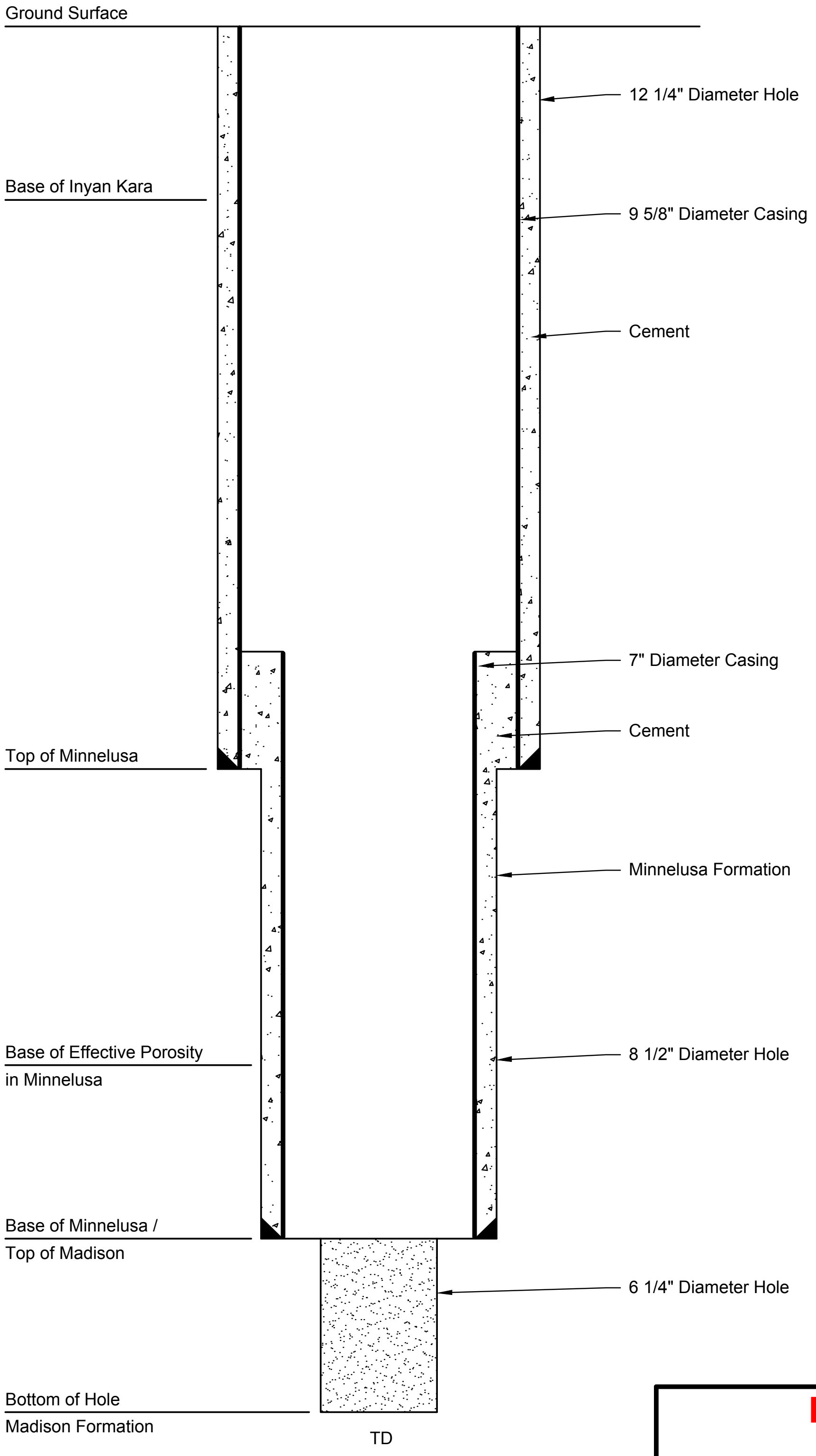
The top of the Madison Limestone where the wells will be constructed is anticipated to be 2,700 to 3,100 feet below ground surface, based on available structure contour maps produced by the USGS (see Figure 3-7). Total well depths are anticipated to range from approximately 2,700 to

3,400 feet, depending on the depth to the top of the Madison Limestone and the drilling depth into the Madison. The base of casing will be established at or just below the top of the Madison Limestone. Wells will be completed as shown in Figure 2-2. There are no water-level data for the Madison within the project area. Based on regional potentiometric surface maps (Driscoll et al., 2002; Strobel et al., 2000; Konikow, 1976), it is anticipated that the water level will be about 3,700 feet in elevation, or about 100 feet below ground surface to 100 feet above ground surface at the Madison well locations within the project area.

The well casing material will be steel with grade, wall thicknesses, and threads appropriate for the depth of the well. Well casing diameter will be selected according to the size of pump to be installed in the well. Nominal (inside) casing diameters may range between 7 inches and 9-5/8 inches (Figure 2-2). Wellbore diameters will be about 1-1/2 to 3 inches larger than the outer diameter of the casings to provide for sufficient grouting annulus. Approximate casing and associated borehole diameters are summarized in Table 2-3. Madison wells will be completed as open holes and therefore will not have screens or gravel packs.

Table 2-3. Approximate Madison Well Casing and Borehole Diameters

Casing Outside Diameter (in)	**Borehole Diameter (in)**	**Approximate Depth (ft)**
9-5/8	12-1/4	0-1,800 (top of Minnelusa)
7	8-1/2	1,800–2,900 (top of Madison)
open hole	6-1/4	2,900–3,200



Not to Scale

Figure 2-2

Madison Well
Completion Diagram

Dewey-Burdock Project

DRAWN BY	S. Hetrick
DATE	17-May-2012
FILENAME	MadisonComplete1.dwg

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3.0 HYDROGEOLOGIC SETTING

3.1 Geology

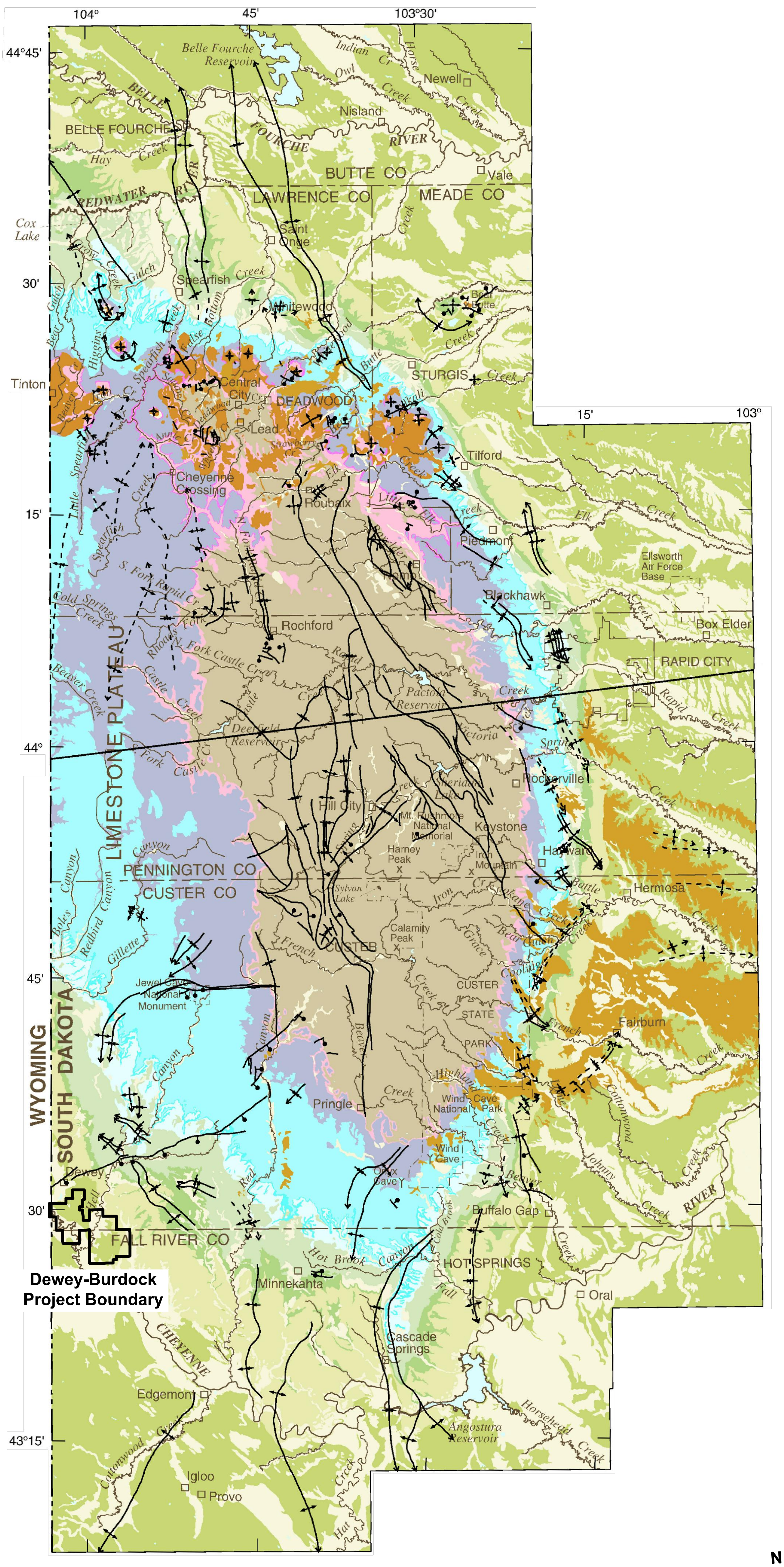
A summary of regional geology and stratigraphy of the Madison Limestone is provided in the following sections.

3.1.1 Regional Geology

The Dewey-Burdock Project is located in the Great Plains physiographic province on the southwestern flank of the Black Hills Uplift in the southwest corner of South Dakota. The Powder River Basin lies west of the project area. Figure 3-1 presents the regional geologic map of the project area. Figure 3-2 is a stratigraphic column of the Black Hills area.

Located in western South Dakota and northeastern Wyoming, the Black Hills represent the easternmost uplift associated with the Laramide Orogeny. The hills are characterized by an elongate northwest-trending dome about 125 miles long and 60 miles wide. According to Lisenbee and DeWitt (1993), uplifting began during the Paleocene about 65 to 63 million years ago and likely continued into the Eocene. After millions of years of erosion, igneous and metamorphic Precambrian rocks lie exposed in the central portions of the hills unconformably surrounded by a package of gently to moderately dipping Paleozoic and Mesozoic sediments becoming progressively younger toward the basin. Paleozoic strata were deposited on a broad, flat plain covered by warm, shallow seas. Numerous disconformities during the Paleozoic time indicate intermittent transgressions and regressions when seas advanced from west to east in response to tectonic activity. Paleozoic deposits include beach, shallow marine, carbonate, and evaporate units (Redden and Lisenbee, 1996). Early Mesozoic sediments were deposited on a flat, low-lying coastal plain and in shallow seas. These deposits are primarily mudstone, shale, and sandstone. Overlying Tertiary age deposits consist primarily of local material derived as a result of post-Laramide-uplift erosion. Recent deposits include alluvium and floodplain terrace deposits. Regional structure contour (and potentiometric) maps of major aquifers within the Black Hills have been published by the USGS as part of the Black Hills Hydrology Study (Carter et al., 2002a; Strobel et al., 2000).

Additional information about regional and local geology and stratigraphy is available in Powertech (USA)'s application to the NRC for a source and byproduct material license for the Dewey-Burdock Project (Powertech, 2009).



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

Source: Carter et al. (2003)

EXPLANATION

HYDRO-GEOLOGIC UNITS	STRATI-GRAPHIC UNITS	MAP UNITS
Unconsolidated units	QTac	Alluvium, terraces, and colluvium, undifferentiated
White River aquifer	Tw	White River Group
Tertiary intrusive units	Tui	Undifferentiated intrusive igneous rocks
Cretaceous-sequence confining unit	Kps	Pierre Shale to Skull Creek Shale, undifferentiated
Inyan Kara aquifer	Kik	Inyan Kara Group
Jurassic-sequence semiconfining unit	Ju	Morrison Formation to Gypsum Spring Formation, undifferentiated
Spearfish confining unit	TRPs	Spearfish Formation
Minnekahta aquifer	Pmk	Minnekahta Limestone
Opeche confining unit	Po	Opeche Shale
Minnelusa aquifer	PIPm	Minnelusa Formation
Madison aquifer	MDme	Madison (Pahasapa) Limestone and Englewood Formation
Ordovician-sequence semiconfining unit	Ou	Whitewood Formation and Winnipeg Formation
Deadwood aquifer	O€d	Deadwood Formation
Precambrian aquifer	p€u	Undifferentiated igneous and metamorphic rocks

FAULT—Dashed where approximated. Bar and ball on downthrown side

ANTICLINE—Showing trace of axial plane and direction of plunge. Dashed where approximated

SYNCLINE—Showing trace of axial plane and direction of plunge. Dashed where approximated

MONOCLINE—Showing trace of axial plane. Dashed where approximated

DOME—Symbol size approximately proportional to size of dome. Dome asymmetry indicated by arrow length

Miles
0 5 10 20
0 5 10 20 30
Kilometers

N

Figure 3-1

Geologic Map of
the Black Hills

Dewey-Burdock Project

DRAWN BY	Bonner, Hetrick
DATE	14-May-2012
FILENAME	BlackHillsGeoMap.dwg

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

Source: Driscoll et al. (2002)

§ Modified based on drill-hole data

Figure 3-2

Stratigraphic Column of the Black Hills Area

Dewey-Burdock Project

DRAWN BY	Mays, Hetrick
DATE	30-May-2012
FILENAME	StratColBlackHills.dwg

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3.1.2 Stratigraphy of the Minnelusa Formation

The Minnelusa Formation in the project area ranges from 800 to more than 1,000 feet in thickness (Carter et al., 2003). The upper half is composed of sandstones, limestone, dolomite, and shale with occasional anhydrite. In addition to sandstone and dolomite, the middle and lower portions contain shale and anhydrite which generally has been removed by dissolution in or near the outcrop areas (Braddock, 1963). The lower half of the formation has considerable secondary permeability where dissolution of thick bedded anhydrite and gypsum strata has resulted in extensive collapse breccia formation and large solution cavities in some areas where groundwater circulation has leached away significant quantities of soluble minerals. Based on detailed analysis of the potential occurrence of breccia pipes and karsting in the vicinity of the project area, no breccia pipes exist within the project area. The thickness of the Minnelusa formation increases from north to south and ranges from 375 feet near Belle Fourche to 1,175 feet near Edgemont (Carter and Redden, 1999). Near Rapid City, the Minnelusa is 400 to 600 feet thick and the secondary porosity is concentrated in the basal, 100-foot thick portion of the upper half (Green and Rahn, 1995). At Cascade Spring, collapse brecciation has formed within the upper half of the Minnelusa where anhydrite has been removed by solution, accounting for the majority of the secondary porosity responsible for groundwater flow (Hayes, 1999). The Minnelusa Formation is disconformably overlain by the Permian-age Opeche Shale, which is overlain by the Minnekahta Limestone (Driscoll et al., 2002).

3.1.3 Stratigraphy of the Madison Limestone

The Madison Limestone (Mississippian age), also known locally as the Pahasapa Limestone, lies conformably above the Englewood Formation (Figures 3-3 and 3-4) and unconformably below the Minnelusa Formation. The Madison Limestone consists of a sequence of marine carbonates and evaporates deposited mainly in a shallow, warm-water environment. It is a massive, medium to fine crystalline, gray to buff limestone and dolomite. Bed thickness is variable with thinner beds being slope-forming units between more massive cliffs. Its massive beds are distinct cliff formers throughout the Black Hills. In the upper, less resistant part, major caves, such as Jewel and Jasper Caves, have formed. Fossils found within the Madison Limestone include corals, brachiopods, and worm burrows.

After deposition of the Madison Limestone, a period of sea-level regression left the top of the limestone exposed to weathering and erosion for a period of approximately 50 million years. During this time period, significant erosion, karstification, and soil development occurred, resulting in the formation of numerous dissolution features “such as small cavities, collapse

Figure 3-3. Lower Madison Limestone along Grace Coolidge Creek.

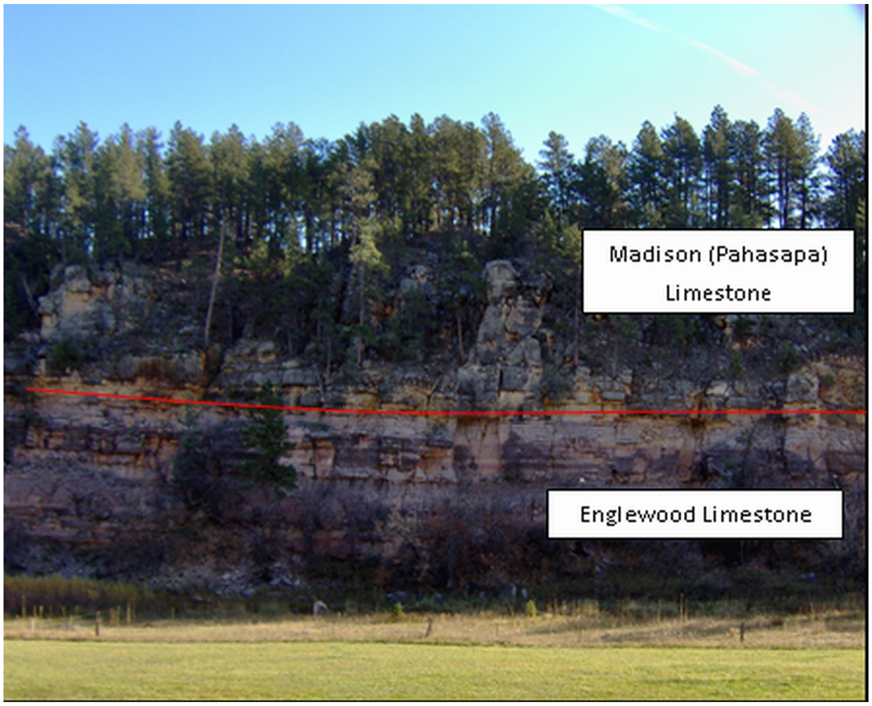

Figure 3-4. The Madison (Pahasapa) Limestone—Englewood Limestone Contact along Battle Creek.

structures, and natural bridges" within the upper part of this formation (Yancey, 1978). As part of this soil development, a terra rosa paleosol formed at the top of the Madison Limestone consisting of red claystone and siltstone with large chunks of karstic limestone.

During this period of extensive erosion, rainwater, made slightly acidic during its passage through the air, infiltrated slowly down through the limestone, following and enlarging fractures and ultimately creating solution cavities in the upper part of the Madison Limestone (Peter, 1985).

Figure 3-5 shows the major geologic structures in the southern Black Hills. This figure also shows the trace of Geologic Cross Section A-A', which is presented as Figure 3-6.

The thickness of the Madison Limestone increases from south to north in the Black Hills area, ranging from almost zero on the southeastern flank to 1,000 feet east of Belle Fourche (Driscoll et al., 2002). Within the southern Black Hills, the Madison Limestone ranges in thickness from 200 to 400 feet (Carter et al., 2003). Figure 3-7 is a regional map showing the thickness of the Madison Limestone. This figure shows that the Madison Limestone is about 400 feet thick in the vicinity of the project area.

The closest outcrop of the Madison Limestone is about 16 miles northeast of the Dewey-Burdock Project. Upgradient of the project area, the Madison dips southwesterly away from the core of the hills. At the project area, the elevation of the top of the Madison is approximately 450 to 1,050 feet (Carter and Redden, 1999), or 2,700 to 3,100 feet below ground surface (Figure 3-8).

In the Rapid City area the upper 150 feet of the Madison Limestone are composed predominantly of sandy limestone that exhibits extensive solution breccia and cave fill deposits as well as open caverns. The lower 240 feet are composed predominantly of less soluble dolomite that exhibits little or no secondary permeability (Greene and Rahn, 1995). The degree and extent of secondary porosity due to solution enlargement of fractures in the Madison Limestone in the project area are not known. In general, the upper portion of the Madison has an abundance of solution cavities, many of which are thought to have developed as paleo-karst in late Mississippian and early Pennsylvanian time when the region was elevated above sea level for approximately 50 million years before the return of the Pennsylvanian-Minnelusa Sea (Sando, 1985). The paleokarst was largely filled in, collapsed and cemented by red terrigenous shales and siltstones of the overlying Pennsylvanian Amsden and Minnelusa formations. The removal of cave fill and karst development were reactivated following uplift of the Laramide structures, and geologically young karst was superimposed on all the soluble carbonates that comprise specific layers of the Madison and Minnelusa formations by steep gradients and voluminous circulation of fresh

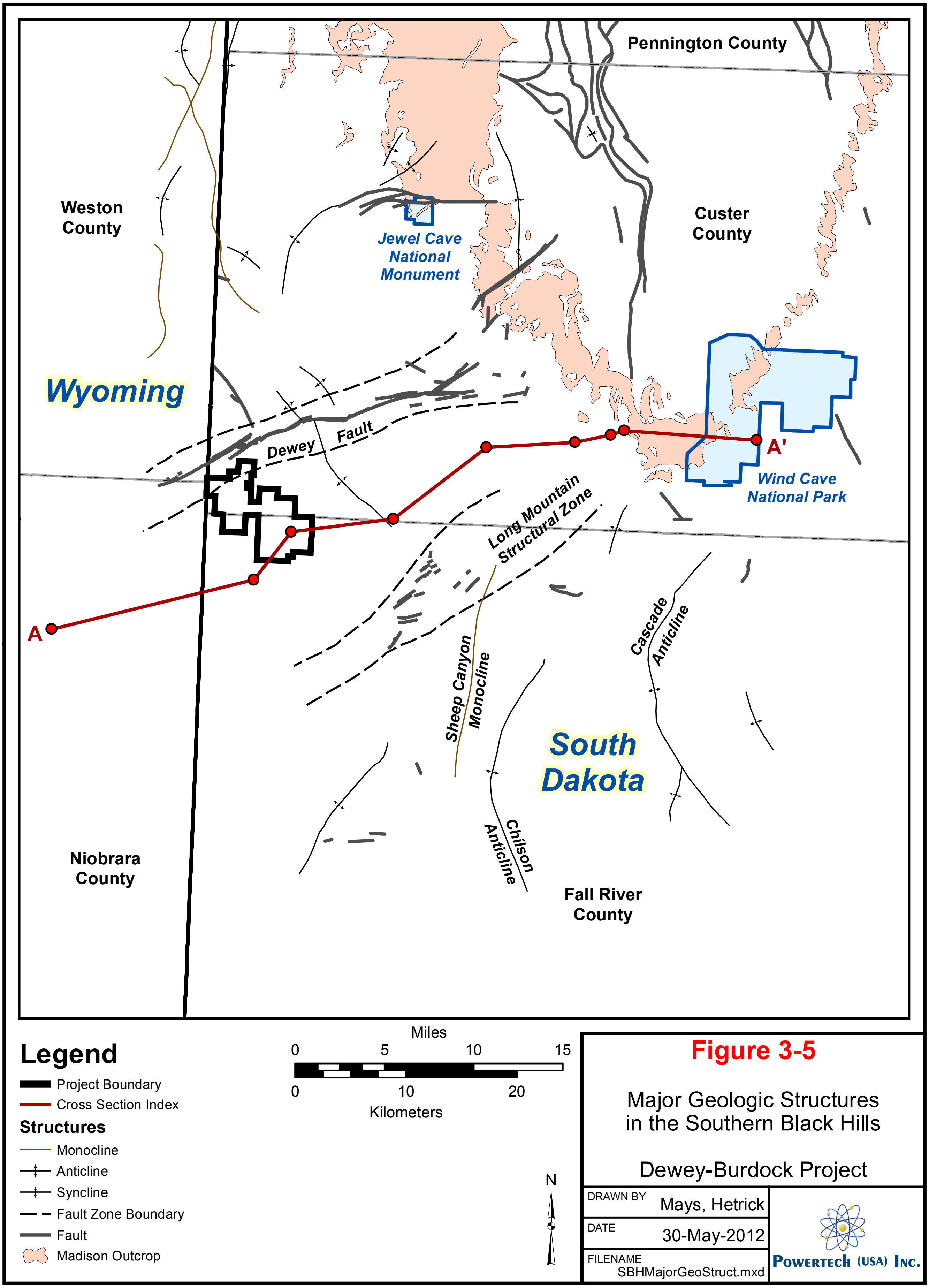

Figure 3-5

Major Geologic Structures in the Southern Black Hills

Dewey-Burdock Project

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DATE	30-May-2012
FILENAME	SBHMajorGeoStruct.mxd

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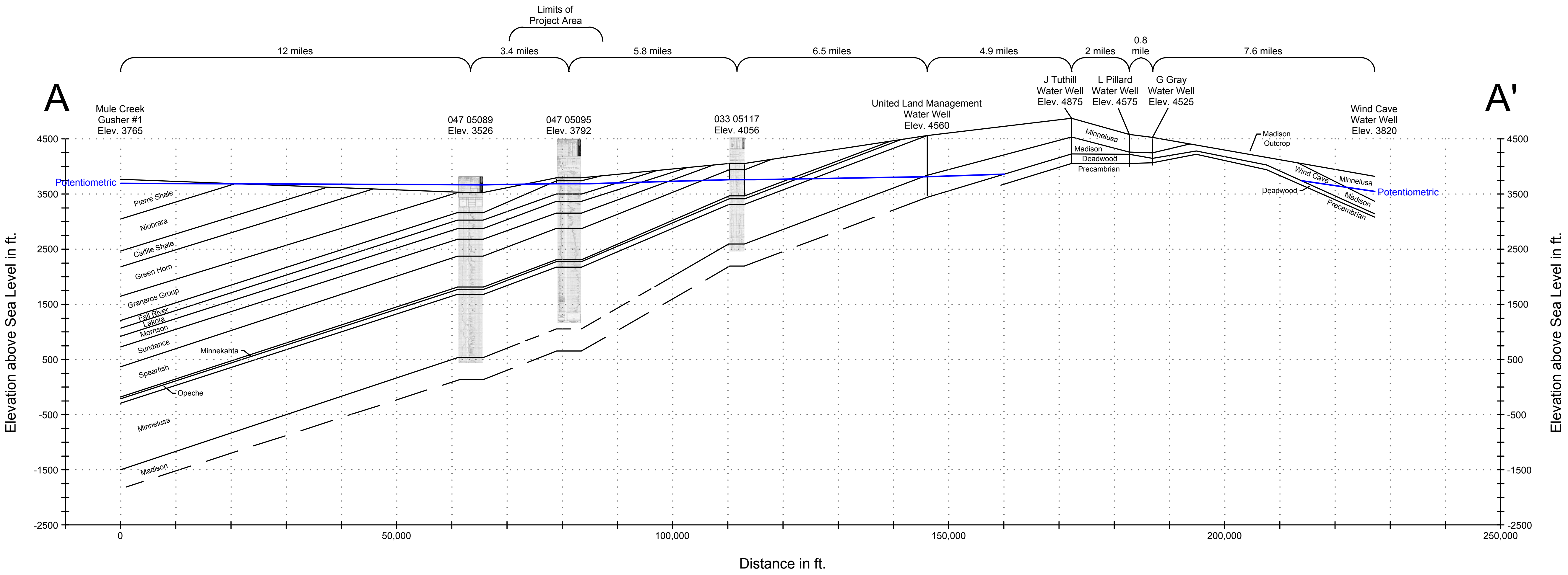
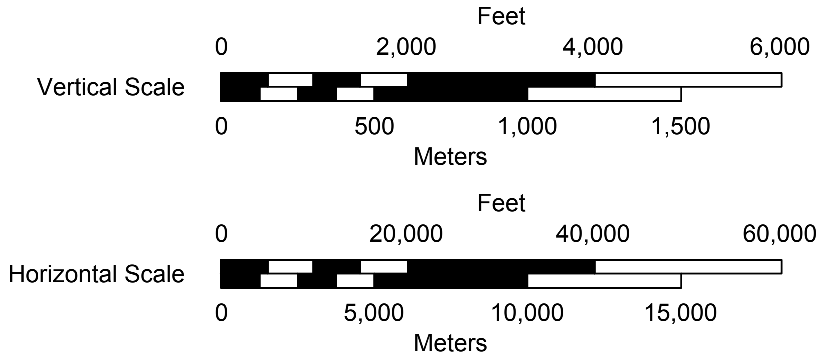


Notes:
1) Potentiometric surface from Figure 3-14 when well data not available.
2) Top of Madison from Figure 3-8 when well log not available.
3) Madison outcrop data from Figure 3-1 and USGS topographic maps.
4) Top of Deadwood from Figures 3-7 and 3-8 when well log not available.

Vertical Exaggeration: 10 : 1



Legend

047 05089
Elev. 3526 Well name or API No. with ground elevation at well

Figure 3-6

Geologic Cross Section A - A'

Dewey-Burdock Project

DRAWN BY	Lichnovsky
DATE	06-Jun-2012
FILENAME	CrossSecAA.dwg

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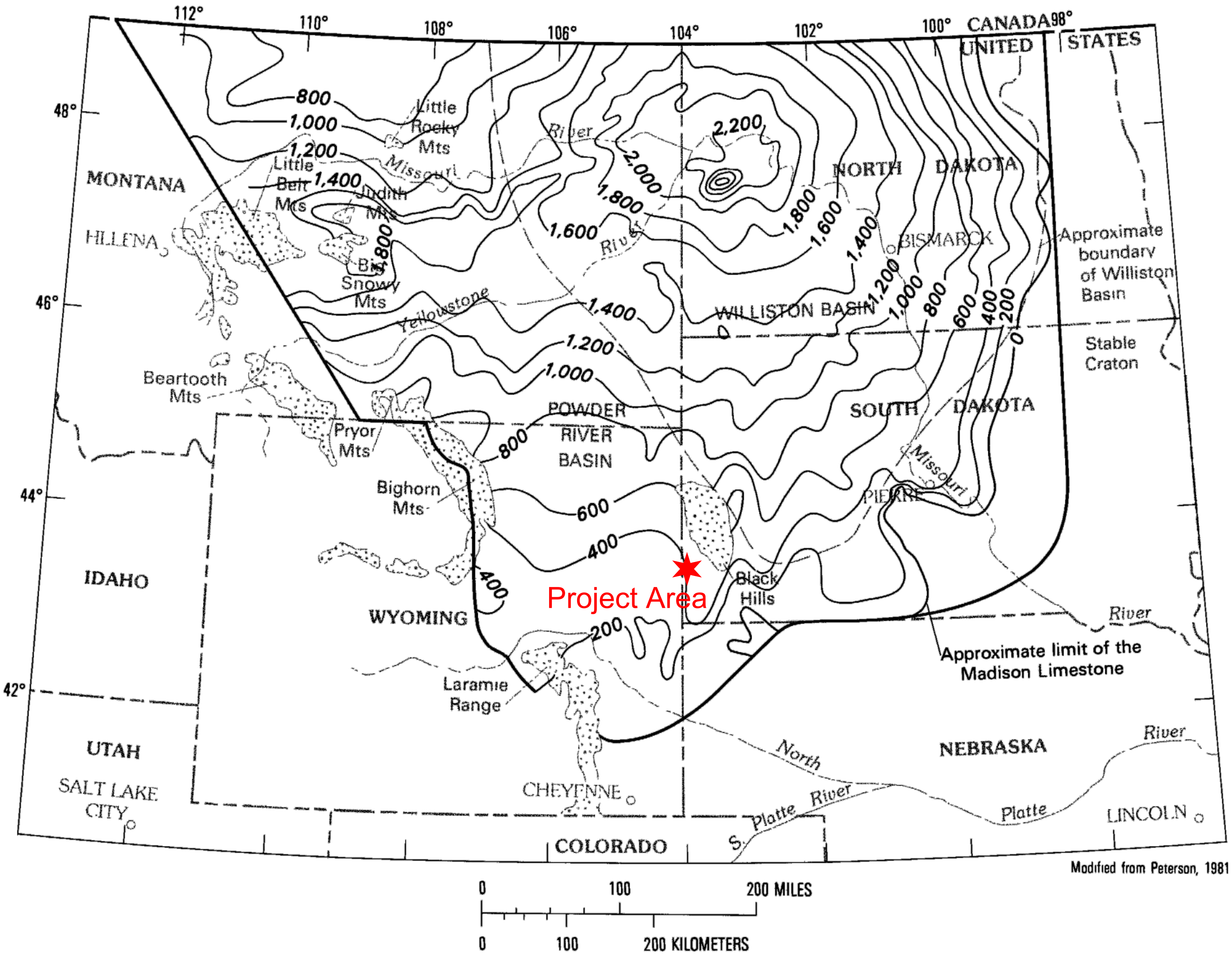

Modified from Peterson, 1981

EXPLANATION

▨ **MISSISSIPPIAN OR OLDER ROCKS**—Exposed at land surface

—600— **LINE OF EQUAL THICKNESS OF MADISON LIMESTONE**—Interval 200 feet

PROJECT-AREA BOUNDARY

Note: Project-area boundary denotes study area boundary from Busby et al. (1995) and not Dewey-Burdock Project Area

Source: Busby et al. (1995)

Figure 3-7

Isopach Map
Madison Formation

Dewey-Burdock Project

DRAWN BY	S. Hetrick
DATE	30-May-2012
FILENAME	BusbyMadIsopach.dwg

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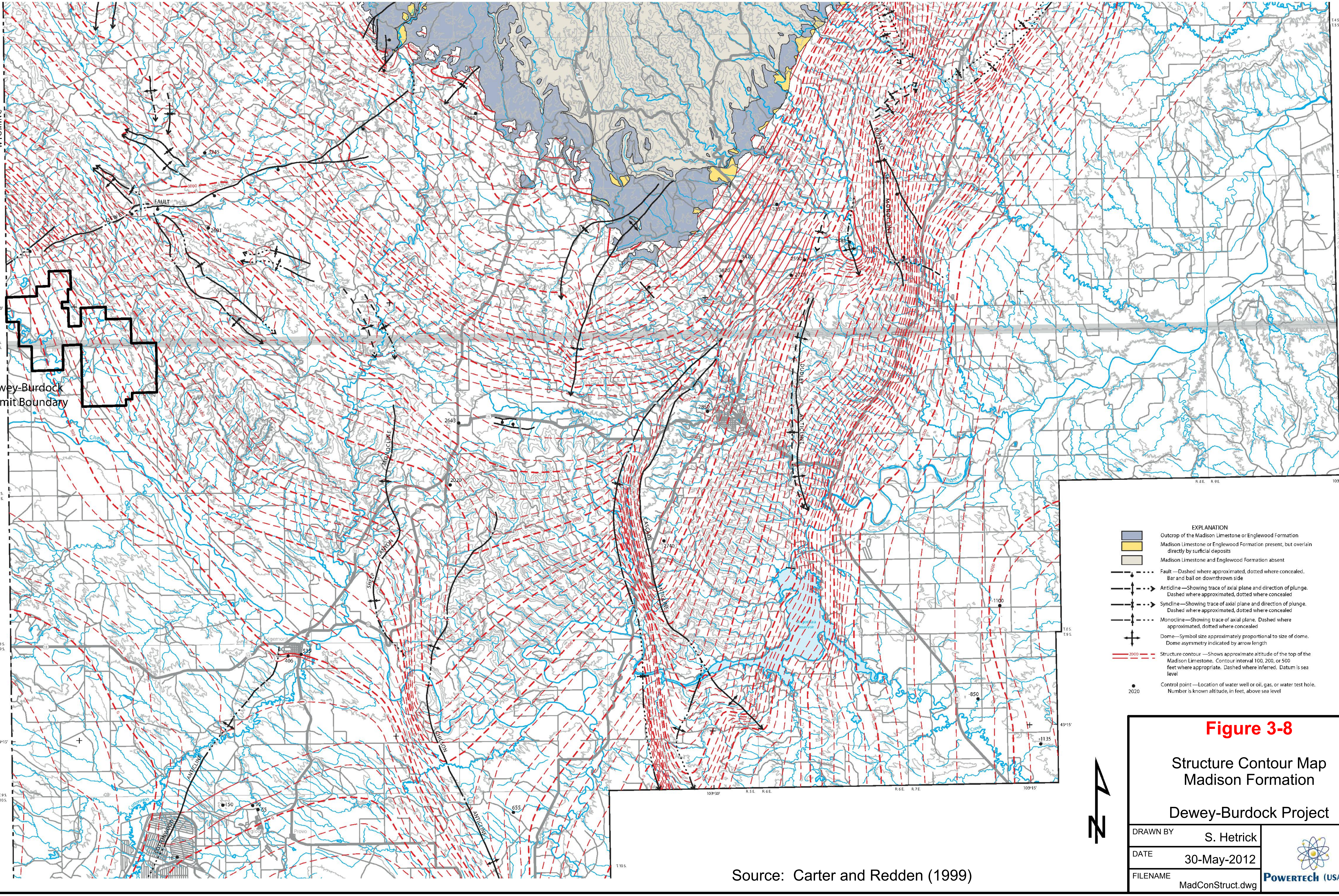

EXPLANATION

- ▨ Outcrop of the Madison Limestone or Englewood Formation
- ▨ Madison Limestone or Englewood Formation present, but overlain directly by surficial deposits
- ▨ Madison Limestone and Englewood Formation absent
- Fault —Dashed where approximated, dotted where concealed. Bar and ball on downthrown side
- Anticline —Showing trace of axial plane and direction of plunge. Dashed where approximated, dotted where concealed
- Syncline—Showing trace of axial plane and direction of plunge. Dashed where approximated, dotted where concealed
- Monocline—Showing trace of axial plane. Dashed where approximated, dotted where concealed
- Dome—Symbol size approximately proportional to size of dome. Dome asymmetry indicated by arrow length
- 2000 Structure contour —Shows approximate altitude of the top of the Madison Limestone. Contour interval 100, 200, or 500 feet where appropriate. Dashed where inferred. Datum is sea level
- ● 2020 Control point —Location of water well or oil, gas, or water test hole. Number is known altitude, in feet, above sea level

Source: Carter and Redden (1999)

Figure 3-8

Structure Contour Map
Madison Formation

Dewey-Burdock Project

DRAWN BY	S. Hetrick
DATE	30-May-2012
FILENAME	MadConStruct.dwg

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carbonated water that could remove large quantities of limestone, resulting in fracture enlargement and the formation of caves over a relatively short period of time (Huntoon, 1985).

Greene and Rahn (1995) show a strong correlation between cave passageway orientations of 15 major cave systems radiating away from the Black Hills Uplift. These are depicted on Figure 3-9. The cave orientations are strongly controlled by the dominant hydraulic gradients inferred from structural and potentiometric surface maps constructed from well data (see discussion on hydrogeology in the next section).

3.2 Hydrogeology

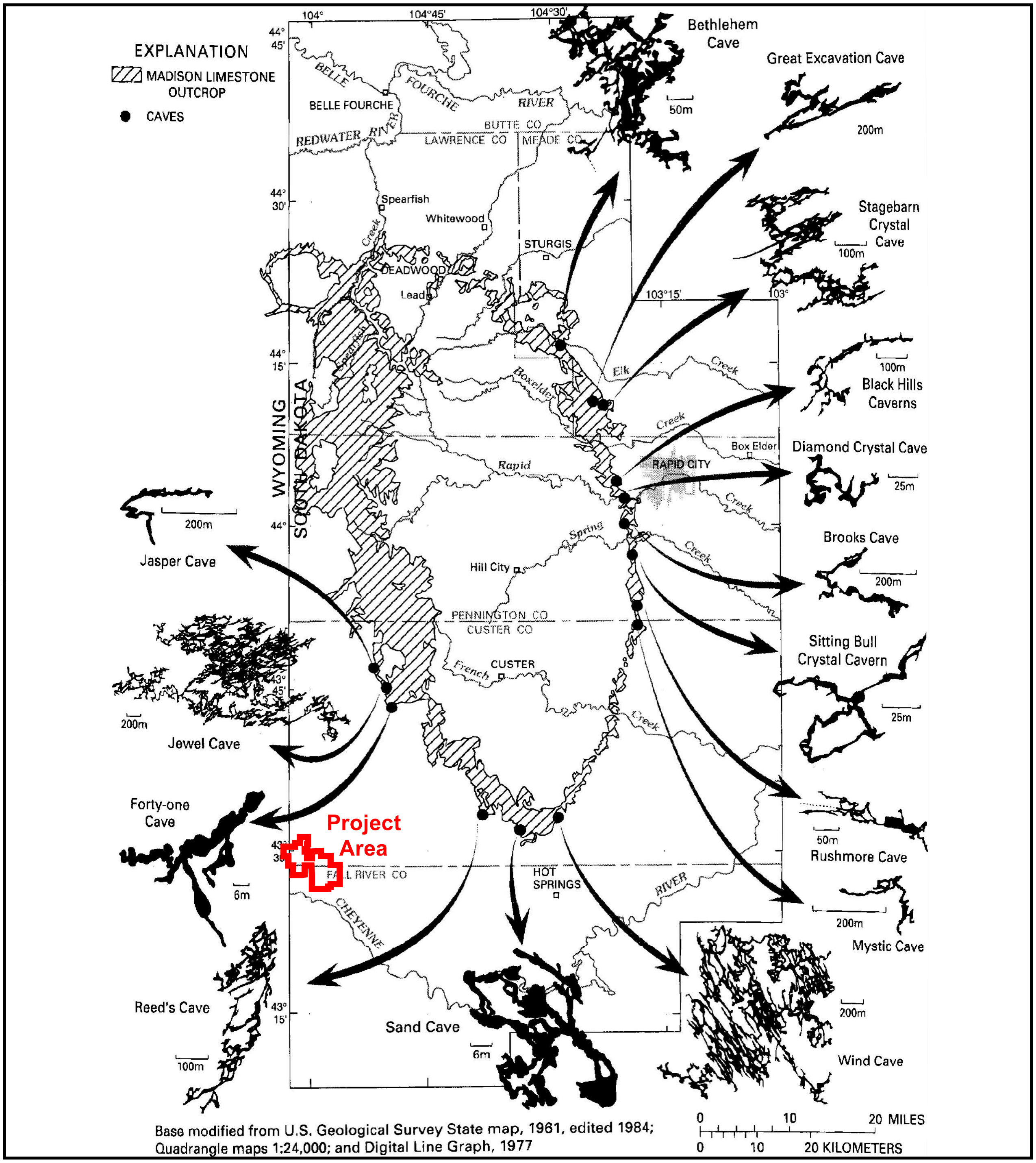
3.2.1 Regional Hydrogeology

The Black Hills Uplift is the principal recharge area for the regional bedrock aquifer systems in southwestern South Dakota and northeastern Wyoming. Regionally, four principal aquifers are utilized as major sources of water supply. These are the Inyan Kara Group, Minnelusa Formation, Madison Limestone, and Deadwood Formation. In addition to these four major aquifers, other units including the Precambrian, Minnekahta Limestone, Sundance Formation, and Unkpapa Sandstone are utilized locally as sources of water supply at or near the outcrop areas in the central portion of the Black Hills.

Figure 3-10 presents a simplified view of the hydrogeologic setting of the Black Hills. Within the project area, none of the deeper regional aquifers below the Sundance Formation is used as a water supply, mainly because of the availability of shallower sources and the poor water quality in the deeper aquifers. There are no water supply wells within 5 miles of the project area completed in the Madison Limestone. The closest municipal wells are the Edgemont Madison wells, which are approximately 15 miles to the south-southeast of the proposed Madison wells. The focus of this report is the Madison aquifer. Information on other aquifers in and near the project area can be found in Powertech (USA)'s NRC license application (Powertech, 2009), Inyan Kara water right application, and groundwater discharge permit application.

3.2.2 Groundwater Recharge

Regionally, the Madison aquifer is recharged predominantly by infiltrating precipitation and streamflow losses along outcrops. The relative contribution of each of these recharge components is variable in the Black Hills with recharge being dominated by precipitation on the western limestone plateau and streamflow along the eastern hills (Carter et al., 2001b). Comparison between stream hydrographs and a nearby Madison observation well response showed strong correlation between aquifer recharge (approximately 30 feet of head change



Base modified from U.S. Geological Survey State map, 1961, edited 1984; Quadrangle maps 1:24,000; and Digital Line Graph, 1977

Legend

🟥 Project Boundary

Source: Greene and Rahn (1995)

N

Figure 3-9

Map of the Black Hills Showing Locations of 15 Major Caves

Dewey-Burdock Project

DRAWN BY	Mays, Hetrick
DATE	30-May-2012
FILENAME	BHCaveLocs.mxd

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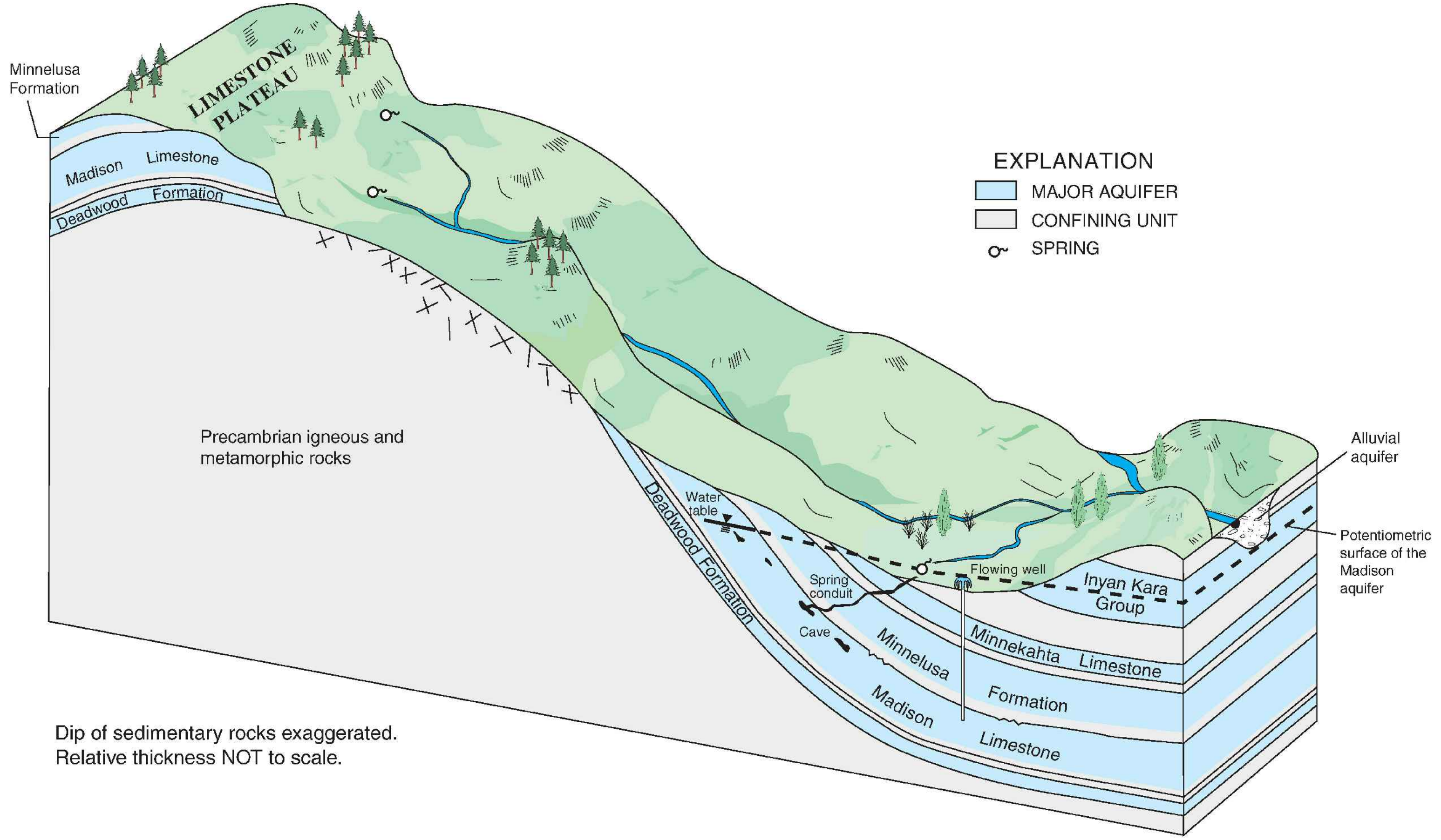

Source: Carter et al. (2003)

Figure 3-10

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

Dewey-Burdock Project

DRAWN BY	Mays, Hetrick
DATE	30-May-2012
FILENAME	Driscoll_L.dwg

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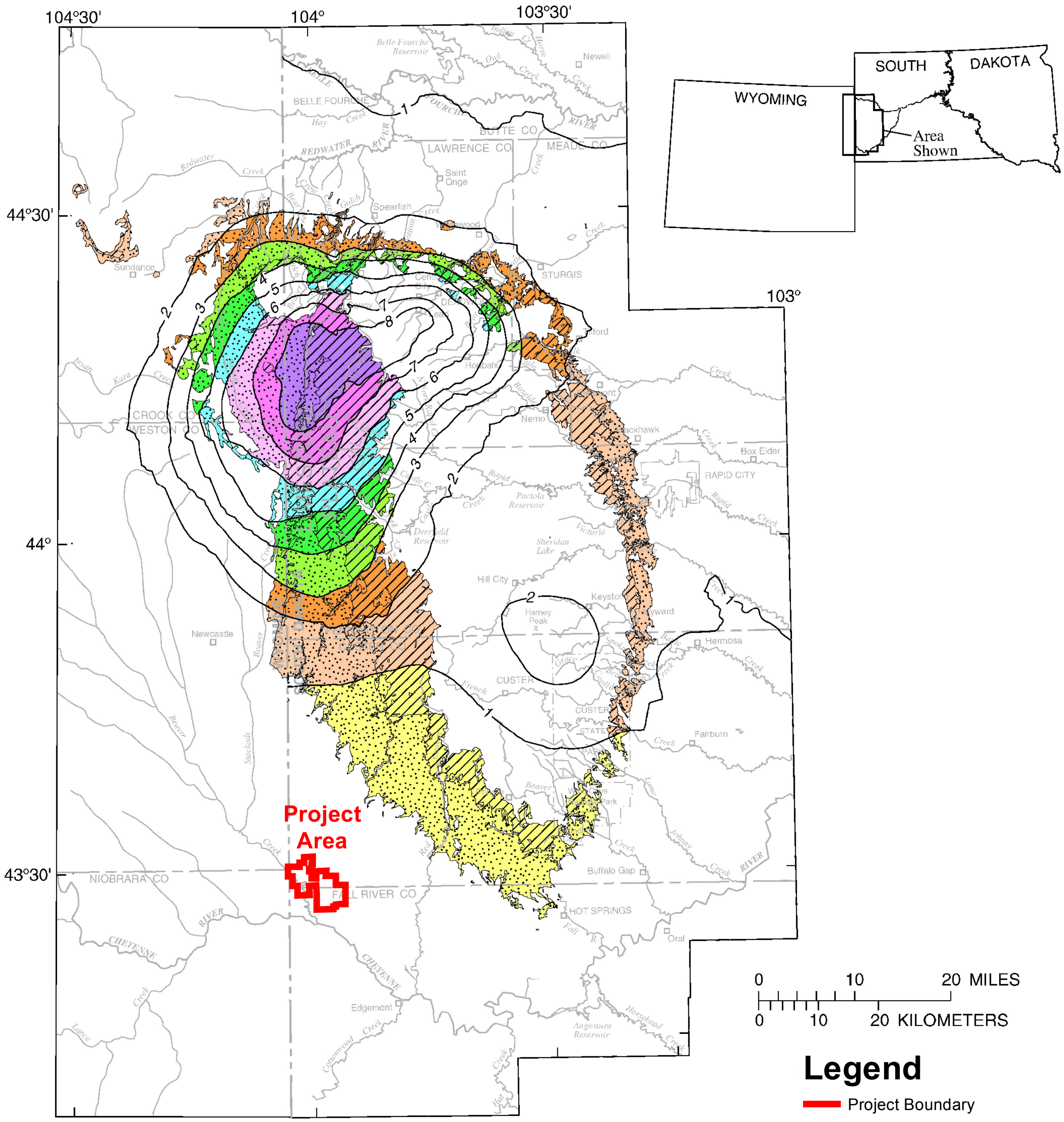
during runoff events) and streamflow in Boxelder Creek, which is on the eastern flank of the Black Hills near Rapid City (Green and Rahn, 1995).

Groundwater travels downdip through fractures or solution cavities from the recharge zones through the unconfined portion of the aquifer until it eventually becomes confined beneath a low-permeability confining layer. Because the Madison is stratigraphically below the Minnelusa, it crops out at higher elevations than the Minnelusa along the Black Hills Uplift. Therefore, vertical head gradients between the two aquifers are predominantly upward, so there is some potential for the Madison to recharge (lose water to) the Minnelusa throughout the area of confined flow. USGS water quality database information shows water quality differences that are indicative of isolation between the Minnelusa and Madison in the vicinity of the project area (Powertech, 2010). In particular, the water quality in the Minnelusa is expected to be poor, while, based on regional information (including the city of Edgemont wells), the Madison is assumed fresh in the project area. Since there is no evidence for aquifer communication between the Madison and the Minnelusa in the vicinity of the project area, this component of recharge (discharge) was ignored for the purposes of this study.

The Black Hills region has a semiarid climate. The average annual temperature is 46.7°F, with July having the warmest average temperature at 72.8°F and January the coldest at 23.0°F (Powertech, 2009). The average precipitation increases from 16 inches in the southern Black Hills, near Hot Springs, to 28 inches in the northern hills, around Lead (Carter et al., 2001a). The Madison outcrop area upgradient of the project area receives an average of approximately 18.5 inches of precipitation per year (Carter et al., 2001a).

Not all of the precipitation that falls on the outcrop will recharge the aquifer. Precipitation that does not infiltrate either runs off or remains in the soil pores to be consumed by evapotranspiration. It is estimated that an average of less than 1 inch of precipitation that falls each year recharges the Madison aquifer in the area northeast of the Dewey-Burdock Project (Figure 3-11). Refer to Section 5.2.1 for an estimate of average annual recharge to the project area from precipitation.

Streamflow losses also contribute to recharge of the Madison aquifer. As streams and creeks flow across the Madison outcrop, large amounts of water are lost through sinkholes and porous streambeds. Hortness and Driscoll (1998) quantified streamflow losses on several Black Hills creeks. Although measured streamflow loss data are not available for Hell Canyon or Red Canyon, the only major drainages that cross the Madison outcrop upgradient of the project area, within Hell and Red canyons and other smaller drainage channels surface flow is rare even after



Legend

🟥 Project Boundary

Base modified from U.S. Geological Survey digital data,
1:100,000 and City Engineer's map, Rapid City, 1991

Source: Williamson and Carter (2001)

EXPLANATION

▨ OUTCROP OF THE MADISON LIMESTONE FOR WHICH PRECIPITATION RECHARGE IS PRESCRIBED

░ OUTCROP OF THE MINNELUSA FORMATION FOR WHICH PRECIPITATION RECHARGE IS PRESCRIBED

— *2* — LINE OF EQUAL YIELD POTENTIAL--Number indicates average annual yield potential. Interval 1 inch

AVERAGE ANNUAL RECHARGE, IN INCHES

- 🟨 Less than 1
- 🟧 Between 1 and 2
- 🟧 Between 2 and 3
- 🟩 Between 3 and 4
- 🟩 Between 4 and 5
- 🟦 Between 5 and 6
- 🟪 Between 6 and 7
- 🟪 Between 7 and 8
- 🟪 Between 8 and 9

Figure 3-11

Average Annual Recharge
from Precipitation on Outcrops
of the Madison Limestone
and Minnelusa Formation
Dewey-Burdock Project

DRAWN BY Mays, Hetrick
DATE 30-May-2012
FILENAME AvgAnnRecharge.mxd

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substantial rainfall (Carter et al., 2001b), which suggests that a large percentage of streamflow is lost to groundwater recharge where these streams cross the Madison outcrop zone.

Based on a USGS study (Carter et al., 2002b), the long term (1931–98) average for combined precipitation and streamflow recharge to the Madison aquifer in the Black Hills is about 190 cfs, only a portion of which would be available within the project area. The total Madison outcrop area directly upgradient from the project area (within the model domain discussed in Section 5) is about 4.8 percent of the total outcrop area shown on Figure 3-11, while the maximum proposed Madison usage (1.228 cfs) is less than 0.7 percent of the estimated long-term average recharge to the Madison aquifer. The total withdrawal from the Madison aquifer in the Black Hills area is about 11 million gallons per day or 17 cfs (Carter et al., 2001a).

Within the study area of the USGS Black Hills Hydrology Study, the Madison aquifer has an estimated 62.7 million ac-ft of recoverable water in storage (Driscoll et al., 2002). The method used to estimate the amount of water in storage by Driscoll et al. 2002 was also used to estimate water in storage within the vicinity of the project area. Driscoll et al. estimated water in storage by multiplying the area of the aquifer times the saturated thickness of the aquifer times the effective porosity. Within the model domain discussed in Section 5.1, the total area of the saturated Madison Limestone is approximately 118,193 acres. The effective porosity is assumed to be 0.05, which is the effective porosity used by Driscoll et al. The saturated thickness of the Madison Limestone is estimated at 300 feet (assuming the bottom 100 feet of the Madison Limestone is ineffective as an aquifer). The resulting estimate of water in storage within the model domain presented in Section 5.1 is 1.8 million ac-ft.

The Dewey-Burdock Project proposes to use up to 888.8 ac-ft per year. Assuming this quantity were used for 20 years, which is a conservatively high estimate of Madison usage for the Dewey-Burdock Project, the total volume of water withdrawn would be approximately 17,800 ac-ft. This is only 1 percent of the estimated water in storage in the Madison aquifer within the model domain discussed in Section 5.1.

Within the project area there is no documented evidence of recharge to the Madison aquifer from underlying or overlying aquifers. It is assumed that the lower Minnelusa serves as a confining layer in the project area. More information will be available when the first deep wells are drilled on site (either Madison wells or Class V deep disposal wells) and pumping tests are conducted.

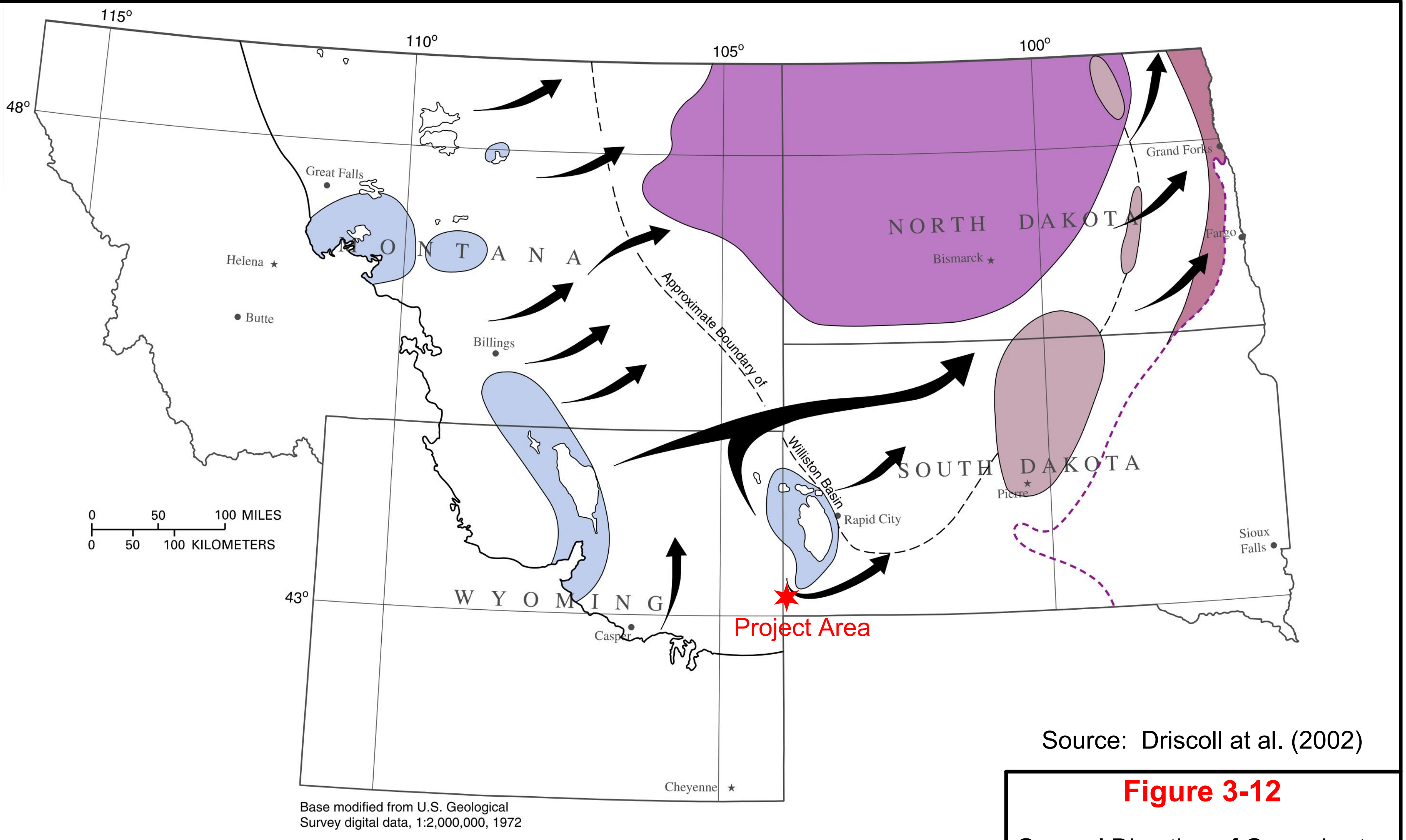
3.2.3 Groundwater Flow

Throughout the Black Hills, including the project area, the groundwater flow in the Madison aquifer is generally radially outward from the outcrop areas. Near the outcrop, the Madison aquifer is under water table conditions, but as the formation dips away from the Black Hills Uplift, the hydraulic head rises above the top of the Madison, causing confined artesian conditions (Figure 3-10). The potentiometric surface and generalized groundwater flow directions and flow zones for the Madison aquifer are shown on Figures 3-12 through 3-14. Figure 3-12 shows the regional groundwater flow direction in Paleozoic aquifers in the Northern Great Plains, and Figure 3-13 shows the Madison aquifer flow directions by zone along with estimated transmissivity. As described in Section 2.6, based on regional potentiometric surface maps, it is anticipated that the water level in the Madison is about 3,700 feet in elevation in the project area, or about 100 feet below ground surface to 100 feet above ground surface at the Madison well locations within the project area. It is possible that Madison wells in the project area could be flowing artesian.

Figure 3-12 illustrates that on a regional basis water flows away from the Black Hills and ultimately toward the northeast. In the vicinity of the project area, flow is toward the southwest from the Black Hills Uplift and turns southeast as water flows away from the outcrop and around the southern Black Hills (Figure 3-13).

Figure 3-14 shows the potentiometric surface of the Madison aquifer in the southern Black Hills as depicted by Driscoll et al. (2002), which was modified from Strobel et al. (2000). This potentiometric surface was augmented with water elevations from five DENR observation wells and three other wells. The water elevations for these wells are depicted on Figure 3-14 along with the time period during which the measurements were made. The average water elevation is shown for the DENR observation wells, for which measurements are available over multiple years, while only one or two measurements were available for the other wells. Following is a brief discussion of the additional water elevation data depicted on Figure 3-14.

The DENR Madison observation wells depicted on Figure 3-14 include Boles Canyon (CU-93C), Hells Canyon (CU-95A), Minnekahta Junction (FR-92A), Veterans Home (FR-95A), and 7-11 Ranch (CU-91A). The average water elevations at these wells do not exactly match the potentiometric surface, but they are within the depicted contour interval. For example, the nearest DENR observation well to the project area, Hells Canyon (CU-95A), had an average measured water elevation of 3,735 feet from 1995 to 2011. This falls within the general potentiometric contour interval shown on Figure 3-14 of 3,700 to 3,800 feet.



Source: Driscoll at al. (2002)

EXPLANATION

▭	RECHARGE AREA
▭	DISCHARGE AREA FOR MADISON AND MINNELUSA AQUIFERS (via adjacent aquifers)
▭	DISCHARGE AREA FOR DEADWOOD AQUIFER (via adjacent aquifers, springs, and seeps)
▭	EXTENT OF GROUND WATER WITH DISSOLVED SOLIDS CONCENTRATION GREATER THAN 100,000 MILLIGRAMS PER LITER
- - -	EASTERN LIMIT OF DEADWOOD AQUIFER--Dashed where approximately located
➜	DIRECTION OF GROUND-WATER FLOW

Figure 3-12

General Direction of Groundwater Flow in Paleozoic Aquifers in the Northern Great Plains Dewey-Burdock Project

DRAWN BY	S. Hetrick
DATE	30-May-2012
FILENAME	PaleozoicGWFlow.dwg

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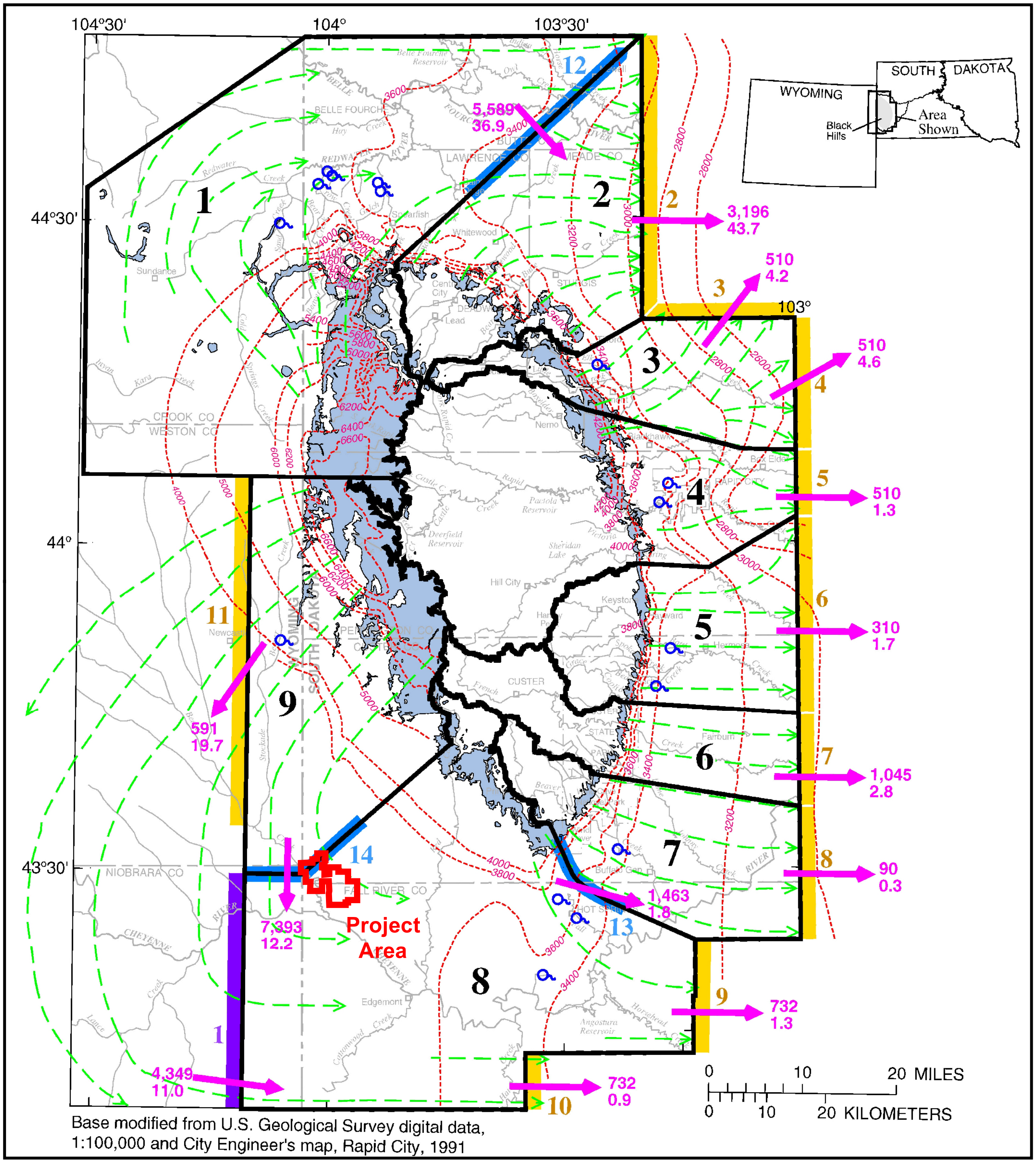

Base modified from U.S. Geological Survey digital data, 1:100,000 and City Engineer's map, Rapid City, 1991

EXPLANATION

▭	OUTCROP OF MADISON LIMESTONE AND ENGLEWOOD FORMATION (from Strobel and others, 1999; DeWitt and others, 1989)
---4000---	POTENTIOMETRIC CONTOUR--Shows altitude at which water would have stood in tightly cased, nonpumping wells (modified from Strobel and others, 2000a; Greene and Rahn, 1995). Contour interval 200 feet. Dashed where inferred. Datum is sea level
– – →	GENERAL DIRECTION OF GROUND-WATER FLOW
8	SUBAREA--Number is subarea number
1	EXTERIOR INFLOW ZONE--Area where ground water is assumed to be entering the study area. Number is zone number
10	EXTERIOR OUTLOW ZONE--Area where ground water is assumed to be exiting the study area. Number is zone number
12	INTERIOR SUBAREA FLOW ZONE--Area where ground water is assumed to be crossing subarea boundaries. Number is zone number
→ 732 1.3	DIRECTION OF FLOW ACROSS FLOW ZONE--Upper number is transmissivity estimate in feet squared per day; lower number is estimated flow in cubic feet per second
♂	LARGE ARTESIAN SPRING

Legend

—	Project Boundary

Source: Carter et al. (2001a)

N

Figure 3-13

Subareas, Generalized Groundwater Flow Direction and Flow Zones for the Madison Aquifer Dewey-Burdock Project

DRAWN BY	Mays, Hetrick
DATE	30-May-2012
FILENAME	SubGenGWFlow.mxd

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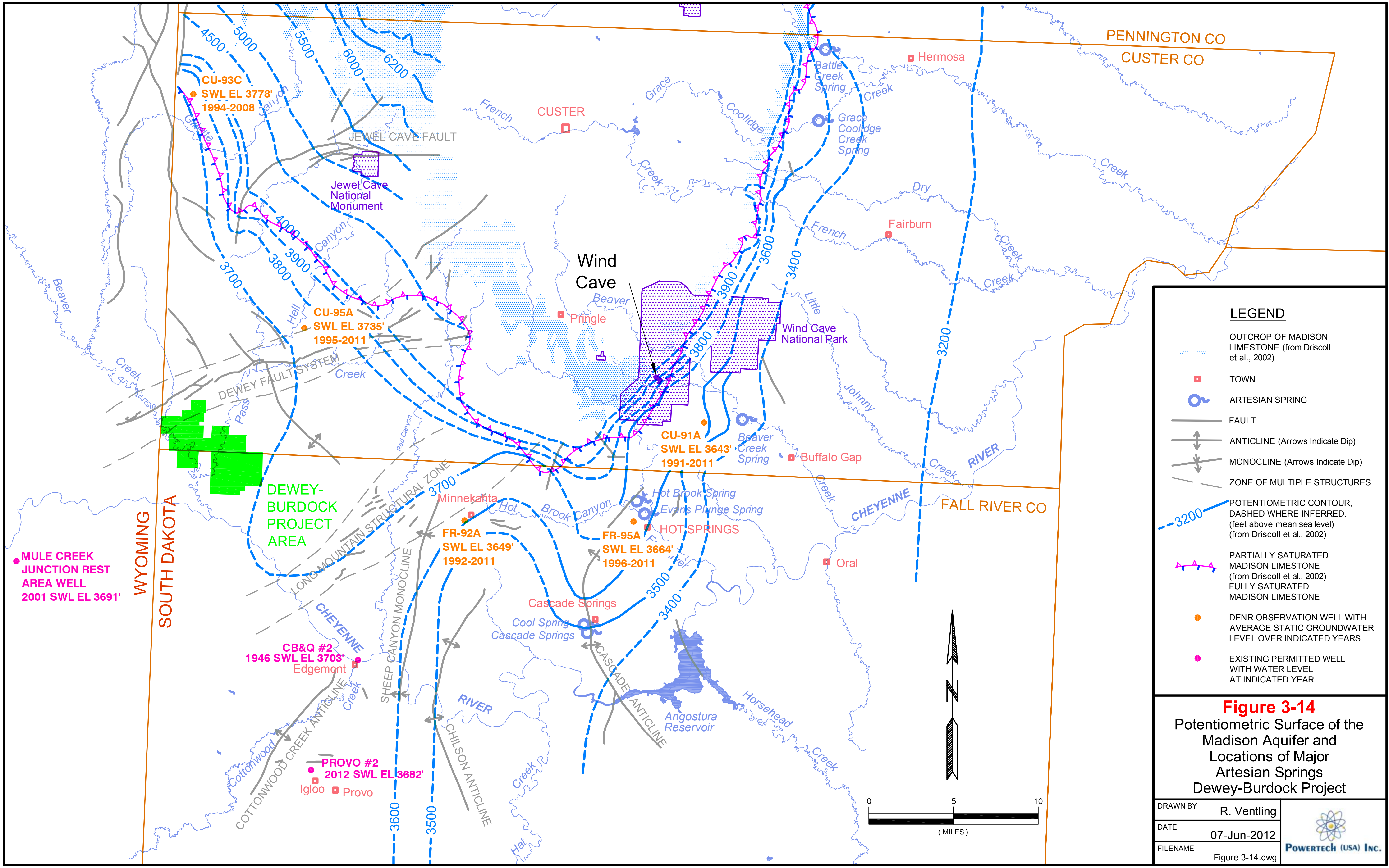


Figure 3-14
Potentiometric Surface of the Madison Aquifer and Locations of Major Artesian Springs
Dewey-Burdock Project

The three other wells included on Figure 3-14 include the CB&Q Railroad Company #2 well (DENR well completion record 7792), the Provo #2 well (DENR water right 1850-2), and the Mule Creek Junction Rest Area well (also referred to as the Mule Creek Gusher #1, Wyoming SEO water right U.W. 140768). The water elevation for the CB&Q #2 well was obtained from the well completion report, which indicates that the shut-in pressure was 110 psi in 1946. Based on the surveyed ground elevation of 3,449 feet reported on the well completion report, the estimated 1946 water elevation was approximately 3,703 feet. This is somewhat higher than the potentiometric surface for Edgemont depicted on Figure 3-14, which is between 3,600 and 3,700 feet. The difference might be attributed to withdrawals from multiple Edgemont municipal wells, which could have drawn down the potentiometric surface near Edgemont. Powertech (USA) visited the Edgemont wells in March 2012 and inquired about obtaining current shut-in pressure measurements from any of the operating or non-operating municipal wells. City of Edgemont personnel declined the request over concerns that increased pressure could damage the well casings. They indicated that they believed the shut-in pressure could be as high as 110 psi.

The water elevation indicated on Figure 3-14 for the Provo #2 well was calculated based on shut-in pressure measurements provided by the town of Provo and DENR well completion records. The reported shut-in pressure on April 12 and 22, 2012 was 12 psi, with pressure stabilization reportedly occurring within 10 minutes each time the well was shut in. These measurements agree with a shut-in pressure measurement of 11 psi observed by maintenance personnel during well refurbishment in June 2009. Powertech (USA) estimates that the pressure measuring point elevation is approximately 3,654 feet based on the well completion records. Therefore, the 2012 water elevation was calculated to be 3,682 feet. This generally falls within the 3,600 to 3,700 feet potentiometric surface contour interval shown on Figure 3-14 for Provo.

The Mule Creek Junction Rest Area well completion report indicates that the static water level was 74 feet below ground surface in 2001. It also reports that the ground surface elevation is approximately 3,765 feet. Based on this information, the water elevation was approximately 3,691 feet in 2001. Mule Creek Junction is west of the area covered by the potentiometric surface map presented in Driscoll et al. (2002); however, the 2001 water surface elevation generally agrees with Konikow (1976), which depicts a potentiometric surface contour interval of 3,600 to 3,700 feet at Mule Creek Junction.

Locally, flow patterns are also influenced by geologic structures such as faults, monoclines, anticlines, and synclines. A map of structural features in the southern Black Hills is provided in Figure 3-5. Features such as the Dewey Fault just north of the project area and several major folds in the southern Black Hills may influence the groundwater flow patterns.

The difference between the potentiometric surfaces depicted on Figures 3-13 and 3-14 can likely be attributed to scale and contour interval, since both sets of investigators likely used the same or similar source data.

3.2.4 Springs

Based on data presented by Driscoll et al. (2002) and the chemical analysis comparison of the source aquifers, the three large springs located on structures at the southern end of the Black Hills Uplift (Beaver Creek Spring, Fall River Springs and Cascade Springs) predominantly discharge water from the Madison aquifer. Some dissolved Minnelusa minerals also were noted by Driscoll et al. in the analysis of water from Beaver Creek Spring and Cascade Springs. Spring discharge varies depending on aquifer recharge. Table 4-5 in Section 4.2.2 shows that Beaver Creek Spring flow varies between 10 and 15 cfs, Fall River Spring flow varies between 20 and 30 cfs and Cascade Spring flow varies between 18 and 22 cfs. Smaller springs are even more dependent on seasonal and annual variations in precipitation and generally flow only following a rainfall or snowmelt event (e.g., City Springs, Elk Creek Spring, Battle Creek Spring, and Grace Coolidge Creek Springs).

According to Naus et al. (2001), artesian springs in the Black Hills study area are a relief mechanism that provides somewhat of an upper limit for hydraulic head in the Madison and Minnelusa aquifers. Artesian spring flow responds relatively slowly in locations where hydraulic head is substantially above the land surface, with faster response in locations where hydraulic head is near land surface.

3.3 Hydraulic Properties

Hydraulic properties of the Madison aquifer including porosity, hydraulic conductivity, and transmissivity are described in the following sections.

3.3.1 Porosity

The porosity of a soil or rock is the ratio of the volume of voids to the total volume (Freeze and Cherry, 1979). The total porosity is a combination of primary porosity and secondary porosity. Primary porosity is the void or pore space within the matrix and is usually low for limestone (Freeze and Cherry, 1979). Secondary porosity results from fractures, caves, and various dissolution features. Effective porosity, or permeability, is the volume of interconnected pore space that contributes to fluid flow. Freeze and Cherry (1979) state that the total porosity of karst limestone ranges from 5 to 50 percent. Using borehole resistivity tests, Greene (1993) found the average total porosity of the Madison to be 35 percent around the Rapid City area. In the Williston Basin, the average total porosity of the Madison Limestone is 11 percent with an effective porosity of 5 percent (Rahn, 1985). Data from Peterson (1978) indicate the total porosity in the Powder River Basin is about 5 to 15 percent. Based on available information, estimates of porosity of the Madison aquifer beneath the project area are likely similar to that reported by Rahn (1985) and Peterson (1978) with total porosity ranging from 5 to 15 percent and effective porosity around 5 percent.

3.3.2 Hydraulic Conductivity and Transmissivity

The measure of the ability of fluids to move through the aquifer is known as permeability. The more commonly used term is hydraulic conductivity (*K*), which is defined by Lohman (1972) as the volume of water at the existing kinematic viscosity that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow. Well tests in the Rapid City area found hydraulic conductivity values for the Madison aquifer between 5 and 1,300 feet per day (Tan, 1994). Vertical conductivity in the overlying confining beds of the lower Minnelusa Formation was found to be between 5.3×10^{-3} and 2.7 feet per day (Long and Putnam, 2002). Hydraulic conductivity values throughout the Black Hills Region are shown in Table 3-1.

Transmissivity of an aquifer is defined as the rate at which groundwater at the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient (Lohman, 1972). Transmissivity values throughout the Black Hills region are shown in Table 3-1. Greene (1993) conducted pumping tests on Rapid City wells and calculated transmissivity values between 1,300 and 56,000 ft^2/day. Similar values and wide ranges have been observed throughout the Black Hills region. Values of hydraulic conductivity and transmissivity calculated for the Madison aquifer based on pumping tests should only be taken as estimates, however, because of the heterogeneous nature of the aquifer material and variations in fracture intensity (and hence, secondary porosity). Based on hydrologic budgets for the Madison aquifer in the Black Hills, the USGS estimated transmissivity near the project area to be 7,393 ft^2/day (Figure 3-13).

3.3.3 Storage Coefficient

The volume of water an aquifer takes into or releases from storage per unit area per unit change in hydraulic head is the storage coefficient, *S* (Lohman, 1972). Storage coefficient is a dimensionless property that ranges from zero to the effective porosity of the aquifer. Based on aquifer tests in the Black Hills area, the confined storage coefficient for the Madison varies between 1×10^{-4} and 2×10^{-3} (Long and Putnam, 2002).

Table 3-1. Estimates of the Hydraulic Conductivity, Transmissivity, Storage Coefficient, and Porosity for the Madison Aquifer from Previous Investigations

Source	**Hydraulic Conductivity (ft/d)**	**Transmissivity (ft^2/d)**	**Storage Coefficient**	**Total Porosity/ Effective Porosity**	**Area Represented**
Konikow (1976)	–	860–2,200	–	–	Montana, North Dakota, South Dakota, Wyoming
Miller (1976)	–	0.01–5,400	–	–	Southeastern Montana
Blankennagel et al. (1977)	2.4×10^{-5}–1.9	–	–	–	Crook County, Wyoming
Woodward-Clyde Consultants (1981)	–	3,000	2×10^{-4}–3×10^{-4}	–	Eastern Wyoming, western South Dakota
Blankennagel et al. (1981)	–	5,090	2×10^{-5}	–	Yellowstone County, Montana
Downey (1984)	–	250–3,500	–	–	Montana, North Dakota, South Dakota, Wyoming
Plummer et al. (1990)	–	–	1.12×10^{-6}–3×10^{-5}	–	Montana, South Dakota, Wyoming
Rahn (1985)	–	–	–	0.10/0.05	Western South Dakota
Cooley et al. (1986)	1.04	–	–	–	Montana, North Dakota, South Dakota, Wyoming, Nebraska
Kyllonen and Peter (1987)	–	4.3–8,600	–	–	Northern Black Hills
Imam (1991)	9.0×10^{-6}	–	–	–	Black Hills area
Greene (1993)	–	1,300–56,000	0.002	0.35/–	Rapid City area
Tan (1994)	5–1,300	–	–	0.05	Rapid City area
Greene et al. (1999)	–	2,900–41,700	3×10^{-4}–1×10^{-3}	–	Spearfish area
Carter et al. (2001a)	–	100–7,400	–	–	Black Hills area
Long and Putnam (2002)	–	500-20,000	$3x10^{-4}$	–	Rapid City area

Modified from Driscoll et al., 2002

3.3.4 Well Yields

Of all the aquifers in the Black Hills, the Madison aquifer has the highest mean and median well yield (Driscoll et al., 2002). Yields range from 2 to 4,000 gpm, with the median and mean yields being 20 and 200 gpm, respectively (Driscoll et al., 2002). A well recently drilled into the Madison aquifer about 10 miles north of the project area yielded 75 gpm (see Appendix B). Flows from Madison wells in Edgemont have exceeded 500 gpm. Based on similarities in location, it is reasonable to expect that well yields in the project area may be similar to those at Edgemont. As described in Section 2.3, one well may have sufficient yield to serve the entire project.

3.3.5 Aquifer Anisotropy

Occurrence and movement of groundwater in a karst aquifer such as the Madison aquifer is primarily through enlarged fractures and dissolution channels. The regional groundwater flow pattern is reflected in the potentiometric surface and geologic structure and is controlled by the spatial distribution of hydraulic conductivity. The standard principals of groundwater flow in a porous-media aquifer must be applied with caution to carbonate karst systems. Understanding the movement and occurrence of groundwater in a carbonate system requires careful evaluation of the processes that formed the karst features. It is these features together with localized structural deformation that impart anisotropy and heterogeneity to the flow system (Greene and Rahn, 1995).

The Madison Limestone forms a very large and extensive aquifer surrounding the Black Hills. Much of the regional permeability is associated with karstification at the end of the Mississippian Age (Back et al., 1983). However, during the post-Laramide time, as the Black Hills were uplifted, karstification was renewed and increased permeability was superimposed on the Mississippian paleokarst. In the outcrop area, modern cave development enhanced the Mississippian karst development and produced a very permeable aquifer, especially in the recharge areas (Greene and Rahn, 1995). The Madison aquifer is neither homogeneous nor isotropic. Local anisotropies in the aquifer are due to jointing, solution-enlarged openings, and a regional change in thickness of the aquifer characterized by general thickening northward. Figure 3-9 shows the mapped passageways of the 15 major cavern networks surrounding the Black Hills and reveals that the cave passageways are oriented roughly perpendicular to the potentiometric contours shown on Figure 3-14 (i.e., parallel to groundwater flow direction).

Table 3-1 summarizes available hydraulic parameters for the Madison aquifer collected at various locations within the region. Greene (1993) analyzed aquifer testing results of water supply wells completed in the Madison aquifer near Rapid City. Based on electric log and caliper log signatures available from the open hole portions, Greene concluded that most of the porosity of the Madison aquifer at one of the wells (RC-6) was predominantly limited to open fractures and solution features occurring in the upper 100 to 200 feet of the 450-foot thick Madison Limestone sequence. During one of the tests, drawdown in 14 observation wells was measured. The data indicated that the transmissivity in the direction of the major axis may be 2 to 10 times larger than the transmissivity in the direction of the minor axis. Long and Putnam (2002) developed a flow model to simulate karstic Madison aquifer conditions near Rapid City. In their model they estimated that anisotropy ratios ranged from 5:1 to 20:1.

The anisotropy of the Madison aquifer described above is believed to exist within the aquifer immediately updip of the project area. As a result, aside from any effects of barriers or boundaries, drawdown from the proposed Madison wells would preferentially propagate primarily downdip or updip from the project area (i.e., southwest – northeast).

3.4 Water Quality

Water quality of the Madison will be a critical factor in its suitability for facility use and aquifer restoration at the Dewey-Burdock Project. As there are no Madison wells in the project area, this section includes a summary of water quality characteristics for the Madison aquifer in the Black Hills region. Appendix A contains water quality results from samples from four wells used as municipal water by the city of Edgemont, and Appendix B contains the well log and water quality results of a recently drilled Madison well north of the project area, herein referred to as the Lamb Madison well.

3.4.1 Physical Properties

Physical water quality properties in the Madison aquifer within the Black Hills area include specific conductance, pH, temperature, hardness, noncarbonate hardness, and alkalinity (Table 3-2). Water temperature generally increases with increasing well depth because of the geothermal gradient. Water temperature in the project area is anticipated to be between 20 and 40°C (Carter et al., 2003).

The mean specific conductance in the Black Hills area is 632 µS/cm (Williamson and Carter, 2001). By comparison, the mean specific conductance measured in Edgemont wells (Appendix A) is 1,731 µS/cm, and the specific conductance measured at the Lamb Madison well is 446 µS/cm (Appendix B). The highest specific conductance values are generally found

Table 3-2. Summary of Physical Properties of Madison Aquifer Water Samples

Property/Dissolved Constituent	Number of Samples	Mean	Median	Minimum	Maximum
Specific conductance (µS/cm)	110	632	460	290	3,360
pH (standard units)	126	7.4	7.6	6.1	8.5
Temperature (°C)	74	19	15	7.0	63
Hardness (mg/L as $CaCO_3$)	127	284	250	22	1,600
Noncarbonate hardness (mg/L as $CaCO_3$)	18	114	95	0	460
Alkalinity (mg/L as $CaCO_3$)	82	203	181	136	363

Source: Williamson and Carter, 2001

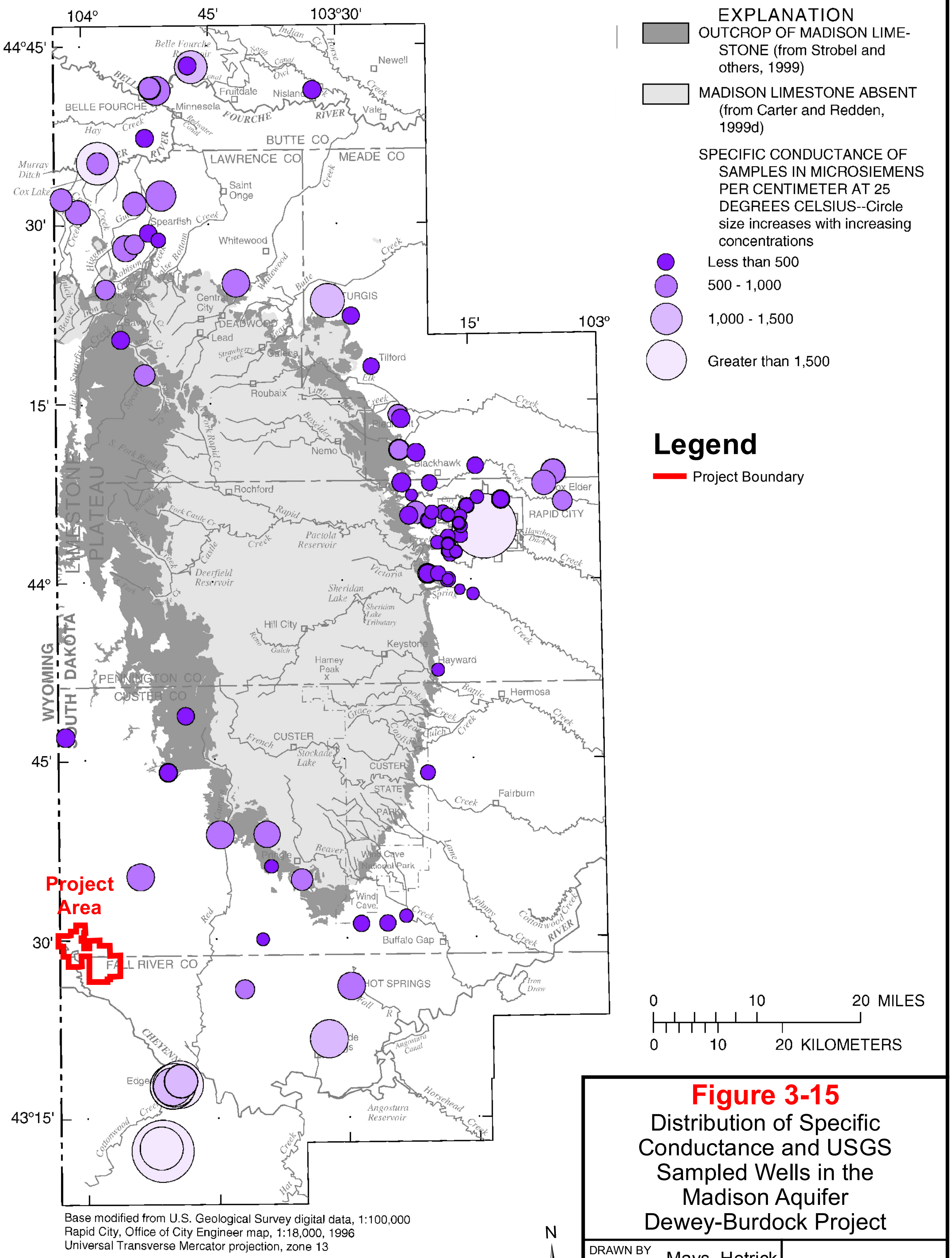
farthest from outcrop. Figure 3-15 shows the distribution of specific conductance in the Madison aquifer and the general distribution of sampled wells. (For a full list of groundwater sampling sites in the Black Hills area, refer to Table 15 in Williamson and Carter, 2001.)

3.4.2 Common Ions

Summary statistics for common ions in Madison aquifer water samples are displayed in Table 3-3. Trilinear diagrams illustrate spatial variations and major ion chemistry trends by showing percentages of major ions. The trilinear diagram shown in Figure 3-16 illustrates that calcium-magnesium-bicarbonate and calcium-sodium-sulfate are the dominate water types. Sulfate concentrations are generally low (<250 mg/L) and are dependent on the amount of anhydrite in the formation (Naus et al., 2001).

As shown on Figure 3-16, the aquifer's dominant common ions include calcium, magnesium, and bicarbonate. These ions occur because of the dissolution of dolomite. In the southwestern Black Hills, the Madison aquifer has higher concentrations of chloride, sulfate, and sodium. Calcium, sodium, potassium, sulfate, chloride, and silica concentrations in the Madison aquifer tend to increase with increasing well depth (Williamson and Carter, 2001).

North of the project area, the Lamb Madison well was sampled for nitrate, sulfate, and sodium (Appendix B). Concentrations were compared to the Edgemont wells. The Lamb Madison well nitrate value was 0.4 mg/L in comparison to a mean value of 0.1 mg/L at the Edgemont wells Sulfate was not detected (i.e., less than the laboratory reporting limit) at the Lamb Madison well,



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

Source: Williamson and Carter (2001)

Figure 3-15
Distribution of Specific Conductance and USGS Sampled Wells in the Madison Aquifer
Dewey-Burdock Project

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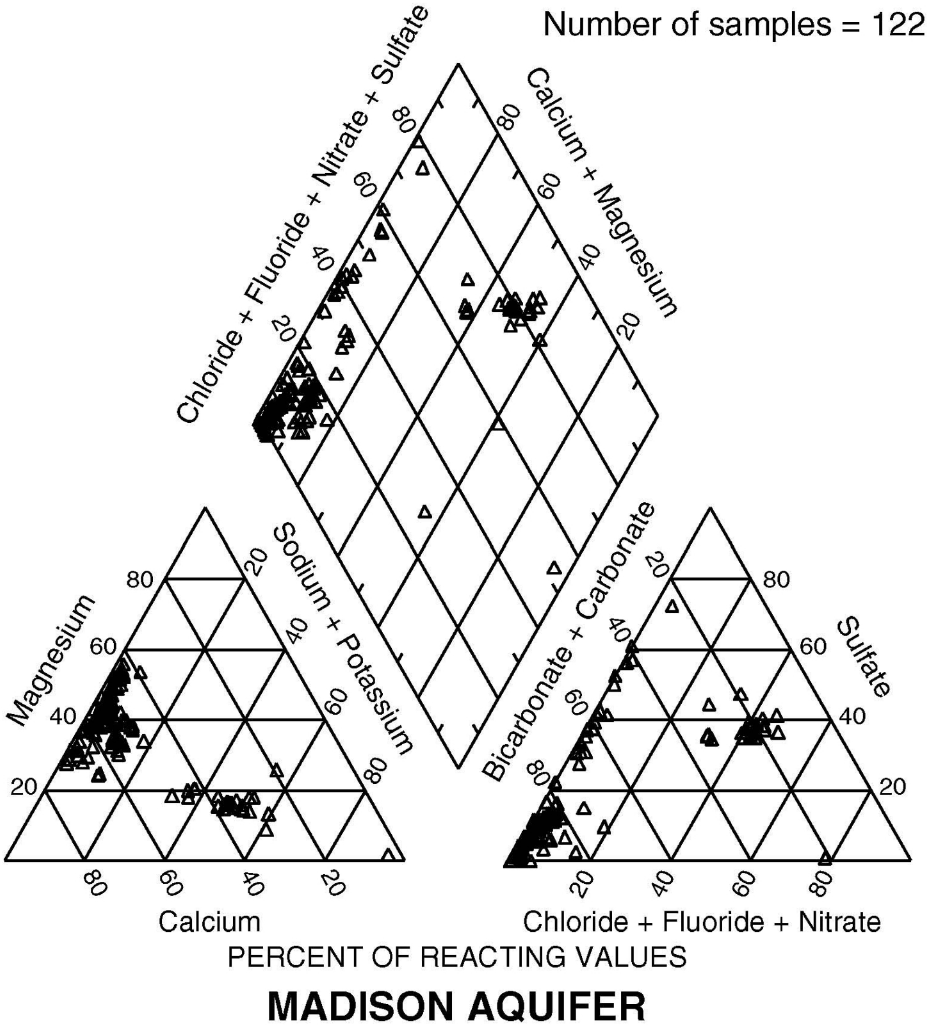
Table 3-3. Summary of Concentrations of Common Ions in the Madison Aquifer

Dissolved Constituent	Number of Samples	Number of Censored Samples[(a)]	Mean	Median	Minimum	Maximum
Solids, residue at 180°C (mg/L)	80	0	490	260	162	2,300
Solids, sum of constituents (mg/L)	99	0	428	260	161	1,820
Calcium (mg/L)	127	0	70	54	5.6	430
Magnesium (mg/L)	127	0	26	25	2.0	120
Sodium (mg/L)	122	0	39	5.4	0.8	260
Sodium (%)	103	0	14	6.0	1.0	57
Sodium adsorption ratio	41	0	1.0	0.2	0	18
Potassium (mg/L)	24	0	6.0	2.8	0.7	55
Bicarbonate (mg/L)	41	0	250	222	166	454
Carbonate (mg/L)	24	0	0.3	0	0	6
Sulfate (mg/L)	127	10	96	23	<1.0	453
Chloride (mg/L)	124	15	55	3.5	0.2	1,000
Fluoride (mg/L)	89	0	0.7	0.4	0.1	18
Bromide (mg/L)	4	0	0.18	0.10	0.1	0.4
Iodide (mg/L)	2	0	0.03	0.03	0.01	0.04
Silica (mg/L)	62	0	11	11	3.4	34

(a) For some constituents, multiple lab reporting limits were used, resulting in censored values at various levels. If the majority of detectable levels were less than some censored values, the censored values were removed because they do not provide additional information for describing the data set.

Source: Williamson and Carter, 2001



From Williamson and Carter, 2001

Figure 3-16. Trilinear Diagram Showing Proportional Concentrations of Common Ions in the Madison Aquifer while the mean value at Edgemont was 301 mg/L. The sodium concentration was also much lower at the Lamb Madison well (0.4 mg/L compared to 157 mg/L mean at Edgemont). This limited dataset indicates that there is a wide variation in water quality in the southwestern Black Hills; it is expected that the water quality in the Madison at the project area will lie somewhere between these two examples.

3.4.3 Major Reactive Minerals

Calcite ($CaCO_3$), dolomite ($CaMg(CO_3)_2$), and anhydrite ($CaSO_4$) are the major reactive minerals in the Madison aquifer. These chemical compounds interact with water and dissolved gasses, helping define the groundwater chemical composition within the aquifer. As meteoric water infiltrates the aquifer, these minerals react with the low-pH water and dissolve, reducing the pH and increasing the concentrations of these ions. With distance from the outcrop, the water in the aquifer can become saturated with respect to calcium, magnesium, and carbonate. Here, precipitation of calcite can take place because of the existence of calcite and anhydrite in each aquifer (common ion effect) and dedolomitization. According to the USGS, dedolomitization occurs when waters saturated with calcite and dolomite drive additional dolomite dissolution along with calcite precipitation (Naus et al., 2001).

3.4.4 Radionuclides

The amount of naturally occurring radionuclides in the Madison aquifer is generally low. Gross alpha and radium-226 concentrations increase with increasing well depth, while all other radionuclides vary geographically. Gross beta as cesium-137 and as strontium/yttrium-90 are most prevalent in the southern Black Hills, while thorium is the highest in the eastern and southern Black Hills. Tritium is most common in the eastern and northern Black Hills. Only 1 of the 45 uranium samples (located in the southern Black Hills) exceeded the MCL of 30 µg/L; only 1 of the 12 radon samples (located in the eastern Black Hills) exceeded the proposed EPA radon MCL of 300 pCi/L (Williamson and Carter, 2001). Table 3-4 summarizes the concentrations of radionuclides in the Madison aquifer.

3.4.5 Aquifer Mixing

Based on the results of geochemical analysis of groundwater from numerous wells and springs in the region and the complexity of the cave and karst zones, breccia pipes, and dissolution networks observed extensively in the Madison and Minnelusa formations around the Black Hills, it is apparent that in some areas geologic features facilitate hydraulic cross-connections between the Madison and Minnelusa aquifers. This can result in considerable mixing between the

Table 3-4. Summary of Concentrations of Radionuclides in the Madison Aquifer

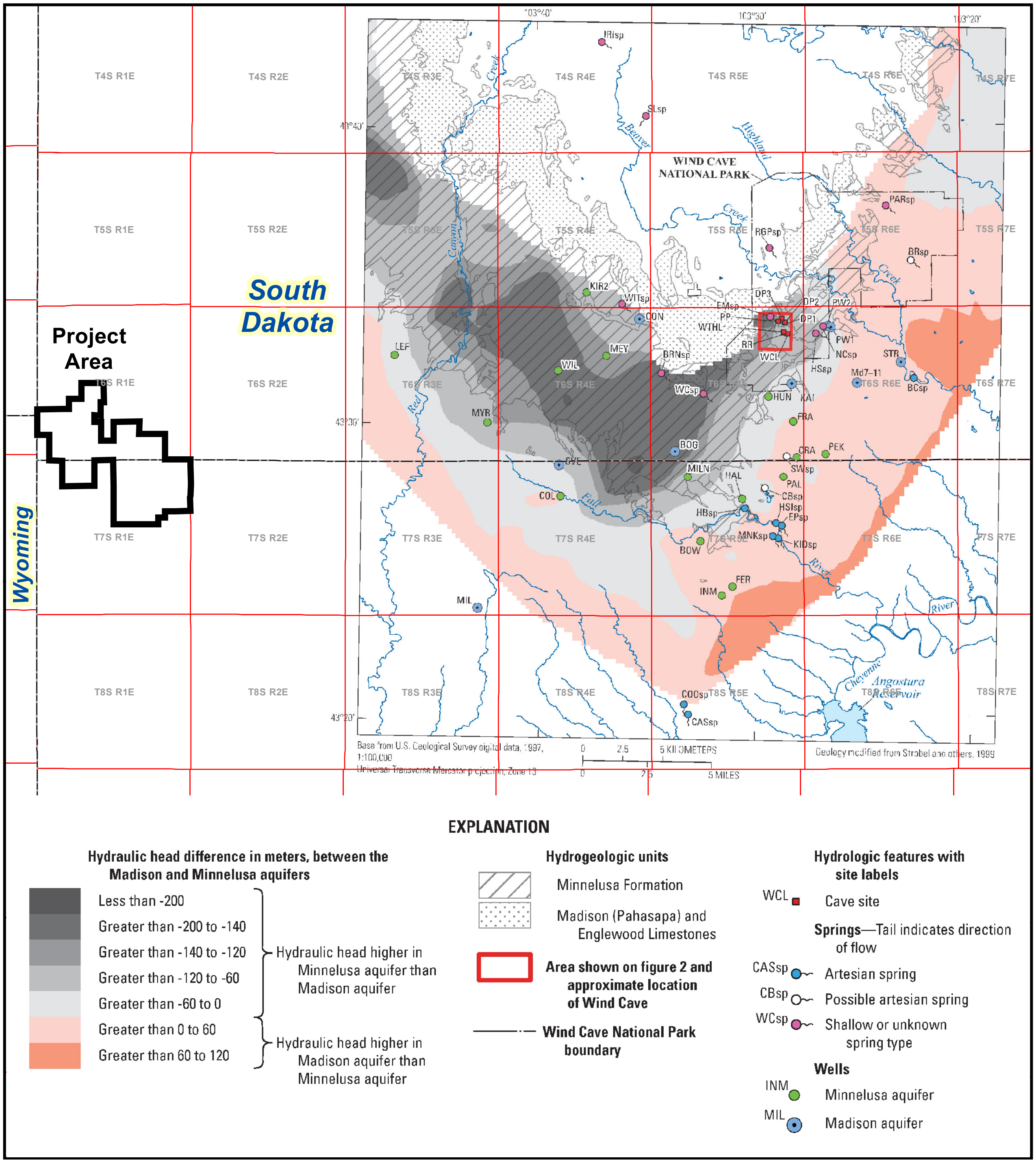
Dissolved Constituent	Number of Samples	Number of Censored Samples[(a)]	Mean	Median	Minimum	Maximum
Alpha radioactivity as thorium-230 (pCi/L)	16	3	4.6	4.1	1.1	16
Gross alpha as uranium-natural (pCi/L)	8	1	7.6	7.4	2.2	14
Gross alpha as uranium-natural (µg/L)	30	1	7.7	6.2	1.7	21
Gross beta as cesium-137 (pCi/L)	36	3	5.3	4.4	2.5	19
Gross beta as strontium/yttrium-90 (pCi/L)	29	0	4.0	3.3	2.0	13
Radium-226 (pCi/L)	12	1	1.2	1	<0.1	3
Radium-228 (pCi/L)	8	8	–	–	<1.0	<1
Radon-222 (pCi/L)	12	2	186	190	<80	300
Thorium (µg/L)	18	13	7.4	5.5	<5.0	22
Tritium (pCi/L)	27	10	29	6.0	<1.0	105
Uranium (µg/L)	45	0	3.8	2.3	0.1	39

(a) For some constituents, multiple lab reporting limits were used, resulting in censored values at various levels. If the majority of detectable levels were less than some censored values, the censored values were removed because they do not provide additional information for describing the data set.

Source: Williamson and Carter, 2001

generally lower TDS water of the Madison and the typically higher TDS water of the Minnelusa (Driscoll et al., 2002). The potentiometric surface elevation of the Madison tends to be higher than that of the overlying Minnelusa, and where vertical pathways exist mixing of water between the units is not uncommon as noted at artesian springs (Driscoll et al., 2002). Figure 3-17 depicts head differences between the Madison and Minnelusa aquifers along the southern tip of the Black Hills Uplift (Long et al., 2012). While this figure does not encompass the project area specifically, it shows that typically there is a positive head difference between the Madison and Minnelusa moving southwest away from the outcrop toward the project area. As described previously, there is no evidence of communication between the Madison and Minnelusa in the vicinity of the project area based on water quality differences.

In 2011, Long and Valder proposed that by comparing the hydrochemical signatures from five hydrogeologic domains, an end-member mixing model of principal component analysis (PCA) of



Legend

▬ Project Boundary

Source: Long et al. (2011)

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Figure 3-17

Difference in Hydraulic Head between the Madison and Minnelusa Aquifers Dewey-Burdock Project

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groundwater within Wind Cave could be used to determine the origin of the groundwater. Their model estimated that Wind Cave received most of its groundwater inflow from local surface recharge with an additional 33 percent from an upgradient Precambrian aquifer. Artesian springs in the vicinity of Wind Cave primarily received water from regional groundwater flow. Long and Valder's water-quality-based model indicates that most of the groundwater encountered in the Wind Cave sampling sites originates as recharge to Madison and Minnelusa aquifers on the nearby outcrops or within the nearby Precambrian aquifer domain, but up to 5 percent of the contributions to the Wind Cave sites had a west-to-east flow component. Similarly, Long et al. (2012), as part of a four-year study of the groundwater flow, quality and mixing in relation to Wind Cave National Park, concluded that the Wind Cave sampling sites received 38 percent of their groundwater inflow from local surface recharge, 34 percent from the upgradient Precambrian aquifer, 26 percent from surface recharge immediately to the west of Wind Cave and 2 percent from regional groundwater flow.

4.0 POTENTIAL DRAWDOWN

4.1 Analytical Predictions

AQTESOLV (Version 4.0) was used to approximate analytical drawdown solutions. AQTESOLV's solution uses the Theis equation, which assumes that the Madison is a confined, homogeneous aquifer of infinite extent and does not receive significant recharge or leakage from the Deadwood or Minnelusa aquifers. From the information provided in Section 3, it is clear that the Theis assumptions are not valid on a regional basis. The aquifer is neither infinite nor homogeneous as is illustrated on Figure 3-14. The Dewey Fault is less than one mile north of the project area and may represent a barrier to flow in that direction. About 13 or so miles northeast of the project area is the boundary between the unconfined and confined portions of the aquifer. The storage coefficient no doubt increases with distance northeast from the project area. Toward the southeast, between the project area and the city of Edgemont, the Long Mountain Structural Zone, if it extends down to the Madison Limestone, may represent another barrier or at least a zone of anisotropy. Therefore, the drawdowns predicted with AQTESOLV must be used with caution; for the purposes of this report drawdowns predicted in this manner are considered unreliable at a distance of more than a few miles from the proposed Madison wells.

For simplification, this analysis combined the potential impacts of pumping at both the Dewey and Burdock areas to a single point located between the two proposed Madison well locations, approximately in the center of the project area. This approach over-predicts the maximum anticipated drawdown at the hypothetical pumping site and presents a conservative representation of the anticipated potential impacts at distance from the project. The duration of pumping from the Madison will be about 7 to 20 years based on the proposed project schedule; to be conservative, this analysis included a pumping duration of 20 years, the default term limit for water rights (see Section 2.5). Using the appropriation rate over 20 years should result in a conservatively high prediction of potential drawdown impacts, although as shown below the difference in drawdown between pumping durations of 10 and 20 years is small.

The list of parameters used in AQTESOLV is presented in Table 4-1. The Madison pumping rate of 551 gpm was used to represent the requested appropriation volume. Based on Figure 3-7, the Madison Limestone is about 400 feet thick in the vicinity of the project area. An aquifer thickness of 300 feet was used, because the entire thickness may not be effective (see Section 3.3.5). Based on Figure 3-6, it is also presumed that the Madison is highly confined at this location. Reported transmissivity values for the Madison vary greatly throughout the Black Hills (see Section 3.3.2). Since there are no aquifer tests in the project area, a transmissivity of 7,393 ft^2/day was used based on regional estimates made by the USGS (Figure 3-13). A typical value

Table 4-1. Parameter Values Used in AQTESOLV Prediction

Parameter	Units	Value
Pumping Rate	gpm	551
Saturated Thickness	ft	300
Transmissivity	ft^2/day	7,393
Kv/Kh	---	0.1
Storativity	---	10^{-4}

of the ratio of vertical to horizontal conductivity is 0.1; there is no information to justify a different value. A storativity value of 10^{-4} was used; this value is representative of the confined portion of the Madison aquifer in the Black Hills (Long and Putnam, 2002).

Using AQTESOLV, drawdown versus time plots were produced for the centroidal pumping location and for observation points spaced at 1, 2.5 and 5-mile distances (Table 4-2 and Figure 4-1). The center of pumping has a computed drawdown of about 33.3 feet after 20 years of simulated pumping. Given that this analysis assumes the pumping rate of 551 gpm occurs at single location rather than being divided among two or more wells, it is likely that this calculation overestimates the maximum drawdown that will be achieved.

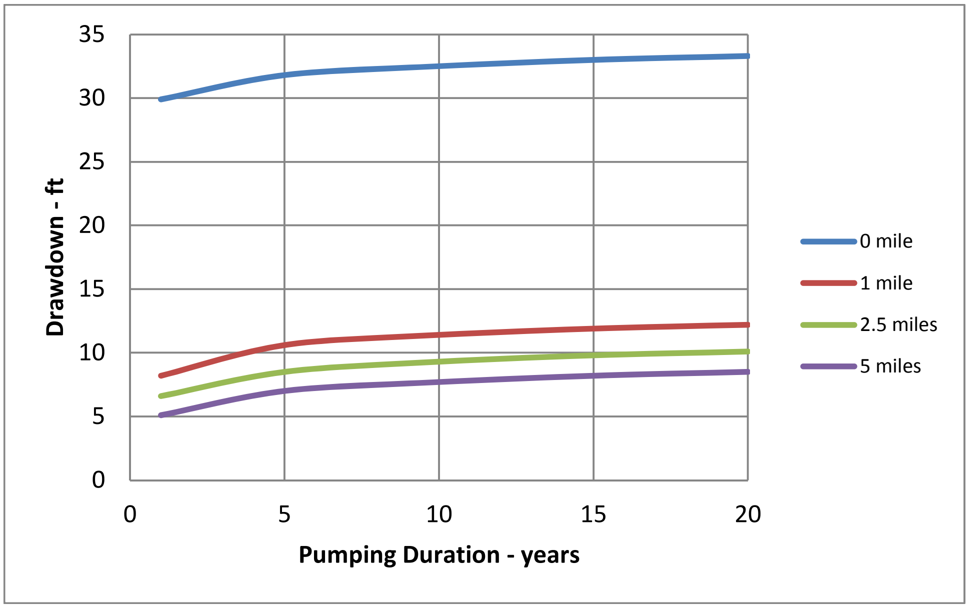
Table 4-2. AQTESOLV Drawdown Predictions (ft)

Distance from Pumped Centroid (Miles)	Pumping Duration (Years)				
	1	5	10	15	20
0	29.9	31.8	32.5	33.0	33.3
1	8.2	10.6	11.4	11.9	12.2
2.5	6.6	8.5	9.3	9.8	10.1
5	5.1	7.0	7.7	8.2	8.5

Review of the information in Table 4-2 and Figure 4-1 supports the following conclusions:

1. Within a distance of 5 miles from the center of the project area, where the assumptions inherent in the Theis method of drawdown calculations are reasonably satisfied, the maximum computed drawdown from the withdrawal of 551 gpm would be about 8.5 feet after 20 years.
2. Computed drawdown is relatively insensitive to pumping duration. At a distance of 5 miles from the center of pumping, the drawdown after 20 years of pumping is only 0.8 foot more than the drawdown after 10 years of pumping.

3. Near the center of the project area the available drawdown above the top of the Madison Limestone is about 2,800 feet (see Figure 3-6). The maximum computed drawdown, even assuming the entire 551 gpm is obtained from a single well, would only comprise about 1 percent of this available drawdown. At a distance of 5 miles from the pumping well, not much beyond the proposed Dewey-Burdock Project NRC license boundary, the maximum computed drawdown of 8.5 feet represents only 0.3 percent of the available drawdown above the top of the Madison.



Note: Distances shown are distances from pumped centroid

Figure 4-1. Predicted Drawdown Versus Time

Extrapolation of these computed drawdowns beyond a distance of about 5 miles is difficult due to a lack of data. Some inferences can be drawn in consideration of the information provided in Section 3. For example, toward the northeast from the project area, drawdown will be limited by the increasing storativity in the direction of the boundary between confined and unconfined conditions in the Madison aquifer. Conversely, toward the southwest, as the confining head on the Madison increases, drawdown could extend farther due to a decreasing storativity. However, any potential effects will be offset by the increasing available head above the Madison aquifer. To the north and northeast of the project area, drawdowns could be increased vs. what would be calculated using the Theis equation if the Dewey Fault is an effective barrier to flow in that direction. To the southeast, the Long Mountain Structural Zone could have a similar effect if it is a barrier to flow in that direction. This structure is about 10 miles from the center of the project area so any effects are likely to be minor. Furthermore, the Theis drawdown calculations ignore recharge to the project area. Recharge is expected to minimize any drawdown.

4.2 Potential Impacts to Existing Users

According to criteria for granting a water permit set forth in SDCL 46-2A-9, a proposed diversion will be approved only if it can be developed without unlawfully impairing existing rights. Existing Madison water rights and domestic wells are protected from adverse impacts per ARSD 74:02:04 and 74:02:05; these rules provide that an adverse impact or impairment is one that inhibits a well's ability to produce water independently of artesian pressure. In other words, if water levels in the Madison aquifer decline and the pump level can be lowered and still have the ability to produce water, the well is not considered impaired. In accordance with SDCL 46-1-4 and Board-adopted findings, an increase in operating cost or decrease in production is not considered an adverse impact.

4.2.1 Wells and Existing Water Rights

The Water Rights Program does not have any record of water rights or wells completed into the Madison aquifer within the project area or within a 5-mile radius around the proposed Madison wells. DENR does not require permits for domestic water uses and water distribution systems that do not pump more than 18 gpm. The Lamb Madison well discussed in Section 3.4 is a domestic well and therefore was not included in DENR water right records. Based on DENR records, there are 19 licensed or permitted water rights for the Madison aquifer within Fall River and Custer counties. Table 4-3 and Figure 4-2 provide information and locations for the licensed or permitted water rights. A water right permit may have more than one diversion point and multiple permits may have the same diversion point. The discharge rate in Table 4-3 is indicative of the appropriated discharge rate for the permit, not the individual discharge point; for example, Wind Cave National Park has two discharge points that combined reserve a total of 0.15 cfs. DENR also has record of other water rights applications that have been submitted but are not licensed; they are shown in Table 4-4 and Figure 4-3. This category includes applications and water rights that have been canceled, deferred, withdrawn, or reserved for future use.

The Madison wells used for municipal water supplies in Edgemont are about 15 miles southeast of the proposed Dewey-Burdock Project Madison wells, across the Long Mountain Structural Zone and near the crest of the Cottonwood Creek Anticline (See Figure 3-5). The potentiometric surface near Edgemont was historically around 3,700 feet above sea level (see Figure 3-14), or around 200 feet above land surface. Drawdown in this direction may not reach Edgemont. A

Table 4-3. Licensed or Permitted Madison Groundwater Rights Diversion Points within Fall River and Custer Counties

Permit/Right No.	Name	Use	Discharge (cfs)	Distance[(a)] (miles)
306-2	City of Edgemont	Municipal	0.31	15.2
419-2	Wind Cave National Park	Commercial, Irrigation	0.15	23.5
419-2	Wind Cave National Park	Commercial, Irrigation	0.15	28.3
735-2	Tennessee Valley Authority	Industrial	0.66	15.3
761-2	City of Edgemont	Municipal	0.410	15.1
858-2	Childers(b)	Irrigation	9.360	12.9
858-2	Childers(b)	Irrigation	9.360	13.2
858-2	Childers(b)	Irrigation	9.360	13.2
858-2	Childers(b)	Irrigation	9.360	13.7
1850-2	Provo Township	Municipal, Rural Water System	0.450	19.7
1903-2	Citation Oil and Gas Corporation	Industrial	0.260	24.8
2298-2	City of Edgemont(b)	Recreational, Municipal	1	15.2
2302-2	Streeter	Rural Water System	0.033	30.7
2392-2	Schwarz Trust	Commercial, Recreational	0.25	25.8
2393-2	Tetrad Corporation	Domestic	0.26	24.8
2440-2	Tetrad Corporation	Domestic	0.167	21.9
2532-2	Hermosa Water Users Association	Rural Water System	1.11	42.2
2546-2	Streeter	Rural Water System	0.210	30.7
2610-2	United Order of South Dakota	Suburban Housing Development	0.210	13.3
2615-2	Fall River Water Users District	Rural Water System	0.67	32
2629-2	Fall River Water Users District	Rural Water System	1	28.8
2633-2	Southern Black Hills Water System	Rural Water System	0.67	32.3
2634-2	Streeter	Rural Water System	0	30.7

(a) Approximate distance calculated from the centroid of Madison diversion points, located equal distances between the proposed Dewey and Burdock Madison diversion points.

(b) Indicates water right is for a combination of surface and groundwater rights.

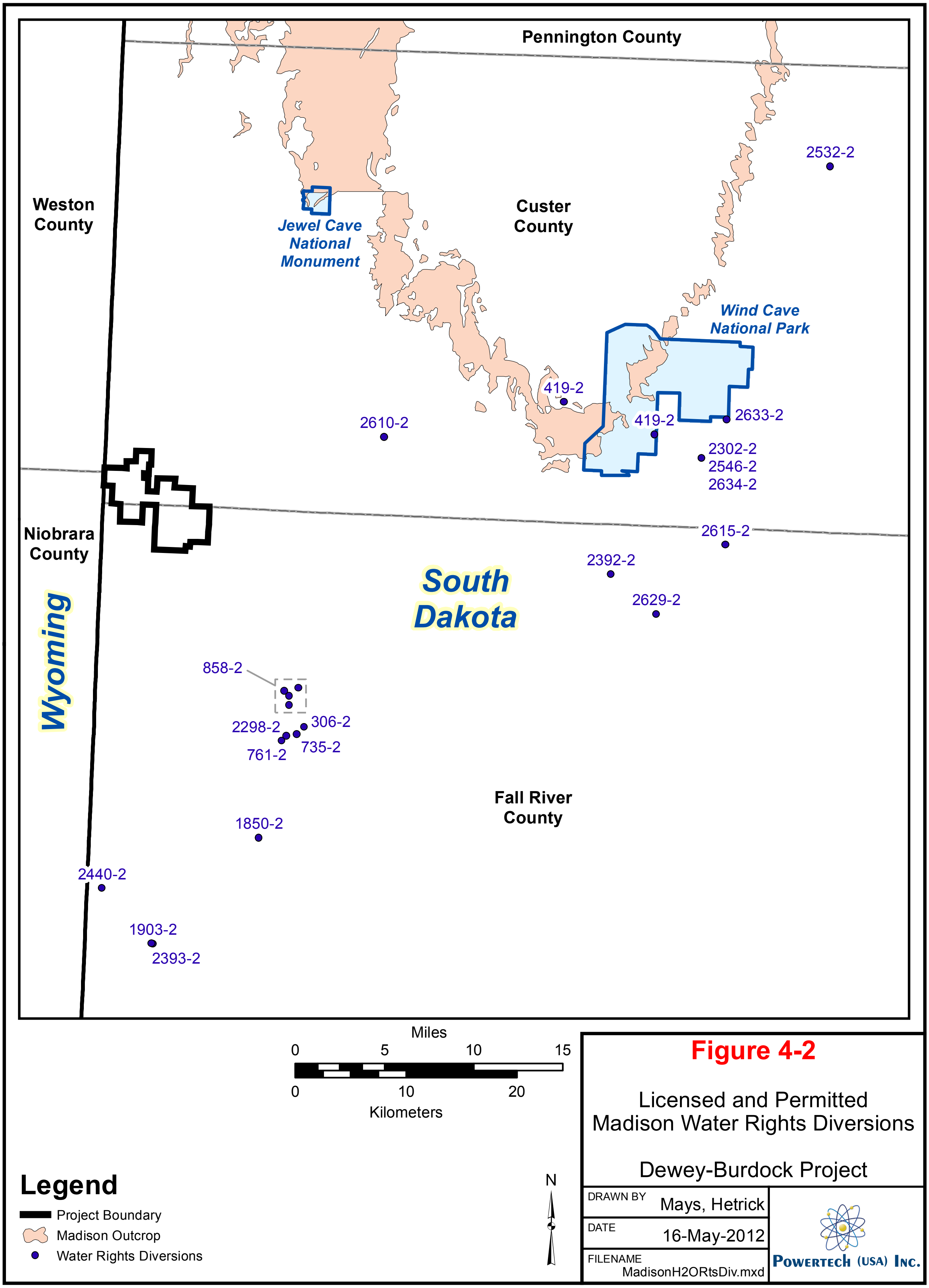


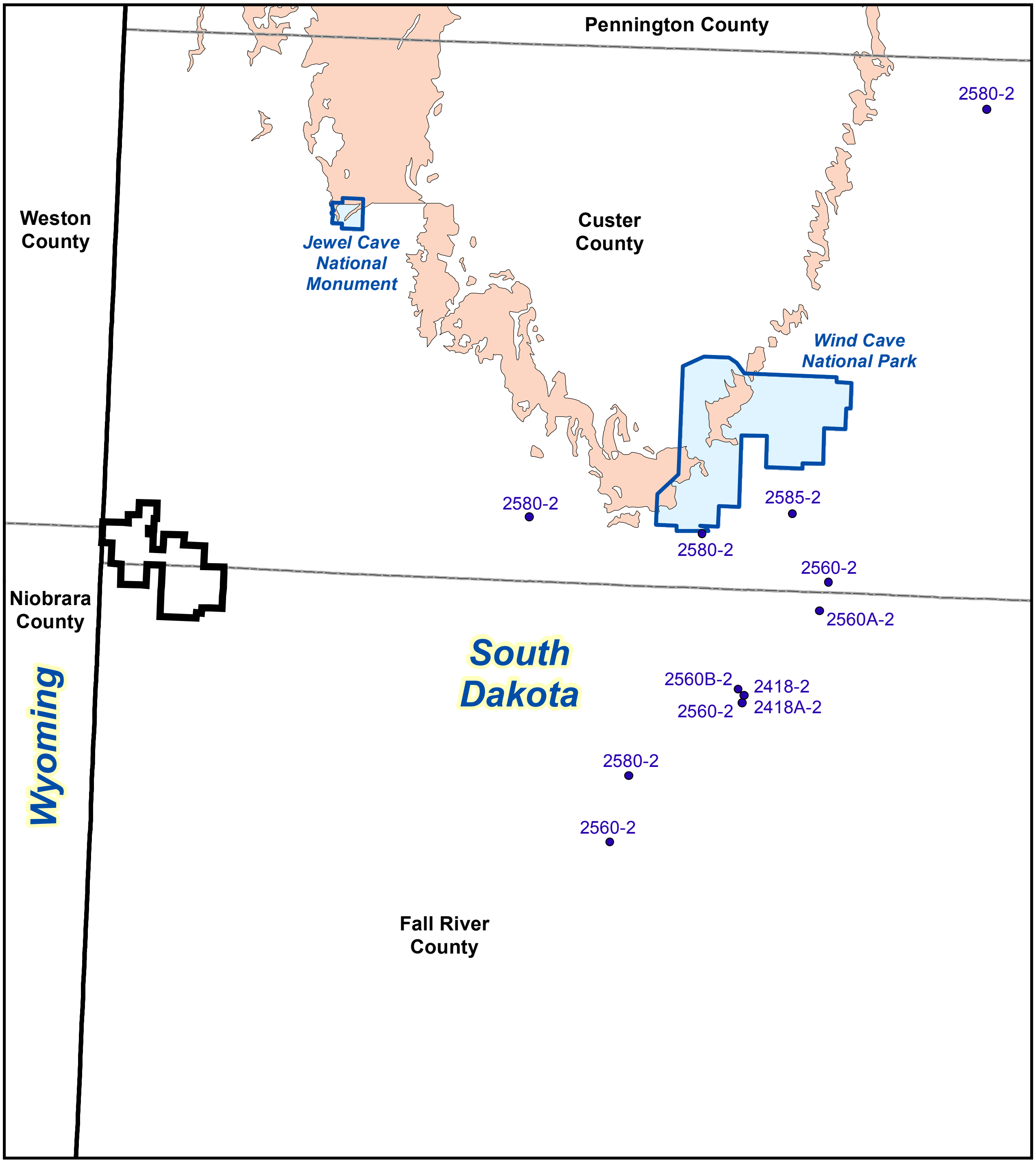
Figure 4-2

Licensed and Permitted Madison Water Rights Diversions

Dewey-Burdock Project

Table 4-4. Additional Madison Groundwater Rights Applications within Fall River and Custer Counties

Permit/Right No.	Name	No. Diversions	Status	Use	cfs
2418-2	Fall River Water Users District	1	Canceled	Rural Water System	0.67
2560-2	Fall River Water Users District	1	Future Use	Rural Water System	0
2418A-2	Fall River Water Users District	1	Withdrawn	Rural Water System	0
2580-2	Southern Black Hills Water System	1	Future Use	Rural Water System	0
2585-2	Southern Black Hills Water System	1	Deferred	Rural Water System	2.67
2560A-2	Fall River Water Users District	1	Future Use	Rural Water System	0
2560B-2	Fall River Water Users District	1	Future Use	Rural Water System	0
2560-2	Fall River Water Users District	2	Future Use	Rural Water System	0
2580-2	Southern Black Hills Water System	3	Future Use	Rural Water System	0



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▬ Project Boundary

▨ Madison Outcrop

● Water Rights: Future Use, Cancelled, Deferred

Figure 4-3

Future Use, Cancelled or Deferred
Madison Water Rights

Dewey-Burdock Project

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DATE	16-May-2012
FILENAME	MadisonH2ORtsFutrUse.mxd

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comparison between Table 4-2, which shows a maximum anticipated drawdown 5 miles away of 8.5 feet, and the distance of approximately 3 times this length to the Edgemont wells suggests that the drawdown would be much less than 8.5 feet. This would leave the potentiometric surface at Edgemont far above the land surface with the wells continuing to flow freely. Any small decline in head caused by the proposed Powertech (USA) appropriation would not adversely impact the municipal supply wells at Edgemont.

In Wyoming, all wells are required to be permitted by the State Engineer's Office (SEO). To determine which wells could potentially be completed in the Madison, a spatial analysis of the SEO data was conducted to identify wells that are within 30 miles of the project area and have a total depth greater than 2,000 ft. A table and map of these wells are presented in Appendix C. The nearest known Madison wells in Wyoming are just over 5 miles northwest of the Dewey-Burdock Project boundary, which would place them across the Dewey Fault from the project area.

The city of Newcastle, about 25 miles north-northwest of the project area, is by far the largest user of Madison water within a 30-mile radius. The city has six Madison wells and uses about 950,000 gallons of water per day (Wester-Wetstein & Associates, 2002). Based on system responses from historical use it is likely there would be little to no measurable response in Newcastle from pumping at the Dewey-Burdock Project. There has been no significant decline in the potentiometric surface of the aquifer over the last 40 years (Wester-Wetstein & Associates, 2002). Additionally, the Dewey Fault and other geologic structures that likely act as flow barriers separate the project area from Newcastle, and drawdown is not expected to propagate a significant distance to the northwest due to the anisotropic conditions in the Madison.

Given the distance between the proposed Dewey-Burdock Project Madison wells and all existing Madison aquifer supply wells, adverse impacts to other Madison users are unlikely. The nearest Madison wells are more than 5 miles from the proposed wells, where the maximum estimated drawdown is only 8.5 feet after 20 years of pumping as shown in Table 4-2.

4.2.2 Caves and Springs

There are several caves and springs located within the Madison Limestone in the southern Black Hills (See Table 4-5, Figure 3-14 and Section 3.2.4.). Jewel Cave National Monument and Wind Cave National Park are both hosts to world-class caves formed within the Madison Limestone. Jewel Cave National Monument is located about 18 miles north-northeast of the project area. The cave consists of over 100 miles of passages and lies entirely above the water table. Wet or

Table 4-5. Major Madison Source Springs within Fall River and Custer Counties

Name	Flow (cfs)	Elevation (ft)	Head (ft)	Distance[(a)] (miles)
Cascade Springs	18–22	3,440	3,495	24
Hot Springs				
Hot Brook	<5	3,625	3,700	24
Evans Plunge	<5	3,465	3,610	24
Fall River	20–30	3,415	3,580	24
Beaver Creek Spring	10–15	3,460	3,480	31

From Naus et al., 2001

(a) Distance calculated from the centroid of Madison diversion points or equal distances between the proposed Dewey and Burdock Madison diversion points.

dripping areas in the cave are the result of downward percolation of precipitation and flow through the unsaturated vadose zone (National Park Service, 1994). As stated previously, drawdown estimates are based on distance and average aquifer properties; results from the investigation presented in Table 4-2 cannot be extrapolated to Jewel Cave as this area is separated from the Dewey-Burdock Project by the Dewey Fault and several smaller structural features. Jewel Cave is also located upgradient from the boundary between confined and unconfined conditions in the Madison (See Figure 3-14). It is predicted that there will be no effect on the Madison water table at Jewel Cave.

Wind Cave National Park is 21 miles east of the project area. Wind Cave itself is approximately 26 miles from the nearest proposed Madison well in the project area. The park encompasses portions of the Madison outcrop area on the southeast flank of the Black Hills Uplift (Figure 3-14). The majority of Wind Cave lies above the water table, although a few pools exist within the lower reaches that likely define the groundwater table in that region. The potentiometric surface elevation at Wind Cave is about 3,800 feet (see Figure 3-14). There also are several seeps and springs within the National Park. Table 4-3 shows Wind Cave National Park currently has a water right permit for two diversions (including wells and springs). Significant impacts or unlawful impairments to the National Park's water resources are unlikely if Powertech (USA)'s water rights applications are approved because of the distance between the Dewey-Burdock Project and Wind Cave National Park and the prevailing direction of groundwater flow indicated by Figures 3-6, 3-13, and 3-14. The groundwater flow paths do not indicate that water from the project area is contributing to Wind Cave, but rather that the potentiometric surface at Wind Cave is most influenced by outcrop recharge within the park itself. The cross section in Figure 3-6 indicates a groundwater divide between the project area and Wind Cave and suggests that the Madison may be entirely above the water table, and most certainly is at most only partially saturated, near this groundwater divide. Given a fractured, heterogeneous aquifer like the Madison, the probability that pumping at the Dewey-Burdock Project would actually be discernible at Wind Cave is so remote as to be negligible. The flow net analysis in Section 5 provides a demonstration that recharge and groundwater flow from the outcrop to the project area is more than sufficient to provide the 551 gpm requested by this appropriation.

There are no natural springs in the project area. On USGS topographic maps of the area, two springs are located northwest of the project area in Section 18, Township 6 South, Range 1 East. The two springs are identifiable on 2010 CIR satellite imagery obtained from the National Agriculture Image Program (NAIP) of the USDA Farm Service Agency.

Three major spring systems in the southern hills emanate from Madison aquifer waters south of Wind Cave National Park. These springs include Cascade Springs, Hot Springs, and Beaver Creek Spring (Table 4-5, Figure 3-14). In this report, Hot Springs refers to all the springs in the Hot Springs area, including Hot Brook, Evans Plunge, and the Fall River, noting that Fall River flow includes flow from Hot Brook, Evans Plunge, and several smaller Madison and Minnelusa springs.

Spring discharge provides the base flow for some major creeks in the southeastern Black Hills; a significant decline in potentiometric level therefore has the potential to reduce spring discharge. Some of these spring-fed creeks have associated surface water rights. Current discharge ranges from 10 to 15 cfs at Beaver Creek Spring, 18 to 22 cfs at Cascade Springs, and about 20 to 30 combined cfs at Hot Springs (including Evans Plunge, Hot Brook, and other springs) (Naus et al., 2001). The potentiometric level and ground elevation for each of these springs is provided in Table 4-5.

To significantly affect the groundwater flow rates and spring discharge, a large change in hydraulic gradient would have to occur in the vicinity of the springs. Based on data from Naus et al. (2001), the head at each of these springs is currently well above the land surface. At Cascade Springs, the potentiometric level is about 55 feet above the land surface; the difference in head and ground surface elevation at Hot Springs ranges from 75 to 165 feet. The artesian head above ground surface at Beaver Creek Spring is the lowest at 20 feet. More than 22 miles and several structural features separate the project area from Cascade Springs and Hot Springs. The Beaver Creek Spring is located over 30 miles away on the east side of the Cascade Anticline. The Cascade Anticline is essentially a groundwater divide between the project area and Beaver Creek Spring. As such, no impacts to Beaver Creek Spring are expected as a result of the project. Similarly, potential impacts to the other springs are expected to be negligible. As the analytical drawdown estimate in Section 4.1 demonstrates, the drawdown even after a relatively conservative 20-year pumping period will be relatively small. When the effects of recharge, anisotropy of the aquifer, and available water in storage are factored in, no impacts to the springs are anticipated from the Dewey-Burdock Project. Permitted and future use water rights (Figures 4-2 and 4-3) that are in closer proximity to these springs would be more likely to impact these springs than the Dewey-Burdock Project wells.

5.0 FLOW NET ANALYSIS

Drawing upon the description of hydrologic and geologic information presented in Section 3, a conceptual model domain is established that includes the project area and the portion of the Madison aquifer that would supply water to the proposed Madison wells. A flow net calculation is used to show that the proposed Dewey-Burdock Project Madison wells will use only a small part of the available Madison aquifer water within the conceptual model domain. It is also demonstrated in this section that because of the large confining head (hydraulic head above the top of the aquifer) of the Madison aquifer in the project area, the relatively small amount of water to be appropriated (551 gpm), the distance from the project area to the nearest Madison aquifer wells, and the presence of hydrologic and geologic boundaries, the proposed Madison wells will not unlawfully impair existing rights.

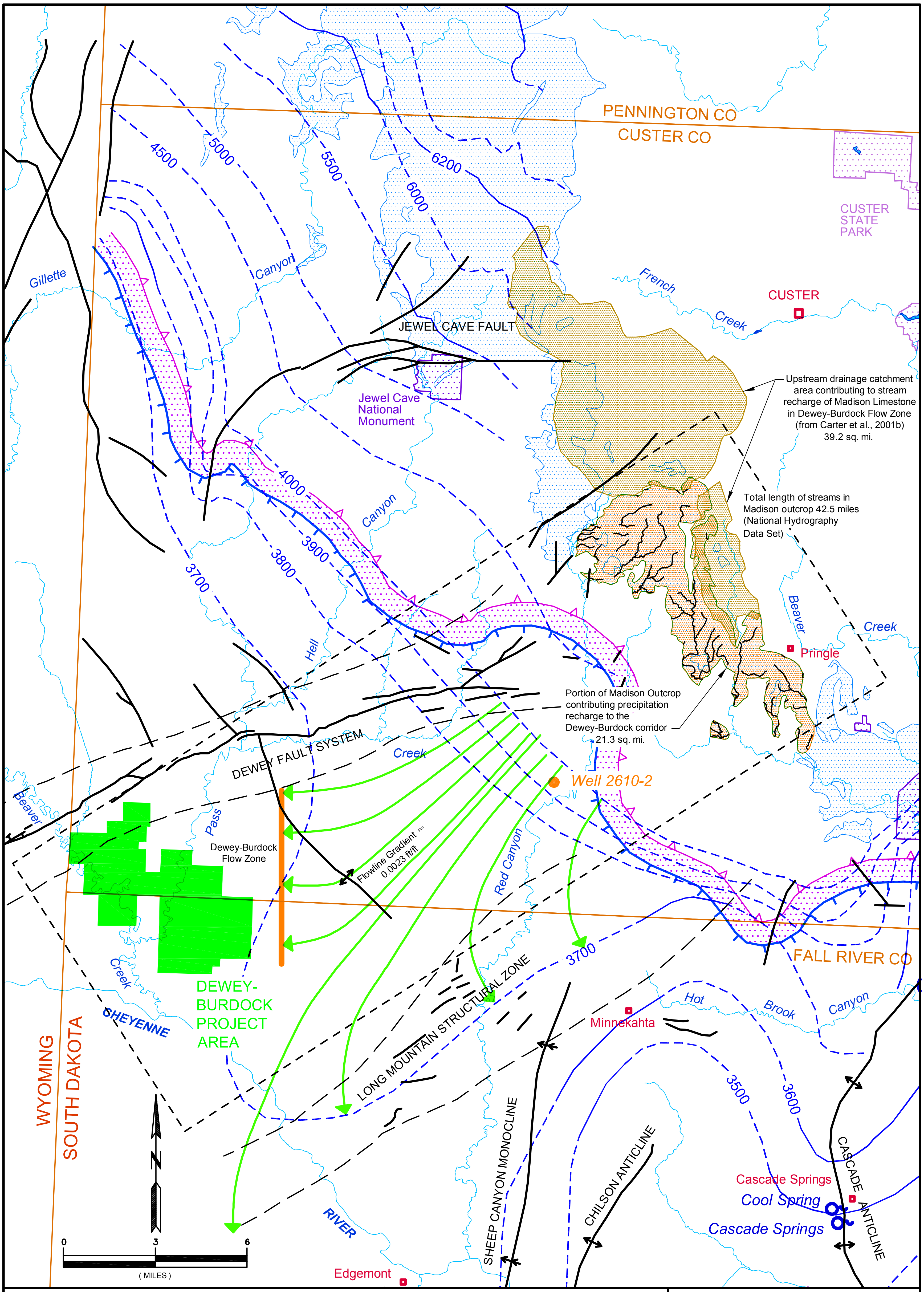
5.1 Conceptual Model Domain

The conceptual groundwater model domain includes the following elements:

1) Boundary conditions, which include known recharge zones in the northeastern portions of the model domain and faults and other mapped structures which constitute likely barriers or restrictions to groundwater flow.
2) System drains, which include mapped springs, other Madison aquifer wells, and regional groundwater flow out of the model domain toward the west and southwest.
3) A structure contour map of the top of the Madison Limestone, which together with the potentiometric surface describes the available drawdown above the top of the Madison aquifer.
4) A potentiometric surface of the Madison aquifer, which defines flow directions and heads available to wells.
5) Hydraulic parameters including transmissivity, hydraulic conductivity, saturated thickness and flow gradients that enable calculation of groundwater flow rates into and within the model domain.

These elements were used to describe the direction and approximate rate of movement of water within the model domain from the recharge zones along the Madison outcrop in the northeastern portion of the model domain toward the project area in the southwestern portion of the model domain and beyond. The model domain and hydrogeologic features used to construct the conceptual groundwater flow model are described in Section 3 and shown on Figure 5-1.

As Figure 5-1 shows, the model domain is oriented northeast to southwest. The northeastern boundary of the model domain is the Madison outcrop, where recharge to the Madison aquifer occurs. The direction of groundwater flow in the Madison aquifer, which is generally radially



LEGEND

- OUTCROP OF MADISON LIMESTONE (from Driscoll et al., 2002)
- ▪ TOWN
- ARTESIAN SPRING
- FAULT
- ANTICLINE (Arrows Indicate Dip)
- MONOCLINE (Arrows Indicate Dip)
- ZONE OF MULTIPLE STRUCTURES
- 3200 POTENTIOMETRIC CONTOUR, DASHED WHERE INFERRED. (feet above mean sea level) (from Driscoll et al., 2002)
- PARTIALLY SATURATED MADISON LIMESTONE
- FULLY SATURATED MADISON LIMESTONE from Driscoll et al., 2002)
- FLOWLINE
- FLOW ZONE USED TO CALCULATE INFLOW TO DEWEY-BURDOCK PROJECT
- CONCEPTUAL FLOW MODEL DOMAIN

Figure 5-1
Conceptual
Groundwater Flow
Model Domain

Dewey-Burdock Project

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DATE	07-Jun-2012
FILENAME	Figure 5-1.dwg

POWERTECH (USA) INC.

K:\Powertech\12021\DWGS\Figure 5-1.dwg 6/7/2012 9:56:46 AM raven outward from the core of the Black Hills Uplift (see Section 3.2.3), is parallel to the long axis of the model domain from the recharge area southwestward past the project area and out toward the Powder River structural basin. The northwest boundary of the model domain corresponds roughly with the Dewey Fault system, and the southeast boundary generally follows the Long Mountain Structural Zone.

5.2 Construction of the Conceptual Groundwater Flow Model

5.2.1 Recharge

As discussed in Section 3.2.2, groundwater in the Madison aquifer regionally flows off the Black Hills Uplift and eventually, more slowly at a reduced gradient, to the southeast and east toward the Kennedy Basin in south-central South Dakota and the Williston Basin in North Dakota (Driscoll et al., 2002). This is illustrated on Figures 3-12 and 3-13.

Within the model domain shown on Figure 5-1 the Madison aquifer is recharged by infiltration of precipitation and streamflow at the outcrop. Recharge from precipitation is in the range of up to 1 inch per year (see Section 3.2.2 and Figure 3-11). The surface area of the Madison outcrop in the model domain (Figure 5-1) is about 21.5 square miles. At a conservatively low recharge estimate of 0.5 inch per year, the average annual recharge to the Madison aquifer from precipitation infiltration within the model domain is estimated to be about 573 ac-ft, equivalent to a flow rate of about 0.79 cfs or 360 gpm.

As discussed in Section 3.2.2, streamflow infiltration can be a significant component of total recharge. There are numerous places where entire streams disappear into solution cavities or fractures in karst topography. The Madison outcrop within the model domain is overlain by more than 42 miles of stream channel. The catchment area upstream of Red Canyon and other drainages that cross the Madison outcrop within the model domain is 39.2 square miles. Carter et al. (2001b) developed stream recharge calculations for ungaged drainages within the Black Hills. As part of their study, they identified representative gaging stations where flow measurements were available and used those measurements to estimate the flow in drainages where no gaging stations were available. Carter et al. (2001b) developed stream recharge estimates which included the 10 drainages in the conceptual model domain as well as 8 additional drainages to the east, which had a combined total drainage area of 51.47 square miles. Of this, 39.2 square miles contribute runoff to the two drainages within the model domain (76.2 percent of the area). Carter et al. (2001b) estimated the recharge to the drainages for the period from 1992 to 1998. The minimum estimated recharge was 2.02 cfs in 1992, and the maximum estimated recharge was 15.30 cfs in 1995, with an average recharge of 7.6 cfs. Taking only the portion of the drainages within the model domain (39.2 square miles), the estimated stream recharge in the model domain would range from 1.5 cfs to 11.6 cfs and average 5.8 cfs. Most of the streams generally lose their entire flow as they cross the Madison and Minnelusa outcrops (Carter et al. 2001b). Since the streams cross the Madison outcrop first, recharge to the Madison is assumed to be greater and more consistent than recharge to the Minnelusa. Streamflow recharge to the Madison aquifer within the model domain is therefore estimated to be in the range of 5.8 cfs (2,600 gpm).

The total combined recharge to the Madison aquifer from infiltration of precipitation and streamflow is estimated to be about 6.6 cfs (2,960 gpm). This is much more than is being requested by the Dewey-Burdock Project and, as shown later, is more water than is estimated to flow from the recharge zone through the Madison aquifer toward the project area. This excess of recharge over intra-aquifer flow is not surprising given the number of springs that emanate from Madison outcrop zones around the perimeter of the Black Hills.

5.2.2 System Drains

Outflows from the conceptual groundwater model domain include Madison wells and lateral flow through the western model boundaries. As described in Section 3.2.4, several natural springs are located along the southern tip of the Black Hills, with the larger springs located on major anticlinal structures. None of these springs is in the model domain, and the springs are not considered in the conceptual groundwater flow model calculations presented later in this section.

Existing and potential Madison wells are discussed in Section 4.2.1 and listed in Tables 4-3 and 4-4. Locations of licensed or permitted Madison wells are shown on Figure 4-2. Only one of these wells, Permit 2610-2, is within the model domain shown on Figure 5-1. This well is appropriated by United Order of South Dakota for a suburban housing development for 0.21 cfs (94 gpm). The well is about 13.3 miles up-gradient from the center of the project area and is shown on Figure 5-1.

5.2.3 Potentiometric Surface

The potentiometric surface of the Madison aquifer presented in Driscoll et al. (2002), which was modified from Strobel et al. (2000), was used for this conceptual model (Figure 3-14).

A review of the potentiometric surface depicted on Figures 3-14 and 5-1 provides a significant amount of information regarding water movement within the region. Two of the nearest springs, Cool Spring and Cascade Springs, are located on the Cascade Anticline where the potentiometric surface is shown to bulge southward along the anticline. Immediately to the west of the Cascade

Anticline, a trough in the potentiometric surface suggests a zone of higher hydraulic conductivity within the Madison aquifer between the Chilson Anticline and the Cascade Anticline. Between the Chilson Anticline and the Long Mountain Structural Zone the potentiometric surface steepens, suggesting that geologic structure may limit the permeability in the east-west direction.

5.2.4 Hydraulic Conductivity

Consistent with Section 4 of this report, it is assumed that parameters used in the AQTESOLV drawdown prediction are appropriate for the central portions of the model domain (i.e., away from geologic boundaries). These parameters are listed in Table 4-1.

5.3 Flow Net Analysis

A flow net was constructed for the model domain at the location shown on Figure 5-1. This is the same type of analysis used by Carter et al. (2001a) for the much larger area shown on Figure 3-13. Darcy's equation in the following form was used to estimate the amount of groundwater flowing through the model domain in the vicinity of the project area:

$Q = KiA$

Where: Q = flow rate in ft^3/day,

K = hydraulic conductivity in ft/day,

i = groundwater flow gradient (ft/ft), and

A = cross sectional area of the aquifer in ft^2.

The flow rate was calculated at the flow zone shown on Figure 5-1 where the flow lines are approximately parallel. Note that the flow lines shown on Figure 5-1 were developed using classical flow net analysis techniques where the flow lines are drawn perpendicular to the potentiometric surface lines. These lines demonstrate flow direction but not magnitude. Hydraulic conductivity was calculated as transmissivity (7,393 ft^2/day) divided by saturated thickness (300 ft, assuming that the bottom 100 feet of the Madison Limestone is ineffective as an aquifer) or 24.6 ft/day (see Table 4-1). The groundwater flow gradient approaching the flow zone indicated on Figure 5-1 is about 100 feet in 8 miles or about 0.0023 ft/ft, slightly steeper than the 0.0017 gradient developed by Carter et al. (2001a) for flow zone 14, sub-area 9 (see Figure 3-13).

According to the potentiometric surface presented on Figure 3-14, the local flow direction approaching the project area still trends southwestward and has not yet turned to the south and southeast to join the regional flow around the southern end of the Black Hills as depicted on Figure 3-13. The project area has a width of about 6 miles in a direction normal to the direction of flow at the location shown on Figure 5-1. For a width of 6 miles and an aquifer thickness of 300 feet, the cross-sectional area at which the Darcy calculation was applied is 9,504,000 ft^2. Using these values, the groundwater flux across the flow zone shown on Figure 5-1 was calculated as:

$Q = 24.6$ ft/day x 0.0023 ft/ft x 9,504,000 ft^2 = 537,700 ft^3/day or 6.2 cfs.

This calculation indicates that the groundwater flux through the portion of the Madison aquifer that would provide water to the Dewey-Burdock Project Madison wells is over 3 times greater than the combined amount of water requested by this application (1.228 cfs) and the only other Madison water right within the model domain (Permit 2610-2, permitted for 0.67 cfs, see Table 4-3). The estimated potential recharge to this model domain (see Section 5.2.1) exceeds this groundwater flux. These approximate calculations based on best available information and accepted analytical techniques demonstrate a reasonable probability that there is unappropriated water for the Powertech (USA) Madison water right application.

Due to the Madison aquifer anisotropy discussed in the literature, any potential drawdown would tend to propagate primarily in the updip and downdip directions, which limits potential impacts to the northwest and the southeast. This supports the conclusion that potential impacts to Madison wells near Edgemont will be minimal. Since available recharge and calculated groundwater flux entering the Dewey-Burdock Project model domain is much greater than the amount of water that will be used for the project, the recharge is expected to limit updip drawdowns. The only known permit for a Madison well in the model domain is about 13 miles updip (northeast) from the project area. This demonstrates reasonable probability that there will be no unlawful impairment of existing water rights.

The potential updip drawdown is not expected to result in any impacts to Wind Cave National Park. As shown on Figure 3-6, the Madison aquifer becomes partially saturated between the project area and Wind Cave. Aquifer drawdown for a given volume of water pumped from the aquifer is less in an unconfined aquifer. In the confined portion of the aquifer around the project area the estimated storage coefficient is 1×10^{-4}, which means that for 1 foot of drawdown the aquifer will yield 1×10^{-4} ft^3 of water. A typical storage coefficient (actually specific yield) in an unconfined aquifer would be 0.1, which means that for 1 foot of drawdown the aquifer would yield 0.1 ft^3 of water. Therefore, drawdowns propagating from the project area northeastward toward the unconfined portion of the aquifer will be smaller for a given amount of water produced.

5.4 Conclusions

This report demonstrates that there is a reasonable probability that unappropriated water is available in the Madison aquifer as required by SDCL 46-2A-9 to satisfy the Powertech (USA) application. It is also demonstrated that important regional groundwater features will not be impaired. These features include the hot springs located at the southern tip of the Black Hills, the cave systems, and other Madison aquifer water wells including the Edgemont and Newcastle wells. Recharge and groundwater flux in the portion of the Madison aquifer that will supply water to the proposed Dewey-Burdock Project wells exceed the amount of water that is requested in this application. Jewel Cave is above the water table and separated from the project area by the Dewey Fault system. Wind Cave National Park is located on the east slope of the Black Hills Uplift and is separated from the project area by a groundwater divide and a zone in the Madison aquifer that is only partially saturated and may be totally above the water table. As a result, drawdown from the Dewey-Burdock Project is not expected to propagate to Wind Cave National Park.

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