MEMORANDUM November 17, 2016

SUBJECT: Technical Memorandum Documenting the Capture Zone Analysis for Eleven Private Drinking Water Wells in and near the Dewey-Burdock Uranium In-Situ Recovery Project Site Northwest of Edgemont, South Dakota

FROM: Valois R. Shea, Underground Injection Control Program Permit Writer

TO: Powertech (USA) Inc. Dewey-Burdock Class III Area Permit File
SD31231-00000

INTRODUCTION

This memorandum documents the process used for, and conclusions resulting from, conducting the capture zone analyses (CZA) for 11 private drinking water wells located within and down-gradient from the Dewey-Burdock Uranium In-Situ Recovery (ISR) Project Site. The Dewey-Burdock Project Site is located approximately 13 miles northwest of Edgemont, in southwest Custer County and northwest Fall River County, South Dakota. The CZA, in the context of this memorandum, refers to the determination of the portion of the aquifer from which a well draws groundwater. This memorandum serves as supplemental information to the *U.S. EPA Region 8 Underground Injection Control Program Aquifer Exemption Record of Decision* for the Dewey-Burdock site.

Powertech (USA) Inc. (Powertech) submitted a Class III Permit Application for the authorization of injection wells to inject lixiviant for uranium recovery at the Dewey-Burdock Project Site. As part of the Class III Permit Application, Powertech has also requested an aquifer exemption (AE) for portions of the Inyan Kara Group aquifers at the Project Site that would allow injection to take place to mobilize uranium within the ore-bearing portions of the Inyan Kara aquifers. The aquifers proposed for exemption are the uranium-bearing aquifers within the Inyan Kara Group. The horizontal extent of the proposed AE area is shown by the dashed green line in Figure 1. The proposed vertical extent of the AE area is shown in Figure 2.

Area of review means the area surrounding an injection well described according to the criteria set forth in 40 CFR §146.06 or in the case of an area permit, the Project Area plus a circumscribing area the width of which is either 1/4 of a mile or a number calculated according to the criteria set forth in §146.6. Powertech proposed an Area of Review of 2 kilometers (km) (1.2 miles) outside the Dewey-Burdock Project Boundary. (For more information about the Dewey-Burdock Area of Review, see Section 4.0 of the Class III Draft Area Permit Fact Sheet.)

There are 19 private wells located within approximately 1.2 miles of Dewey-Burdock Project Site boundary that are being used, or have been used, for drinking water. These wells are listed in Table 1. Ten of these wells are located outside the Dewey-Burdock Project Boundary. Nine wells are located inside the Project Boundary. One well, well 16, is located inside the AE boundary Powertech proposed with the Class III Area Permit. The locations of these 19 wells and the Area of Review boundary are shown in Figure 3.

Of the ten wells located outside the project boundary, six wells are located up-gradient or cross-gradient relative to the direction of groundwater flow and the Project Boundary. As discussed later in this document under the section entitled *Area Examined For Drinking Water Wells*, no CZA was performed for these six wells.

Table 1. Nineteen Private Drinking Water Wells within the Dewey-Burdock Project Area of Review. **Nineteen Private Drinking Water Wells within the Dewey-Burdock Project Area of Review.**

Well ID#	Section/Township/Range	Well Completion Aquifer/ Project Area Location	Location Relative to Groundwater Flow Direction and Project Boundary
2	SESE Sec 16 T7S R1E	Chilson Southwest of Burdock	Down-gradient
7	NWNW Sec 23 T7S R1E	Fall River South of Burdock	Down-gradient
8	SWSE[1] Sec 23 T7S R1E	Fall River South of Burdock	Down-gradient
13	NWNW Sec 3 T7S R1E	Chilson Burdock	Inside
16	NWSE Sec 1 T7S R1E	Chilson Burdock	Inside
18	SWSW Sec 9 T7S R1E	Fall River West of Burdock	Down-gradient
40	SWNW Sec 30 T6S R1E	Inyan Kara Dewey	Inside
41	SWNE Sec 31 T6S R1E	Unknown Dewey	Inside
42	SWNE Sec 5 T7S R1E	Chilson Dewey	Inside
43	SWSE Sec 34 T6S R1E	Chilson Burdock	Inside
96	SWSW Sec 22 T41N R60W (in Weston County, WY)	Chilson West of Dewey	Cross-gradient
102	SWNE Sec 18 T6S R1E	Chilson North of Dewey	Up-gradient
107	SWNE Sec 18 T6S R1E	Fall River North of Dewey	Up-gradient
109	NENW Sec 17 T6S R1E	Chilson North of Dewey	Up-gradient
115	SENE Sec 18 T6S R1E	Fall River North of Dewey	Up-gradient
138	NENE Sec 18 T6S R1E	Fall River North of Dewey	Up-gradient
703	SWSE Sec 1 T7S R1E	Unkpapa Burdock	Inside
704	SWNE Sec 5 T7S R1E	Chilson Dewey	Inside
4002	NWSW Sec 30 T6S R1E	Inyan Kara Dewey	Inside

[1] The South Dakota Water Well Completion Reports database (http://denr.sd.gov/des/wr/dblogsearch.aspx) contains an Artesian Well Repair form for well 8 indicating that the well is located in SESW Section 23. Figure 17.1 of the Class III Permit Application shows well 8 located in SWSE Section 23. Checking the location on Google Maps indicates the well is located as shown on Figure 17.1 of the Class III Permit Application.

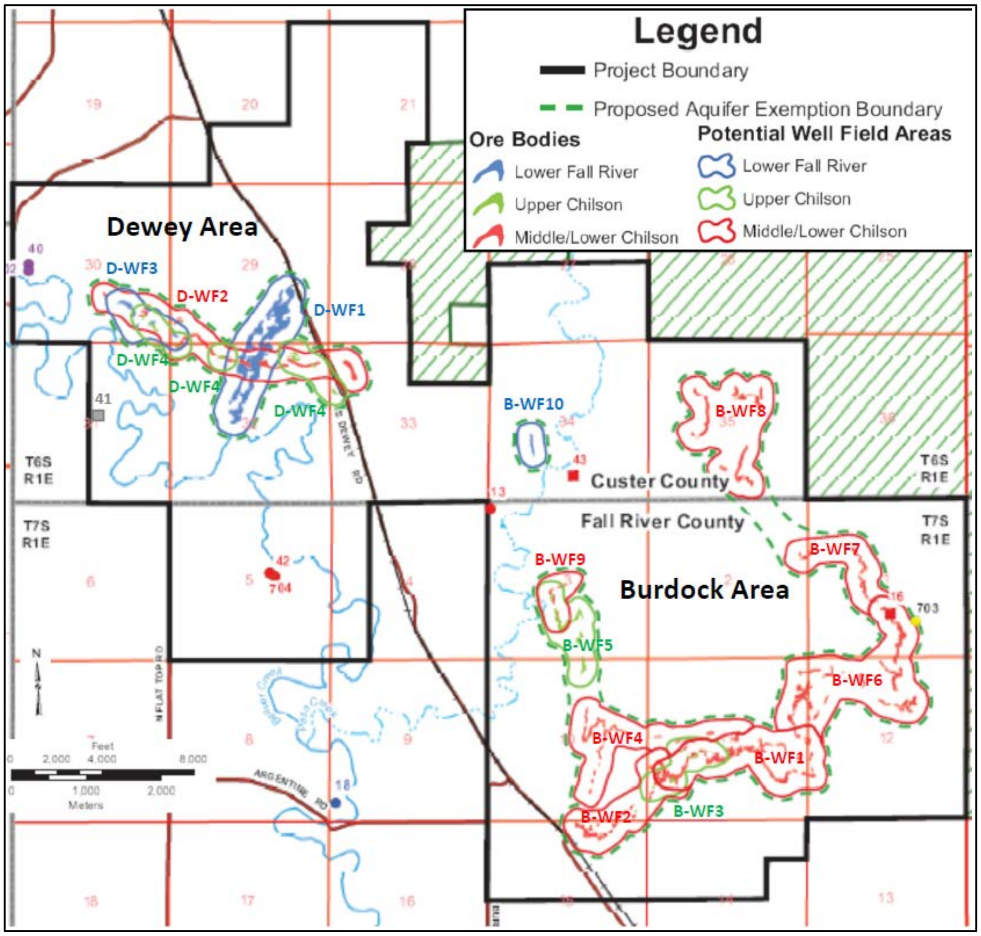

Figure 1. Map Showing the Dewey-Burdock Project Area and the Proposed AE Area

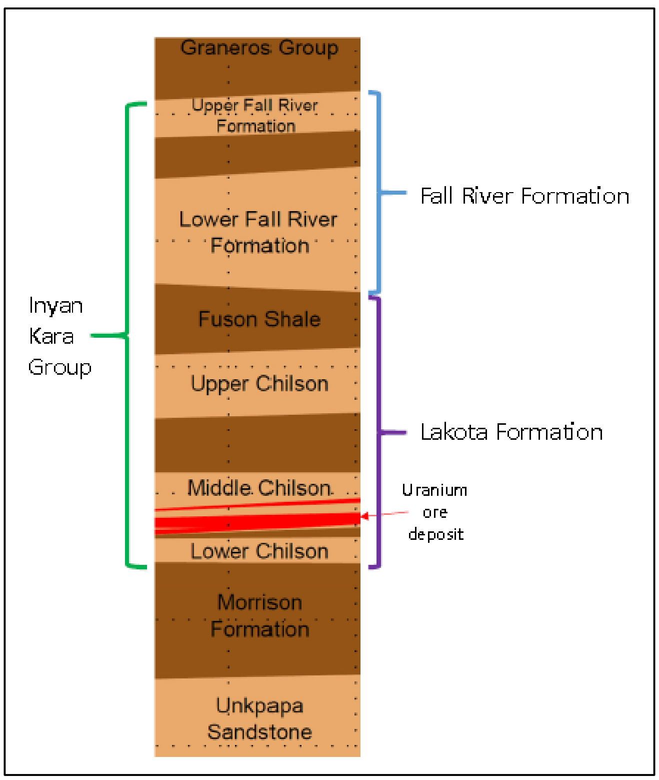

Figure 2. The Aquifer Formations and Confining Zones of the Inyan Kara Group.

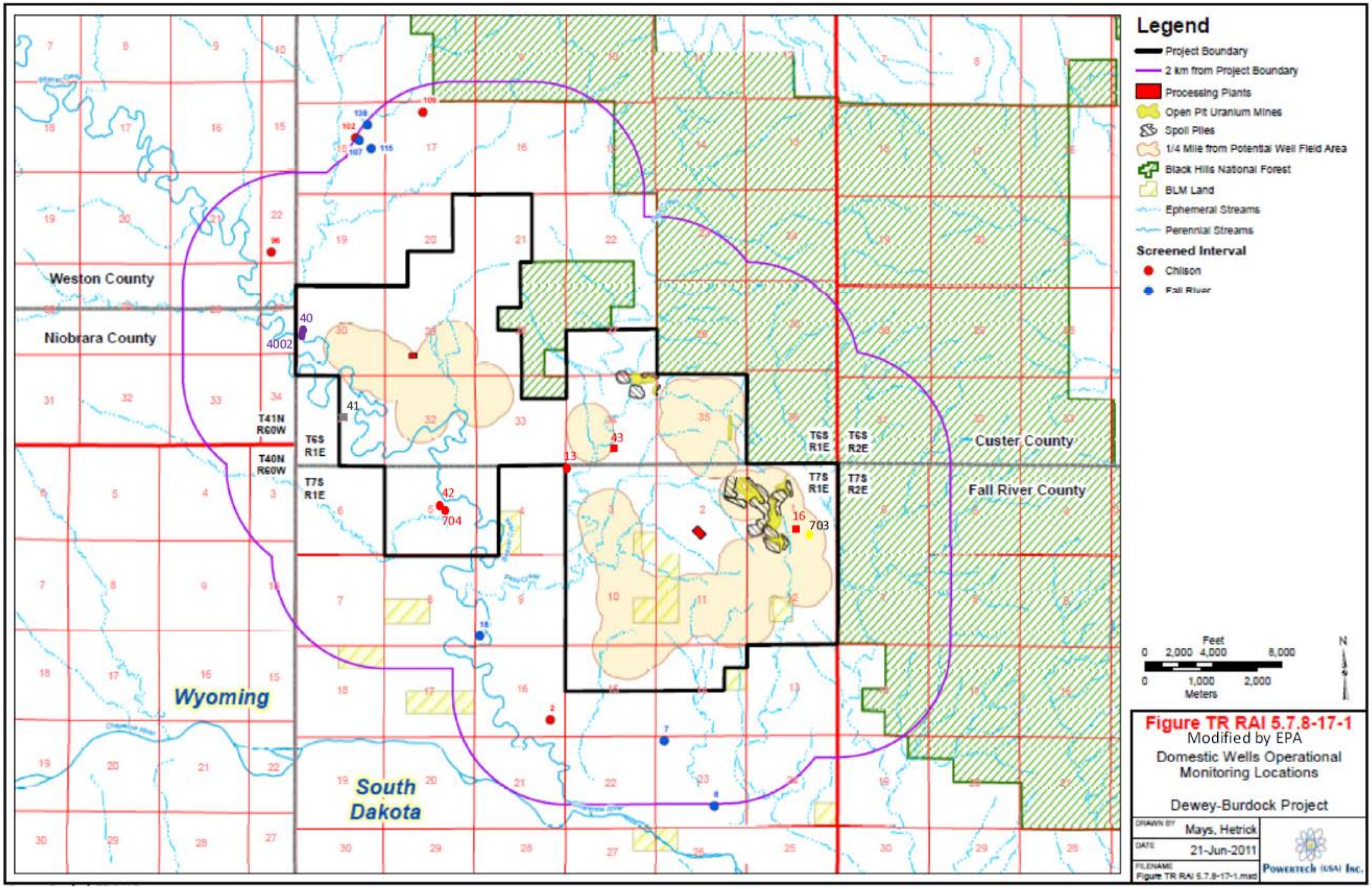

Figure 3. Location of the Nineteen Private Drinking Water Wells Located within the Dewey-Burdock Area of Review

No CZA was performed for two of the nine wells inside the project boundary. Well 703 is completed in the Unkpapa Sandstone. The Unkpapa Sandstone is not part of the Inyan Kara Group, which contains the aquifers proposed for exemption. The Unkpapa Sandstone is located stratigraphically below and is hydrologically separated from the Inyan Kara aquifers by the Morrison Formation lower confining zone, as shown in Figure 2. Because this well is not drawing groundwater from the aquifers proposed for exemption, no CZA was needed for this well.

Well 16 is located within the AE boundary that Powertech proposed in the Class III Permit Application. As discussed later in this document, well 16 was once used as a drinking water well. Although well 16 is no longer being used as a drinking water well, it is still being used as a stock-watering well. Because well 16 is still in use and could potentially be used once again for drinking water, the EPA has proposed two options for approval of the AE requested by Powertech. The first option is to propose approval of all the wellfields except for the two within which well 16 is located, Burdock wellfields 6 and 7. This scenario is shown in Figure 4. The second option is to allow Powertech the opportunity to plug and abandon well 16 before the EPA issues the final permit decision, then the EPA will approve the AE area that Powertech proposed with the Class III Permit Application, including Burdock wellfields 6 and 7. This scenario is shown in Figure 1. Under the second option for AE approval, well 16 is drawing water from inside the AE boundary, so no CZA is needed to determine whether the well 16 CZA crosses the AE boundary. Under the second option for AE approval, well 16 is located up-gradient of the two wellfields nearest the location of well 16, Burdock wellfields 1 and 8. Because well 16 is located up-gradient of Burdock wellfields 1 and 8, the EPA did not need to calculate the up-gradient extent of the capture zone for well 16. The EPA calculated the width of the capture zone for well 16 to verify that it did not cross the aquifer exemption boundaries for Burdock wellfields 1 and 8.

The wells for which a CZA was performed include four wells located outside of and down-gradient from the project boundary and seven wells located inside the project boundary, but outside the proposed AE area. The purpose for conducting a CZA for these eleven wells is to determine if any of the wells are currently using groundwater within the proposed AE area. The CZA delineates a well's capture zone to determine if the capture zone intersects the AE area. If none of the capture zones for all of the private wells currently being used for drinking water in or near the Dewey-Burdock Project Site intersects the AE area, then the EPA can conclude that groundwater within the proposed AE area is not currently being used for drinking water per 40 CFR 146.4(a).

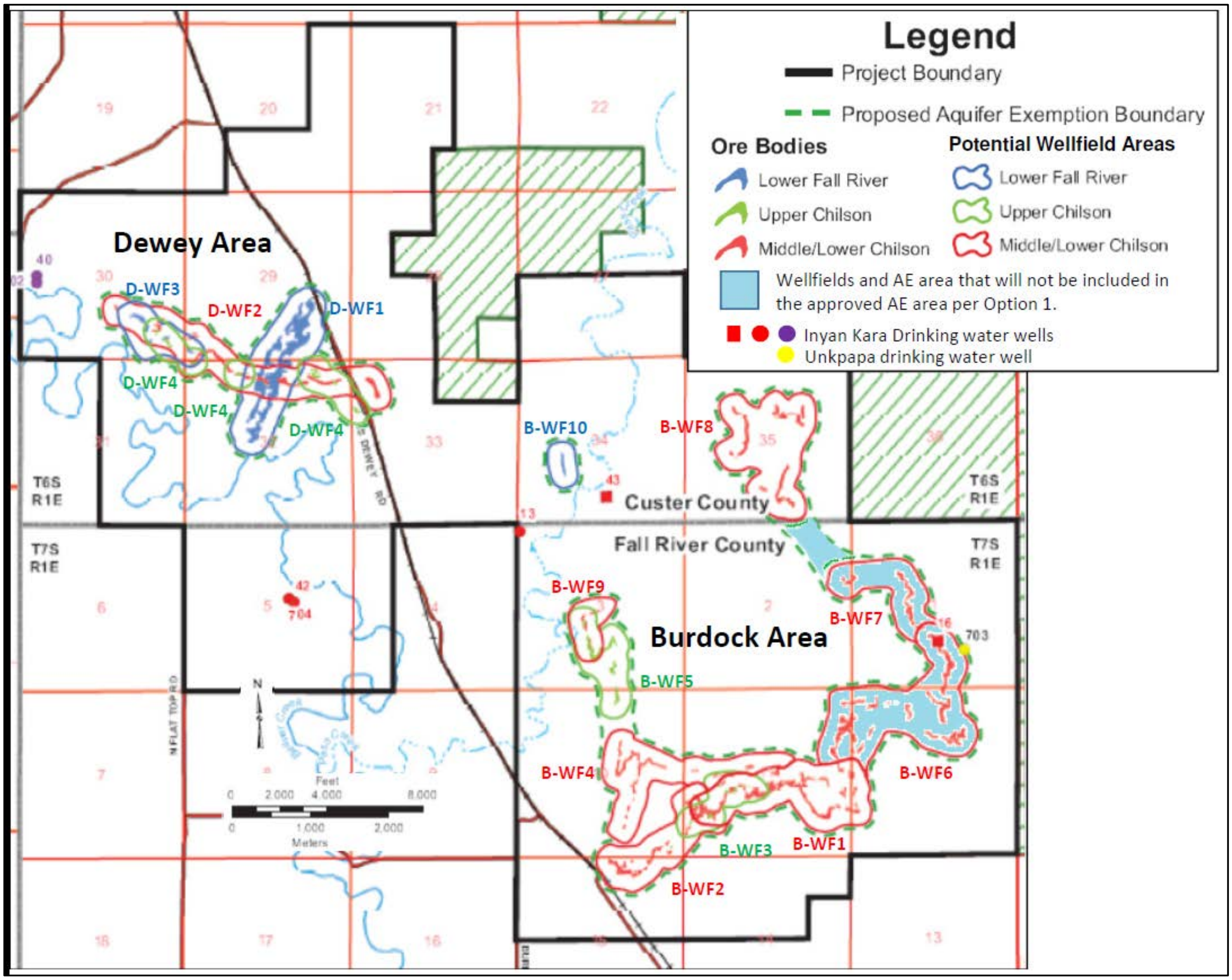

Figure 4. Approved AE Area under Option 1.

BACKGROUND

The Office of Ground Water and Drinking Water (OGWDW) Director's July 24, 2014 Memorandum entitled *Enhancing Coordination and Communication with States on Review and Approval of Aquifer Exemption Requests Under SDWA* contains a list of information that should be considered in the EPA's evaluation and approval of AEs. The information provided in this technical memorandum is intended to address the following questions in the OGWDW memorandum:

Are there any public or private drinking water wells within and nearby the proposed exempted area for which the proposed exempted portion of the aquifer might be a source of drinking water?

What is the appropriate area to examine for drinking water wells? Although guidance 34[2] *says it should be a minimum of 1/4 miles, the determination of an appropriate area is on a case by case basis. Describe the area and give a rationale.*

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[2] *Guidance for Review and Approval of State Underground Injection Control (UIC) Programs and Revisions to Approved State Programs.* GWPB Guidance #34 http://www.epa.gov/ogwdw/uic/pdfs/guidance/guide-memo_guidance-34_review_state_prog.pdf

Are there any public or private drinking water wells or springs capturing (or that will be capturing) or producing drinking water from the aquifer or portions thereof within the proposed exemption area?

- *Evaluate the capture zone of the well(s) in the area near the proposed project (i.e., the volume of the aquifer(s) or portions(s) thereof from within which groundwater is expected to be captured by that well.)*
- *A drinking water well's current source of water is the volume (or portion) of an aquifer which contains water that will be produced by a well in its lifetime. What parameters were considered to determine the lifetime of the wells?*

PUBLIC OR PRIVATE DRINKING WATER WELLS WITHIN AND NEARBY THE PROPOSED AE AREA

Figure 5 shows the Dewey-Burdock Project Area boundary (the solid black line) and the proposed AE boundary (the green-dashed line). The round symbols shown on the map in Figure 5 represent private wells that are currently being used for drinking water. The color of the circle indicates the aquifer formation from which each private well is drawing groundwater. The aquifer formations within the Inyan Kara Group are shown in Figure 2. The confining zones for the Inyan Kara Group aquifers are the Graneros Group and the Morrison Formation shales. The Fuson Shale is the confining zone separating the Fall River Formation and the Chilson Sandstone units of the Lakota Formation.

The square symbols represent private wells that have been used for drinking water in the past, but are no longer being used for drinking water at the time of the proposed AE approval. These include wells 16, 41 and 43.

Figure 5 shows the locations of 14 of the 19 private drinking water wells within and near the Project Area. The five up-gradient private wells are not shown on this map. The nearest public drinking water wells to the Dewey-Burdock Project Area are located in Edgemont, South Dakota 13 miles southeast. The Edgemont wells are completed in the Madison Formation aquifer.

Well 16 is the only well located within the proposed AE boundary that has used the Inyan Kara groundwater for drinking water. No record of this well was found in the South Dakota water well databases; therefore, no use designation had been formally assigned to the well. In Appendix B of the Class III Permit Application, Powertech included information related to well 16 from Tennessee Valley Authority (TVA) records indicating that the well was constructed in the mid-1970s and is 330 feet deep. Based on that depth, the well is completed in the Chilson Sandstone. Well 16 is located in a uranium ore body as shown in Figure 5. Laboratory analyses of groundwater samples Powertech collected from the well show the groundwater exceeds drinking water standards for gross alpha and radium 226. Powertech set up an agreement with the well owner that removed the well from drinking water use and Powertech supplies bottled water as drinking water to the well owner. Powertech disconnected the well from the residence by removing the pipeline between the well and the residence. Well 16 will continue to be used for stock water until Powertech removes the well from private use prior to start-up of ISR operations. Powertech submitted a *Water Well Completion Report* to the South Dakota State Engineer which classifies the current well use as stock watering.

Based on well 16 usage noted above, the EPA may conclude that this well does not currently supply Inyan Kara groundwater for use as drinking water for human consumption. However, under South Dakota regulations, the definition of domestic well includes stock watering as well as human drinking water. Therefore, classifying the well as a stock watering well does not legally prevent the well from supplying human drinking water. Because of the lack of legal distinction between a stock watering well and a drinking water well, the EPA cannot make the determination that well 16 does not currently supply Inyan Kara groundwater for use as drinking water for human consumption. No CZA was performed on well 16, because it is clear from its location that well 16 is drawing water from inside the AE boundary.

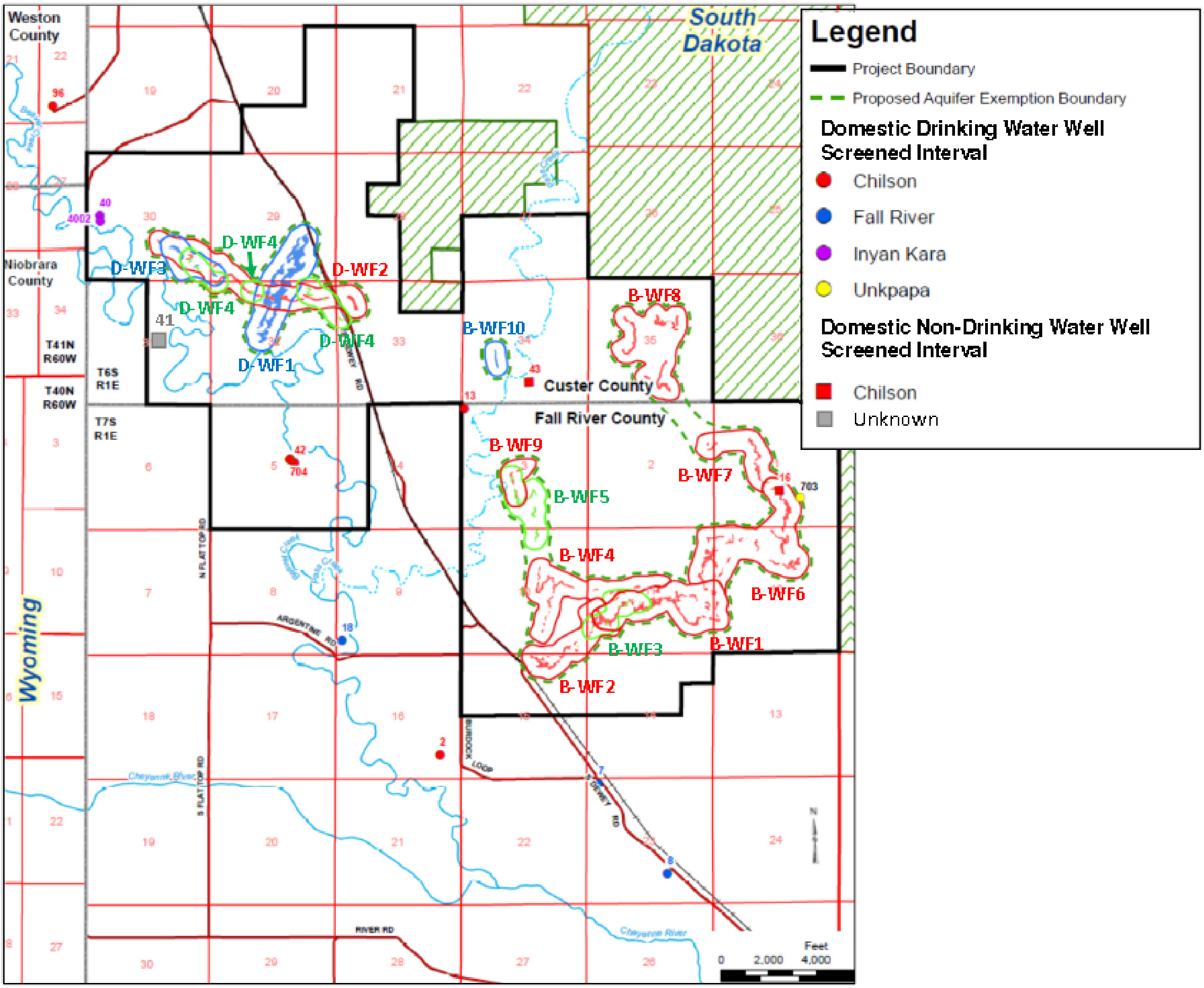

Figure 5. Map Showing the Dewey-Burdock Project Area, the Proposed AE Area and 14 Private Drinking Water Wells Located within and near the Project Area.

Wells 41 and 43 are located outside the AE boundary, but inside the Dewey-Burdock Project Boundary. Well 41 is shown as a stock watering well on Plate 3.1, which is the Area of Review Map included with the Class III Permit Application. Plate 3.1 also indicates that there is a residence located near the well and TVA records indicate that well 41 was a domestic well at some time in the past. The EPA asked Powertech to determine if there actually is a residence located near well 41 and, if so, to find out what the drinking water source for that residence is. Powertech checked the residence, found that no one was currently living in the residence and informed the EPA that the residence is uninhabitable. Powertech could not identify what the drinking water source was for the abandoned residence. There are no records indicating the formation of completion for well 41. TVA historic records indicate well 41 flows at a rate of 12 gallons per minute. Powertech states that well 43 is also associated with an uninhabitable residence and is no longer being used at all for any purpose. Historic records for well 43 indicate it is completed in the Chilson Sandstone. Powertech has landowner agreements in place that will allow Powertech to remove these wells from private use before commencing ISR operations. Because these two wells were once used for drinking water, CZAs were conducted for each of the wells to determine if the capture zone for either well crosses the AE boundary.

AREA EXAMINED FOR DRINKING WATER WELLS

Table 1 lists the 19 private drinking water located within approximately 1.2 miles of Dewey-Burdock Project Site boundary that are being used, or have been used, for drinking water and provides information about each one. Except for well 8, all the wells are located within the Dewey-Burdock Project Area of Review boundary, which is 1.2 miles (2 km) from the Project Boundary. Powertech set the Area of Review boundary at 1.2 miles beyond the Project Area Boundary to coincide with the 2 km boundary of investigation used for the Nuclear Regulatory Commission license application. The EPA reviewed this Area of Review boundary and determined that this distance provides an adequate buffer zone for evaluating the effects of ISR operations outside the proposed AE boundary. This distance was proven to be more than adequate based on CZA results. Because well 8 is located down-gradient from, and just outside of, the Area of Review Boundary, it was included in the CZA. Wells 96, 102, 107, 109, 115 and 138 are located cross-gradient from the project site. Well 96 is the closest of these wells, located approximately 6,250 feet from the AE boundary for Dewey wellfield 2. No CZA was performed for these cross-gradient wells, because 1) they are located cross-gradient, and most are up-gradient, of the AE area and 2) as shown in Table 7, the largest capture zone width calculated for a well completed in the Inyan Kara aquifers is less than 6,250 feet. No CZA was performed for well 16 because the capture zone for this well intersects the AE area. No CZA was performed for well 703 because it is completed in the Unkpapa Formation which lies below the Inyan Kara and is hydrologically separated from Inyan Kara aquifers by the Morrison Formation lower confining zone for the Inyan Kara.

CZA METHODOLOGY

The Capture Zone Equations

Two different equations were used for the CZA: 1) the first equation calculates the up-gradient extent of the capture zone; and 2) the section equation calculates the maximum width of the capture zone.

Equation for Calculating the Up-gradient Extent of a Well's Capture Zone: The first equation, which was used to calculate the up-gradient extent of the capture zone, is equation 4-7 in Section 4.4.3 of the EPA *Handbook on Ground Water and Wellhead Protection*[3]. This equation is based on the Uniform Flow Equation and calculates the up-gradient extent of a "zone of contribution" (ZOC) surrounding a pumping well. When there is a slope in the aquifer potentiometric surface, the ZOC is asymmetric, extending farther up-gradient than down-gradient as illustrated in Figure 6. For the purposes of this CZA, the ZOC is considered to be the capture zone for the pumping well.

[3] Ground Water and Wellhead Protection Handbook, EPA/625/R-94/001, September, 1994

$$t_x = n/Ki\ [r_x - (Q/2\pi Kbi)\ln\{1 + (2\pi Kbi/Q)r_x\}] \quad (4\text{-}7)$$

where

t_x = travel time from point x to a pumping well
n = porosity
r_x = distance over which ground water travels in T_x,
    r_x is positive (+) if the point is upgradient, and
    negative (–) is downgradient

Q = discharge
K = hydraulic conductivity
b = aquifer thickness
I = hydraulic gradient

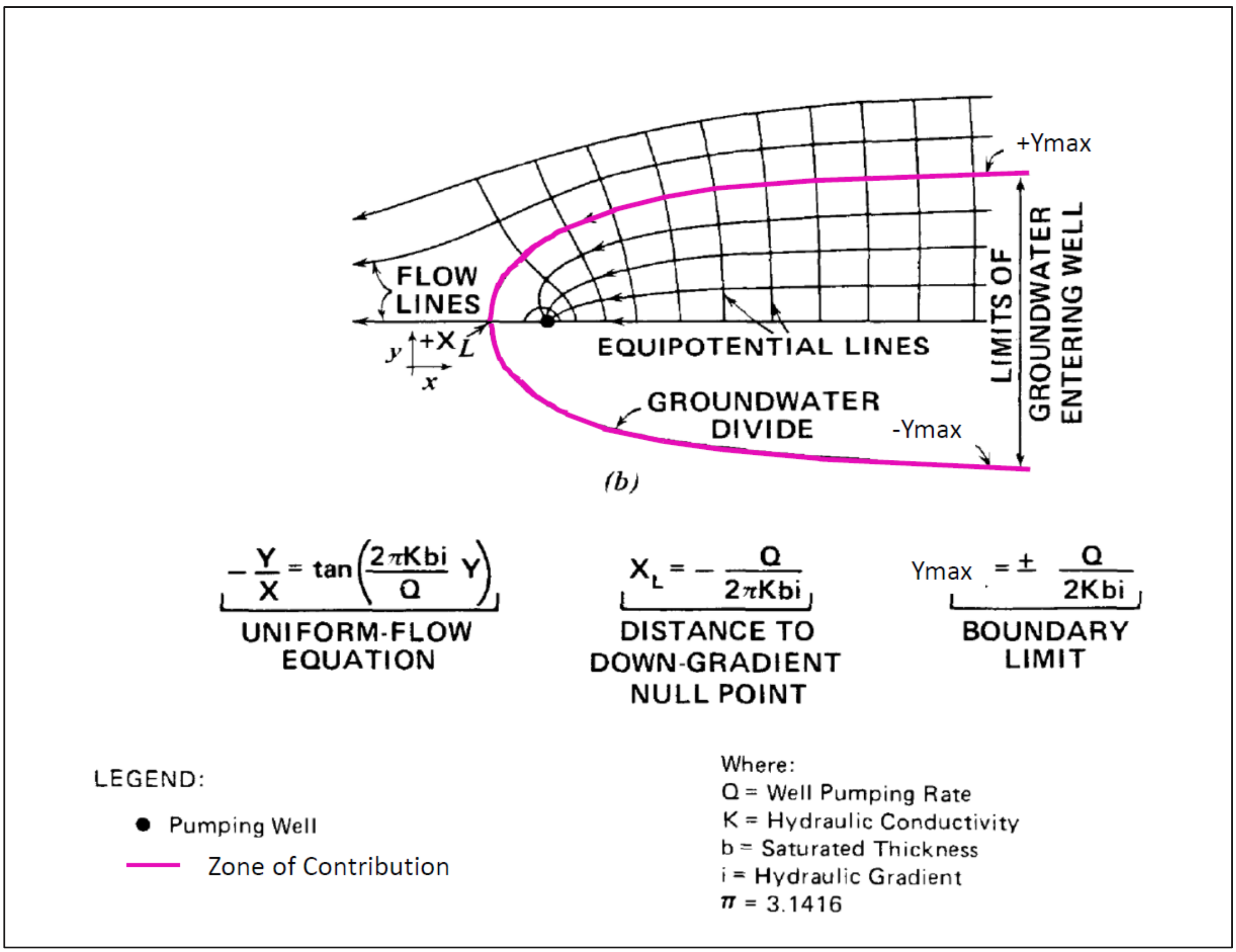

Figure 6. The Zone of Contribution Shape of a Pumping Well Completed in an Aquifer in which the Potentiometric Surface Has a Slope Formed by the Aquifer Flow Gradient.

Since **Transmissivity T=Kb**, the EPA substituted Transmissivity (T) in the above equation for hydraulic conductivity (K) and aquifer thickness (b). The reason for this substitution is because the transmissivity values were more directly based on results from the aquifer pump tests conducted by Powertech and the TVA. The hydraulic conductivity values were calculated from the transmissivity values. For a discussion of the aquifer pump tests and the aquifer parameters determined from pump test results, see Appendix J of the Class III Area Permit.

The Uniform Flow Equation assumes the well is continuously pumping with steady state flow. This is a very conservative estimate of the well flow, because it greatly overestimates the up-gradient extent of the capture zone for each well. In reality each well is being pumped only intermittently.

Implications of Assuming a Continuously Pumping Well in the CZA

As stated above, the assumption that the well is continuously pumping results in a very large over estimation of the up-gradient extent of the well capture zone. When a well is pumped continuously, the capture zone is continually expanding up-gradient over time. When a well stops pumping, the capture zone decreases in size as the aquifer potentiometric surface begins recovering from pumping. A private well is not pumped continuously; therefore, under actual conditions of private well use, the capture zone increases while the well is pumped, then decreases when well pumping stops. As a result of the underlying assumption of continuous pumping associated with the CZA equation the EPA used, the capture zones calculated for each well in this analysis greatly overestimates the actual captures zone up-gradient extent for an intermittently pumping private drinking water well.

Equation for Calculating the Maximum Width of a Well's Capture Zone: The width of a well's capture zone is important to consider when a well is located cross-gradient from the AE area. In order to determine the maximum width the capture zone can attain, the boundary limit equation found in Figure 4-10 of the EPA *Handbook on Ground Water and Wellhead Protection* was used:

$$\text{Boundary limit} \quad Ymax = \pm \frac{Q}{2Kbi}$$

Transmissivity was used in this equation instead of Kb.

Spreadsheets Containing the CZA Calculations: The Excel spreadsheets entitled *CaptureZoneCalculations_2047.pdf* and *CaptureZoneCalculations_1000gpd_2047*.pdf contain all the CZA calculations for each well for which a CZA was performed and the input parameters used for each equation. These two spreadsheets are part of the administration record for the Class III Draft Area Permit and are available on the EPA Region 8 UIC Program website: https://www.epa.gov/uic/uic-epa-region-8.

Each spreadsheet contains worksheets labeled for each well for which a CZA was performed. Table 2 lists the wells for which a CZA was performed. Wells 40 and 4002 are located so closely together they were treated as a single well for the purpose of the CZA and there is one worksheet containing the calculations for both wells. Similarly, wells 42 and 704 are located so closely together they were treated as a single well for the purpose of the CZA and there is one worksheet containing the calculations for both wells. Because the formation of completion for well 41 is unknown, there are two worksheets for well 41: 1) the CZA calculations using input values for the Fall River and 2) the CZA calculation using

Well ID#	Sec,Township Range	Screened Interval & Project Site Area	Distance & Direction from Aquifer Exemption Boundary	Year Constructed/# Years & Days of Operation through 2047	Historic Values for Flow rate gpm
2	SESE Sec 16 T7S R1E	Chilson Burdock	4,600' downgradient from B-WF2	1930s, Use 1930 43,100 days	30 gpm which is greater than the SEO allows without water rights permit Use 18 gpm / 25,920 gpd
7	NWNW Sec 23 7S 1E	Fall River Burdock	4,750' crossgradient from B-WF2	Late 1950s, Use 1958 32,873 days	4.25 gpm 6,120 gpd
8	SWSE Sec 23 23 7S 1E	Fall River Burdock	9,625' crossgradient from B-WF2	Well repair form 1951. Casing had corroded away. Assume original well drilled in 1930 43,100 days	2.5 gpm 3,600 gpd
13	NWNW Sec 3 T7S R1E	Chilson Burdock	1,750' downgradient from B-WF10	1950s, Use 1950 35,795 days	Notice of well construction says well flows at 1 gpm, 1,440 gpd
18	SWSW Sec 9 T7S R1E	Fall River Burdock	7,880' downgradient from B-WF4	Late 1920s to early 1930s Use 1930 43,100 days	8 gpm 11,520 gpd
40	SWNW Sec 30 T6S R1E	Inyan Kara Dewey	2,187.5' crossgradient from D-WF2	1969 28,855 days	2 gpm 2,880 gpd
41	SWNE Sec 31 T6S R1E	Fall River Dewey	2,750' downgradient From D-WF3 3,300' crossgradient from D-WF1	No information Use 1930; 43,100 days	12 gpm 17,280 gpd
41	SWNE Sec 31 T6S R1E	Chilson Dewey	3,000' downgradient From D-WFs 2&4 3,300' crossgradient from D-WF1	No information Use 1930; 43,100 days	12 gpm 17,280 gpd
42	SWNE Sec 5 T7S 1E	Chilson Dewey	4,800' downgradient From D-WF4	1949 36,160 days	Flows 30 gpm, Use 18 gpm 25,920 gpd
43	SWSE Sec 34 T6S R1E	Chilson Burdock	3,600' crossgradient from B-WF8 875' crossgradient from B-WF10	No information Use 1930; 43,100 days	No info Use 18 gpm 25,920 gpd
704	SWNE Sec 5 T7S 1E	Chilson Dewey	4,800' downgradient From D-WF4	2008 14,611 days	No info Use 18 gpm 25,920 gpd
4002	NWSW Sec 30 T6S R1E	Inyan Kara Dewey	2,125' crossgradient from D-WF2	1940s Use 1940 39,448 days	No info Use 18 gpm 25,920 gpd

Table 2. Well Location Information and the Values for Age and Flow Rate of Well Used in the Capture Zone Equation.

input values for the Chilson. In some cases, there was more than one value for porosity, aquifer thickness and transmissivity for some of the wells. The worksheets for these wells contain calculations using all the possible input values. The calculated values that result in the largest capture zone were used for the CZA for each well.

Equation Input Parameters

Travel time: *Travel time* means the time it took groundwater to travel from the up-gradient edge of the well's capture zone to the well location. The age of the well was used as the travel time value, t_x, for the equation. The life of each well is based on the well construction date through the end of 2047. The end of 2047 was used because by this time the EPA expects that, if the final Class III Area Permit is issued as a Final Permit, Powertech will have completed ISR operations at Dewey-Burdock Project Area.

The EPA performed another set of calculations to determine how long it would take the capture zone for each well to extend far enough to reach the AE boundary. Table 3 shows this distance for each of the wells. Wells 7, 8, 40 and 4002 are located cross-gradient to the AE boundary relative to the direction of groundwater flow. The equation that calculates the maximum width of a capture zone does not include a time variable; therefore, capture zone width is independent of the time a well will be pumping groundwater from the aquifer. As a result, the capture zone for these wells will never intersect the AE boundary. Because the direction of groundwater flow is nearly due west at the location of well 18, the nearest up-gradient AE boundary for well 18 is Burdock wellfield 4. Figure 6 shows the direction of groundwater flow at the location of well 18 based on the aquifer potentiometric surface contours. Direction of groundwater flow is perpendicular to the aquifer potentiometric surface contours.

If no construction date was available for a well, the construction date of the oldest well in the area was used to estimate the travel time input value for the equation. Table 2 shows the well construction dates used to calculate the life of each well for which a CZA was performed.

Powertech has an agreement in place with the owners of all the private wells located within the Dewey-Burdock Project Area that allows Powertech to remove each well from private use prior to start-up of ISR operations. Therefore, the wells located within the Dewey-Burdock Project Area will no longer be used as drinking water wells once the ISR project begins operation. Powertech will provide a new water supply prior to start-up of ISR operations by installing two wells completed in the Madison Formation: one in the Dewey Area and one in the Burdock Area. Powertech submitted a water rights application to the South Dakota Water Rights Program to obtain water rights to the Madison Formation aquifer.

As mentioned earlier, because wells 40 and 4002 are located so closely together, for the purposes of the CZA, these two wells were considered to be one well, flowing at the combined rate of both wells. The age of the older of the two wells, well 4002, was used in the capture zone calculation, because that is the longer travel time value and results in the larger capture zone. Similarly, wells 42 and 704 were considered to be one well flowing at the combined rate of both wells. The age of the older of the two wells, well 42, was used in the capture zone calculation, because that is the longer travel time value and results in the larger capture zone.

Table 3. Time of Travel for the Capture Zones of the 11 Wells to Reach the AE Boundary

Well ID#	Sec, Township Range	Screened Interval Project Site Area	Distance & Direction from AE Boundary	No. Years after Construction CZ Crosses AE Boundary	Year the CZ Crosses AE Boundary
2	SESE Sec 16 T7S R1E	Chilson Burdock	4,600' down-gradient from B-WF2	376.5	2306
7	NWNW Sec 23 7S 1E	Fall River Burdock	4,750' cross-gradient from B-WF2	Width of capture zone will never increase beyond 402' from well 7 toward B-WF2, so CZ for well 7 will never reach AE boundary	
8	SWSE Sec 23 23 7S 1E	Fall River Burdock	9,625' cross-gradient from B-WF2	Width of capture zone will never increase beyond 340' from well 8 toward B-WF2, so CZ for well 8 will never reach AE boundary	
13	NWNW Sec 3 T7S R1E	Chilson Burdock	1,750' down-gradient from B-WF10	139.75	2089
18	SWSW Sec 9 T7S R1E	Fall River Burdock	7,880' down-gradient from B-WF4	848	2778
40 & 4002	Sec 30 T6S R1E	Inyan Kara Dewey	2,125' cross-gradient from D-WF2	Width of capture zone will never increase beyond 144' from well 4002 toward D-WF2 so CZ for wells 40 & 4002 will never reach AE boundary	
41 Fall River	SWNE Sec 31 T6S R1E	Fall River Dewey	2,750' down-gradient From D-WF3 3,300' cross-gradient from D-WF1	323.6	2253
41 Chilson	SWNE Sec 31 T6S R1E	Chilson Dewey	3,000' down-gradient From D-WFs 2&4 3,300' cross-gradient from D-WF1	90.4	2020
42 & 704	SWNE Sec 5 T7S 1E	Chilson Dewey	4,800' down-gradient From D-WF4	151	2100
43	SWSE Sec 34 T6S R1E	Chilson Burdock	3,600' down-gradient from B-WF8 875' cross-gradient from B-WF10	886.4	2816
				Ymax = 188	

Transmissivity: *Transmissivity* is a hydrologic term for a measure in ft^2/day of the amount of groundwater that can be transmitted horizontally through a unit width by the full saturated thickness of the aquifer under a hydraulic gradient of 1 ft/ft. The transmissivity values used for the CZA were taken from the pump test report included as Appendix J of the Class III Permit Application. The TVA performed pump tests in the Dewey Area in 1979 and in the Burdock Area in 1982. For the TVA pump test in the Dewey Area, the pumping well was completed in the Chilson Sandstone. The TVA performed two pump tests in the Burdock Area: one with the pumping well screen open in the Chilson Sandstone and one with the pumping well screen open in the Fall River. The transmissivity values from the TVA pump tests are included in Table 4.

Powertech also performed pump tests in the Dewey and Burdock Areas. For the Powertech pump test in the Dewey Area, the pumping well was completed in the Fall River. For the Powertech pump test in the Burdock Area, the pumping well was completed in the Chilson Sandstone. The transmissivity values from the Powertech pump tests are included in Table 4.

Table 4. Fall River Formation and Chilson Sandstone Transmissivity Values Measured from TVA and Powertech Pump Tests.

	TVA Pump Tests	Powertech Pump Tests
Dewey Area		
Fall River Transmissivity		255 ft^2/day
Chilson Transmissivity	590 ft^2/day	
Burdock Area		
Fall River Transmissivity	54 ft^2/day	
Chilson Transmissivity	190 ft^2/day	150 ft^2/day

There are two transmissivity values available for Chilson wells in and near the Burdock Area. For the Chilson wells the calculations were performed using both transmissivity values as shown in the spreadsheets.

The larger the transmissivity value, the longer the up-gradient extent of the capture zone that is calculated. Therefore, it is more conservative to use the larger transmissivity values in the first calculation. However, for calculating the maximum width of the capture zone, the lower transmissivity calculated a wider the maximum extent of the capture zone. Therefore, it is more conservative to use the smaller transmissivity value in the capture zone width calculation. For Chilson wells in and near the Burdock Area, the up-gradient extent of each capture zone is based on the larger transmissivity value and the maximum width of each capture zone is based on the smaller transmissivity value. Tables 4 and 5 show the transmissivity values used in the CZA calculations for each well.

The purple color code used for wells 40 and 4002 in Figure 1 indicates they are completed in the Inyan Kara aquifers, meaning both the Fall River and Chilson aquifers. However, well depth information found in TVA records in Appendix B of the UIC Class III Permit Application indicates the well depths are no deeper than 700 feet, which would have them completed only in the Fall River Formation. Therefore, Fall River parameters were used for the CZA for wells 40 and 4002.

As mentioned earlier, the completion aquifer for well 41 is unknown, so a CZA calculation for well 41 was performed for the Fall River aquifer and the Chilson Sandstone aquifer.

Flow Rate (Q): The *flow rate* is the gallons per minute of groundwater being pumped from a well. The EPA evaluated two different scenarios for flow rate in the CZA equations. No records are available on actual domestic use pumping rates for the 11 private wells. Therefore, in the first scenario, the EPA used the information available on the EPA Water Sense[4] website for residential water use. The website estimates that the average American family of four uses 400 gallons of water per day. On average, approximately 70 percent of that water is used indoors, with the bathroom being the largest consumer (a toilet alone can use 27 percent). The largest family in the Dewey-Burdock area consisted of 10 people, so the EPA increased the estimated water usage for each household with a private well to 1,000 gallons per day (gpd), which would be the expected usage for a household consisting of 10 people. An estimated flow of 1,000 gpd is a conservative estimate for drinking water usage, because it includes 30% expected for outdoor usage and the remaining 70% includes other indoor uses such as laundry, bathing and toilet use.

For the second scenario, the EPA used information available in well records or historic TVA records for flow rates from some of the wells that flowed naturally to the ground surface. These historic flow rates are shown in Table 2. These flow rates represent the maximum flow volume the well is capable of producing if allowed to flow freely to the ground surface under natural artesian conditions without pumping. For those wells for which no record of flow rate was available, the EPA used the maximum value allowed by the South Dakota State Engineer's Office for a private well without a water rights permit.[5] This flow rate is 18 gallons per minute (gpm) or 25,920 gpd and represents continuous pumping of these wells 24 hours a day. These flow rate values, coupled with the underlying assumption that the well is pumping continuously, are extreme and greatly overestimate the groundwater usage expected for a well serving a single family residence.

The EPA performed calculations using historic flow rates, if available, 25,920 gpd if no historic flow rate was available and a flow rate of 1,000 gpd for each capture zone calculation. The calculations, input values and final results are included in Excel spreadsheets *CaptureZoneCalculations_2047*.pdf and *CaptureZoneCalculations_1000gpd_2047.pdf* , which are part of the administrative record for the Class III Draft Area Permit on the EPA Region 8 UIC Program website: https://www.epa.gov/uic/uic-epa-region-8. As mentioned earlier, because wells 40 and 4002 are located so closely together, for the purposes of the CZA these two wells were considered to be one well, flowing at the combined rate of both wells. Similarly, wells 42 and 704 were considered to be one well flowing at the combined rate of both wells.

Table 5 shows the flow rates used as the input values for each well for which a CZA was performed.

Porosity: Porosity, for the purpose of this calculation is actually the effective porosity, which is the percentage of the aquifer volume that is void space and available to contain groundwater. The porosity values used for the CZA were taken from Table 6.1 in the pump test report included as Appendix J of the Class III Permit Application. These porosity values are based on laboratory analyses of core taken

[4] http://www.epa.gov/WaterSense/pubs/indoor.html

[5] None of the wells in question have a water rights permit; therefore, this is the maximum amount that they would be allowed to pump.

from the Dewey-Burdock site. There are horizontal porosity values and vertical porosity values included in Class III Permit Application, Appendix J, Table 6.1. The horizontal porosity values were used in the CZA calculation.

The Chilson Sandstone (labeled “Lakota Sand”) porosity was measured in core from drillhole DB-07-11-14C located in Section 11, Township 7 South, Range 1 East in the Burdock Area. Two Chilson Sandstone horizontal porosity measurements are listed in Class III Permit Application, Appendix J, Table 6.1 for the core taken from drillhole DB 07-11-14C: 29.56% and 31.90%. There is also a porosity value of 30.5% for the Chilson Sandstone measured in core taken from drillhole DB 07-11-16C also located in Section 11, Township 7 South, Range 1 East in the Burdock Area.

The porosity value for the Fall River Formation was measured in core taken from drillhole DB-07-32-4C located in Section 32, Township 6 South, Range 1 East in the Dewey Area. This porosity value is 29.04%.

Table 5 shows the porosity values used in the CZA calculation for each well.

Hydraulic Gradient: The *hydraulic gradient* in ft/ft is the vertical change in an aquifer’s potentiometric surface elevation (in feet) relative to the horizontal distance (in feet) over which the vertical change is measured. The hydraulic gradient at the location of each well was calculated based on the distance between the contour lines on the potentiometric surface elevation maps for the Fall River and Chilson Sandstone aquifers. The Fall River aquifer potentiometric surface elevation map is Figure 2.3 in the pump test report included as Appendix J in the Class III Permit Application. The Chilson Sandstone aquifer potentiometric surface elevation map is Figure 2.4 in the pump test report included as Appendix J in the Class III Permit Application. If Figures 2.3 and 2.4 are enlarged to 320%, the approximate distance scale is 1 inch = 0.4 miles or 2,112 ft. The hydraulic gradient for each well for which a CZA was performed was calculated from the portions of each potentiometric surface elevation map shown in Figures 7 through 14. The hydraulic gradient values used in the CZA calculations for each wells are shown in Table 6.

Well ID#	Sec, Township Range	Screened Interval	Transmissivity (T) (ft^2/day)	Porosity (n) (%)	Hydraulic Gradient (i) (ft/ft)	Aquifer Thickness b (ft)	Age of well at end of 2047 (days)	Flow Rate (gpd)
2	SESE 16 T7S R1E	Chilson Burdock	150 & 190	0.296 & 0.319	0.00316	63	43,100	25,920 & 1,000
7	NWNW Sec 23 7S 1E	Fall River Burdock	54 & 255	0.29	0.00308	186	32,873	6,120 & 1,000
8	SWSE Sec 23 23 7S 1E	Fall River Burdock	54 & 255	0.29	0.00364	20	43,100	3,600 & 1,000
13	NWNW 3 T7S R1E	Chilson Burdock	150 & 190	0.296 & 0.319	0.00215	45	35,795	1,440 & 1,000
18	SWSW 9 T7S R1E	Fall River Burdock	54 & 255	0.29	0.00364	128	43,100	11,520 & 1,000
40	SWNW 30 T6S R1E	Inyan Kara Dewey	255	0.29	0.00364	150	28,855	2,880 & 1,000
41	SWNE Sec 31 T6S R1E	Fall River Dewey	255	0.29	0.00421	165	43,100	17,280 & 1,000
41	SWNE Sec 31 T6S R1E	Chilson Dewey	590	0.296 & 0.319	0.00631	140	43,100	17,280 & 1,000
42	SWNE 5 7S 1E	Chilson Dewey	590	0.296 & 0.319	0.00646	150	36,160	25,920 & 1,000
43	SWSE 34 T6S R1E	Chilson Burdock	150 & 190	0.296 & 0.319	0.00237	145	43,100	25,920 & 1,000
704	SWNE 5 7S 1E	Chilson Dewey	590	0.296 & 0.319	0.00646	150	14,611	25,920 & 1,000
4002	NWSW 30 T6S R1E	Inyan Kara Dewey	255	0.29	0.00364	150	39,448	25,920 & 1,000

Table 5. The Input Values for All Variables in the Capture Zone Equation, Distance and Direction Each Well Is Located from Nearest AE Boundary and the Calculated Extent of the Capture Zone.

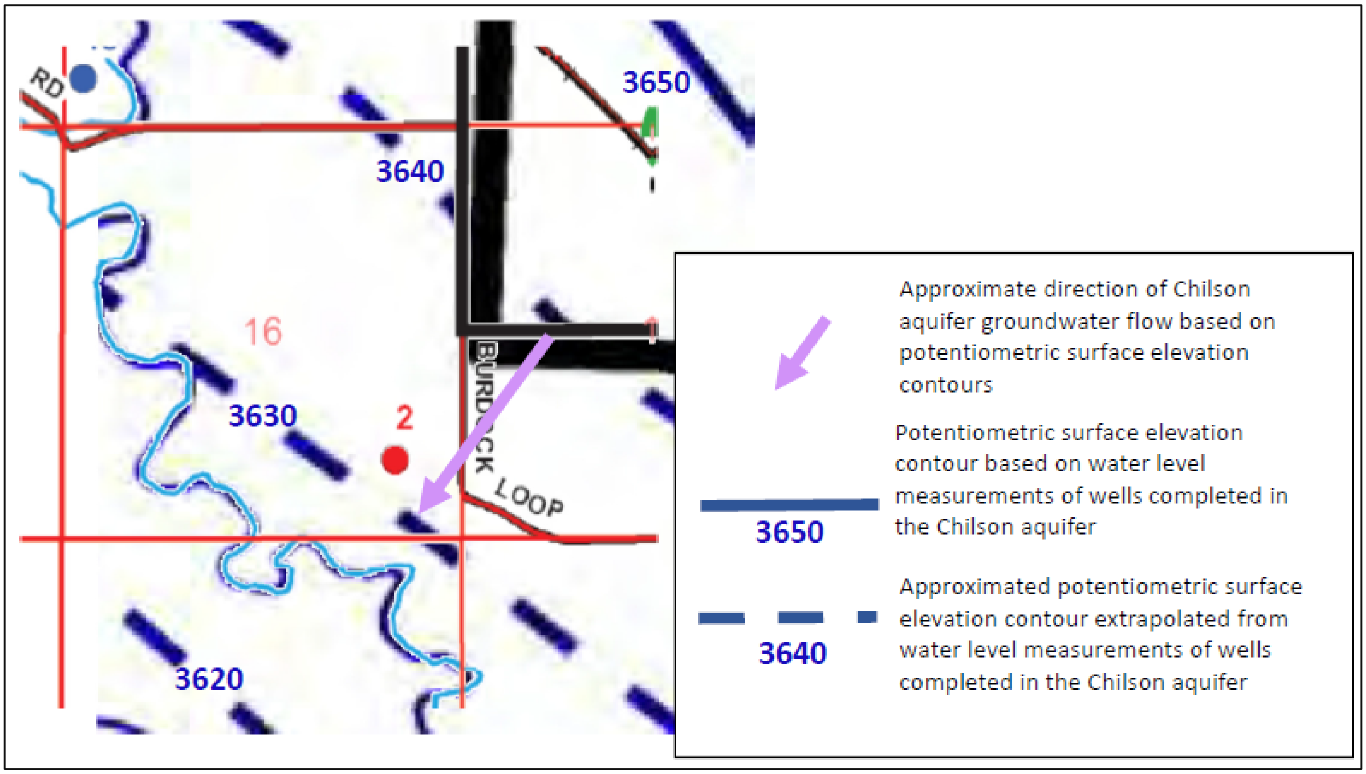

Figure 7. Hydraulic Gradient Calculation for Well 2: At the location of well 2, the Chilson potentiometric surface elevation changes from 3,640 ft to 3,630 ft (10 vertical ft) in 3,168 horizontal ft. Hydraulic gradient = 0.00316 ft/ft.

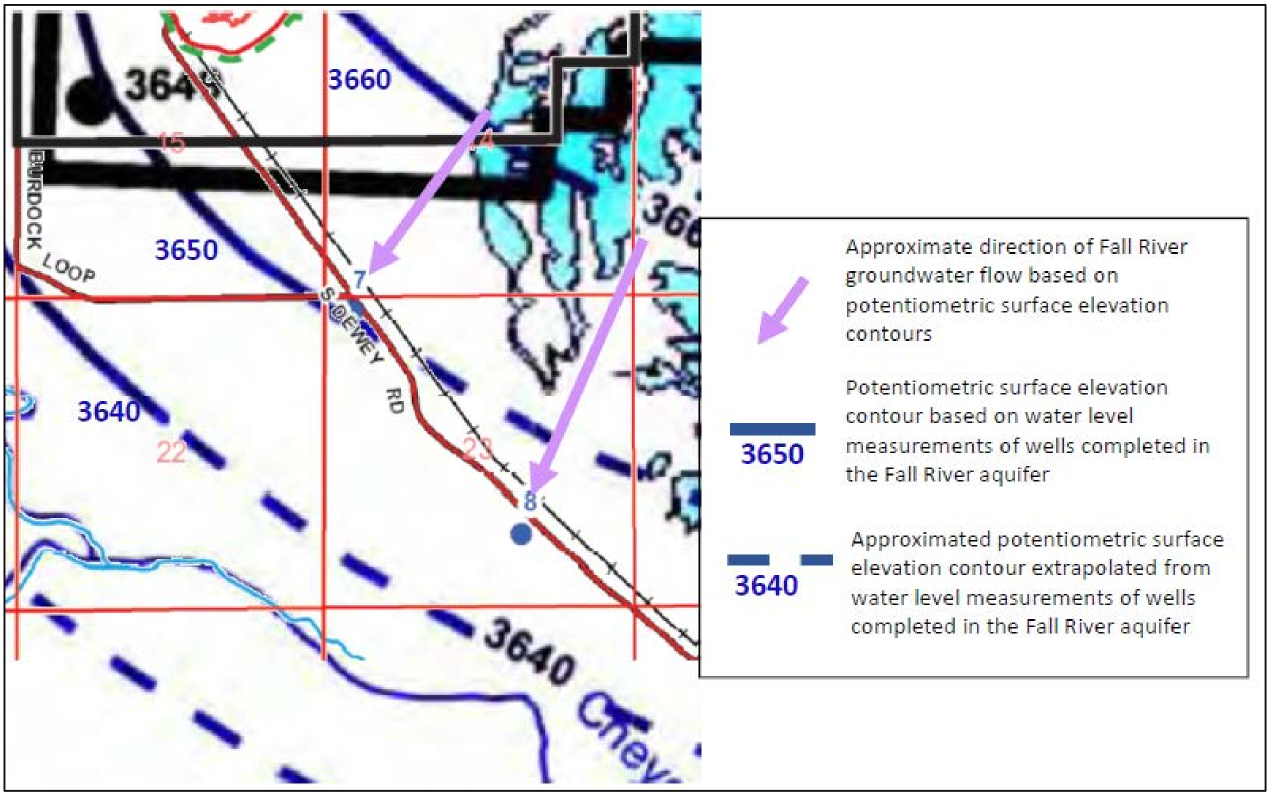

Figure 8. Hydraulic Gradient Calculation for Wells 7 and 8: At the location of well 7, the Fall River potentiometric surface elevation changes from 3,660 ft to 3,650 ft (10 vertical ft) in 3,250 horizontal ft. Hydraulic gradient = 0.00308 ft/ft. At the location of well 8, the Fall River potentiometric surface elevation changes from 3,650 ft to 3,640 ft (10 vertical ft) in 2,750 horizontal ft. Hydraulic gradient = 0.00364 ft/ft.

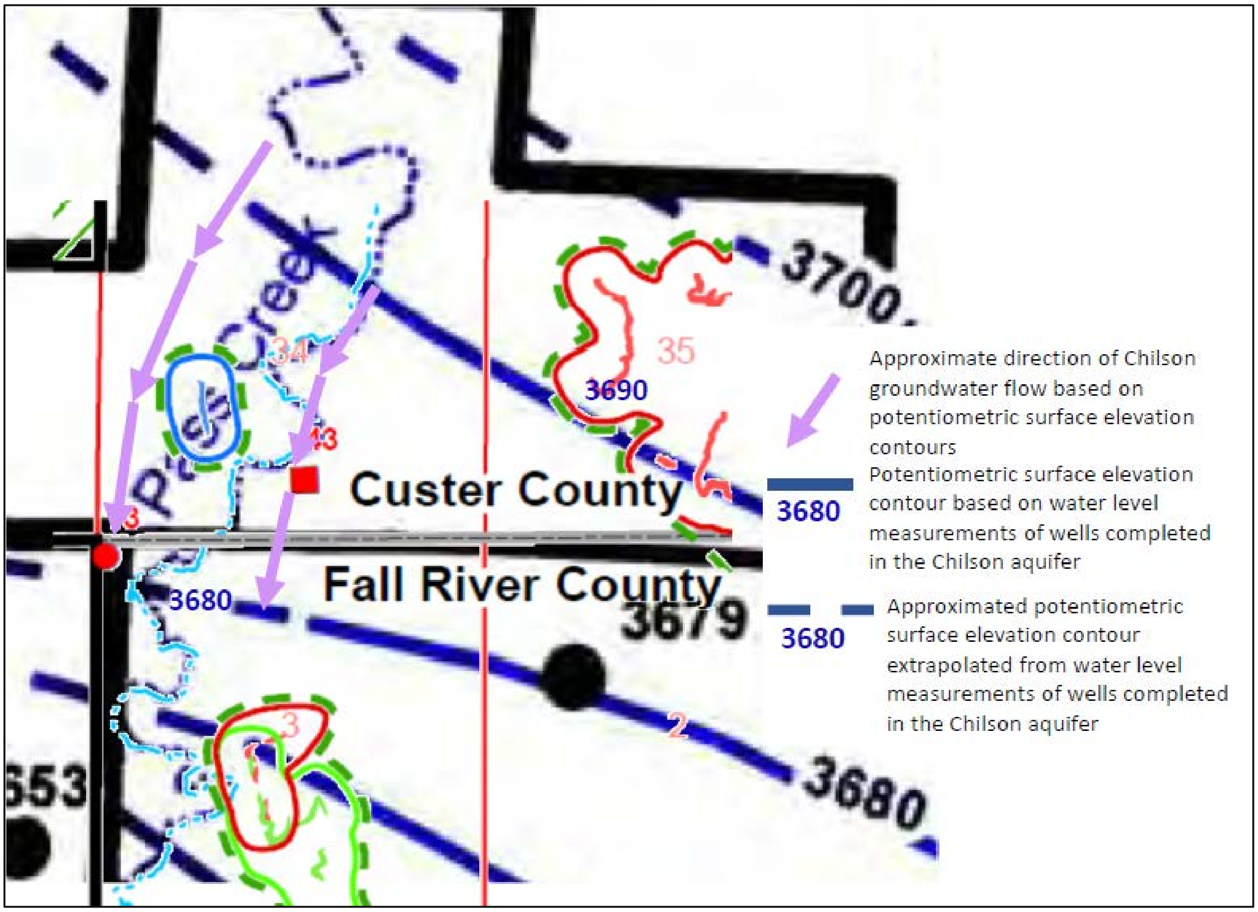

Figure 9. Hydraulic Gradient Calculation for Wells 13 and 43: At the location of well 13, the Chilson potentiometric surface elevation changes from 3,690 ft to 3,680 ft (10 vertical ft) in 4,646.4 horizontal ft. Hydraulic gradient = 0.00215 ft/ft. At the location of well 43, the Chilson potentiometric surface elevation changes from 3,690 ft to 3,680 ft (10 vertical ft) in 4,224 horizontal ft. Hydraulic gradient = 0.00237 ft/ft.

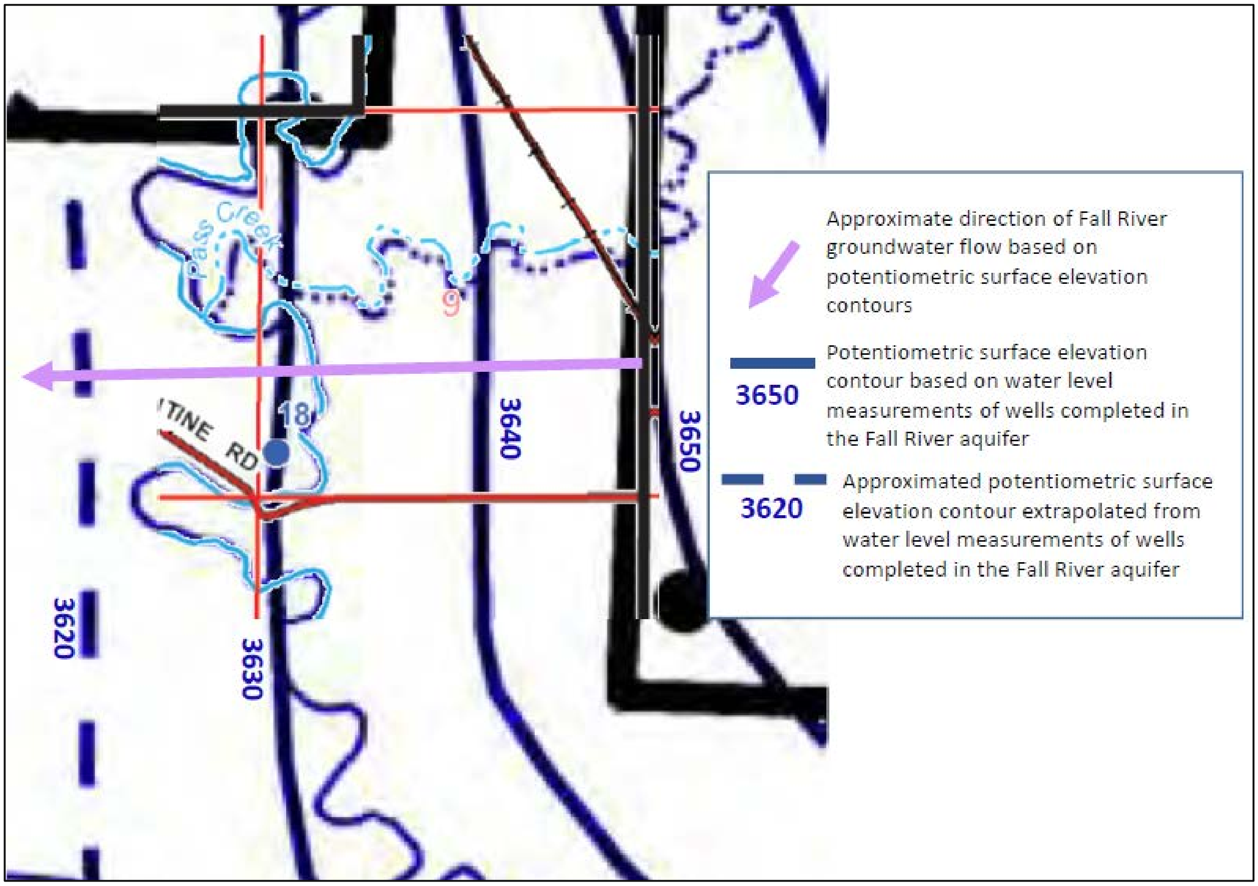

Figure 10. Hydraulic Gradient Calculation for Well 18: At the location of well 18, the Fall River potentiometric surface elevation changes from 3650 ft to 3620 ft (30 vertical ft) in 8,236.8 horizontal ft. Hydraulic gradient = 0.00364 ft/ft.

As mentioned earlier, the purple color code used for wells 40 and 4002 indicates they are completed in the Inyan Kara aquifers, meaning both the Fall River and Chilson aquifers. However, well depth information found in TVA records in Appendix B of UIC Class III Permit App indicates the well depths are no deeper than 700 feet, which would have them completed only in the Fall River Formation. Therefore, the Fall River potentiometric surface map was used to calculate the hydraulic gradient at wells 40 and 4002. Because these two wells are located so closely together, for the purposes of the CZA they were considered to be one well, flowing at the combined rate of both wells. As shown in Figure 11, only one hydraulic gradient was calculated for both wells.

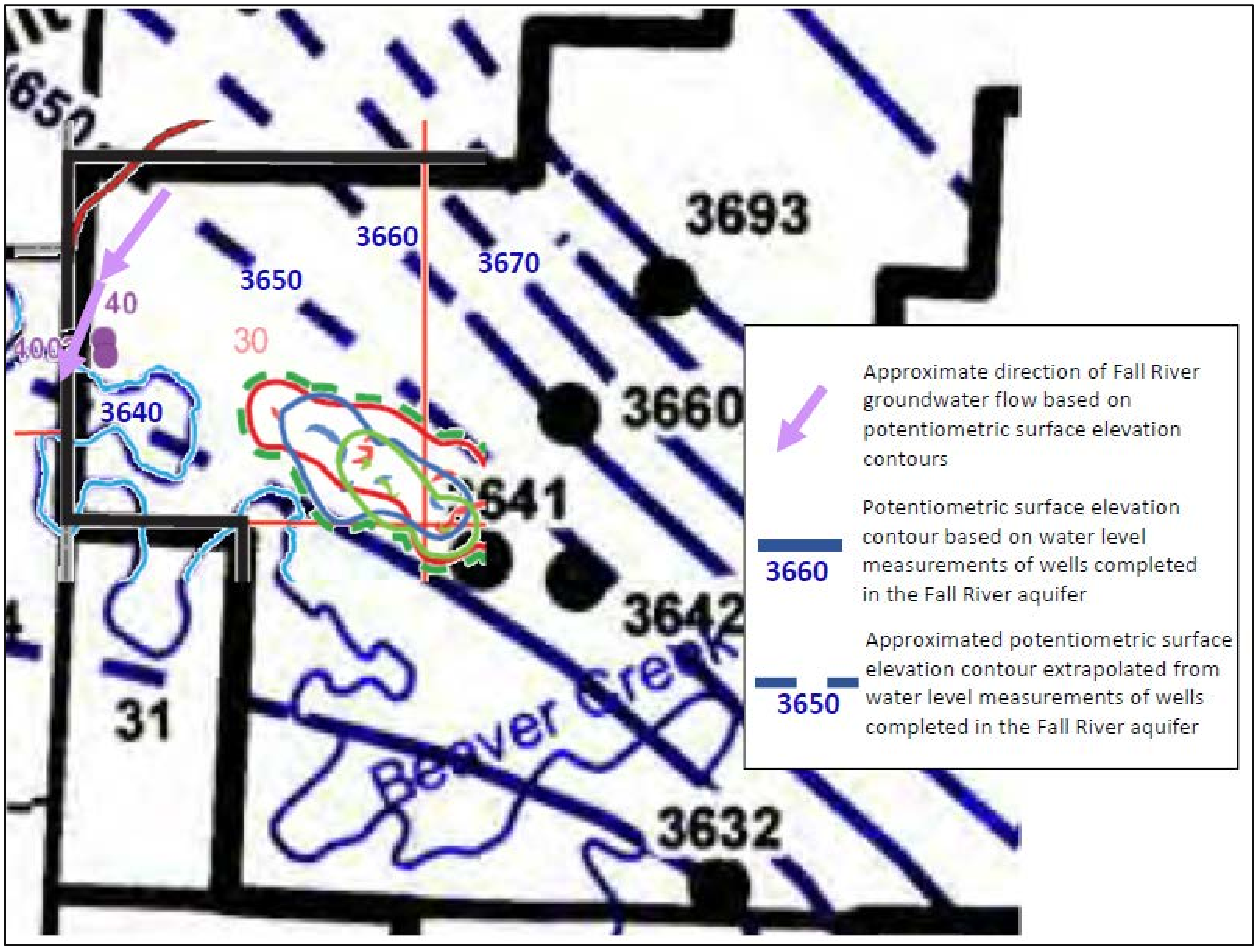

Figure 11. Hydraulic Gradient Calculation for Wells 40 and 4002: At the location of wells 40 and 4002, the Fall River potentiometric surface elevation changes from 3,650 ft to 3,640 ft (10 vertical ft) in 2,745.6 horizontal ft. The hydraulic gradient at this location = 0.00364 ft/ft.

Because the completion aquifer for well 41 is unknown, a CZA calculation for well 41 was performed for both the Fall River aquifer and the Chilson Sandstone aquifer. Figure 12 illustrates the hydraulic gradient of the Fall River aquifer at the location of well 41. The direction of groundwater flow for the Fall River in the location of 41 indicates that well 41 is 2,750 ft directly down-gradient from Dewey Wellfield 3.

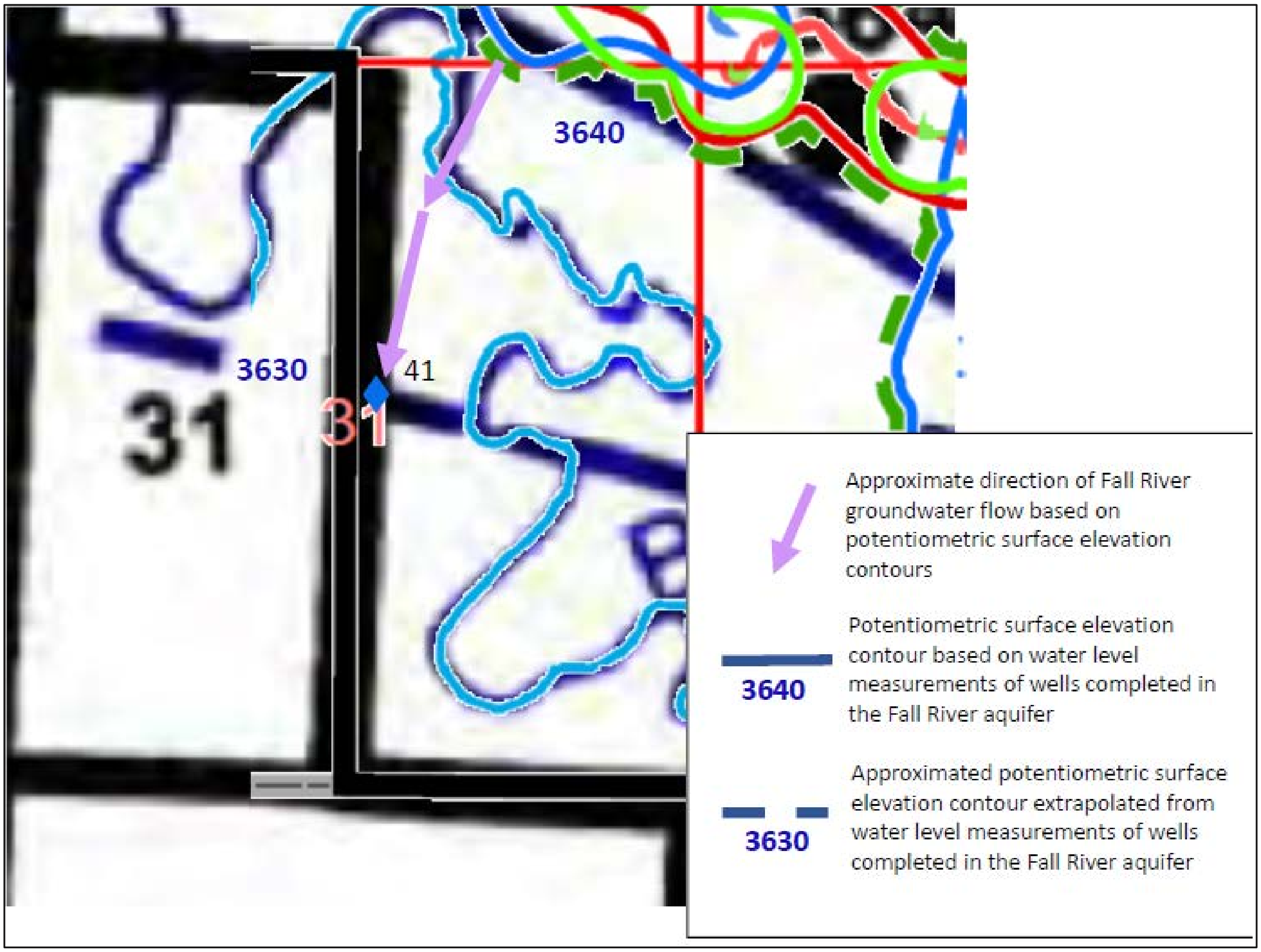

Figure 12. Hydraulic Gradient Calculation of the Fall River Aquifer at Well 41: At the location of well 41, the Fall River potentiometric surface elevation changes from 3,640 ft to 3,630 ft (10 vertical ft) in 2,376 horizontal ft. Hydraulic gradient = 0.00421 ft/ft.

Figure 13 illustrates the hydraulic gradient of the Chilson aquifer at the location of well 41. The direction of groundwater flow for the Chilson in the location of 41 is slightly different from that of the Fall River and indicates that well 41 is 3,000 ft directly down-gradient from Dewey Wellfields 2 and 4.

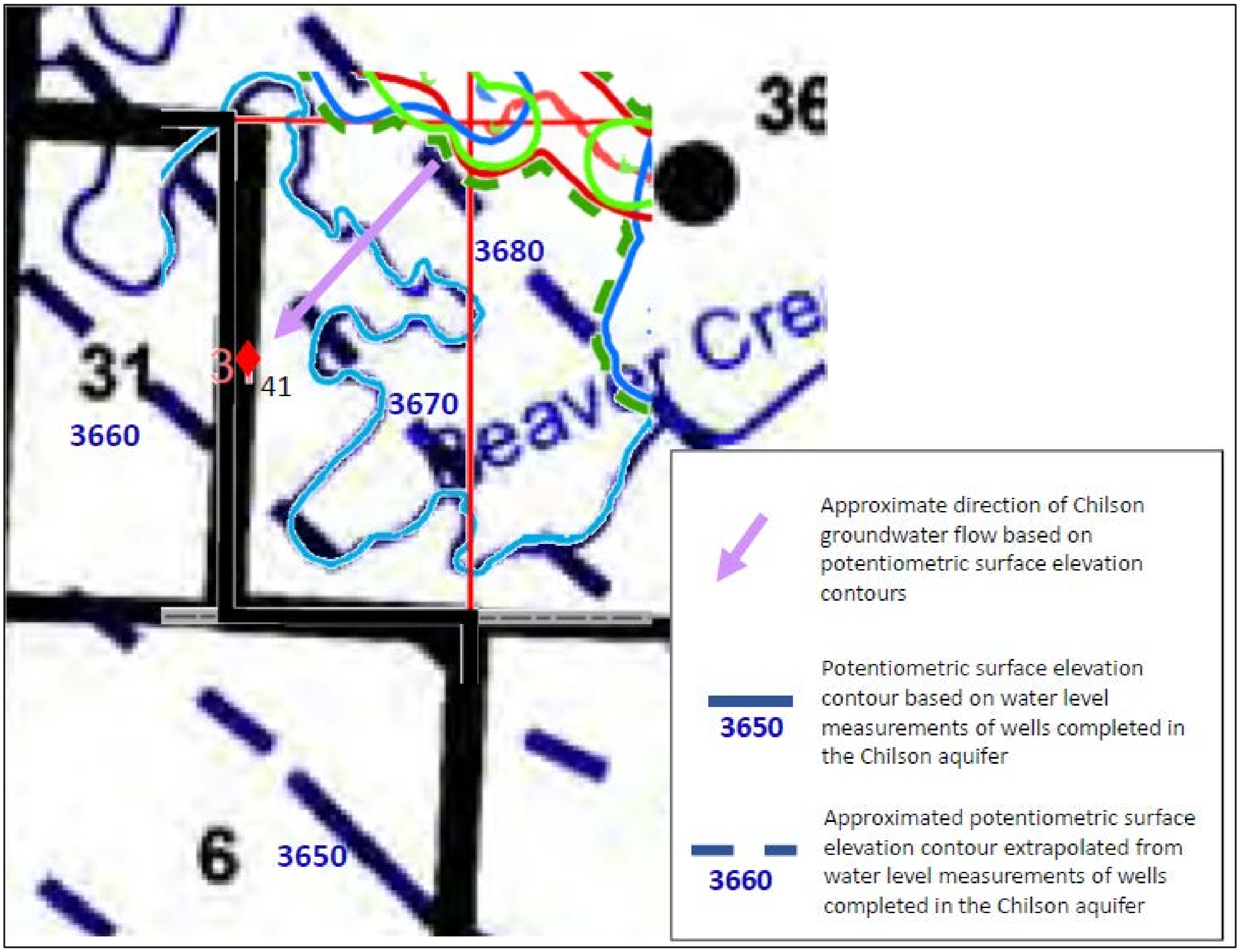

Figure 13. Hydraulic Gradient Calculation of the Chilson Aquifer at Well 41: At the location of well 41, the Chilson potentiometric surface elevation changes from 3,680 ft to 3,650 ft (30 vertical ft) in 4,752 horizontal ft. Hydraulic gradient of 0.00631 ft/ft.

Because wells 42 and 704 are located close together, for the purposes of the CZA these two wells were considered to be one well, flowing at the combined rate of both wells. As shown in Figure 14, only one hydraulic gradient was calculated for both wells.

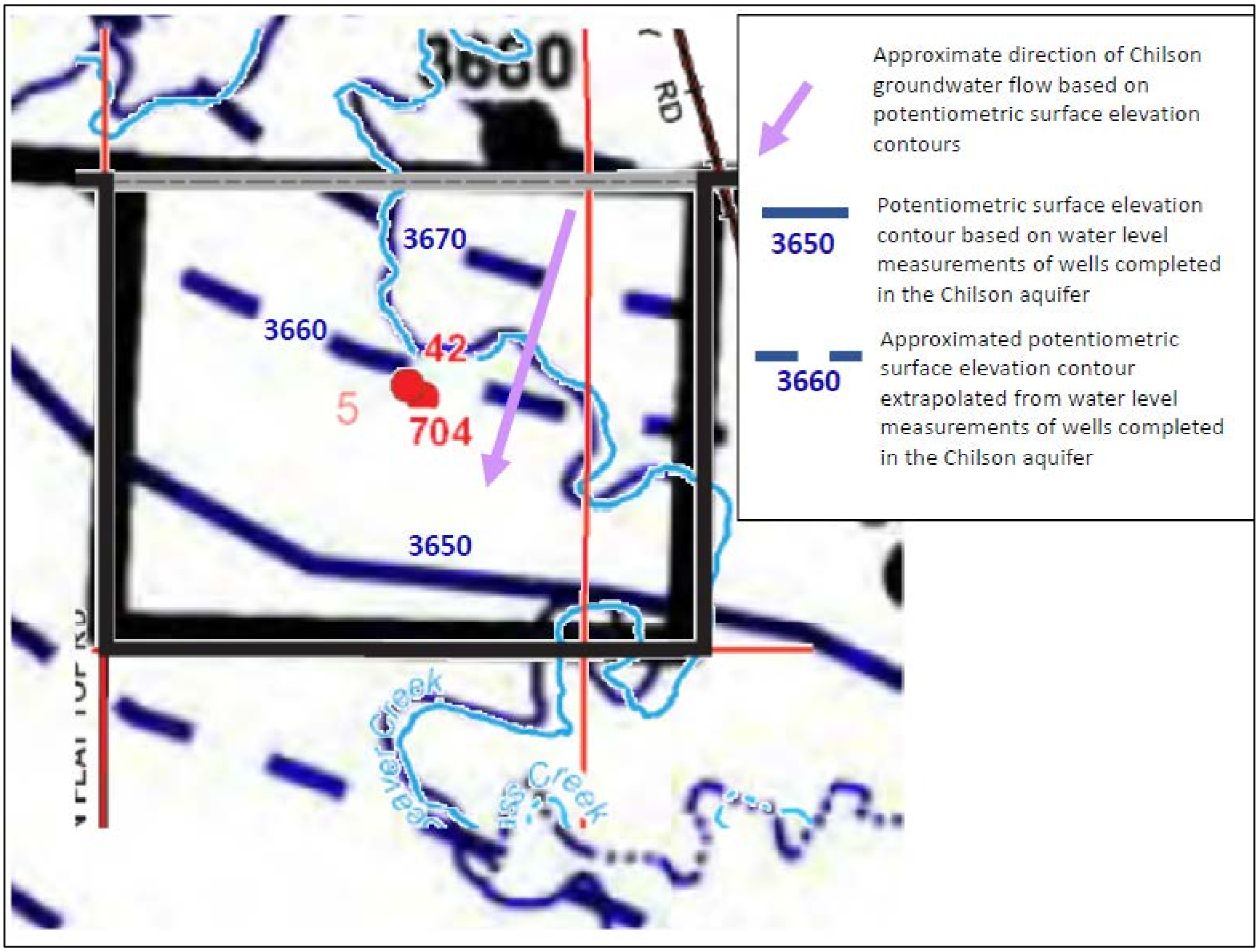

Figure 14. Hydraulic Gradient Calculation of the Chilson Aquifer at Wells 42 and 704: At the location of wells 42 and 704, the Chilson potentiometric surface elevation changes from 3,680 ft to 3,650 ft (30 vertical ft) in 4,646.4 horizontal ft. Hydraulic gradient = 0.00646 ft/ft.

Aquifer Thickness: The aquifer thickness at the location of each well was calculated based on well records, if available, or the aquifer isopach maps included in the Class III Permit Application. Isopach maps show the thickness of a geologic formation using contour lines that represent the formation thickness based on measurements from logs from drill holes and extrapolations of formation thickness between drill hole locations. Plate 6.7 is the Chilson Sandstone isopach map; Plate 6.9 is the Fall River isopach map. Figures 15 through 24 show the information used to determine aquifer thickness in the area of each well.

Table 6 lists the sources for aquifer thickness values used in the CZA calculation for each well for which a CZA was performed.

Table 6. Aquifer Thickness Values Used in the CZA Calculations and Information Sources for Aquifer Thickness

Well #s	Completion Formation	Formation Thickness	Info Source	Shown in Figure #
2	Chilson	63 ft	Notice of Well Construction; well screen	15
7	Fall River	186 ft	From oil and gas test well log API 400475093[6]	16
8	Fall River	20 ft	Length of well perfs from well repair form	17
13	Chilson	45 ft	Notice of Well Construction	18
18	Fall River	128 ft	Plate 6.9 Fall River Isopach Map	19
40 & 4002	Fall River	150 ft	Plate 6.9 Fall River Isopach Map	20
41	Fall River	170 ft	Plate 6.9 Fall River Isopach Map	21
41	Chilson	140 ft	Plate 6.7 Chilson Isopach map	22
42 & 704	Chilson	150 ft	Plate 6.7 Chilson Isopach map	23
43	Chilson	145	Plate 6.7 Chilson Isopach map	24

NOTICE OF WELL CONSTRUCTION

Screen information

slotted 566-608
629-650

Figure 15. Well Screen Information Included on the Notice of Well Construction for Well 2.

E log tops:
Dakota - 185
Lakota - 371
Morrison - 471

Figure 16. Information from Oil and Gas Test Well API 400475093 for Thickness of the Fall River (Dakota) near Well 7.
[“Lakota” in this well log refers to the Lakota Formation which includes both the Fuson and the Chilson, so the top of the Lakota here is actually the top of the Fuson confining zone]

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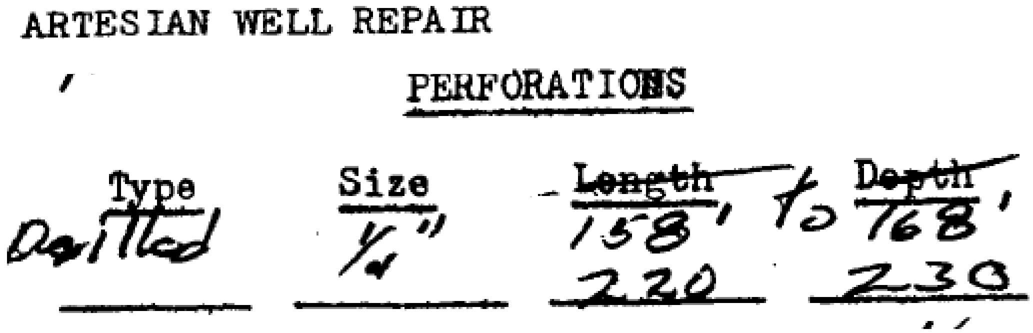
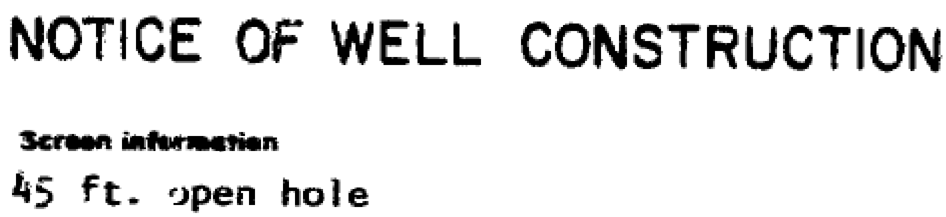
[6] Plate 3.1 of the Class III Permit Application shows how closely well 7 is located to oil and gas test well API 400475093. An excerpt of Plate 3.1 showing the locations of well 7 and oil and gas test well API 400475093 is included in the spreadsheet worksheet for well 7.


ARTESIAN WELL REPAIR

PERFORATIONS

Type	Size	Length	Depth
Drilled	1/4"	158' to	768'
		220	230

Figure 17. Well Perforation Information from Well Repair Form for Well 8.


NOTICE OF WELL CONSTRUCTION

Screen information

45 ft. open hole

Figure 18. Well Screen Information Notice of Well Construction for Well 13.

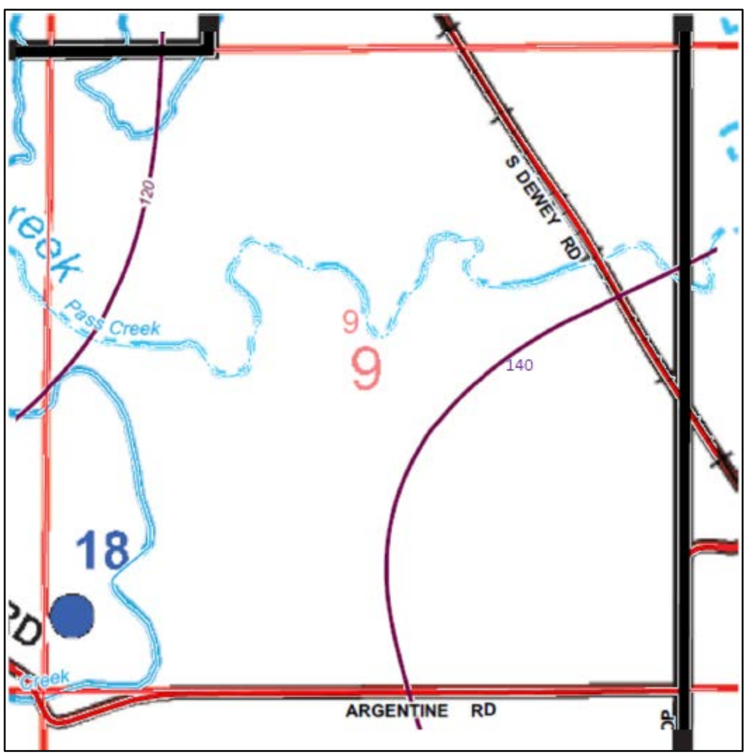


Figure 19. Fall River Thickness at the Location of Well 18 from Plate 6.9, Fall River Isopach Map.

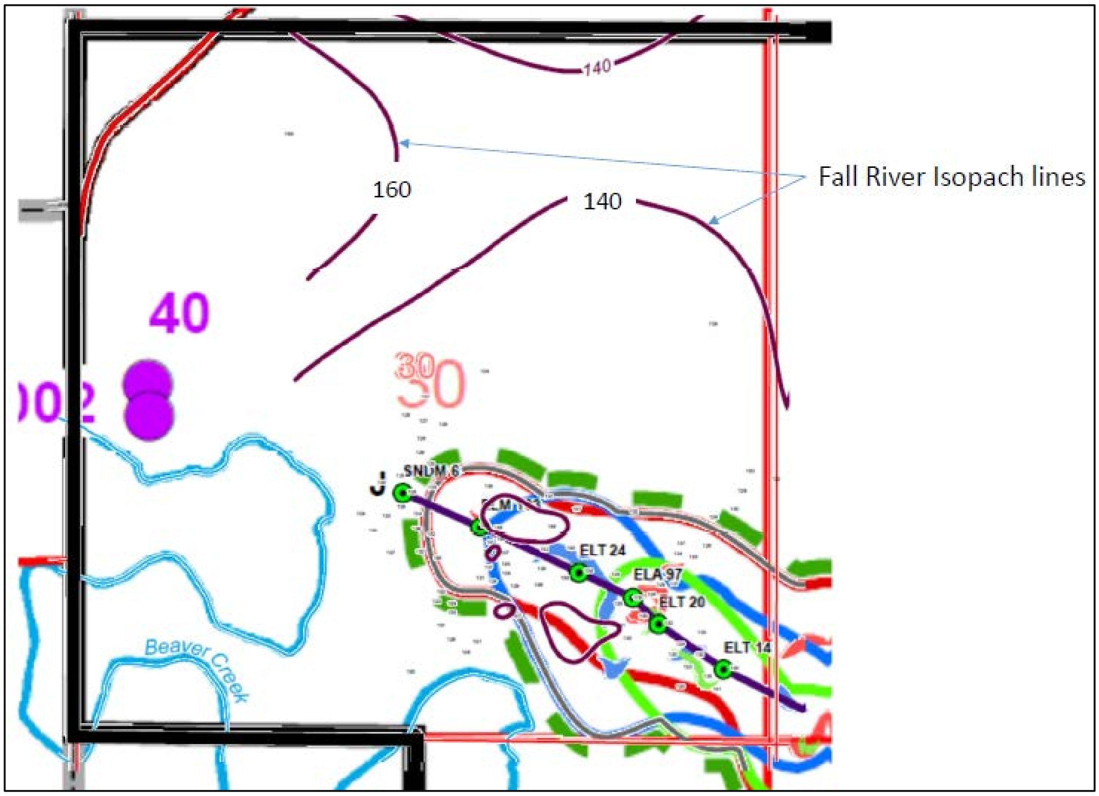


Figure 20. Fall River Thickness at the Location of Wells 40 and 4002 from Plate 6.9, Fall River Isopach Map.

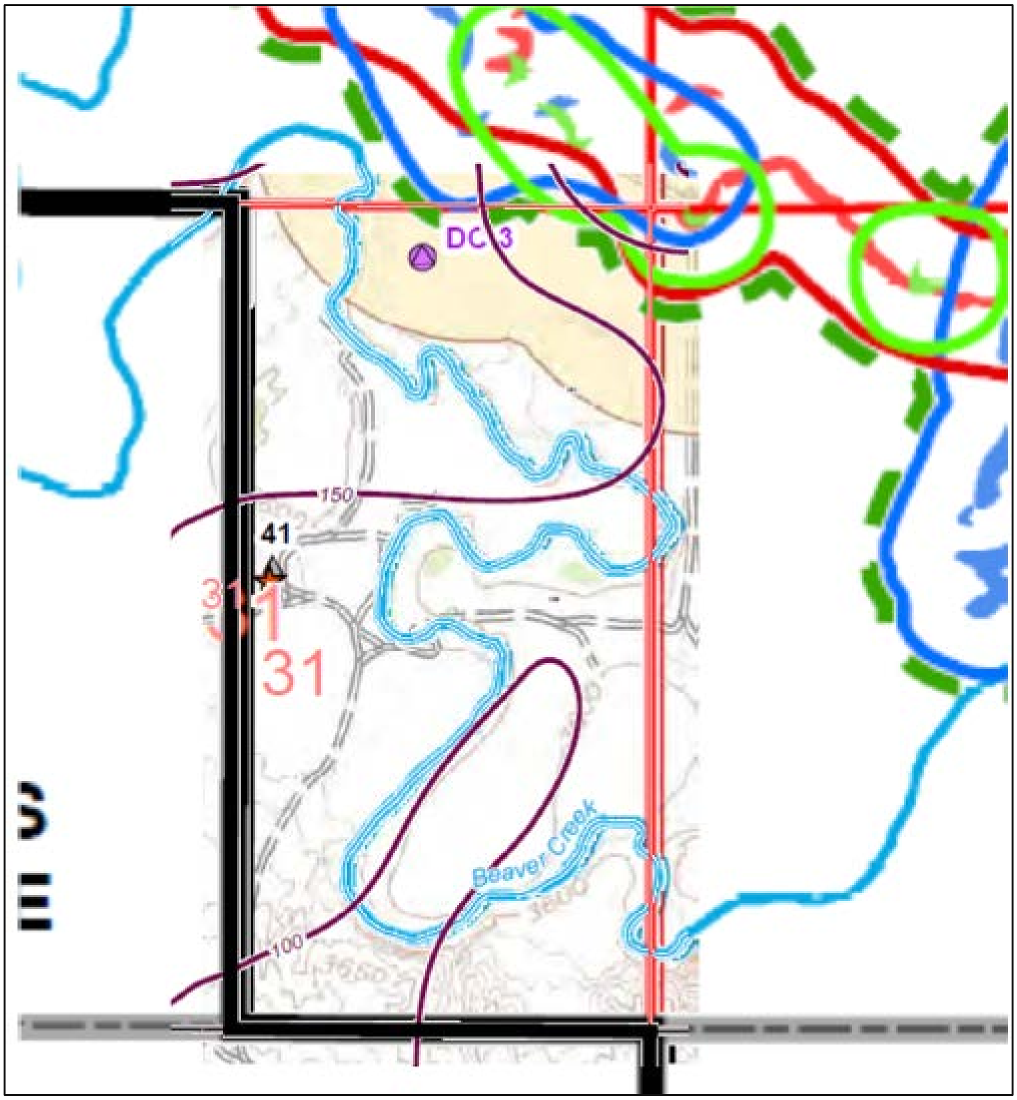


Figure 21. Fall River Thickness at the Location of Well 41 from Plate 6.9, Fall River Isopach Map

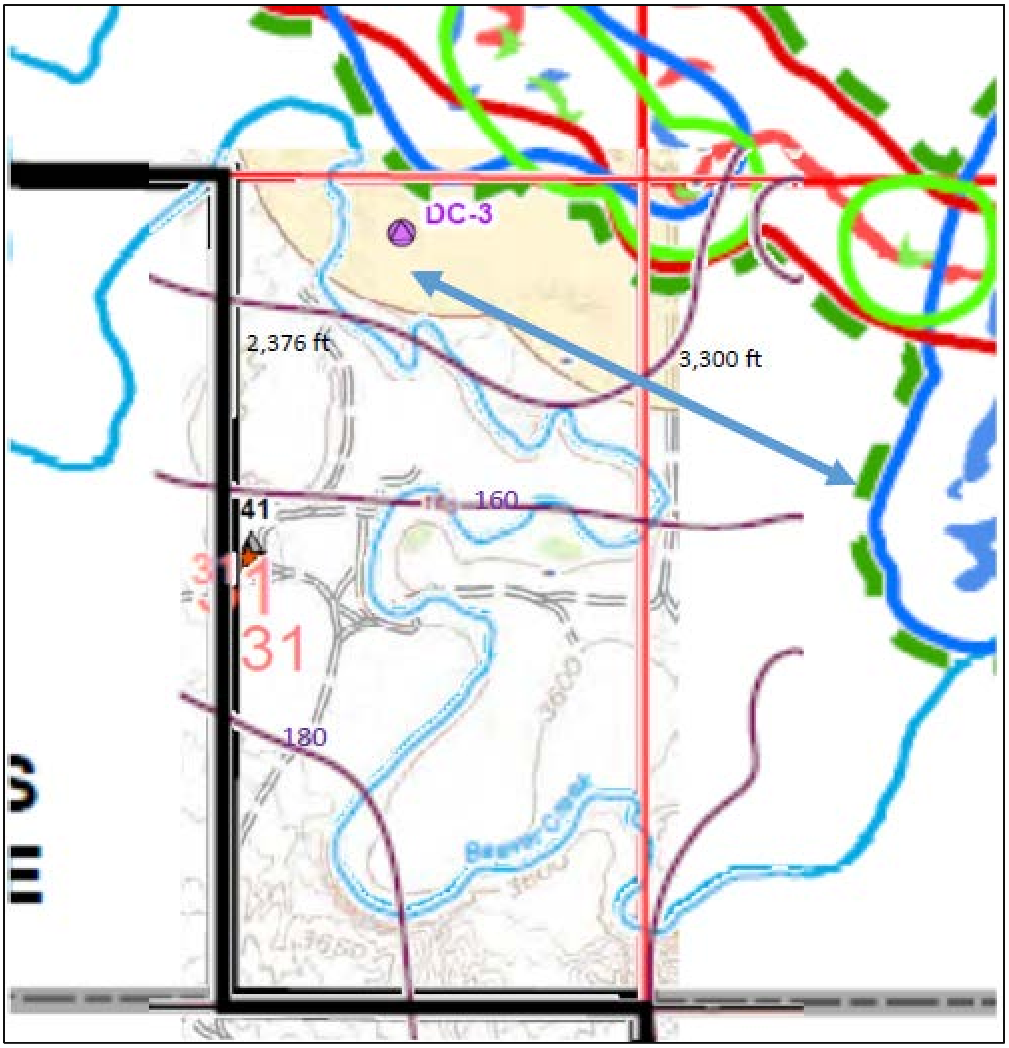


Figure 22. Chilson Thickness at the Location of Well 41 from Plate 6.7, Chilson Isopach Map.

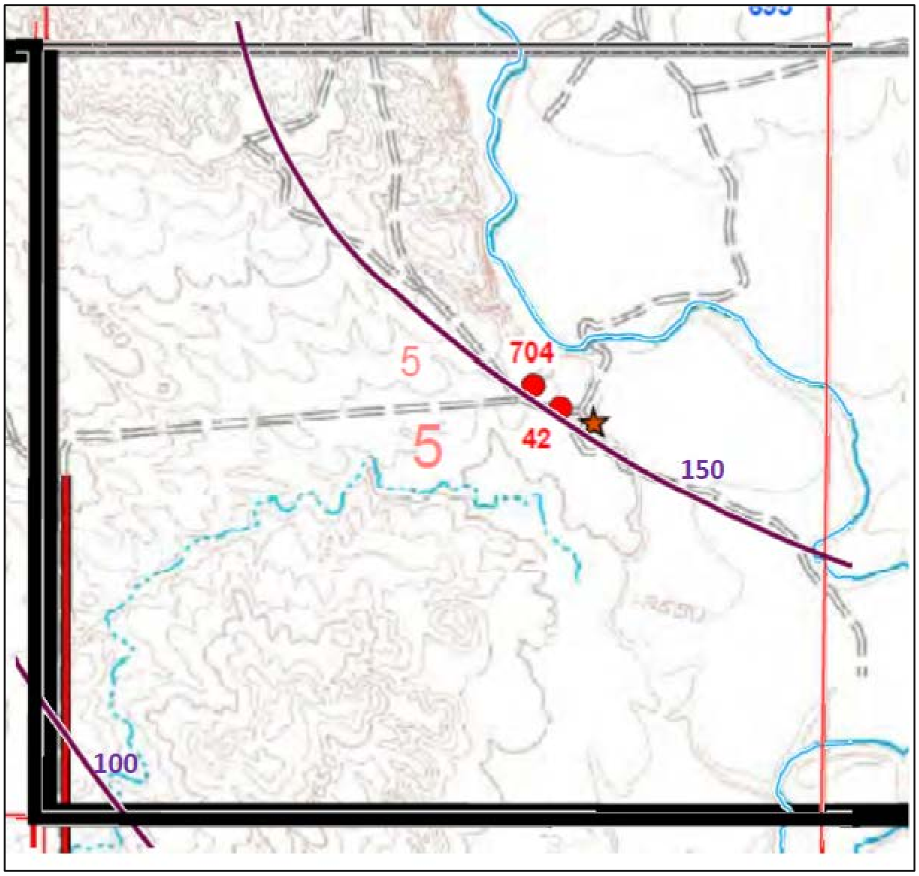


Figure 23. Fall River Thickness at the location of Wells 42 and 704 from Plate 6.9 Fall River Isopach Map

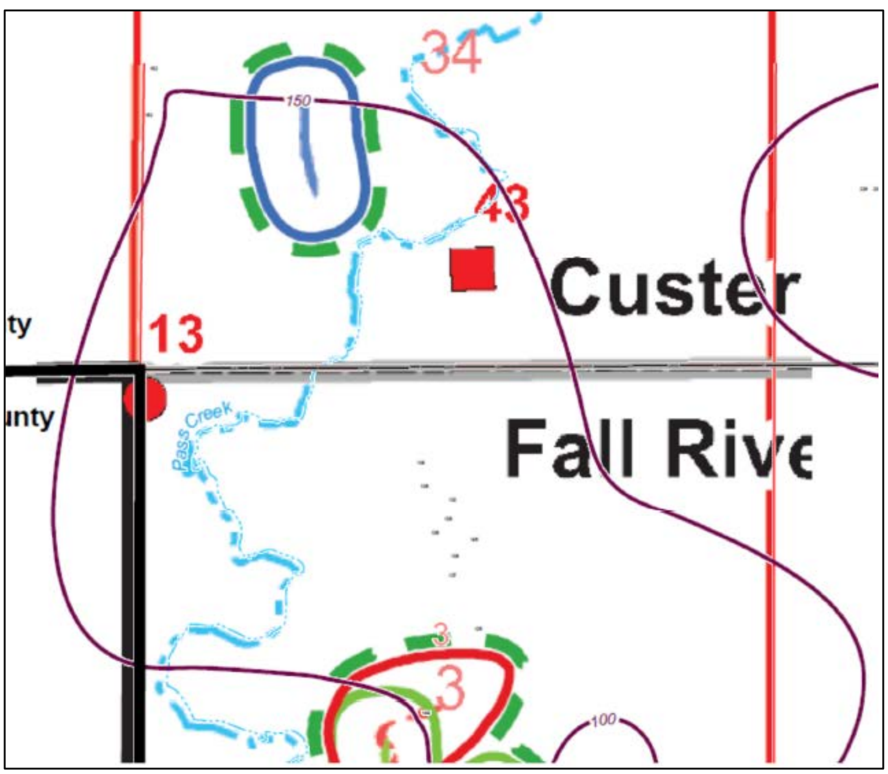


Figure 24. Chilson Thickness at the location of Well 43 from Plate 6.7 Chilson Isopach Map

Results of CZA Calculations

As discussed earlier, two types of CZA calculations were performed: 1) the first calculation yields the up-gradient extent of the capture zone and 2) the section calculation yields the maximum width of the capture zone. The actual calculations are found in Excel spreadsheets *CaptureZoneCalculations_2047*.pdf and *CaptureZoneCalculations_1000gpd_2047*.pdf In cases where there was more than one measurement for an input value, for example porosity or transmissivity, the calculation was performed with each measurement, for example maximum porosity and minimum porosity. The largest calculated values for each well capture zone are listed in Table 7.

Table 7 shows the results of the CZA for each well. Using both the historic flow rate of 12 gpm (17,280 gpd) and the flow rate of 1,000 gpd for well 41 (Chilson completion) resulted in a capture zone that extended up-gradient 1,246 ft and 910 ft, respectively, into the proposed AE area of Dewey wellfields 2 and 4, assuming the well is pumped continuously through 2047. The 12 gpm is the flow rate if the well were allowed to flow freely to the ground surface under natural artesian conditions. This flow rate is over 17 times the flow rate the EPA estimates for a family of ten based on information from the EPA Water Sense website. Well 41 has not been used for drinking water since at least 2006, when Powertech conducted the well survey for the Dewey-Burdock Project Area. The calculation the EPA performed to determine when the capture zone of a well would cross and AE boundary, using the 1,000 gpd flow rate, determined that the AE for well 41 will not cross the AE boundaries for Dewey Wellfields 2 and 4 until the end of the year 2020. This calculation assumes that the well has been pumped continuously since well construction in 1930 and is completed in the Chilson Sandstone. The actual well construction date is unknown, so the EPA used a conservative estimate of the oldest construction date recorded for wells in the area. The EPA does not know if the well is actually completed in the Chilson Sandstone. As discussed above, the assumption of continuous pumping results in a large overestimation of the well capture zone up-gradient extent. In addition, as stated above, it is reasonable to assume that this private well would not be pumped continuously. Because continuous pumping is very likely the only scenario in which this well's capture zone would ever become large enough to cross the AE boundary, EPA concludes that the periodic pumping and recovery typical for private wells such as well 41 would prevent the well's capture zone from ever crossing the AE boundary. Therefore, the EPA is still able to conclude that the capture zone for the Chilson completion of well 41 does not cross the AE boundary.

Using the State Engineer's maximum well flow rate before a water rights permit is needed of 25,920 gpd for well 43 resulted in a capture zone that encompassed all of Burdock wellfield 10 and extended 1,273 feet into the proposed AE area of Burdock wellfield 8. Additional calculations were performed for well 43 to determine the maximum flow rate that would result in the capture zone not crossing an AE boundary. Well 43 could pump up to 4,650 gpd before the width of its capture zone extended cross-gradient to reach the AE boundary of Burdock wellfield 10. The 25,920 gpd flow rate is over 25 times the flow rate the EPA estimates for a family of ten based on information from the EPA Water Sense website. Even the calculated flow rate of 4,650 gpd is over 4.5 time the estimated EPA flow rate for a family of ten. Similar to well 41, the well has not been used for drinking water since at least 2006, when Powertech conducted the well survey for the Dewey-Burdock Project Area. Therefore, the EPA concluded that both flow rates, 17,280 gpd and 4,650 gpd, overestimate private well usage for well 43 completed in the Chilson Sandstone. As discussed earlier, even using a flow rate of 1,000 gpd results in a large overestimation of the well capture zone area, because the equation used for the CZA assumes a well is continuously pumping.

Conclusions

Based on the CZA calculations, the EPA has concluded that the portions of the Inyan Kara aquifers proposed for exemption do not currently serve as a source of drinking water.

Well #	Calculated distances (ft) using well flow rates in Tables 2 and 5		Calculated distances (ft) using 1,000 Gallons per Day		Well location distance from nearest AE Boundary (ft)
	Maximum Upgradient Capture Zone Extent	Maximum Width of the Capture Zone	Maximum Upgradient Capture Zone Extent	Maximum Width of the Capture Zone	
2	2,630′	3,655′	1,522′	141′	4,600′ downgradient from B-WF2
7	765′	2,460′	563′	402′	4,750′ crossgradient from B-WF2
8	7,269′	1,244′	7,029′	340′	9,625′ crossgradient from B-WF2
13	1,317′	299′	1,267′	207′	1,750′ downgradient from B-WF8
18	1,593′	3,917′	1,169′	340′	7,880′ downgradient from B-WF4
40	1,677′	2,074′	985′	144′	2,187.5′ crossgradient from D-WF2
41 (Fall River)	1,554′	1,076′	1,046′	62′	2,750′ downgradient from D-WF 3 3,300′ crossgradient from D-WF1
41 (Chilson)	4,246′	310′	3,910′	18′	3,000′ downgradient from D-WFs 2&4 3,300′ crossgradient from D-WF1
42	3,877′	909′	3,168′	35′	4,800′ downgradient from D-WF4
43	1,374′	4,873′	574′	188′	3,600 crossgradient from B-WF8 875′ crossgradient from B-WF10
704	3,877′	909′	3,168′	35′	4,800′ downgradient from D-WF4
4002	1,677′	2,074′	958′	144′	2,125′ crossgradient from D-WF2

Table 7. Calculated Maximum Up-gradient Extent and Maximum Width of the Capture Zone for Each Well.