REPORT TO THE CHIEF ENGINEER ON
21 WATER PERMIT APPLICATIONS
FROM THE UPPER VERMILLION MISSOURI AQUIFER
FEBRUARY 1, 2014

HISTORY

Twenty one water permit applications proposing to appropriate water from the Upper Vermillion Missouri (UVM) aquifer were filed with the DENR-Water Rights Program since the fall of 2012. The Chief Engineer recommended deferral of 18 of the applications because at the time it was not possible to conclude that unappropriated water was available from the aquifer to satisfy the appropriations. The Water Management Board considered the permit applications along with the Chief Engineer's recommendation and concluded that "In light of the evidence presented, it is not possible to conclude that unappropriated water is available from the UVM to satisfy the proposed appropriations. Significant portions of the aquifer have experienced long-term downward trending water levels. New appropriations from the aquifer should be deferred until it can be determined if water levels in these areas will stabilize under steady withdrawals" (Water Permit Application Nos. 7441-3, et al, Conclusion of Law 15). Three additional applications were filed after February 25, 2013 and were recommended for deferral.

UPPER VERMILLION MISSOURI AQUIFER (UVM)

The Upper Vermillion Missouri aquifer is located in portions of Lincoln, Turner and Clay Counties. An index map for the area is shown in Figure 1.

Previous Investigations

The Upper Vermillion Missouri aquifer consists of a glacial outwash deposit that generally occurs in bedrock low areas. As delineated by Hedges and others (1982), the aquifer extends over an area of approximately 132,900 acres in Clay, Lincoln and Turner Counties. Subsequent investigations for Lincoln, Turner, and Hutchinson Counties (Lindgren and Hansen, 1990; and Niehus, 1994) interpreted the area hydrogeology in a manner that resulted in the configuration of the Upper Vermillion Missouri aquifer encompassing over 204,800 acres (see Figure 2).

2014

A study of the Upper Vermillion Missouri aquifer conducted by the DENR-Geological Survey in 2013-2014 established new boundaries for the main body of the aquifer in Turner County (see Figure 3). Although the southern boundary has not been delineated at this time, data shows that it extends south several miles from the original border as it merges with or transitions into the Lower Vermillion Missouri aquifer. The areal extent of the main body of the Upper Vermillion Missouri aquifer defined by these new boundaries is at least 117,000 acres. A channel deposit extending to the northwest from the main body of the Upper Vermillion Missouri aquifer may be hydrologically connected to the aquifer.

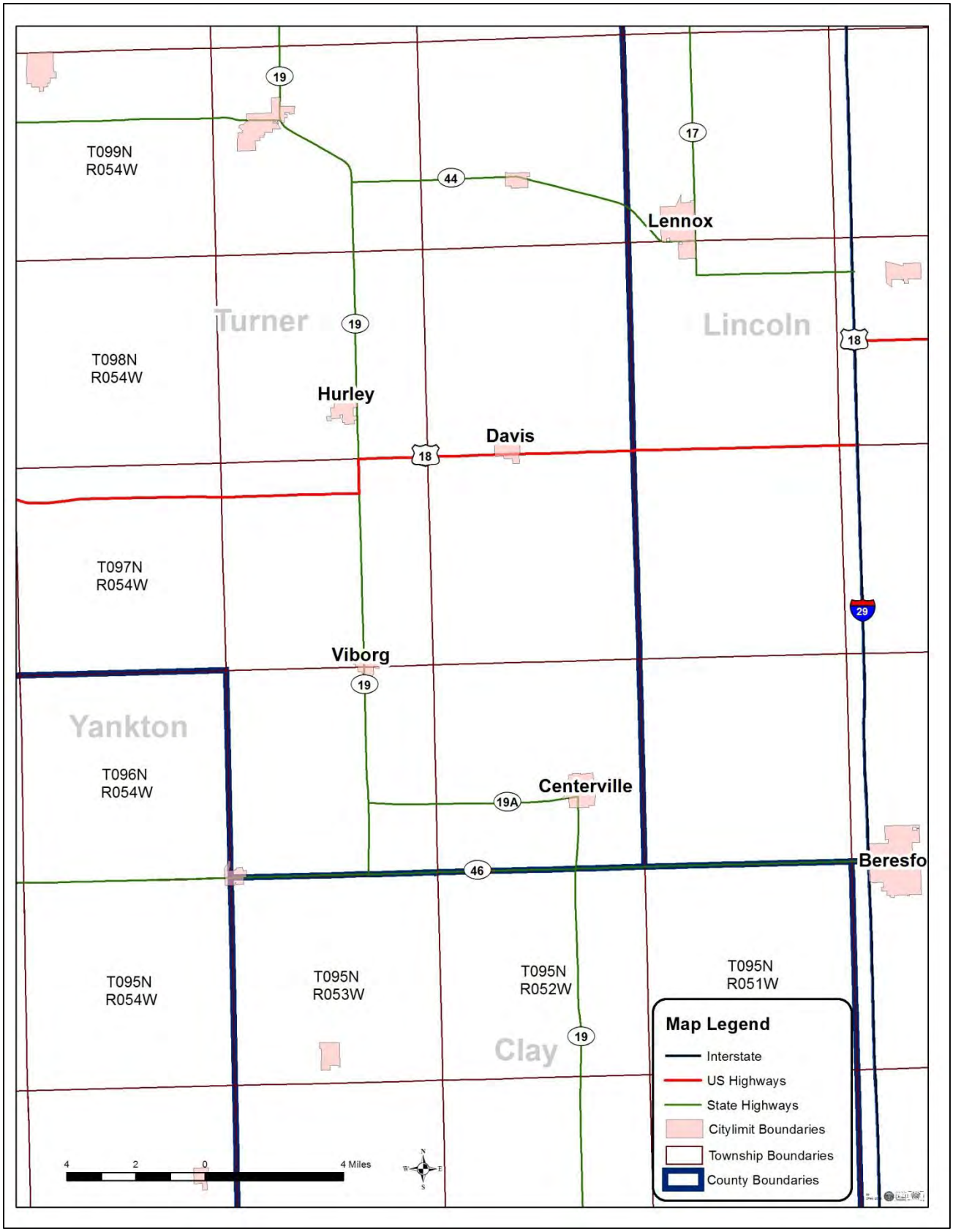

Figure 1. Index map for the area

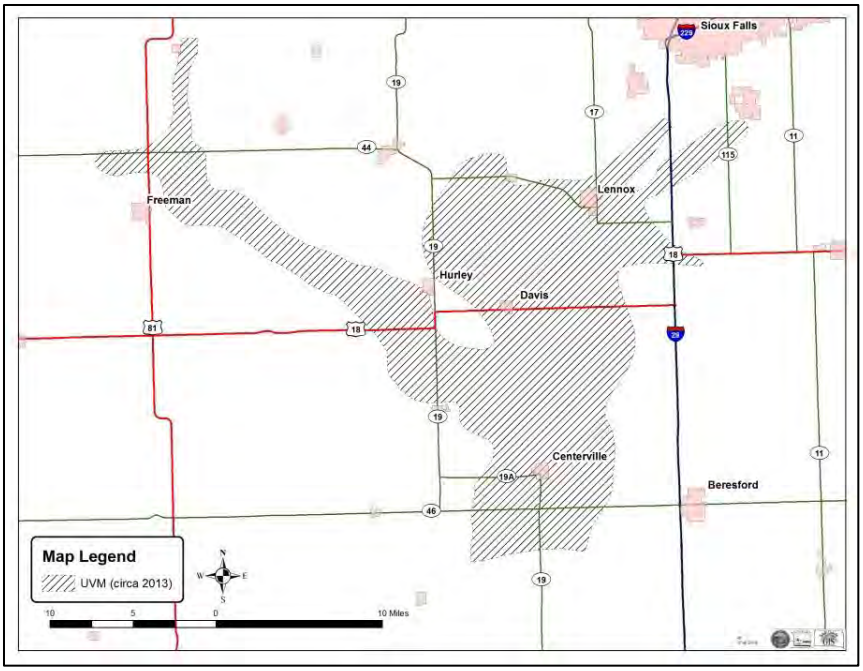

Figure 2. Areal extent of the Upper Vermillion Missouri aquifer considered in 2013 (Buhler, 2012)

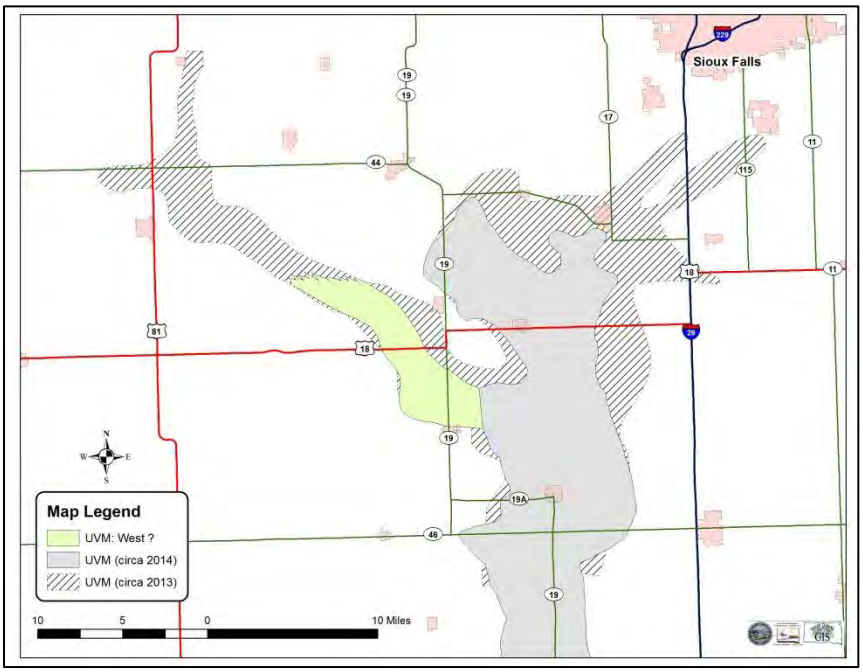

Figure 3. 2014 delineation of the Upper Vermillion Missouri aquifer with areal extent of the Upper Vermillion Missouri aquifer considered in 2013 (Buhler, 2012; modified from DENR-Geological Survey, in progress)

The Upper Vermillion Missouri aquifer occupies portions of a bedrock channel that generally trends north-south. The elevation of the aquifer varies along the length of the channel, but it is primarily below 1,200 feet mean sea level elevation (msl) and above 975 feet msl. The aquifer is

primarily buried by glacial drift, and the top of the aquifer can be over 150 feet below grade. The aquifer is predominantly under confined conditions, and the static water levels of wells in the aquifer typically range from 10-90 feet below grade. The potentiometric surface of the main body of the aquifer (see Figure 4) indicates a north to south groundwater flow direction.

Limited data is available to determine the aquifer characteristics (hydraulic conductivity and storativity) for the Upper Vermillion Missouri aquifer. As part of the ongoing Geological Survey study, sand/gravel samples were collected and analyzed for grain size. Results of the sieve analyses were used to estimate hydraulic conductivity values for the sieved samples. Reported hydraulic conductivity estimates range from 592 to 2,657 ft/day (SD-Geological Survey, in progress).

The hydraulic conductivity for the aquifer was also estimated based on aquifer thickness and the transmissivity calculated from the specific capacities of irrigation wells and two rural water system wells completed into the aquifer where sufficient data was available (Buhler, 2012; Water Rights, 2014b; and Water Rights, 2014c). These hydraulic conductivity values are shown in Table 1, Figure 5 and Figure 6.

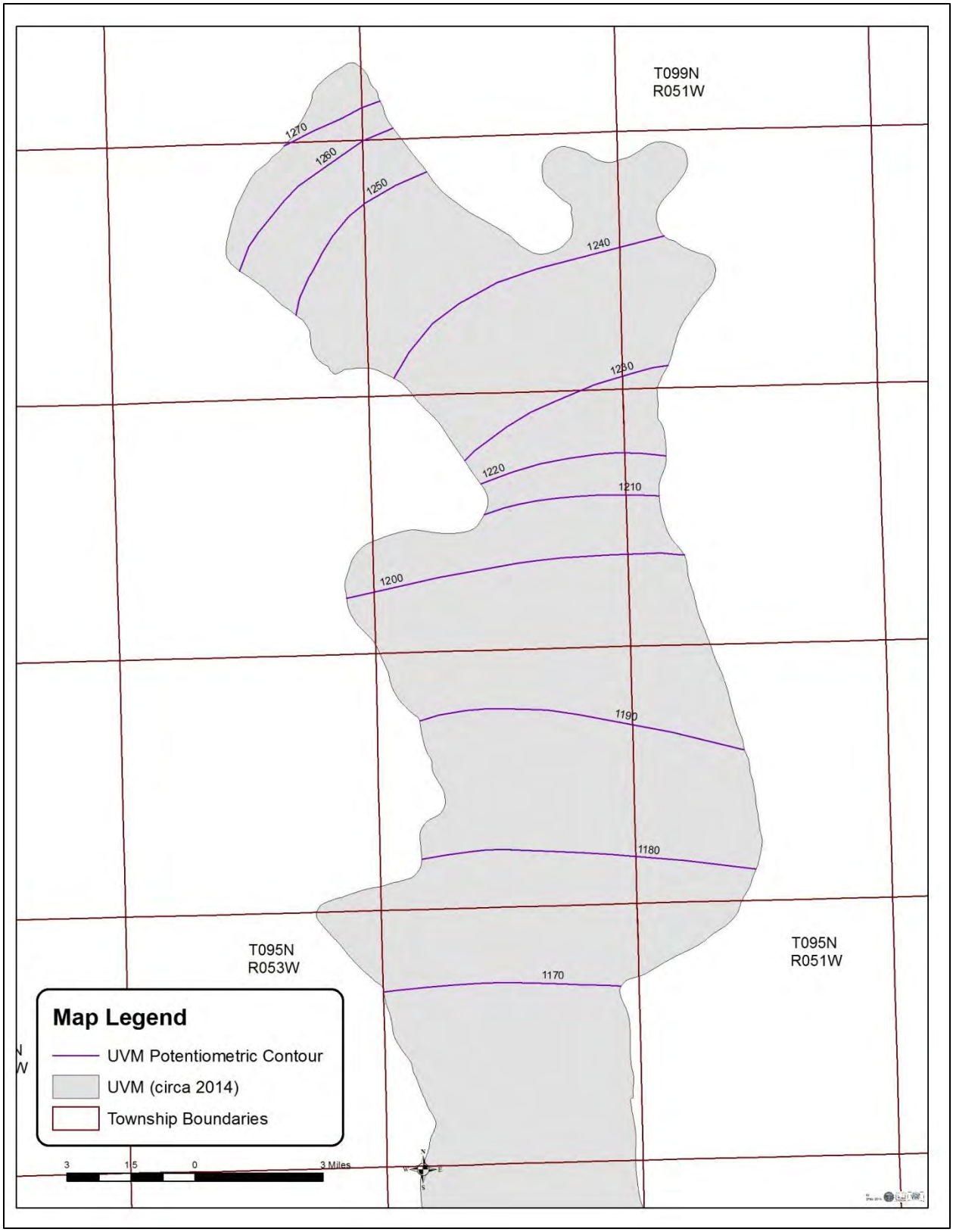

Figure 4. January 21, 2014, potentiometric surface of the main body of Upper Vermillion Missouri aquifer in feet above mean sea level (SD-Geological Survey, in progress)

Permit/Right No.	Drawdown (ft)	Yield (gpm)	Specific Capacity SpC (gpm/ft)	Transmissivity T (gpd/ft	Thickness b (ft)	Hydraulic Conductivity k (gpd/ft2)	Hydraulic Conductivity k (ft/d)
1930-3	15	1200	80	160000	65	2462	329
3784-3	92	900	10	19600	45	436	58
3901-3	9	1000	111	222200	70	3174	424
4265-3	25	900	36	72000	40	1800	241
4560-3	83	800	10	19200	50	384	51
5259-3	6	1400	233	466600	116	4022	538
5352-3	20	2100	105	157500	178	885	118
5371-3	45	860	19	38200	28	1364	182
5425-3	22	1100	50	100000	48	2083	279
5632-3	24	800	33	66600	48	1388	185
5886-3	9	800	89	177800	55	3233	432
5899-3	25	800	32	106600	63	1692	226
5982-3	27	800	30	92400	73	1266	169
6054-3	25	900	36	72000	40	1800	241
6301-3	16	1100	69	137600	70	1966	263
6727-3	13	1100	85	170000	74	2297	307
6727-3	15	1100	73	146667	74	1982	265
6810-3	6	750	125	250000	66	3788	506
6868-3	10	900	90	180000	36	5000	668
6922-3	11	810	74	147200	87	1692	226
6968-3	11	840	76	152800	88	1736	232
6984-3	7	1200	171	342800	101	3394	454
7002-3	11	720	69	102900	115	895	120
7128-3	15	750	50	100000	94	1064	142
Min	*6*	*720*	*10*	*19200*	*28*	*384*	*51*
Max	*92*	*2100*	*233*	*466600*	*178*	*5000*	*668*
Average	*23*	*985*	*73*	*145861*	*72*	*2075*	*277*
Std Dev	*22*	*289*	*50*	*98483*	*32*	*1143*	*153*
Std Dev/Average	*98.4%*	*29.4%*	*69.0%*	*67.5%*	*44.9%*	*55.1%*	*55.1%*

Table 1. Production well data from the Upper Vermillion Missouri aquifer (Water Rights, 2014b; and Water Rights 2014c)

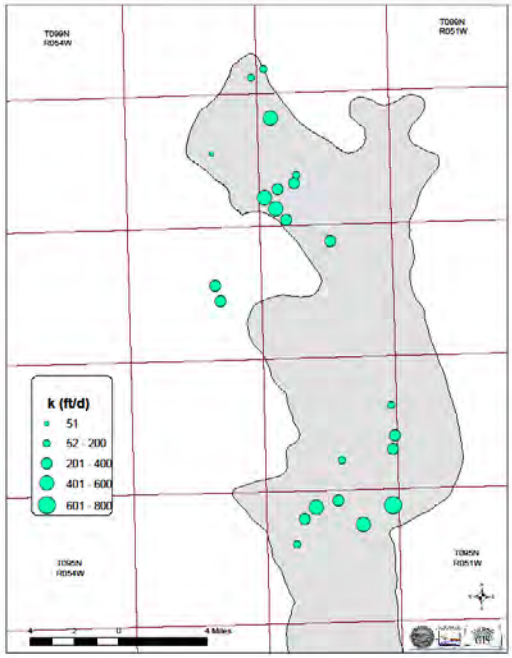

Figure 5. Location of production wells used to calculate hydraulic conductivity

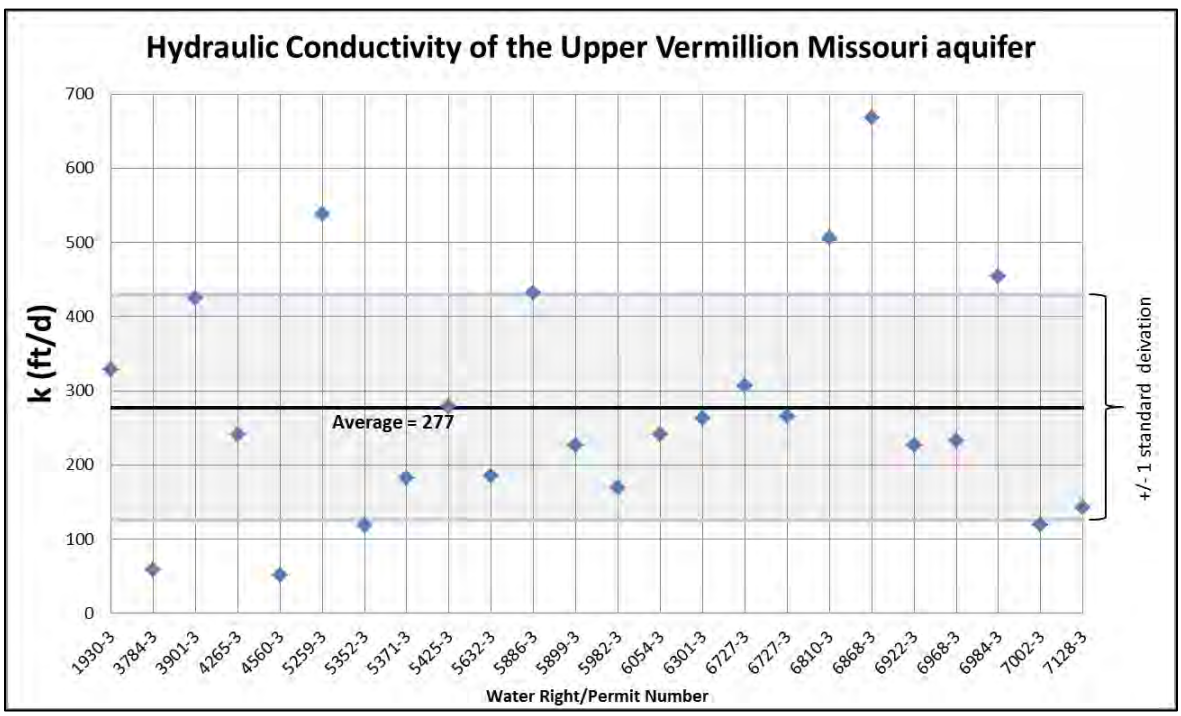

Figure 6. Chart showing the hydraulic conductivities, average hydraulic conductivity and one standard deviation of the Upper Vermillion Missouri aquifer at production wells where data is available (Water Rights, 2014b; and Water Rights 2014c).

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Recharge:
Recharge to the Upper Vermillion Missouri aquifer has not been quantified. Lindgren and Hansen (1990) postulated that recharge to the Upper Vermillion Missouri aquifer occurs through: 1) direct infiltration of precipitation in areas where the aquifer is at or near ground surface; 2) inflow from fractures in the Sioux Quartzite; and 3) inflow from the Niobrara aquifer.

Although the Upper Vermillion Missouri aquifer appears to be in contact with the quartzite and Niobrara aquifer, these areas appear to be limited. The likely source of recharge to the Upper Vermillion Missouri aquifer is leakage from the overlying Parker Centerville aquifer (PAC) where the two aquifers are hydrologically connected. Areas of potential interconnection between the two aquifers are shown in Figure 7.

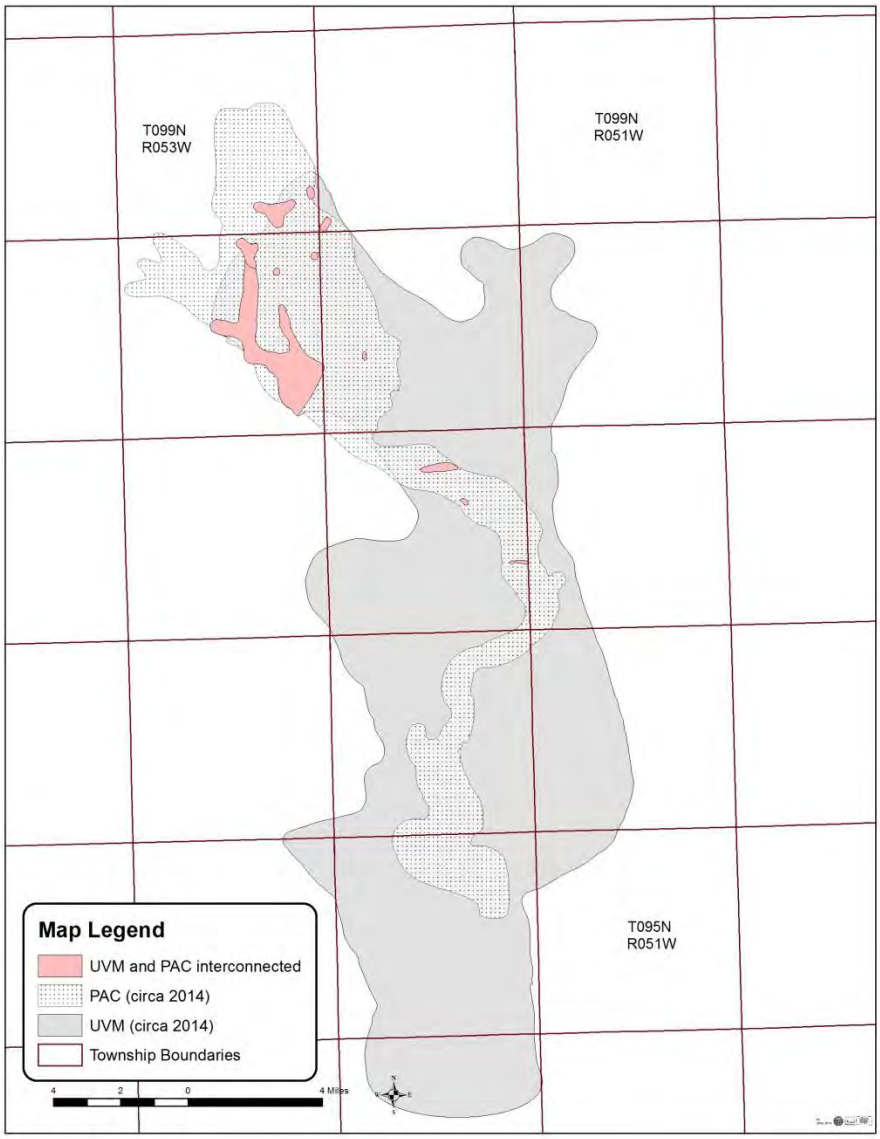

Figure 7. Areal extent of the Upper Vermillion Missouri (UVM) aquifer, the Parker Centerville (PAC) aquifer, and areas where the two aquifers are potentially interconnected (SD-Geological Survey, in progress).

MANAGEMENT UNITS

A system of aquifer and management unit designations for South Dakota was designed to establish a bookkeeping framework of hydrologic data (Hedges and others, 1982). The aquifer and management unit boundaries were chosen to coincide with hydrogeologic boundaries that are "identifiable and which can be documented." Actual boundaries between units were based on one or more of the following criteria:

1. Thinning and/or constriction of the aquifer or management unit.
2. Facies change from high to low permeability of aquifer material.
3. Change from water-table to artesian conditions and vice versa.
4. Ground-water divide.
5. Ground-water discharge point such as stream or lake.
6. Presence of streamflow gaging station.

Although previous aquifer delineations (Hedges and others, 1982; and Lindgren and Hansen, 1990) both identified areas with anomalous gradients of the potentiometric surfaces, they considered the Upper Vermillion Missouri aquifer a single unit.

As the result of work done by the DENR- Geological Survey in 2013-2014, identifiable geologic and hydrologic data suggests two boundaries establishing three management units within the Upper Vermillion Missouri aquifer. Proposed management units are shown in Figure 8.

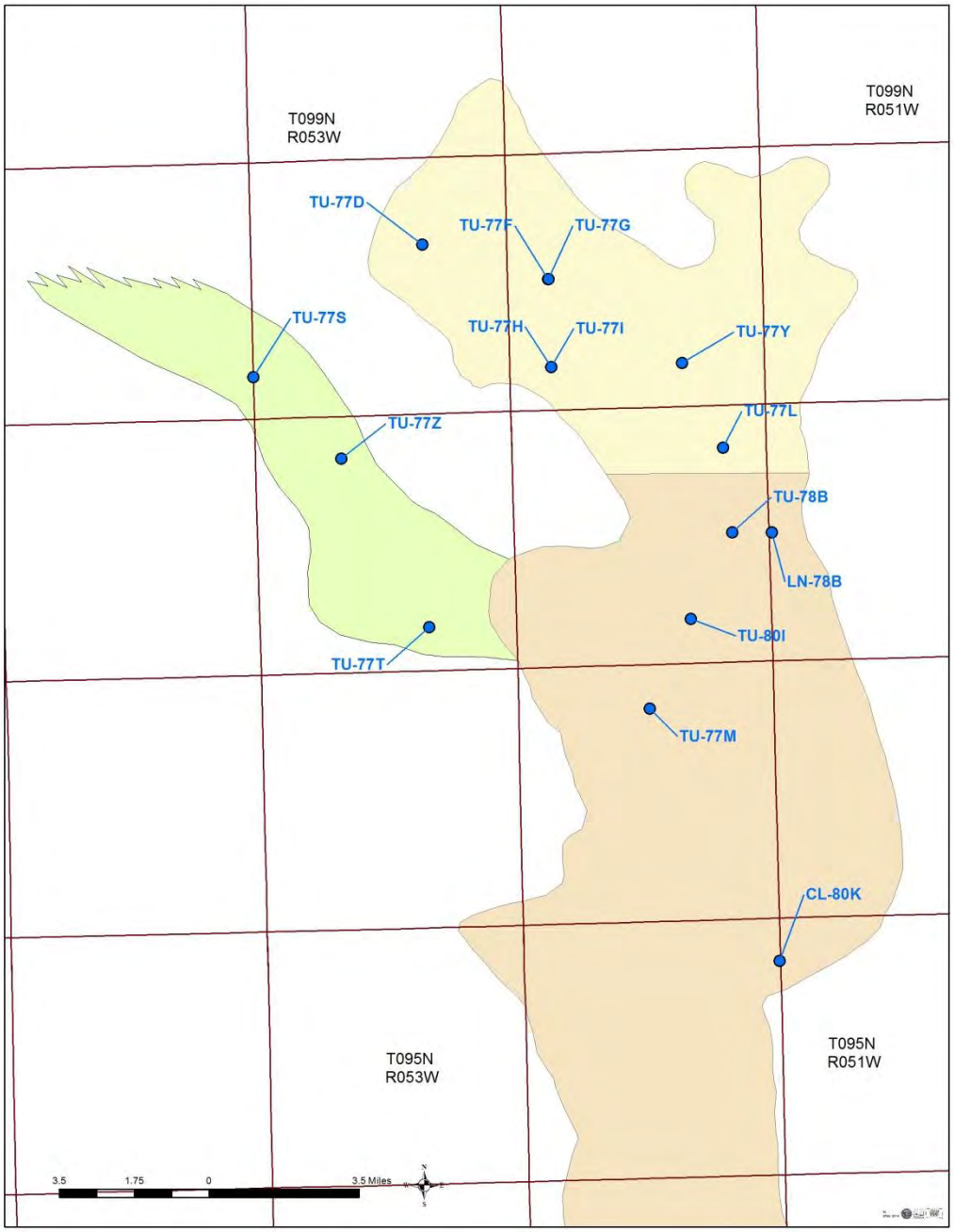

Figure 8. Proposed management units for the Upper Vermillion Missouri aquifer

South Management Unit/West Management Unit Boundary:
In the southeastern portion of T097N-R053W or the southwestern portion of T097N-R052W, three sets of data (i.e. bedrock topography, outwash lithology and aquifer potentiometric surface) identify a boundary between the West management unit and the South management unit of the aquifer.

Bedrock Topography:

Near the confluence of the bedrock channel that enters from the west with the channel that contains the main body of the Upper Vermillion Missouri aquifer, the western channel below 1,100 feet msl constricts by over 20% within three miles (see Figures 9, 10 and 11).

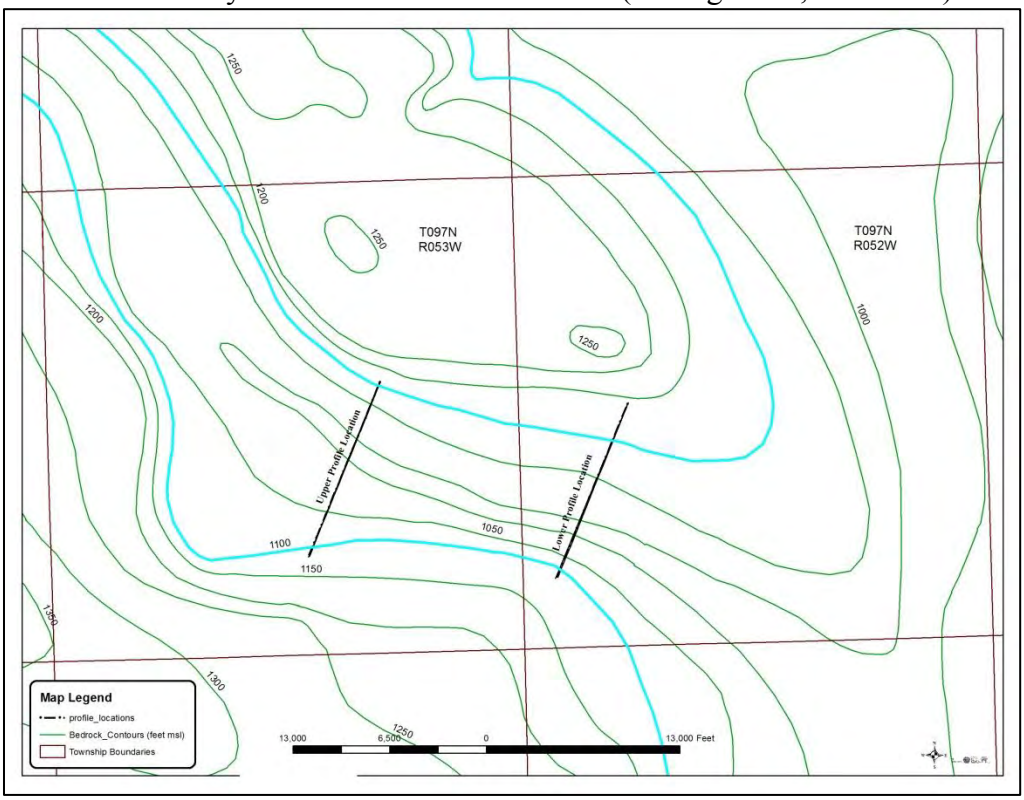

Figure 9. Location of bedrock channel profiles (modified from SD-Geological Survey, in progress)

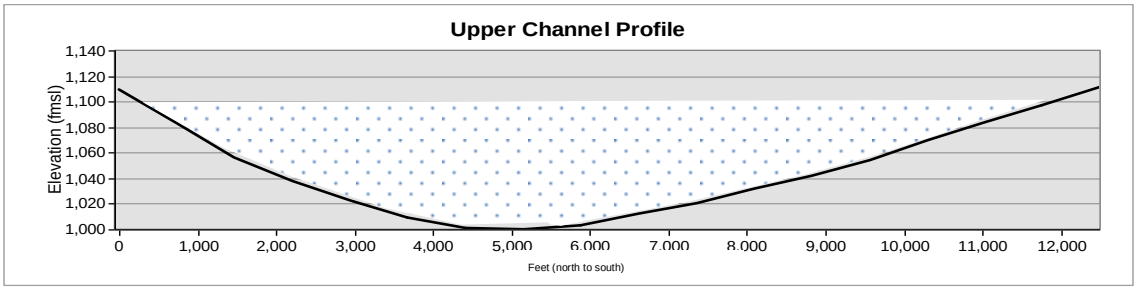

Figure 10. Upper Channel Profile

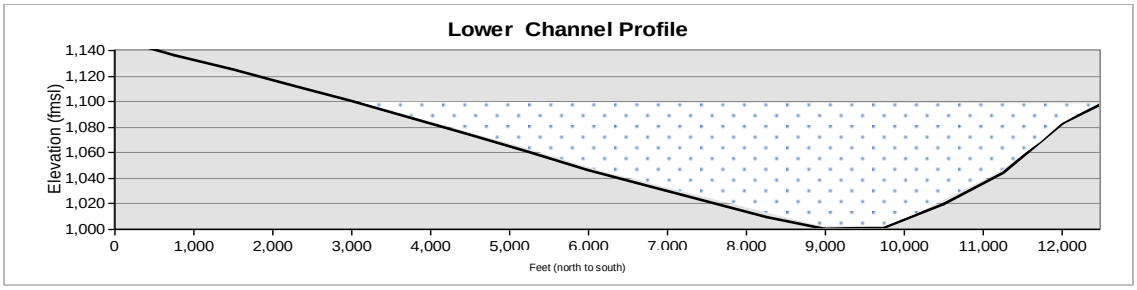

Figure 11. Lower Channel Profile

Lithology:
A west to east cross section through this area indicates the outwash in the western channel thins from approximately 100 feet thick to approximately 50 feet thick across this confluence area. In addition, geologists' logs identify the outwash as "very clayey" in the vicinity of a test hole drilled in the SE¼ of Section 24, T97N-R53W (see Figures 12 and 13).

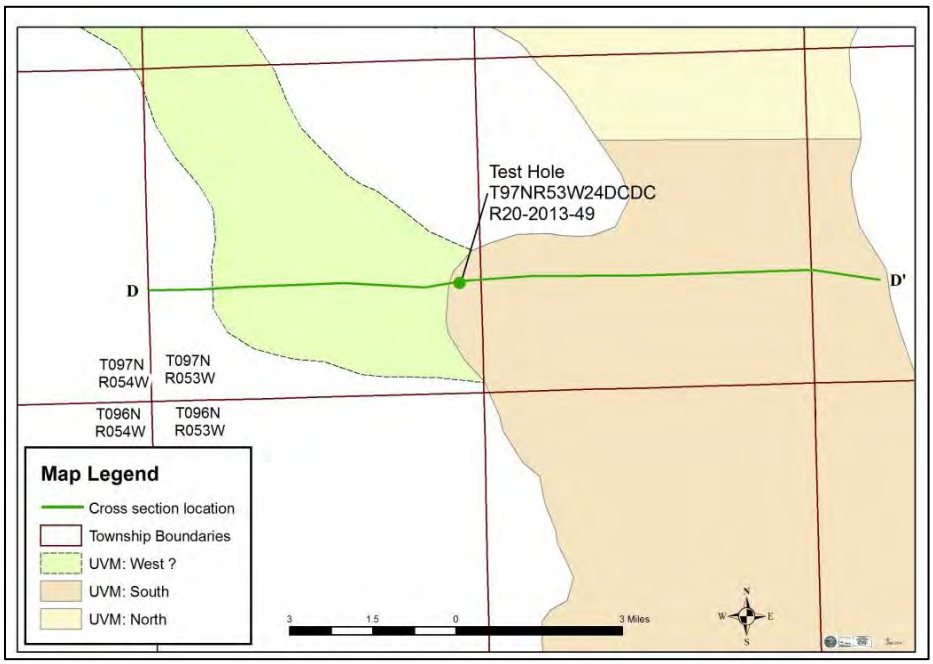

Figure 12. Location of cross Section D-D' and test hole R20-2013-49

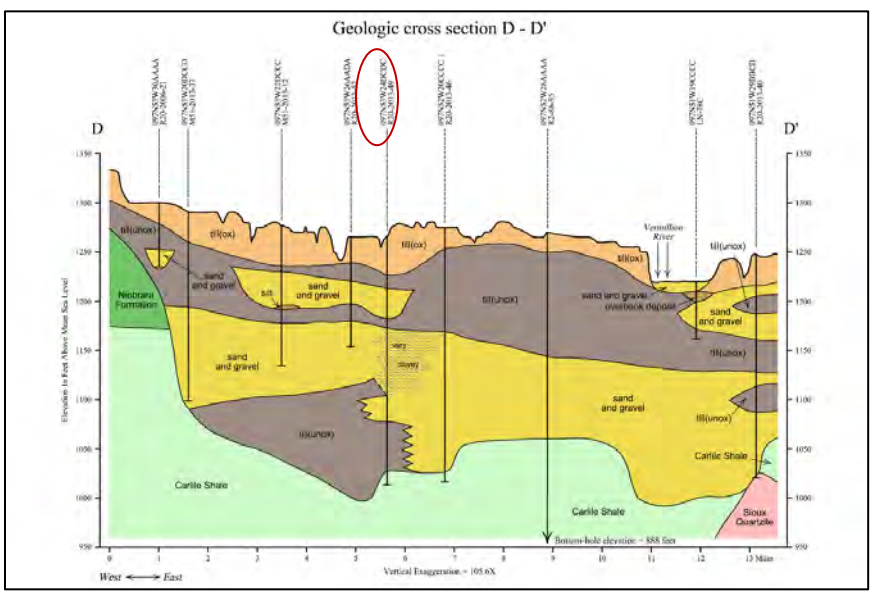

Figure 13. Cross section D-D' (modified from SD-Geological Survey, in progress)

Potentiometric Surface:
A profile of the potentiometric surface near the confluence of the west bedrock channel with the main bedrock channel containing the Upper Vermillion Missouri aquifer identifies a change in the gradient in the area (see Figures 14 and 15). This suggests a lower permeability area that would create a boundary condition.

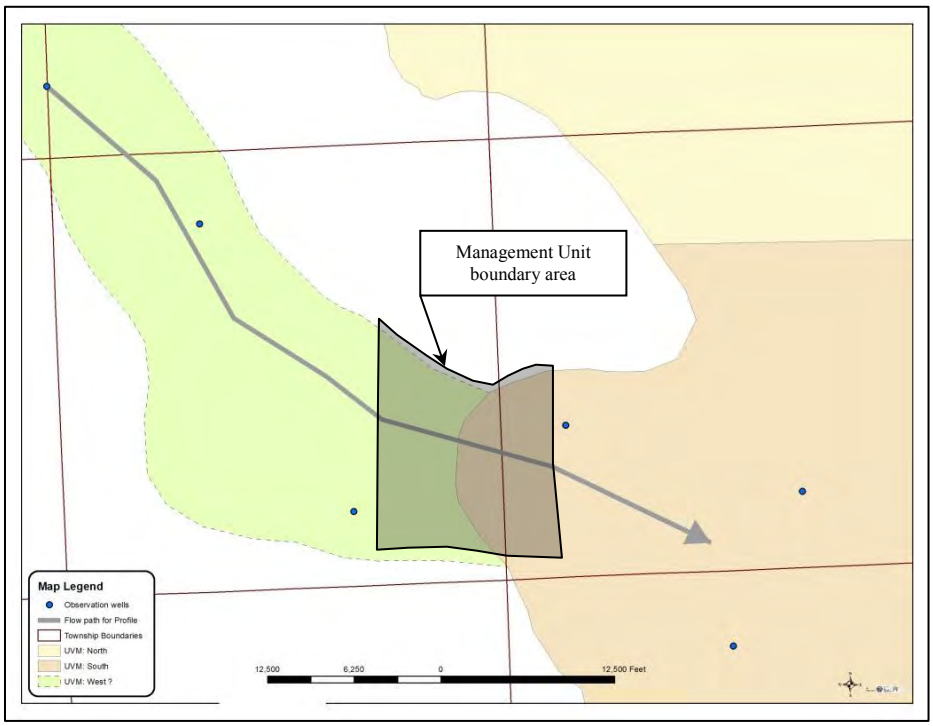

Figure 14. Location of Flow path for Potentiometric Surface Profile

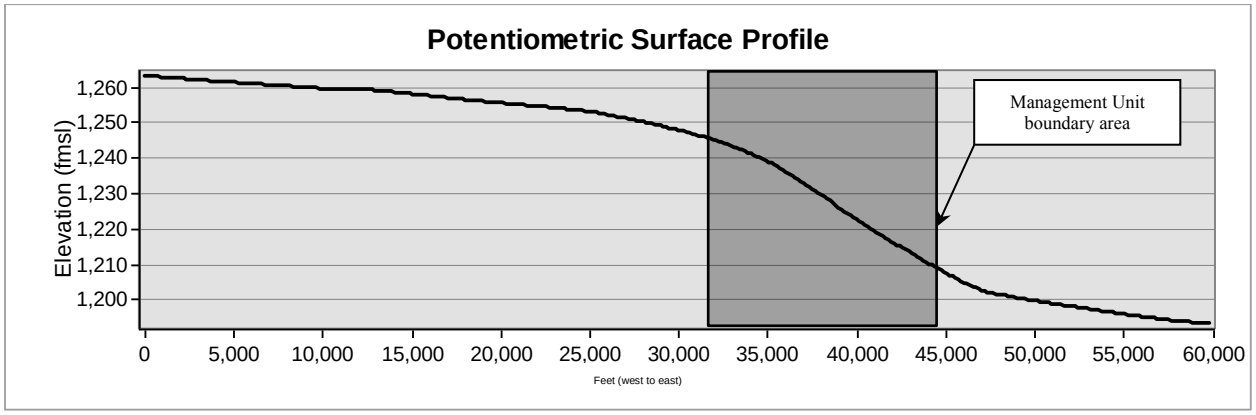

Figure 15. Potentiometric surface profile showing the boundary between the west and south management units of the Upper Vermillion Missouri aquifer

West Management Unit/Northwest Management Unit Boundary:
The West management unit of the Upper Vermillion Missouri aquifer appears to extend northwest beyond the limit used for this report. Data is not available to determine the areal extent of this management unit.

A basal outwash deposit occupies a southeast trending bedrock channel that originates approximately 30 miles northwest of the minimal northwest limit of the proposed West management unit (Tomhave and Schulz, 2004). Past delineations of the Upper Vermillion Missouri aquifer included this outwash deposit as part of the aquifer beginning approximately 18 miles beyond the known northwest limit of the proposed West management unit (see Figures 2 and 8). Water levels of observation wells completed into this basal outwash approximately 15 miles northwest of the West management unit appear to approximately correspond to UVM: West water levels. Observation wells completed into the basal outwash deposit approximately 15 miles northwest of have identified an area of downward trending water levels. The area and chronology of the downward trending water levels appear to correspond with development of the aquifer by TM Rural Water District.

A significant constriction of this bedrock channel exists near the center of T100N-R55W (Tomhave and Schulz, 2004). The narrowing of the channel appears to be located in an area where the bedrock incised by the channel changes. In addition, profiles of the pre-development (circa 1990, 1995, 2000) potentiometric surface all identify a groundwater flow gradient decrease from (e.g. 3.7 -1.5 feet/mile in 2000) across this same area. Based on this available data, the northern tip of the bedrock channel containing the TM Rural Water District wells should be considered hydrologically distinct from the Upper Vermillion Missouri: West aquifer.

South Management Unit/North Management Unit Boundary:
Geologic and hydrologic data suggests a north/south boundary in the main body of the Upper Vermillion Missouri aquifer near the middle of T97N-R52W.

Geologic evidence of a North/South Boundary:
The bedrock topography identifies a narrowing of the channel containing the Upper Vermillion Missouri aquifer near the middle of T97N-R052W. Geologic cross sections constructed near this area and their location are shown in Figures 16, 17, and 18. The cross sectional area of the Upper Vermillion Missouri aquifer has been outlined in blue in Figures 17 and 18, and the area reported by the DENR-Geological Survey (in progress) is labeled for each cross section. The data indicates the area of the Upper Vermillion Missouri aquifer contracts from approximately 3.3 million square feet to approximately 2.8 million square feet or approximately 15% between cross section B-B' and cross section C-C'. Based on the bedrock channel topography, the channel appears to narrow (i.e. even smaller aquifer area) one to two miles south of the C-C' cross section.

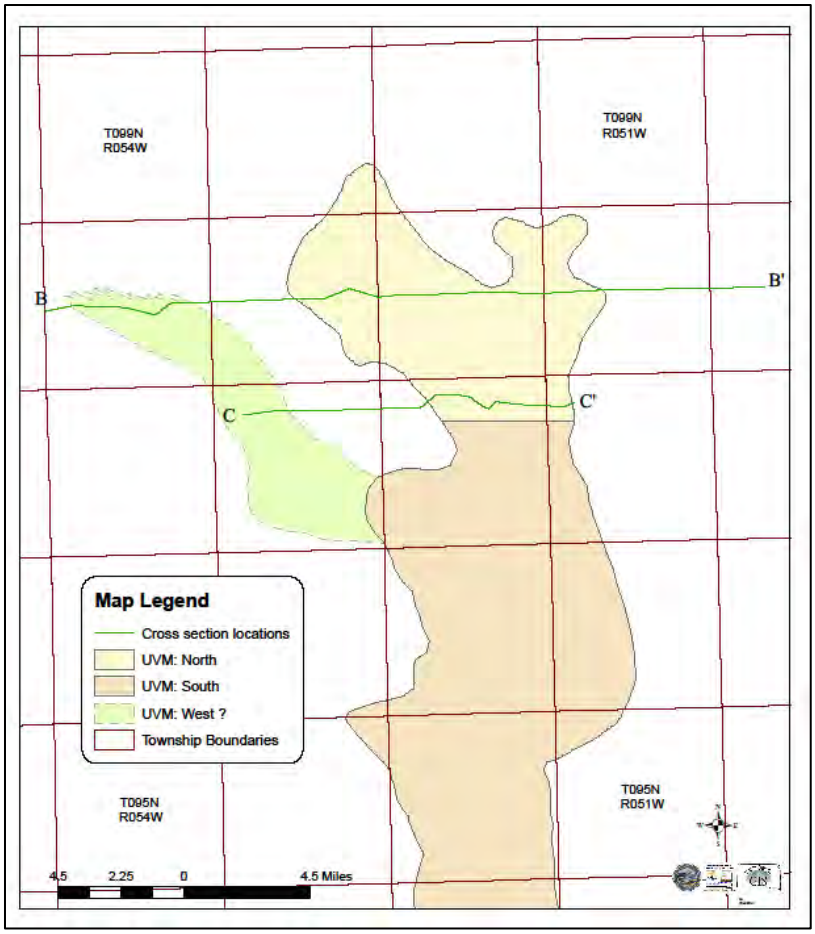

Figure 16. Cross section locations for Figures 17 and 18.

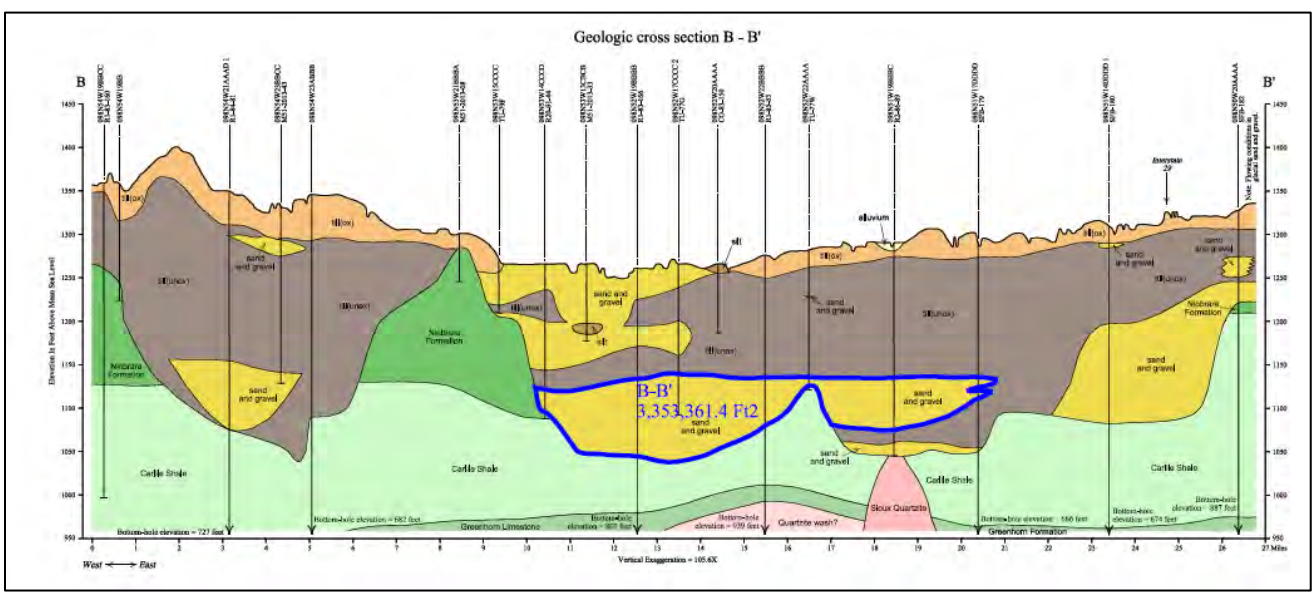

Figure 17. Cross section B-B' through Upper Vermillion Missouri aquifer (SD-Geological Survey, in progress)

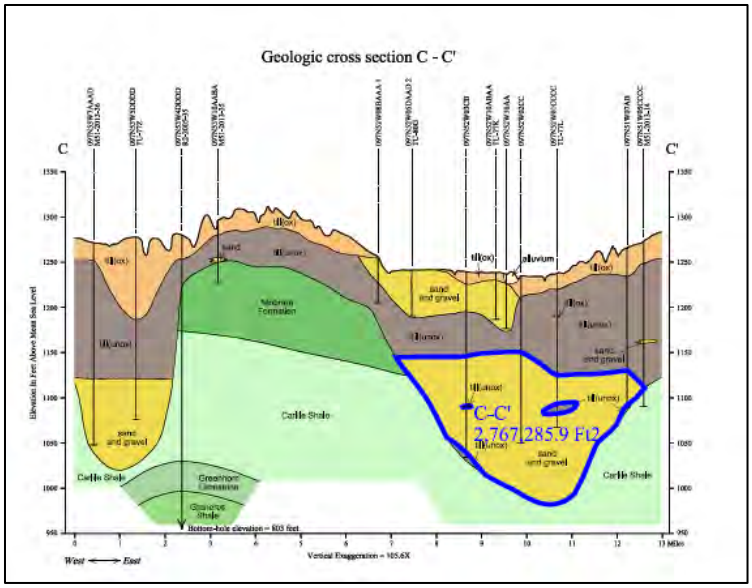

Figure 18. Cross Section C-C' through Upper Vermillion Missouri aquifer (SD-Geological Survey, in progress)

Hydrologic evidence of a North/South Boundary:

The gradient of the potentiometric surface changes from an average of approximately 4.2 feet per mile north of the T97N-T98N line to an average gradient of 9.1 feet per mile in T97N to an average of approximately 3.0 feet per mile south of the T97N-T98N line. This suggests a hydrologic boundary between the northern portion of the aquifer and the southern portion of the aquifer (see Figure 19 and Figure 20).

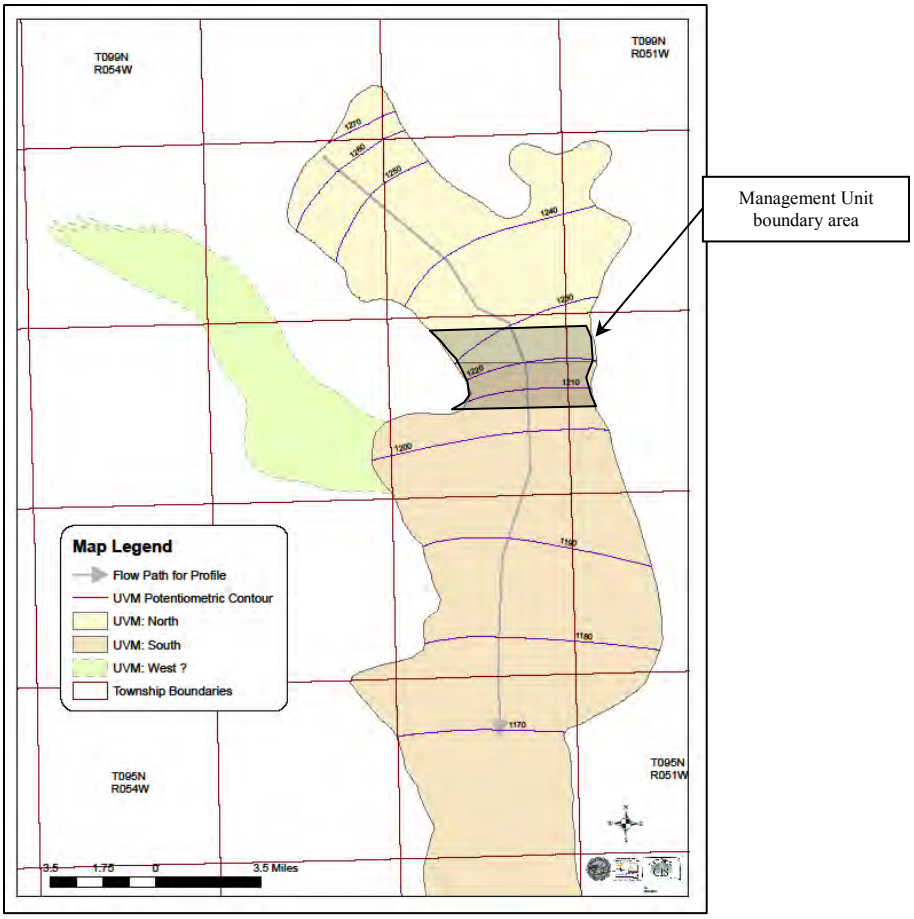

Figure 19. Location of Flow path for potentiometric surface profile

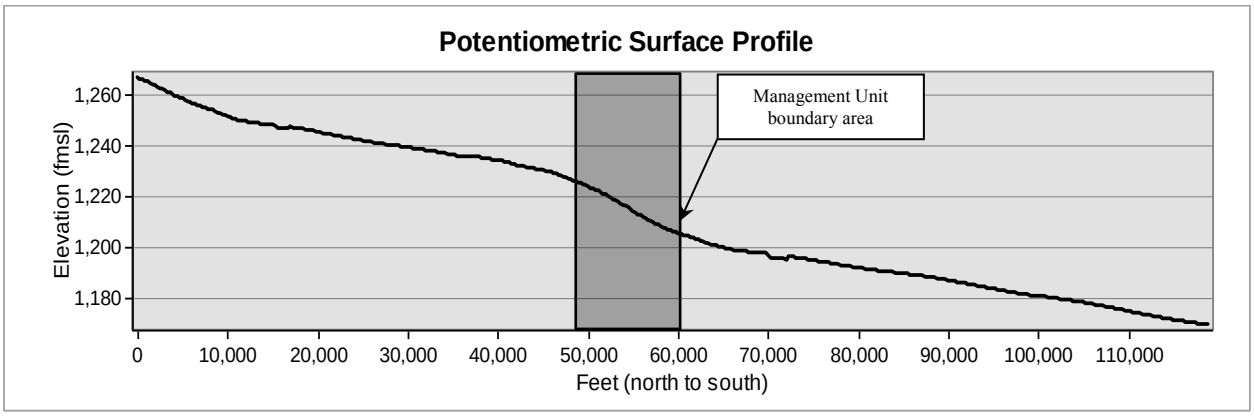

Figure 20. Potentiometric surface profile showing boundary between the north and south management units of the Upper Vermillion Missouri aquifer

The gradient change appears to exist regardless of the climatic conditions or variations in recharge and withdrawal from the aquifer (see Figure 21).

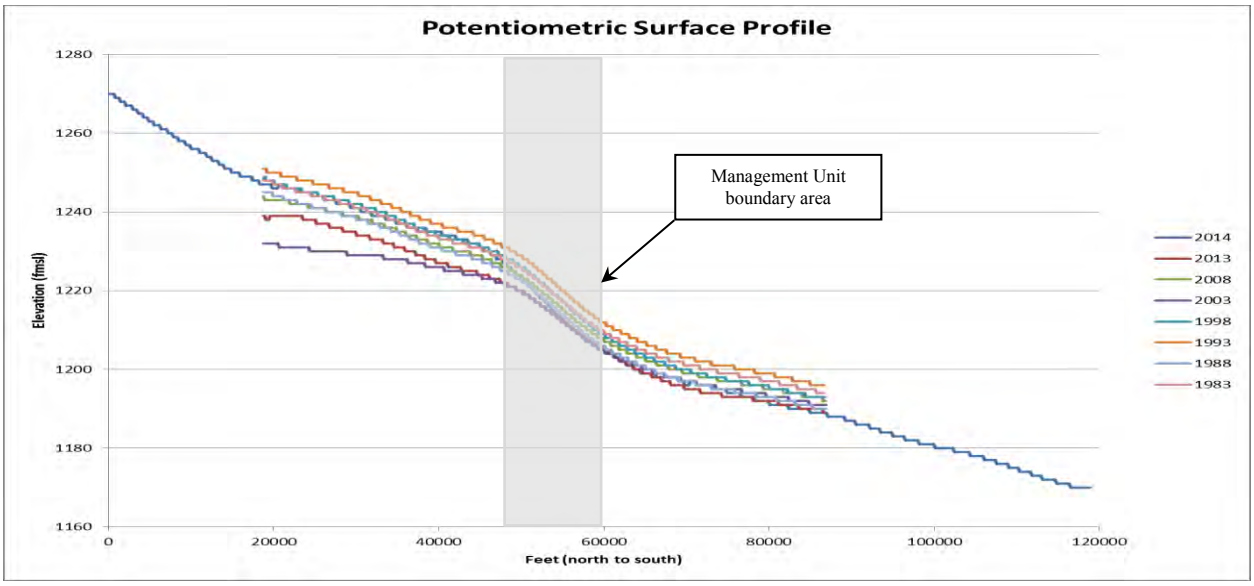

Figure 21. Profile of the potentiometric surface showing a consistent gradient change at the boundary between the North and South Management Units.

DEFERRED PERMIT APPLICATIONS

The water permit applications from the Upper Vermillion Missouri aquifer that are currently in deferred status are shown in Table 2 and Figure 22.

Permit No.	CFS	Well Location	Acres	Acre Location
7535-3	1.78	SW¼ NW¼ Sec. 30, T98N-R53W	65	NW¼ Sec. 30, T98N-R53W
7588-3	1.78	SW¼ Sec. 19, T98N-R53W	160	SW¼ Sec. 19, T98N-R53W
7602-3	1.89	Between NW¼ & NE¼ Sec. 34, T97N-R53W	132	E½NW¼, W½NE¼ Sec. 34, T97N-R53W
7633-3	1.78	SW¼ Sec. 32, T98N-R53W	152	SW¼ of Sec. 32, T98N-R53W
7715-3	2.22	SW¼ Sec. 16, T97N-R53W	156	SW¼ Sec. 16, T97N-R53W
7452-3	1.78	SW¼NE¼ Sec. 32, T98N-R52W	110	W½NE¼,SE¼NE¼ Sec. 32, T98N-R52W
7468-3	1.78	NE¼ Sec. 26, T96N-R51W	152	NE¼ Sec. 26, T96N-R51W
7558-3	1.78	Between NW¼ & SW¼ Sec. 1, T98N-R52W	120	N½SW¼, S½NW¼ Sec. 1, T98N-R52W
7587-3	1.78	SE¼ Sec. 10, T98N-R53W	160	SW¼ Sec. 10, T98N-R53W
7441-3	1.79	SE¼ Sec. 8, T95N-R52W	140	SE¼ Sec. 8, T95N-R52W
7442-3	No add'l	NW¼ Sec. 17, T95N-R52W	40	W½ NE¼ Sec. 17, T95N-R52W
7466-3	1.78	NE¼ Sec. 5, T96N-R51W	152	NE¼ Sec. 5, T96N-R51W
7467-3	1.78	NW¼ Sec. 13, T97N-R52W	152	NW¼ Sec. 13, T97N-R52W
7600-3	3.56	NE¼NW¼ & SW¼ Sec. 12, T96N-R52W (2 wells)	180	NW¼, N½SW¼ Sec. 12, T96N-R52W
7601-3	1.89	NE¼ Sec. 25, T-97N-R53W	132	NE¼ Sec. 25, T97N-R53W
7603-3	1.78	NE¼ Sec. 33, T97N-R52W	120	NE¼ Sec. 33, T97N-R52W
7623-3	1.89	SE¼NW¼ Sec. 24, T97N-R52W	140	NW¼, W½NE¼ Sec 24, T97N-R52W
7653-3	1.67	SW¼ Sec. 8, T96N-R52W	85	W½SW¼, NE¼SW¼ Sec. 8, T96N-R52W
7690-3	1.78	NE¼ Sec. 29, T96N-R52W	160	NE¼ Sec. 29, T95N-R52W
7900-3	1.89	NW¼NE¼ Sec.6, T95N-R51W	136	NE¼ Sec. 6, T95N-R51W
7919-3	1.83	NE¼ Sec. 9, T95N-R52W	83.83	NE¼ Sec. 9, T95N-R52W

Table 2. Deferred Water Permit Applications from the Upper Vermillion Missouri aquifer

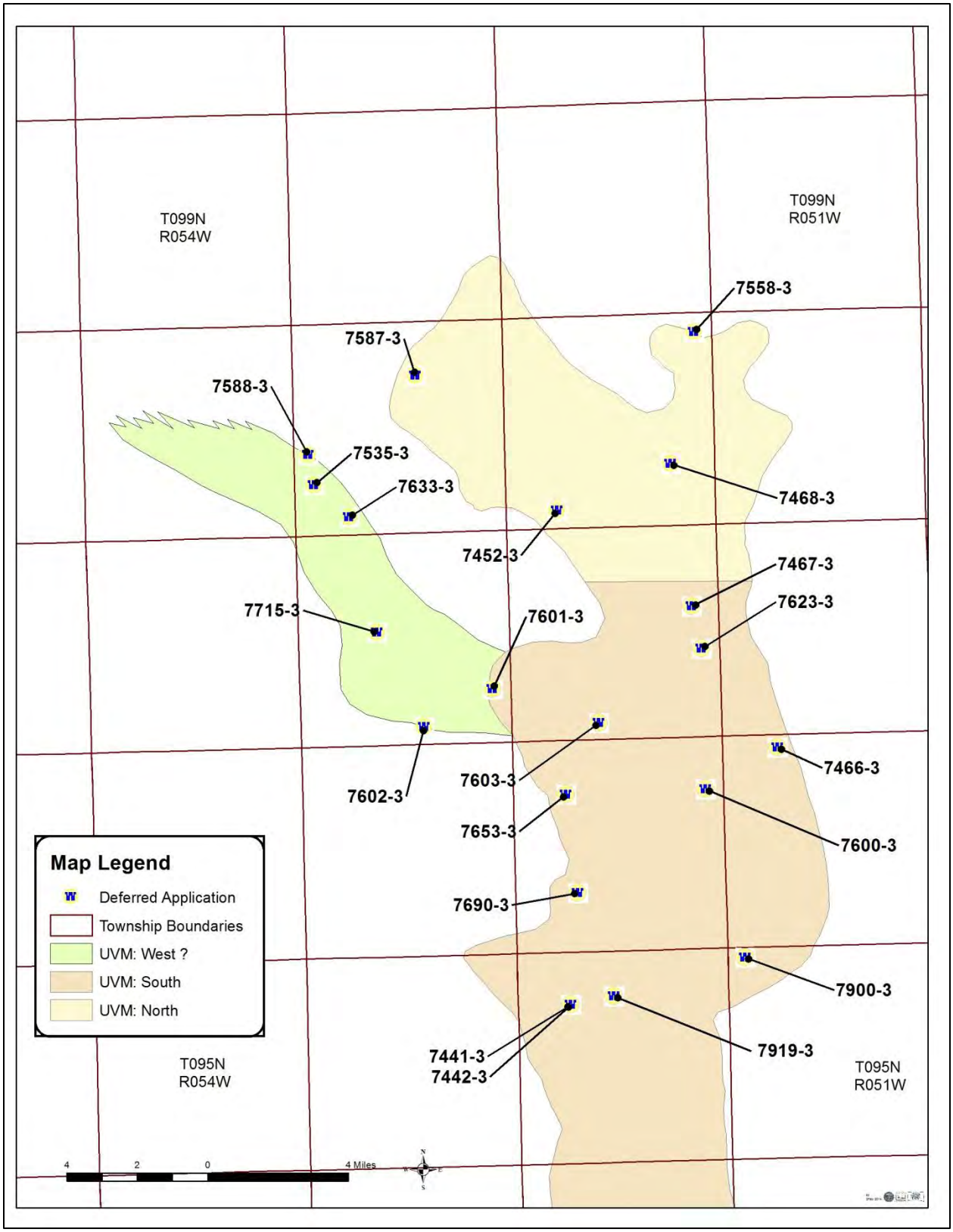

Figure 22. Location of deferred water permit applications and suggested management units of the Upper Vermillion Missouri aquifer

SDCL 46-2A-9

Pursuant to SDCL 46-2A-9, 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 probability of unappropriated water available from the aquifer can be evaluated by considering SDCL 46-6-3.1 which requires "No application to appropriate groundwater may be approved if, according to the best information reasonably available, it is probable that the quantity of water withdrawn annually from a groundwater source will exceed the quantity of the average estimated annual recharge of water to the groundwater source."

In applying SDCL 46-6-3.1, the Sixth Judicial Circuit Court ruled in 2005 that if the Water Management Board uses average annual recharge, then it should also use average annual withdrawals to determine if unappropriated water is available from the aquifer (*Hines v. South Dakota Dept. of Environ. and Nat'l. Resources, Hughes County 04-37* (Memorandum Decision, April 29, 2005).

The 2012 First Judicial Circuit Court's rulings basically stated that data must be presented to show it is probable the average annual recharge exceeds the average annual discharge by at least the amount requested by the water permit application being considered (Memorandum Decision, April 11, 2012).

Administrative Rule of South Dakota Section 74:02:05:07 requires the Water Management Board to rely upon the record of observation well measurements to determine that the quantity of water withdrawn annually from the aquifer does not exceed the estimated average annual recharge to the aquifer.

This report proposes the Upper Vermillion Missouri aquifer can be separated into three management units. Therefore, each management unit will be addressed independently.

SOUTH MANAGEMENT UNIT:

The South management unit of the Upper Vermillion extends south of T97N-R52W into Clay County and encompasses approximately 78,820 acres of the main body of the aquifer. Ten deferred water permit applications (Nos. 7441-3, 7442-3, 7466-3, 7467-3, 7600-3, 7601-3, 7603-3, 7623-3, 7653-3, and 7900-3) and two new permit applications (Nos. 7690-3, and 7919-3) propose to irrigate a total of 1,520.83 acres from the South management unit (See Figure 22). The average annual withdrawal that is expected to be associated with these proposed appropriations was estimated based on the *average application rate* ***per permitted acreage*** for the Upper Vermillion Missouri aquifer (from Table 3) to be 760.4 acre-feet per year. The availability of unappropriated water from this unit was assessed in terms of SDCL 46-6-3.1 through evaluating observation well data and a flow net analysis.

Year	Permitted Acres	Pumpage (ac-ft)	Rate (in/ac)
1979	10350.3	3247	3.764529
1980	9550.3	5082	6.385559
1981	9954.3	4159	5.013713
1982	9878.2	3778.57	4.590193
1983	9815.2	2983.12	3.647143
1984	9815.2	2791	3.412259
1985	9935.2	2479	2.994202
1986	9935.2	3544	4.280538
1987	9848.2	3781	4.607136
1988	9854.2	6753.1	8.22362
1989	10157.2	5758.6	6.803371
1990	10828.7	6626.2	7.342931
1991	10725.7	6220	6.958986
1992	10807.9	1793.2	1.990988
1993	9677.9	534.5	0.662747
1994	9284.9	4313.79	5.575233
1995	9704.9	4484.34	5.544836
1996	9820.2	4672.19	5.709281
1997	9755.2	5408	6.652452
1998	9855.2	5343.85	6.506839
1999	9863.2	5056.06	6.151423
2000	9863.2	6181.55	7.520744
2001	9863.2	6195.66	7.537911
2002	10143.2	7169.69	8.482163
2003	10143.2	5930.9	7.016602
2004	9823.2	7414.06	9.057
2005	9981.2	6856.39	8.243165
2006	10139.2	7906.32	9.35733
2007	10482.5	6983.2	7.994124
2008	11224.5	7467.98	7.983942
2009	11319.6	3878.92	4.112075
2010	11399.3	150.49	0.15842
2011	11399.3	5615.12	5.911016
2012	11458.3	13229.64	13.85508
Min	**9284.9**	**150.49**	**0.15842**
Max	**11458.3**	**13229.64**	**13.85508**
Avg	**10195.8**	**5111.4**	**6.0**

Table 3. Irrigation application rate **per permitted acre** for the Upper Vermillion Missouri aquifer (Water Rights, 1980-2013)

Observation well Data:

The DENR-Water Rights Program monitors five observation wells completed into the South management unit of the Upper Vermillion Missouri aquifer (see Figure 8 for locations). Hydrographs for the observation wells (Figures 23-27) all show upward trending water levels over their periods of record. Hydrographs for the observation wells document changes in climatic conditions along with temporal impacts of pumping. Since climatic conditions mask temporal impacts, well withdrawals from this management unit are not stressing the system to the extent where natural discharge is impacted. Therefore, groundwater outflow is available for "capture." The observation wells in this management unit document unappropriated water is available for appropriation.

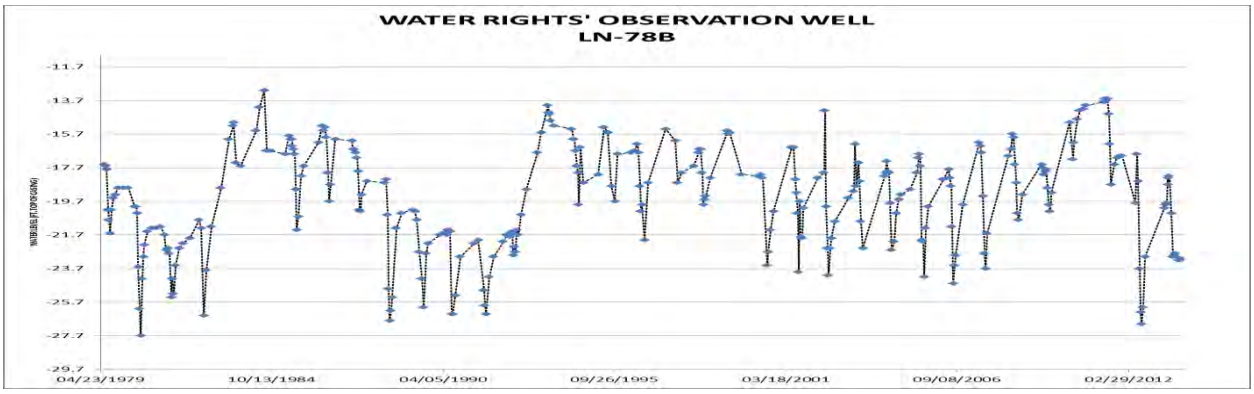

Figure 23. Hydrograph for an observation well completed into the UVM: South (Water Rights, 2014a)

Figure 24. Hydrograph for an observation well completed into the UVM: South (Water Rights, 2014a)

Figure 25. Hydrograph for an observation well completed into the UVM: South (Water Rights, 2014a)

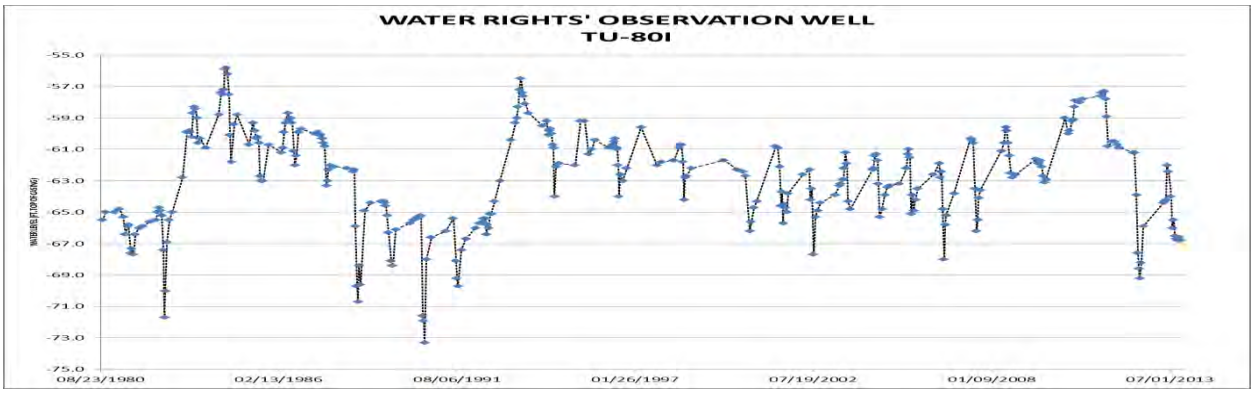

Figure 26. Hydrograph for an observation well completed into the UVM: South (Water Rights, 2014a)

Figure 27. Hydrograph for an observation well completed into the UVM: South (Water Rights, 2014a)

2014 Flow Net Analysis:

Inflows to and outflows from the South management unit of the Upper Vermillion Missouri aquifer were evaluated by interpreting a regional flow net analysis based on the January 21, 2014, water level data from the aquifer. A flow net analysis is a calculation of the amount of water flowing through the aquifer according to the equation:

$$Q = kAI*.0084$$

Where:

Q= flow (ac-ft/yr)
k= Hydraulic Conductivity (ft/d)
A= Area (ft^2)
I= Hydraulic gradient (ft/ft)
.0084= conversion constant

The average hydraulic conductivity from Table 1 (277 ft/d) was applied over the entire aquifer. The cross sectional area reported by the DENR-Geological Survey (in progress) for each cross section (see values in blue on the cross sections) was used in the calculations. The gradient of the potentiometric surface on January 21, 2014, at each cross section was used for the hydraulic gradient. The amount of groundwater outflow from a management unit represents the volume of

water recharging the unit that exceeds discharges from the unit. Groundwater flow was calculated at two locations near the southern extent of the South management unit at cross sections F-F' and G-G' (see Figures 28, 29, 30). The flow calculation data is shown in Table 4. The flow net analysis indicates that there is at least 5,673 acre-feet of water leaving this management unit through groundwater outflow. Therefore, there is a reasonable probability that unappropriated water is available to supply the 760.4 acre-feet per year expected to be used by these twelve applications.

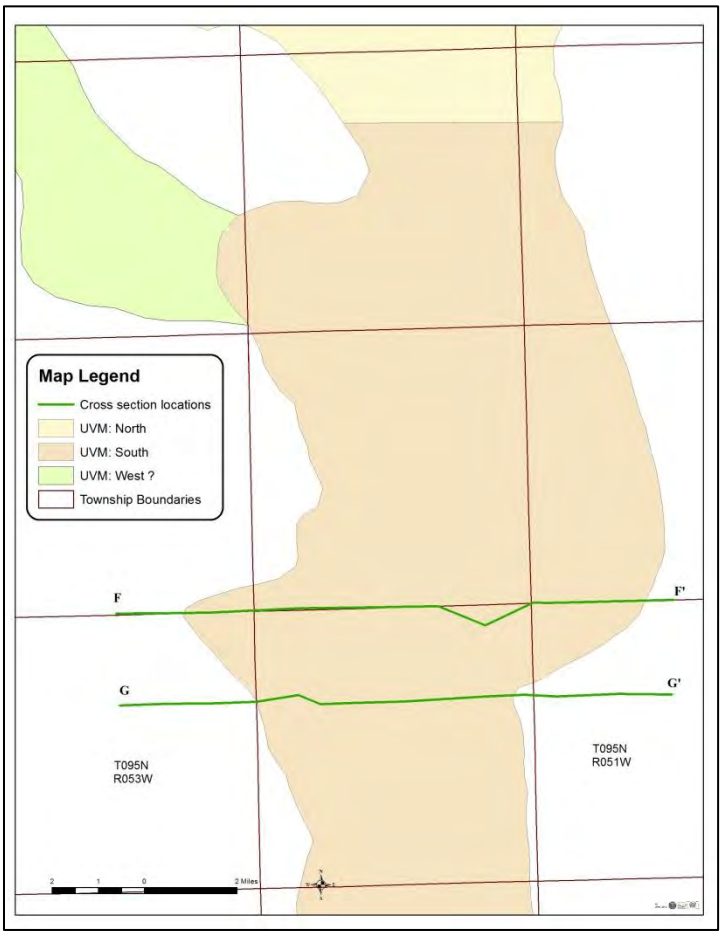

Figure 28. Map showing the location of cross Sections F-F' and G-G'

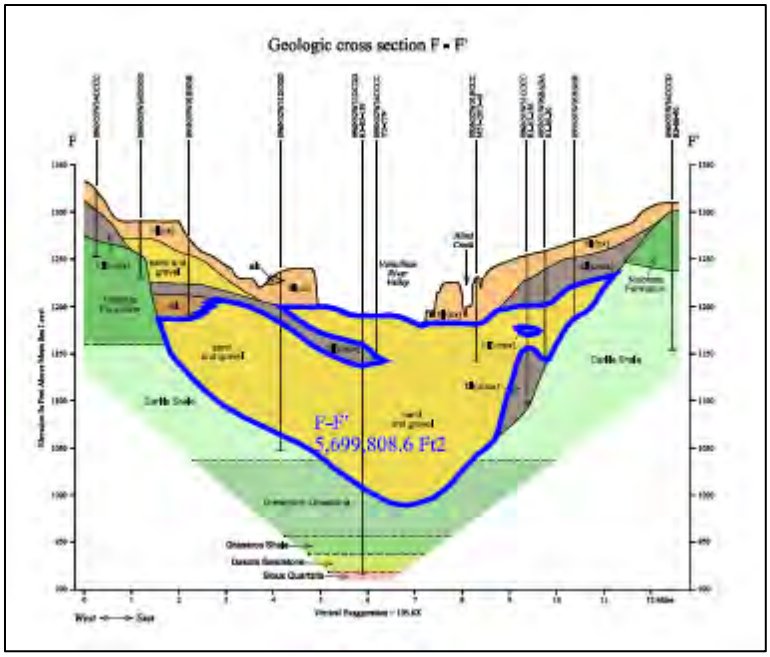

Figure 29. Geologic cross section at F-F' (SD-Geological Survey, in progress)

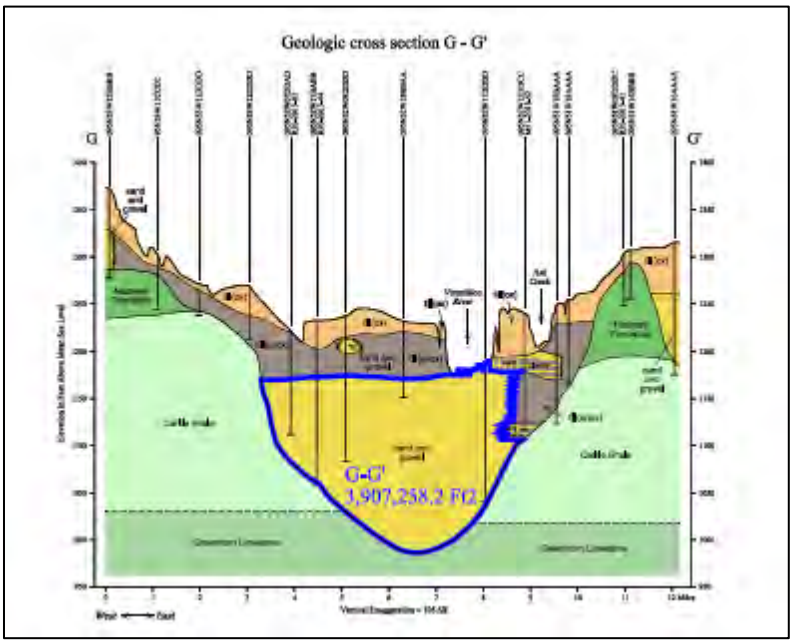

Figure 30. Geologic cross section at G-G'(SD-Geological Survey, in progress)

Cross Section	Area (ft2)	Hydraulic Gradient (ft/ft)	K (ft/day)	Q (ft3/day)	Q (ac-ft/yr)
F-F'	5,699,809	0.00062	277	978,885	***8,223***
G-G'	3907258	0.00062	277	671,033	***5,637***

Table 4. Groundwater flow at southern portion of the South management unit

WEST MANAGEMENT UNIT:

The West management unit of the Upper Vermillion Missouri aquifer extends west from T97N-R53W to at least T98N-R54W and encompasses an estimated 22,750 acres. Five deferred water permit applications (Nos. 7535-3, 7588-3, 7602-3, 7633-3 and 7433-3) propose to irrigate a total of 665 acres from the West management unit (see Figure 22). The expected withdrawal associated with these proposed appropriations was estimated based on the *average application rate* ***per permitted acreage*** for the Upper Vermillion Missouri aquifer (from Table 3) to be 332.5 acre-feet per year. The availability of unappropriated water from this unit was assessed in terms of SDCL 46-6-3.1 through evaluating observation well data and a flow net analysis.

Observation well data

The DENR-Water Rights Program monitors three observation wells completed into the West management unit of the Upper Vermillion Missouri aquifer. Hydrographs for the observation wells (Figures 31-33) all show upward trending water levels over the period of record. The observation wells clearly show changes in climatic conditions along with temporal impacts of pumping. Since climatic conditions mask temporal impacts, well withdrawals from this management unit are not stressing the system to the extent where natural discharge is impacted. Therefore groundwater outflow is available for "capture". The observation wells in this management unit document that unappropriated water is available for appropriation.

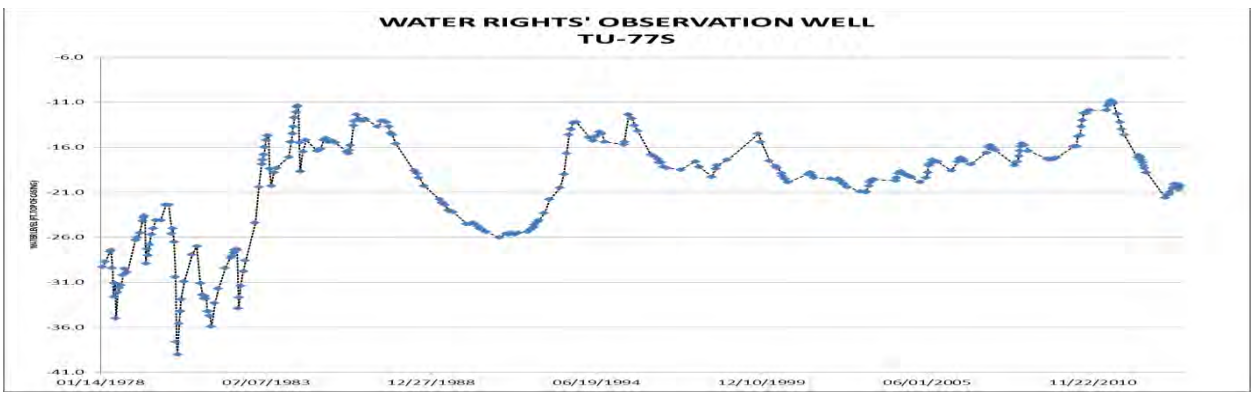

Figure 31. Hydrograph for an observation well completed into the UVM: West (Water Rights, 2014a)

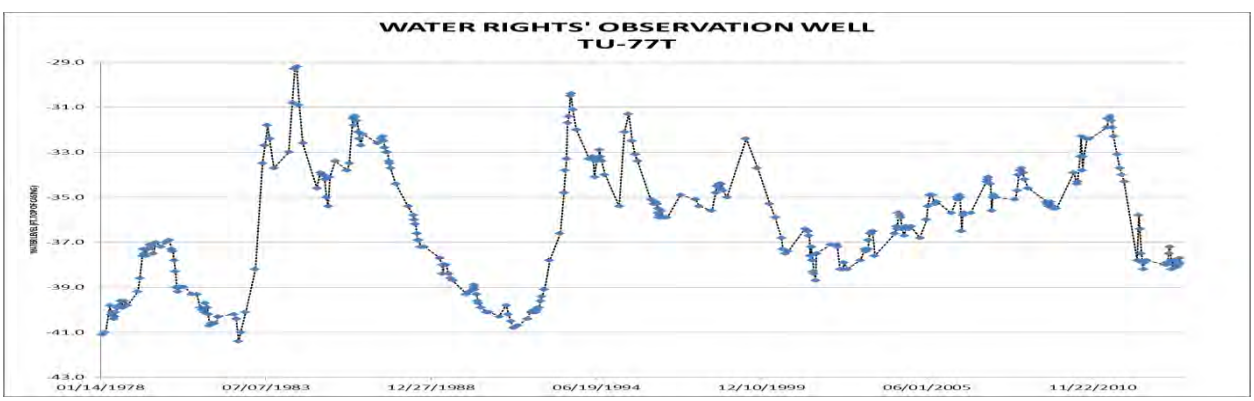

Figure 32. Hydrograph for an observation well completed into the UVM: West (Water Rights, 2014a)

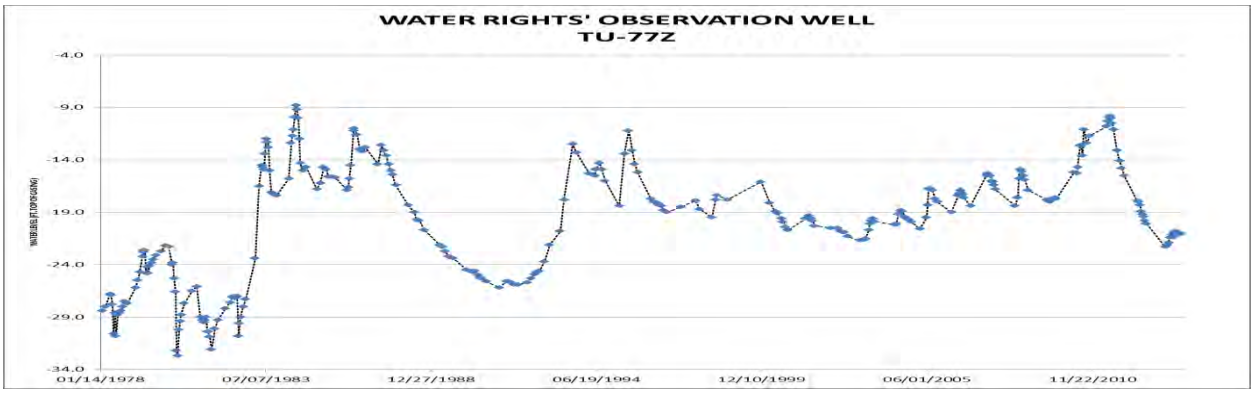

Figure 33. Hydrograph for an observation well completed into the UVM: West (Water Rights, 2014a)

2014 Flow Net Analysis:

The amount of groundwater outflow from the management unit represents the volume of recharge water exceeding withdrawals. Flow was calculated at the location where cross section AA-AA' bisects outwash (See Figures 34 and 35). The calculated flow, using the same equation discussed earlier for the South management unit, is shown in Table 5. The flow net analysis indicates that there is at least 2,681 acre-feet of water leaving this management unit through groundwater outflow. Therefore, there is a reasonable probability that unappropriated water is available to supply the 332.5 acre-feet per year expected to be used by these five applications.

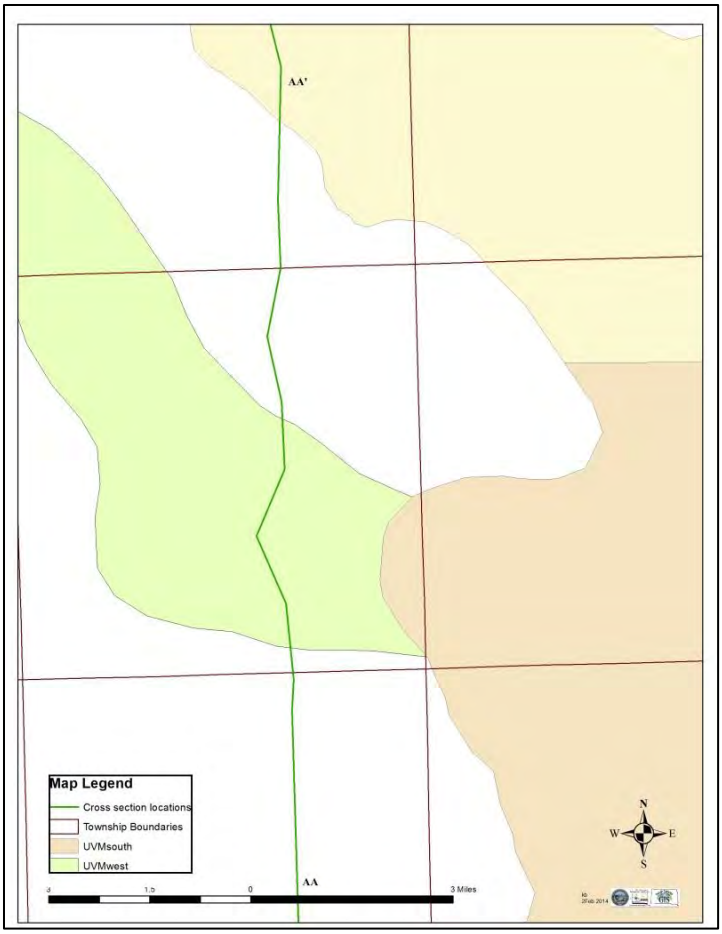

Figure 34. Map showing the location of cross section AA-AA'

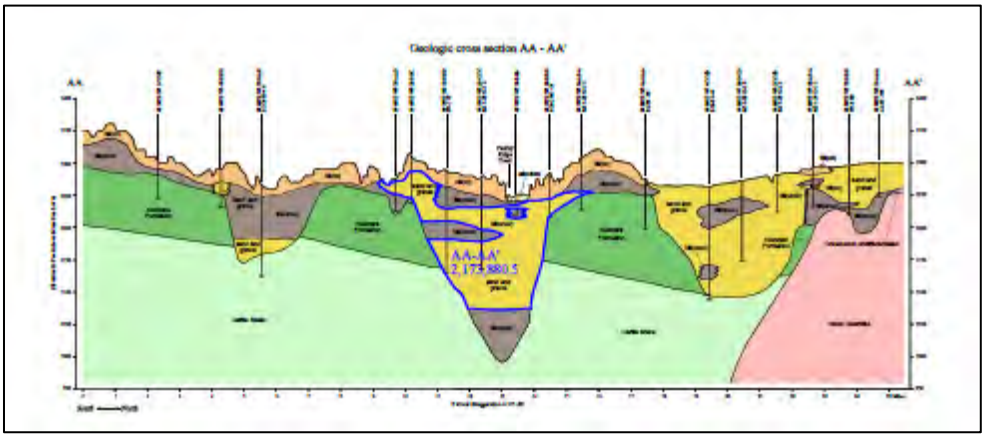

Figure 35. Geologic Cross Section at AA-AA' (SD-Geological Survey, in progress)

Cross Section	Area (ft2)	Hydraulic Gradient (ft/ft)	K (ft/day)	Q (ft3/day)	Q (ac-ft/yr)
AA-AA'	2,173,880	0.00053	277	319,147	2,681

Table 5. Groundwater flow at eastern portion of the West management unit

NORTH MANAGEMENT UNIT:

The North management unit of the Upper Vermillion Missouri aquifer extends north of T97N-R52W and encompasses an estimated 38,110 acres. Four deferred water permit applications (Nos. 7452-3, 7468-3, 7558-3, 7587-3) propose to irrigate a total of 542 acres from the West management unit (See Figure 22). The expected withdrawal associated with these proposed appropriations was estimated based on the *average application rate* ***per permitted acreage*** for the Upper Vermillion Missouri aquifer (from Table 3) to be 271 acre-feet per year. The availability of unappropriated water from this unit was assessed in terms of SDCL 46-6-3.1 through evaluating observation well data.

Observation well Data:

The DENR-Water Rights Program monitors seven observation wells completed into the North management unit of the Upper Vermillion Missouri aquifer (see Figure 8 for locations). Hydrographs for the observation wells (see Figures 36-42) all show downward trending water levels (blue trend line on hydrographs) over the period of record. Trend lines for the minimum annual water levels (green trend lines on hydrographs) are also all trending downward. Except for observation well TU-77F, the maximum annual water level trend (red line on hydrographs) has shown an upward trend.

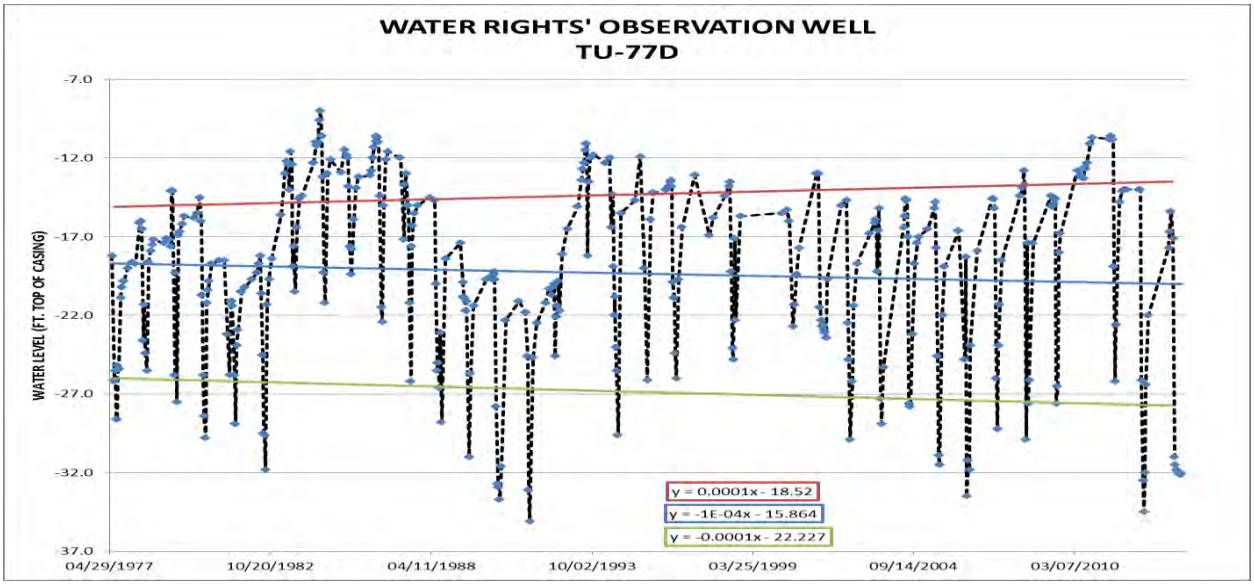

Figure 36. Hydrograph of an observation well completed into the North management unit of the Upper Vermillion Missouri aquifer with trend line (blue), minimum annual water level trend line (green), and maximum annual overall water level trend line (red) (Water Rights, 2014a).

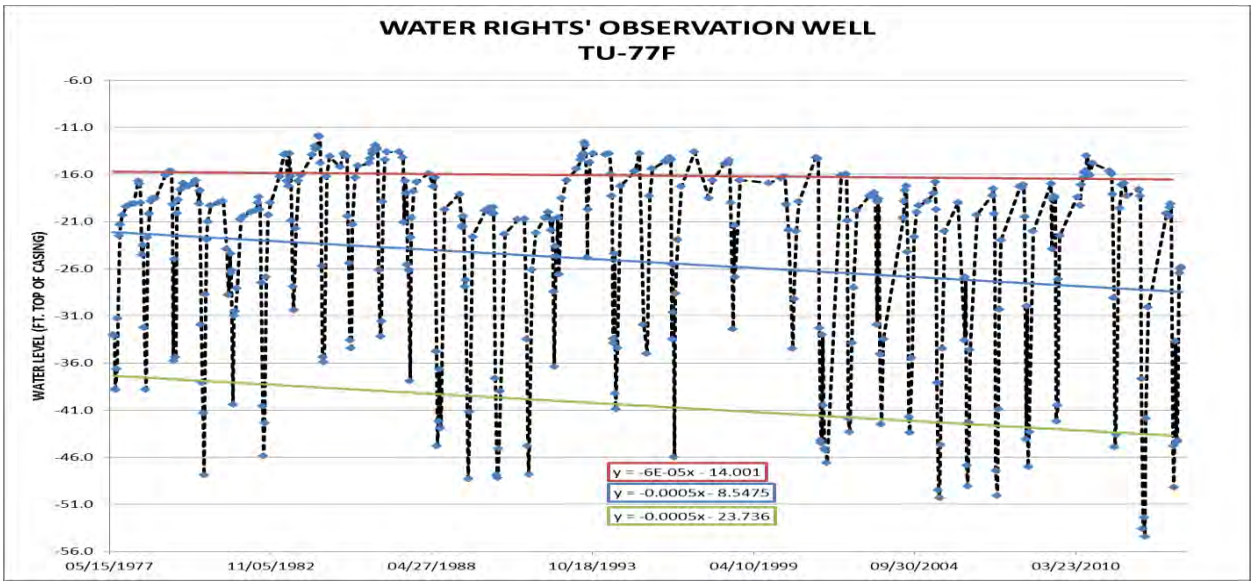

Figure 37. Hydrograph of an observation well completed into the North management unit of the Upper Vermillion Missouri aquifer with trend line (blue), minimum annual water level trend line (green), and maximum annual overall water level trend line (red) (Water Rights, 2014a).

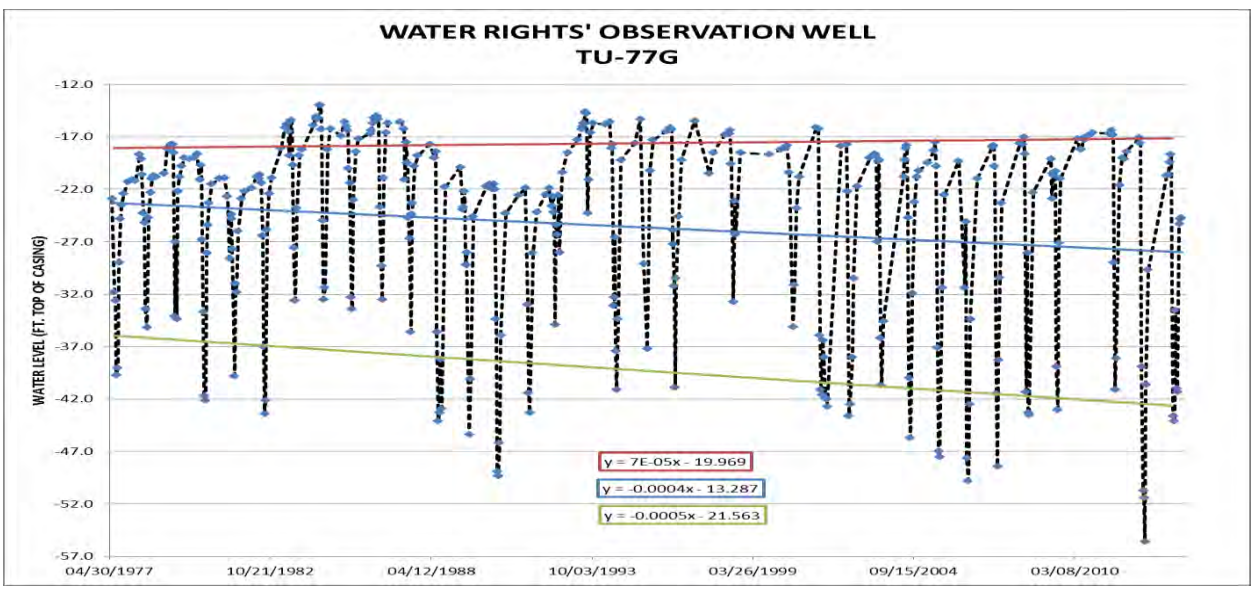

Figure 38. Hydrograph of an observation well completed into the North management unit of the Upper Vermillion Missouri aquifer with trend line (blue), minimum annual water level trend line (green), and maximum annual overall water level trend line (red) (Water Rights, 2014a).

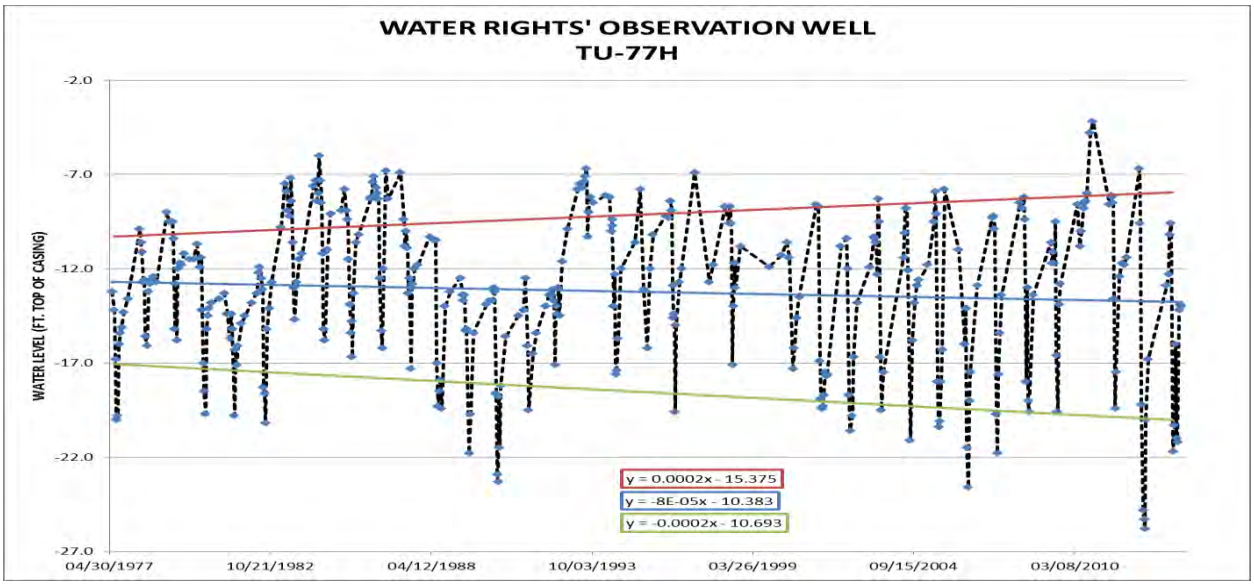

Figure 39. Hydrograph of an observation well completed into the North management unit of the Upper Vermillion Missouri aquifer with trend line (blue), minimum annual water level trend line (green), and maximum annual water level trend line (red) (Water Rights, 2014a).

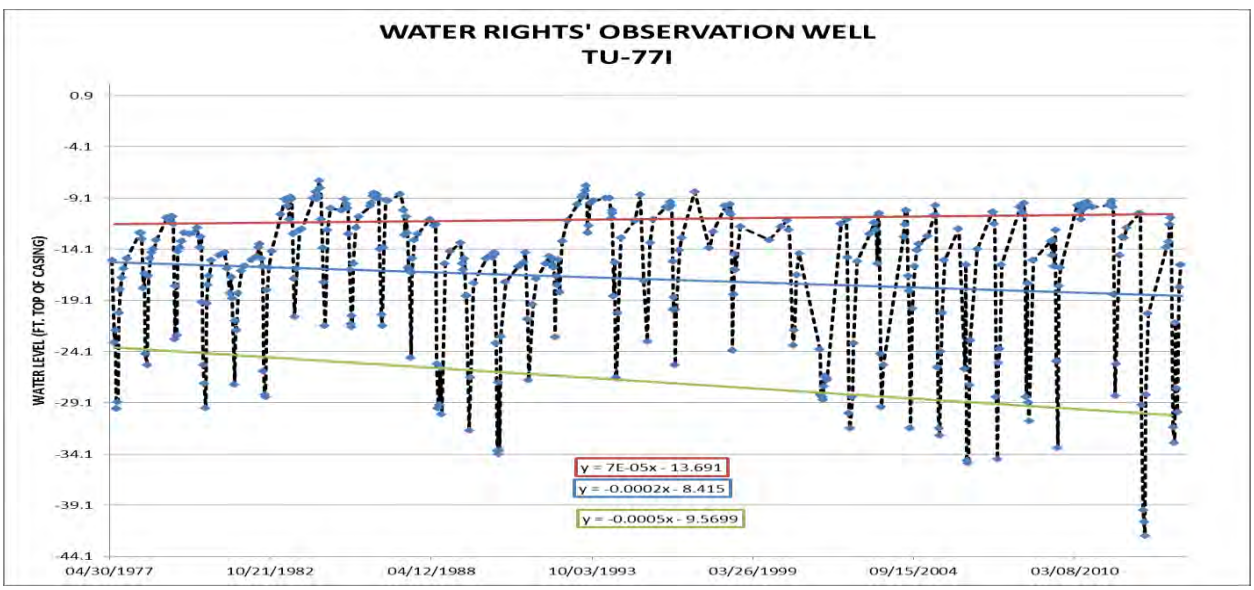

Figure 40. Hydrograph of an observation well completed into the North management unit of the Upper Vermillion Missouri aquifer with trend line (blue), minimum annual water level trend line (green), and maximum annual water level trend line (red) (Water Rights, 2014a).

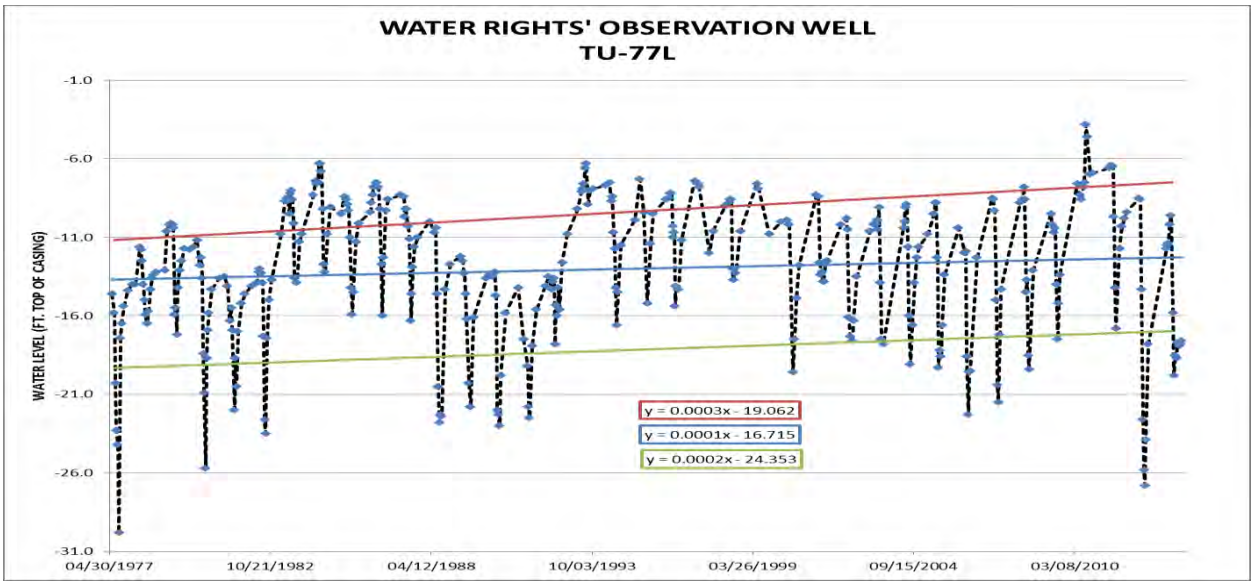

Figure 41. Hydrograph of an observation well completed into the North management unit of the Upper Vermillion Missouri aquifer with trend line (blue), minimum annual water level trend line (green), and maximum annual water level trend line (red) (Water Rights, 2014a).

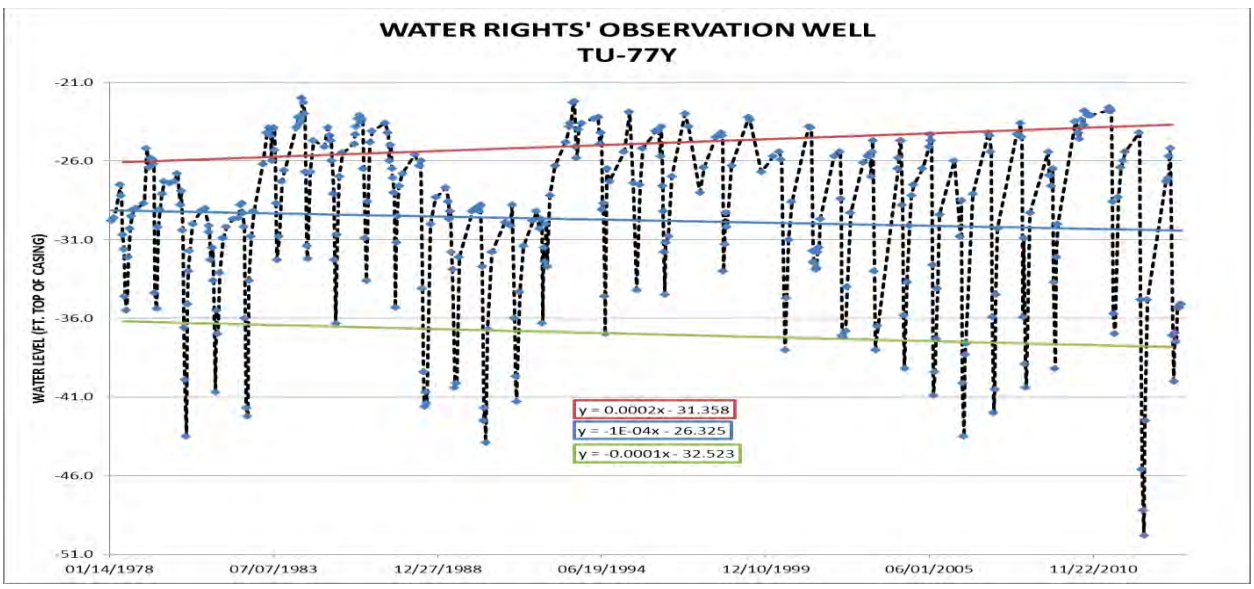

Figure 42. Hydrograph of observation well completed into the North Management Unit of the Upper Vermillion Missouri aquifer with trend line (blue), minimum annual water level trend line (green), and Maximum annual water level trend line (red) (Water Rights, 2014a).

Profiles of the potentiometric surface along a flow path crossing the southern boundary of the North management unit of the Upper Vermillion Missouri aquifer (see Figures 43 and 44) documents that the gradient of the potentiometric surface decreases from 0.000459 ft/ft (2.42 ft/mile) to 0.000228 ft/ft (1.20 ft/mile) when pumping is at a maximum.

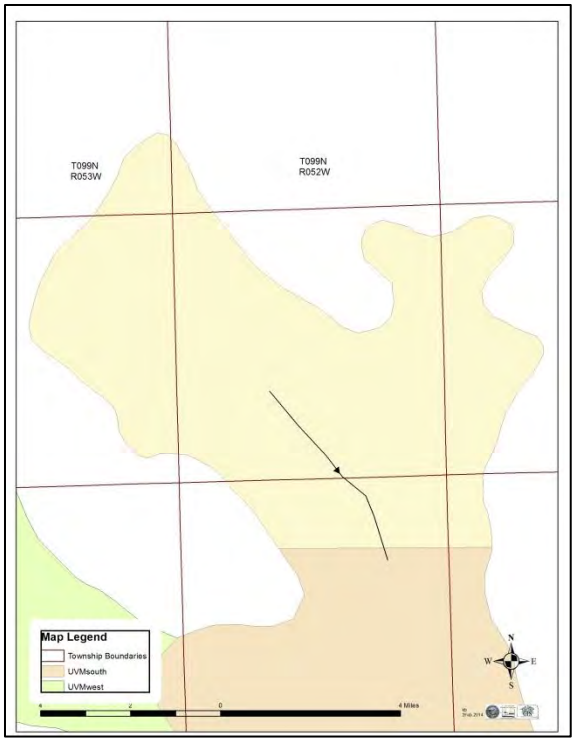

Figure 43. Map showing location of potentiometric surface profile.

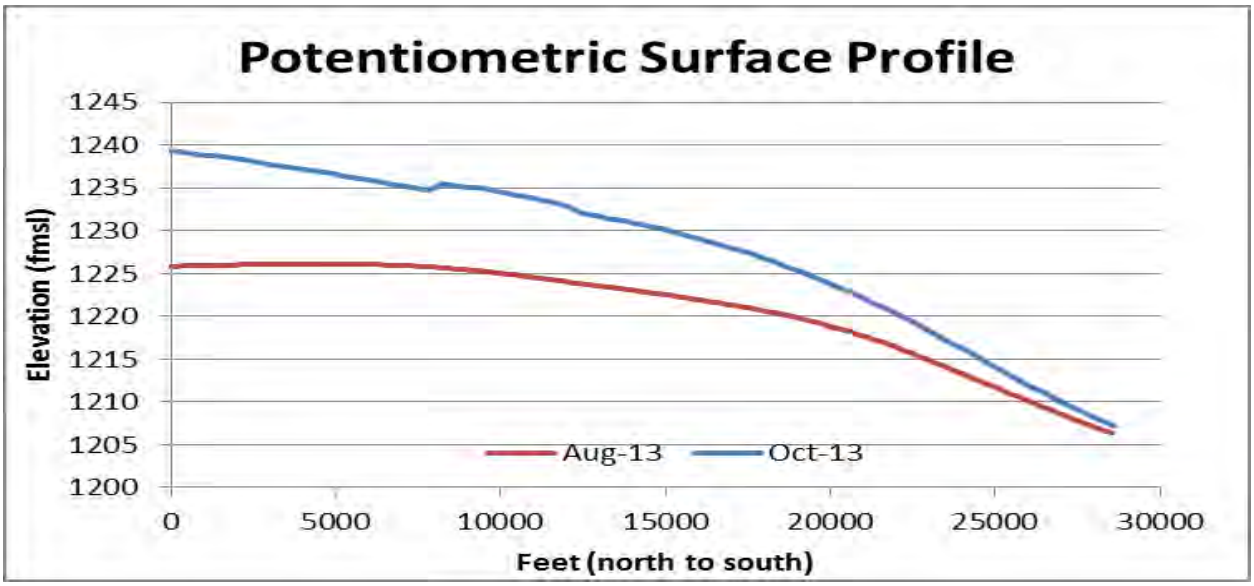

Figure 44. Profile of the potentiometric surface showing stress in North management unit.

The change in slope demonstrates that this portion of the aquifer is being stressed by well withdrawals to the extent that temporal effects are no longer masked by climatic conditions. Unlike the other management units of the Upper Vermillion Missouri aquifer, it is not possible to conclude that unappropriated water is available from this area based on observation well data.

Reported well withdrawals from this management unit have steadily increased in recent years (see Figure 45). The reported pumping from this unit has increased at an average of 80 ac-ft/yr since 2000.

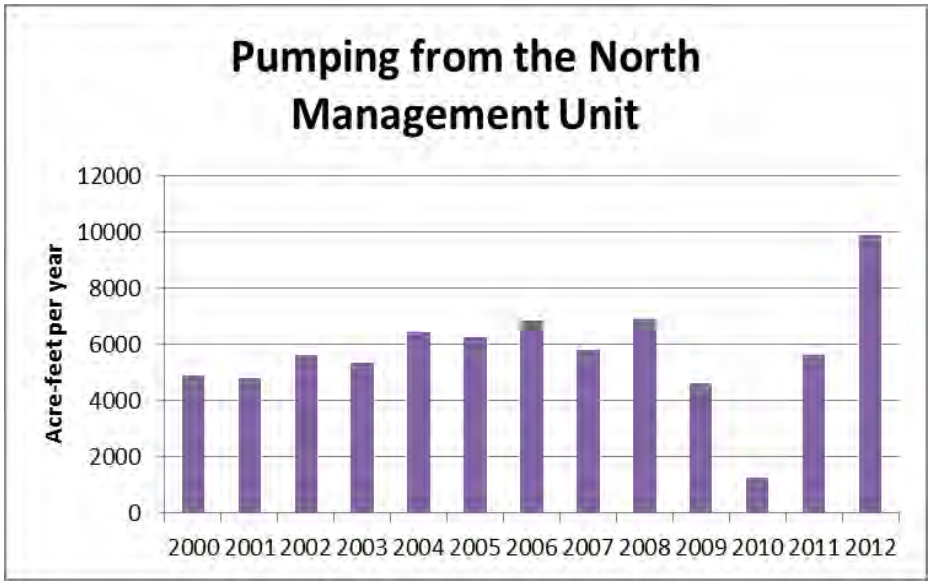

Figure 45. Pumping from the North management unit of the Upper Vermillion Missouri aquifer (Water Rights 1980-2013; Water Rights 2000-2013).

There appears to be an inverse relationship between the increased pumping from the north unit and the decreasing water level trend lines (see Figure 46). At this time data is not available to determine if water levels will stabilize under consistent withdrawals. Therefore, it is not possible to conclude that unappropriated water is available.

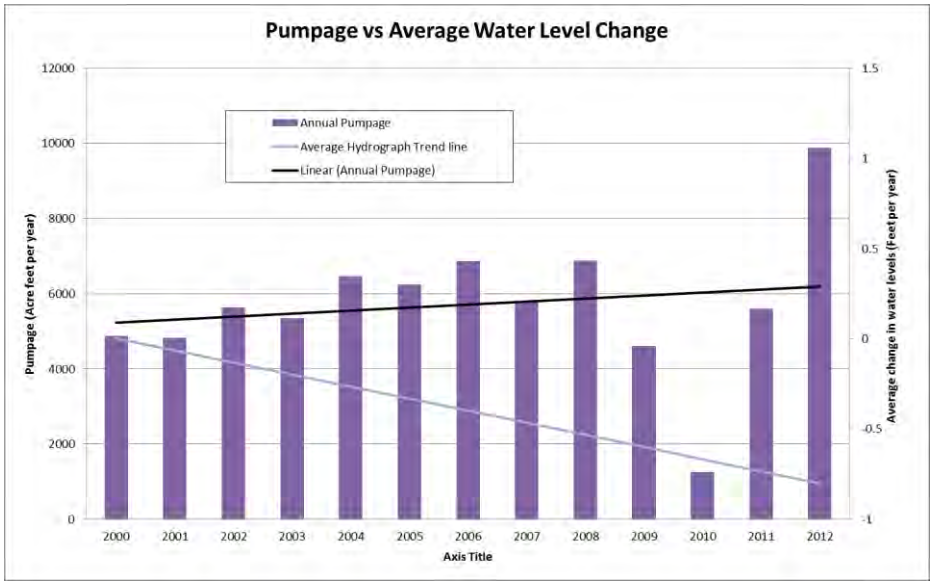

Figure 46. Pumping from the North management unit of the Upper Vermillion Missouri aquifer with trend line plotted with observation well water level trend line data. (Water Rights 1980-2013; Water Rights 2000-2013 and Water Rights 2014a)

Since the observation well data does not support "that the quantity of water withdrawn annually from the aquifer does not exceed average annual recharge to the aquifer" as required by ARSD 74:02:05:07 further evaluation of water availability from North management unit, including a flow net analysis was not performed.

IMPAIRMENT OF EXISTING RIGHTS

Since the Upper Vermillion Missouri aquifer is primarily under artesian conditions, drawdown due to pumping may be fairly large near an individual production well. Drawdown measured in pumping tests of irrigation wells (see Table 1) ranged from 6-92 feet. Well interference has historically not been a problem from the aquifer. Figures 47 and 48 show the location of selected DENR-Water Rights observation wells in relation to concentrations of irrigation wells. Hydrographs for the observation wells (Figures 37, 38, 39, 40 and 24) document drawdown of 5-25 feet. Considering the artesian pressure of the aquifer and natural water level fluctuations, drawdown of that magnitude should not be considered significant.

The Water Management Board has consistently recognized that to place water to maximum beneficial use a certain amount of drawdown may occur. SDCL 46-6-6.1 does not require protection of artesian head pressure as a means of groundwater delivery. However, reasonable domestic use must be assured before irrigation use is allowed. Therefore, when considering irrigation projects, the Water Management Board must give consideration to maintaining artesian head pressure as a method of delivery for domestic wells. To balance interests between irrigation use and delivery of groundwater by artesian pressure, ARSD 74:02:04:20(7) defines an adversely impacted domestic well as:

> "a well in which the pump intake was set at least 20 feet below the top of the aquifer at the time of construction or, if the aquifer is less than 20 feet thick, is as near to the bottom of the aquifer as is practical and the water level of the aquifer has declined to a level that the pump will no longer deliver sufficient water for the well owner's needs."

Depending on the specific characteristics of the Upper Vermillion Missouri aquifer at the proposed well sites, some existing well owners may need to lower their pumps to accommodate possible reduction of head pressure. Therefore, there is a reasonable probability that any well interference from the proposed appropriation will not adversely or unlawfully impair existing nearby wells.

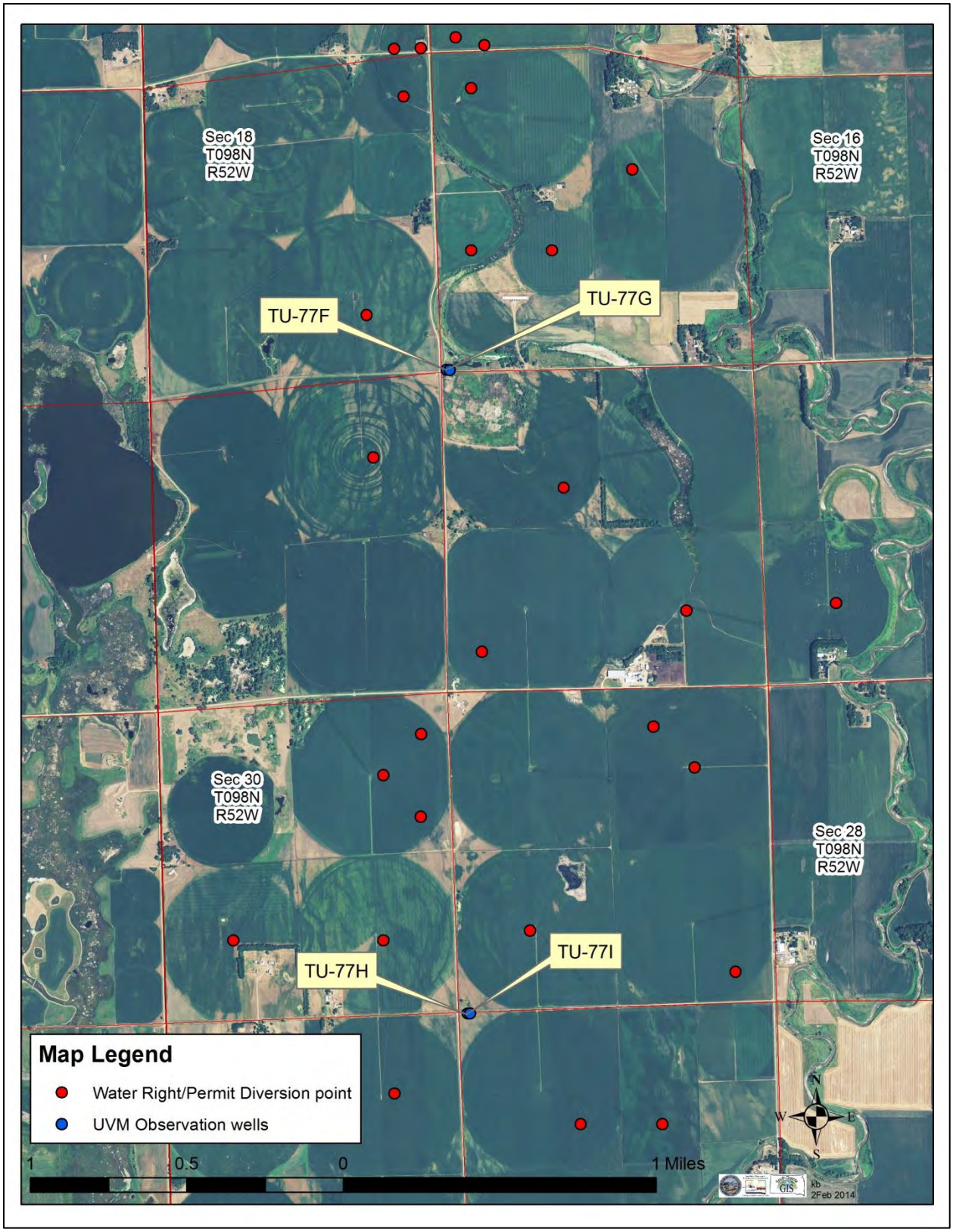

Figure 47. Location of DENR-Water Rights' observation wells TU-77F, G, H, I in relation to irrigation diversion points.

Figure 48. Location of DENR-Water Rights' observation well TU-77M in relation to irrigation diversion points.

CONCLUSIONS:

1. The Water Management Board deferred 18 water permit applications from the Upper Vermillion Missouri aquifer in 2013, because portions of the aquifer have experienced long-term downward trending water levels.
2. Since the Board's initial action to defer the original applications for further study, one additional application has been deferred and two applications are public noticed for deferral.
3. At the time the Board considered the applications, information was not available to distinguish management units within the aquifer.
4. Data is now available to consider three management units of the Upper Vermillion Missouri aquifer.
5. There is a reasonable probability that unappropriated water is available to accommodate the appropriations proposed from the South and West management units of the Upper Vermillion Missouri aquifer (Water Permit Application Nos. 7441-3, 7442-3, 7466-3, 7467-3, 7600-3, 7601-3, 7603-3, 7609-3, 7623-3, 7653-3,7690-3, 7900-3 and 7919-3; and Water Permit Application Nos. 7535-3, 7588-3, 7602-3, 7633-3 and 7715-3.)
6. There is a reasonable probability that the proposed appropriations from the South and West management units can be made without adversely impacting existing water rights.
7. Data is not available at this time to conclude that unappropriated water is available from the North management unit of the Upper Vermillion Missouri aquifer.

Ken Buhler
DENR-Water Rights Program

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