DEPARTMENT OF NATURAL RESOURCES

Ecological and Water Resources - Groundwater Technical Analysis Program

Groundwater Technical Review

Date: 3/26/2019

To: Sara Mielke, Hydrologist, Region 3, St. Paul

From: Scot Johnson PG, Groundwater Specialist, Lake City

Subject: Water Supply Plan for Permit 1976-5086, City of Red Wing, dated 10/16/2017

Reviewed by: Scott Pearson PG, Groundwater Specialist, St. Paul, 3/20/2019

PROFESSIONAL GEOLOGIST

I hereby certify that this plan, specification, or report was prepared by me or under my direct supervision and that I am a duly Licensed Professional Geologist under the Laws of the State of Minnesota.

Print Name: Scot B. Johnson

Signature: Scot B. Johnson

Date: 3/26/2019

License No: 30225

RE: Water Supply Plan for Permit 1976-5086 Red Wing

Introduction

The October 2017 draft Water Supply Plan for the City of Red Wing reported the population served grew from 15,930 in 2005 to 16,524 in 2016 - an increase of 594 citizens (Red Wing, 2017). Over that same time, Residential per Capita Demand (GPCD) dropped from a high of 60.05 gallons in 2007 to a low of 40.22 gallons in 2016. Reported annual water use has trended downward from 1988 through 2018 (DNR, 2019a) as shown in Figure 1.

Red Wing projected that its population will reach 18,707 citizens by 2040. Water use is projected to rise from 559 mg in 2016 to 630 mg in 2040. This is below the currently permitted annual volume of 675 mgy (DNR, 2019a). Red Wing sealed Wells 1-4 which were older Mt. Simon aquifer wells that were not amenable to sending water to a centralized water treatment plant. Red Wing plans to properly seal Well 5 once it can be located.

The City now uses two separate municipal well fields with attendant water treatment plants to remove naturally occurring radium, iron and manganese from the Mt. Simon aquifer water. Each well field is capable of independently supplying all of Red Wing's water needs. Red Wing has requested an amendment to their water appropriation permit to add Well 4-2 with no increase in annual pumping volume.

Hydrogeologic Setting

Red Wing is located within Goodhue County along the Upper Mississippi River in southeastern Minnesota (Figure 2). The Upper Mississippi River serves as the state boundary between Minnesota and Wisconsin. It also serves as the regional groundwater discharge zone for the Tunnel City, Wonewoc and Mt. Simon aquifers. Mississippi River water levels control aquifer base water level elevations. Red Wing is geographically large relative to its population with over 40 square miles within its municipal boundaries (Figure 3).

The majority of Red Wing is located within the Blufflands Landscape, which is characterized, by steep slopes, high topographic relief, well-drained and dissected bedrock plateaus. Thin deposits of unconsolidated materials lay on top of the near surface bedrock (Figure 3). Unconsolidated materials are dominated by pre-Wisconsin till plains, bedrock dominated plateaus, Mississippi River terrace deposits (that represent older floodplains prior to channel down cutting by the glacial River Warren), glacial outwash from melting ice and recently deposited alluvium within stream channels and floodplains (Figure 4).

The upland plateaus along the western and southern perimeter of Red Wing are capped by erosion resistant Prairie du Chien Group formations - the Shakopee Formation and Oneota Dolomite Formation (Figure 5) (Setterholm, 1998). As shown in the plan view map and cross section A-A' (Figure 6), the Jordan, St. Lawrence and Tunnel City Group rock units are dissected by numerous stream valleys with surface water flowing from west to east towards the Mississippi River. The Wonewoc Sandstone, Eau Claire and Mt. Simon Sandstone Formations do not outcrop in the Red Wing area but are buried by terrace, outwash, and alluvial sediments within the Mississippi River valley.

Production Well Information

Red Wing has five-permitted production wells (7-1, 7-2, 7-3, 8-1, and 8-2) open to the Mt. Simon aquifer (Figure 7). In addition, Red Wing has sealed Mt. Simon aquifer Wells 1, 2, 3, and 4 according to MDH rules (Figure 8). Red Wing plans to properly seal Well 5 once it is located in the field.

Red Wing requested appropriation permit 1976-5086 be amended to add Well 4-2 to the permit. Well 4-2 (Unique No. 279479) is an artesian flowing well located within the same well house as the sealed Well 4 (Unique No. 219011). MDH staff documented their inspection and understanding of the historical records for this well in an email dated November 7, 2018 (DNR, 2019a). MDH identified Well 4-2's water use as community supply (municipal) on the Unique No. 279479 Well and Boring Record (MGS and MDH, 2019). Well 4-2 is not connected to the Red Wing water supply distribution system.

Red Wing currently leases Well 4-2, the well house, and the adjacent water reservoir to Xcel Energy as a source of water for their boilers at the nearby incinerator located along the Mississippi River. The well is located outside of the mapped 100-year floodplain at a slightly higher elevation. Construction specifications are not complete for Well 4-2 and it is unknown if the well is properly grouted between the 12, 10 and 8 inch casings. Therefore, Well 4-2 may be a multiple aquifer well with the potential to be open to Tunnel City, Wonewoc and Mt. Simon aquifers. Well 4-2 is actively being pumped by Xcel Energy with a reported water use of 28.5 mg in 2018. Xcel pumps well 4-2 at a rate of 275 gpm and uses approximately 133,000 gallons of water per day which is approximately 49 mgy (Stark, personal comm.). Additional information regarding active production wells is provided in Table 1. Information related to sealed or planned to be sealed production wells can be found in Table 2.

Aquifers Available for Use by the City

Lithostratigraphic and hydrostratigraphic columns for the Red Wing area are provided in Figure 9 (Runkel et al, 2014). Within the Red Wing city limits, the Prairie du Chien, Jordan and Tunnel City aquifers are likely to be unsaturated or only partially saturated due to the steep topography and stream dissection. The Wonewoc aquifer may be available for use in some areas of Red Wing but has not been tapped for municipal water in the past. The Mt. Simon aquifer is the most geographically extensive and readily available aquifer capable of providing the pumping rates and volumes of water required by Red Wing municipal wells. Wells screened within terrace deposits, outwash, and sand and gravel alluvium may provide adequate water but are vulnerable to contamination due to local surface water recharge.

Monitoring Data

Permittee Monitoring

DNR Water Appropriation Permit 1976-5086, as amended in 2007, does not include a groundwater monitoring condition (DNR, 2019a). Red Wing has provided relatively well-documented water level readings from their municipal wells in an electronic spreadsheet format. The water level data appears to have been collected to serve Red Wing's well management needs. The data includes static and pumping (dynamic) water level measurements for the Twin Bluff Well Field (Wells 7-1, 7-2, and 7-3) from 2006 – 2018 and for the Burnside Well Field (Wells 8-1 and 8-2) from 2008-2018 (Figures 10 - 14).

In the Twin Bluff Well Field, about a 50-foot difference between static and pumping water levels are consistently recorded. All three wells show an unexplained uptick in elevation in both static and pumping levels of approximately 50 feet after 2012. Permitted water use in the area has not changed since 2012 so this change in water level is unexplained. Static water levels appear to rebound to near the original static water level recorded (May 1975) for Well 7-1 when the pumps are turned off from 2012 through 2017.

The Burnside Well Field wells maintain a 75 to 100 foot difference in static to pumping water levels with no noticeable uptick in water levels after 2012. Static water levels appear to rebound to near the original static water level recorded (February 2005) for Well 8-1 when the pumps are turned off for the period of record from 2008 through 2018.

The water level data's usefulness is somewhat limited because water level measurements are not tied to a known datum by an elevation survey. In addition, it is unknown if static water levels are fully recovered and stabilized when measured. In Figures 10 through 14, ground surface elevations were estimated using 2-foot contour LiDAR. For Wells 8-1 and 8-2, a stick up length of 2.5 feet was added to estimate the water level measuring point elevations. There were no stick up lengths provided for the Twin Bluff well field Wells 7-1, 7-2, and 7-3.

In the previous round of WSP reviews, DNR identified the need for groundwater monitoring. Because Red Wing pumps greater than 500 mgy, Red Wing was notified that the statewide groundwater monitoring guidance recommends:

1. Instrument and measure water levels in all production and observation wells,
2. Install dedicated water level observation wells in the middle of each well field (2 observation wells), and
3. Install an additional water level monitoring well outside of the well fields.

Statewide groundwater monitoring guidance was conveyed to Red Wing in a DNR WSP comment letter dated February 10, 2015. As outlined below, because of Red Wing's unique situation it may be appropriate to require something a bit less than a literal interpretation of the statewide monitoring guidance document.

On November 28, 2015 Red Wing responded to the DNR's groundwater monitoring guidance with the following counter offer:

> ***Aquifer Water Level Monitoring*** *- We would like to suggest an alternative to the three new monitoring wells that in our opinion could provide better information at a significantly lower capital cost. We would install continuously recording pressure transducers in each of the 5 wells. These would provide static and pumping water levels on a continuous basis that would be monitored and archived through the SCADA system. Since we are able to meet our anticipated future needs with each well field independently, we are able to shut down all the wells at each well field and monitor the aquifer static water level without the impact of any pumping. Likewise, the static level and drawdown from each well can be monitored, and the rate of drawdown and recovery determined. This information could be trended to see if there are any long term changes resulting from the water withdrawal.*

Pump Test Data Analysis

Pump test data sets for three Red Wing production wells were identified in MPARS in the migrated permit file. They include data for City wells Well 7-3 Unique No. 686251 (page 17-21 of pdf), Well 8-1 Unique No. 686252 (page 24-29), and Well 8-2 Unique No. 686258 (page 32- 38). The data sets were analyzed to estimate Mt. Simon aquifer transmissivity and hydraulic conductivity values (DNR, 2019c). The estimated transmissivity and hydraulic conductivity values are summarized and compared to the Prairie Island estimated aquifer parameter values in Table 3 (USGS, 2002). As noted in the USGS report and observed in the analyses of the three Red Wing wells, leakage from the Eau Claire confining unit was not significant and it was appropriate to use the Theis confined aquifer analytical solution. Estimated Mt. Simon transmissivity and hydraulic conductivity values are greater in the Red Wing wells than the Prairie Island well.

A forward solution model was developed in AQTESOLV to assist in the siting of a Mt. Simon observation well at an optimum distance from a well field (Duffield, 2007). Using the Theis analytical solution, a hydraulic conductivity value of 19 ft/day, a storativity value of 0.0003, average aquifer thickness of 240 feet, and 3 hours of pumping every day at 1500 gpm for 10 years it is estimated that observation well should be within ½ mile to detect well field pumping signatures and within 1 mile to detect long-term groundwater level trends (Figure 15).

There is an opportunity to run a future Mt. Simon aquifer test using one production well and two observation wells in the Twin Bluff well field to better understand the Mt. Simon aquifer in the Red Wing area. Specifically, a refined transmissivity, hydraulic conductivity and a storativity value could be determined for the Mt. Simon aquifer with a multi-well aquifer test. The aquifer test opportunity was identified by MDH in Table 9 of the Red Wing Wellhead Protection Plan of Action - WHP Measure (1) (Red Wing, 2016).

DNR Observation Wells

Static water level measurements were taken from DNR Observation Well 25005 (Unique No. 219016) from 1978 to 2003 (Figure 16) (DNR and MPCA, 2019). Construction specifications are summarized in Table 4. This is the same well as Red Wing Well 5 that was never brought on line because of poor water quality. It appears the well was adopted into the DNR Observation Well network after it was abandoned for consideration as a water supply

well. DNR staff searched AP Anderson Park for the well in 2014 as part of the DNR observation well assessment effort with no success in finding the well. Inspection of the Well and Boring Report, as well as the Stratigraphy Report, suggests that the well is open to the unconfined outwash aquifer, the entire Eau Claire Formation and the Mt. Simon aquifer (MGS and MDH, 2019). Reported water level measurements are unlikely to represent only Mt. Simon aquifer water levels.

The City of Red Wing indicated that their intention is to locate the well and properly seal it in accordance with Minnesota Statute 103I and MDH Rules 4725. Red Wing attempted to locate Well 5 in the field in January of 2019 with no success. They plan to try again in the spring using a magnetometer and backhoe. Even if relocated and found to be in good shape, Well 5 should not be reinstated as a DNR observation well or designated as a permit required monitoring well because, in addition to the Mt. Simon aquifer, it is open to the outwash aquifer above the Eau Claire confining unit.

Description of Potential Impacts

Well Interferences

There are no reported well interference complainants or well interference problems listed in the DNR Well Interference database within the Red Wing city limits (DNR, 2019b). The closest well interference complaint occurred 4.5 miles northwest of the Red Wing municipal boundary. The complaint was found to be valid. It was attributed to an unpermitted irrigator pumping from the Jordan aquifer and the issue was resolved. Most, if not all, domestic wells within the Red Wing city limits are open or screened within aquifers other than the Mt. Simon aquifer.

Wellhead protection areas were delineated using groundwater computer model simulations to define underground capture zones for all wells in the two well fields (Figure 17) (Red Wing, 2016). Aquifer parameter values used in the groundwater modeling were based on a USGS aquifer test of a Mt. Simon well on Prairie Island (USGS, 2002). Particle tracking using MODPATH was used to estimate the ten-year porous media time of travel zones for each well. The wellhead protection area boundary for the ten-year time of travel is less than ½ mile from any given well in the well field. The area within the Mt. Simon aquifer affected by municipal well pumping appears to be quite limited. The potential risk for domestic well interference is low.

There are many additional permitted water users in the Red Wing area (Figure 18). To the northwest are a number of major crop irrigators near Prairie Island. Also near Prairie Island, there is a cluster of permits associated with the Xcel Energy Prairie Island nuclear power plant. An additional group of high capacity wells is located to the southeast near the Red Wing Correctional Facility, which includes water supply, non-crop irrigation and industrial processing appropriators. The majority of these appropriators draw their water from aquifers other than the Mt. Simon aquifer. The potential risk for water use conflict is low.

In addition to the City's production wells, there are seven high capacity Mt. Simon aquifer wells within the Red Wing city limits (Figure 19). Permit information is summarized in Table 5. The additional Mt. Simon wells are located to the north at Prairie Island and towards the southeast near the Red Wing Correctional Facility. Two of the wells appear to be unpermitted. Their distance from the municipal well fields, relatively low pumping rates, and small annual volumes suggest that they are unlikely to cause well interference with the Red Wing municipal wells.

Calcareous Fens

The Red Wing 21 calcareous fen is located approximately 3500 feet northeast of the Burnside municipal well field (Figure 20). Based on the mapped bedrock geology, it appears that water from the base of the Wonewoc aquifer discharges at the top of the Eau Claire confining unit. Regional groundwater flow is from south to north towards the Mississippi River. The Eau Claire confining unit isolates the Red Wing 21 calcareous fen Wonewoc aquifer source water from the Mt. Simon aquifer used by the Burnside municipal well field. Red Wing has not requested any increase in pumping rates or annual volume. No impacts to the Red Wing 21 calcareous fen are anticipated.

Surface Water Impacts

Numerous trout streams enter Red Wing from south and west of the city limits including Spring Creek, Trout Brook, and Hay Creek (Figure 21). Groundwater discharge responsible for maintaining summer base flows in the trout streams are from aquifers above the Eau Claire confining unit. Similar to the Red Wing 21 calcareous fen, the Eau Claire confining unit isolates the trout streams from potential pumping impacts associated with municipal use of the Mt. Simon aquifer.

Large streams such as the Mississippi, Cannon and Vermillion Rivers, and their associated floodplain wetlands, are supported largely by surface water runoff within their relatively large watersheds. Red Wing has not requested any increase in pumping rates or annual volume. No impacts to the designated trout streams or other surface water features are anticipated because the City water source is a confined aquifer that is not hydraulically connected to the shallower groundwater dependent resources.

Summary of Current Impacts and Potential Future Impacts

Residential per Capita Demand (GPCD) dropped from a high of 60.05 gallons in 2007 to a low of 40.22 gallons in 2016. Reported annual water use has trended downward from 1988 through 2018. Red Wing projects its population to reach 18,707 citizens by 2040. Water use is projected to rise from 559 mg in 2016 to 630 mg in 2040. This is below the currently permitted volume of 675 mgy. Red Wing has asked for an amendment to their water appropriation permit to add Well 4-2 with no increase in annual pumping volume. Well 4-2 is currently active.

No impacts to surface water, trout streams or calcareous fens are anticipated at the current level of Mt. Simon aquifer use by Red Wing. The potential for well interference or water use conflict appears to be low at the current level of Mt. Simon water use by Red Wing and other permitted appropriators. Based on its location near the Mississippi River and the distance from other high capacity wells, it is unlikely that pumping Well 4-2 will cause well interference, water use conflict or impact surface waters.

Monitoring Needs Discussion

DNR statewide groundwater monitoring guidance criteria for all communities using more than 500 mgy of water (Community E) includes the instrumentation of all production wells and observation wells, the establishment of an observation well in the center of each of the two well fields, and the establishment of one observation well away from the pumping centers. DNR statewide groundwater monitoring guidance is intended to insure that adequate water level data is collected to assure long-term aquifer sustainability.

Red Wing is in a unique hydrogeologic setting that justifies a relaxation of the statewide groundwater monitoring guidance criteria. As described in detail above, all the municipal wells draw water from the confined Mt. Simon aquifer. The Mt. Simon is geographically a very large and productive aquifer and there are no immediate groundwater sustainability concerns in Red Wing. The Mt. Simon is effectively isolated from groundwater dependent water resources by the Eau Claire confining unit. Based on the Wellhead Protection Area ground modeling, the ten-year time of travel is characterized by relatively small radius capture zones. In addition, there is a low potential for domestic well interference or water use conflict in the Mt. Simon aquifer.

Technical Recommendations

The Groundwater Technical Analysis Work Group recommends Red Wing be required to complete the following monitoring tasks as part of any future permit amendment to Red Wing 1976-5086:

1. Install one Mt. Simon aquifer observation well approximately ½ mile away from one of the Red Wing well fields to provide water level trend data. It is recommended that the well be installed on public lands to assure perpetual access to the well.
2. Instrument the observation well and all production wells with pressure transducer dataloggers that are integrated into the Red Wing SCADA system. The dataloggers should be programmed to take hourly depth to water measurements. Datalogger measurements should be submitted to the DNR Groundwater Level Coordinator and Area Hydrologist in the DNR's standard electronic format every quarter.
3. Measure depth to water manually on a quarterly basis at the observation well and production wells from a dedicated measuring point using an electronic tape or steel tape measured to within 0.01 foot. The manual measurements will be used to check and correct the datalogger measurements. The quarterly measurements should be submitted to the DNR Groundwater Level Coordinator and Area Hydrologist in the DNR's standard electronic format every quarter.
4. Survey the observation well and production well measuring points using the 1988 NAVD elevation datum. Well locations must be surveyed and reported in NAD83, Zone 15 UTMs. A copy of the survey must be submitted to the DNR Groundwater Level Coordinator and Area Hydrologist.
5. Seal Well 5 in accordance with Minnesota Statute 103I and MDH Rules 4725. The DNR should be provided a copy of the Well 5 sealing record to be posted in MPARS.
6. MDH recommended an aquifer test be conducted at a Mt. Simon well field in Table 9 of the Red Wing Wellhead Protection Plan of Action - WHP Measure (1). DNR is willing to assist MDH and Red Wing with the aquifer test to determine Mt. Simon aquifer parameter values.

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Table 1. Active production wells (MGS and MDH, 2019) (DNR, 2019a)

Well field location	Twin Bluffs Well Field			Burnside Well Field		Barns Bluff Well
Well name	7-1	7-2	7-3	8-1	8-2	4-2
Unique well no.	216020	151565	686251	686252	686258	279479
UTM location (m) MPARS	535807, 4932320	536099, 4932268	535502, 4932260	529513, 4934587	529564, 4934606	538197, 4935144
Ground elevation (ft) LiDAR	829	834	835	839	848	686
Depth (ft)	630	665	639	655	662	620
Diameter (in)	24/16	24/20/14	24/18	24/18	24/18	1210/8
Aquifer	Mt. Simon	Mt. Simon	Mt. Simon	Mt. Simon	Mt. Simon	*Multiple? Grout?
Open hole interval (ft BGS)	350-630	390-665	384-639	470-665	460-662	154-620
Static water level (ft BGS)	136	158	150	135	161	artesian flowing
Pumping rate (GPM)	1500	1500	1500	1500	1500	275
2017 Pumped Volume (MGY)	75	75	185	75	75	49 requested
Operational dates	<1988-Present	<1988-Present	2007- Present	2006- Present	2006-Present	1922-1944? / 2018?

* Possibly open to Tunnel City, Wonewoc and Mt. Simon aquifers

Table 2. Sealed production wells (MGS and MDH, 2019) (DNR, 2019a)

Well name	1	2	3	4	5
Unique well no.	219012	216017	218623	219011	219016
UTM location (m) CWI	536342, 4934663	536354, 4934663	538721, 4933430	538198, 4935124	531223, 4935247
Ground elevation (ft) LiDAR	684	684	655	686	798
Depth (ft)	488	480	770	620	684
Diameter (in)	18	18	26/20	18	12
Aquifer	Mt. Simon	Mt. Simon	Mt. Simon	Mt. Simon	*Multiple
Open hole interval (ft BGS)	150-488	146-480	385-770	361-620	243-684
Static water level (ft BGS)	16	16	170	Flowing	105
Pumping rate (GPM)	1200	1200	1260	1200	0
Operational dates	1931-2006	1932-2006	1950-2005	1939-2005	Not Operational
Date sealed	9/12/2006	9/13/2006	5/29/2015	10-27-2006	?
MDH seal record number	246210	246211	329231	251610	?

* Open to terrace deposits, Eau Claire and Mt. Simon.

Table 3. Pump test estimated aquifer parameter value summary (DNR, 2019c) (USGS, 2002).

Production Well Name	Unique No.	Transmissivity (ft2/day)	Storativity	Hydraulic Conductivity (ft/day)
Red Wing Well 7-3	686251	5408	NA - single well test	20
Red Wing Well 8-1	686252	4339	NA - single well test	19*
Red Wing Well 8-2	686258	5293	NA - single well test	24
Prairie Island (USGS)	626771	3000	0.0003	10

*Judged to be the best data and curve fit.

Table 4. DNR observation well (DNR and MPCA, 2019) (MGS and MDH, 2019) (DNR, 2019a).

Well Construction	
Well name	25005 / Well 5
Unique well no.	219016
UTM location (m)	531223, 4935247
Measuring point elevation (ft)	800.9
Distance to pumping center (miles)	3.5 Twin Bluffs/1.1 Burnside
Depth (ft)	684
Aquifer	*Multiple
Open hole interval (ft BGS)	243-684
Static water level (ft BGS)	105
Period of record (from date – to date)	1978-2003

* Open to terrace deposits, Eau Claire and Mt. Simon.

Table 5. Mt. Simon aquifer production wells in Red Wing (MGS and MDH, 2019) (DNR, 2019a).

Name	Unique Well Number	Use Type	Permit Number	Annual Permitted Volume (mgy)	Pumping Rate (gpm)
Red Wing Mississippi Links	466829	Non-crop Irrigation	1993-5063	15.0	250
Red Wing Mississippi National	601313	Non-crop Irrigation	1999-5035	16.5	280
Prairie Island 3	783614	Community Supply	May not be permitted	?	400
Xcel Energy	780282	Public Supply	May not be permitted	?	40
Minnesota Correctional Facility	248080	Water Supply	1986-5027	16.0	650
USG (Con Wed Corp)	248808	Industrial Processing	1972-0021	30.0	250
Prairie Island Plant SAB	801757	Other	2015-0785	1.7	80

Figures

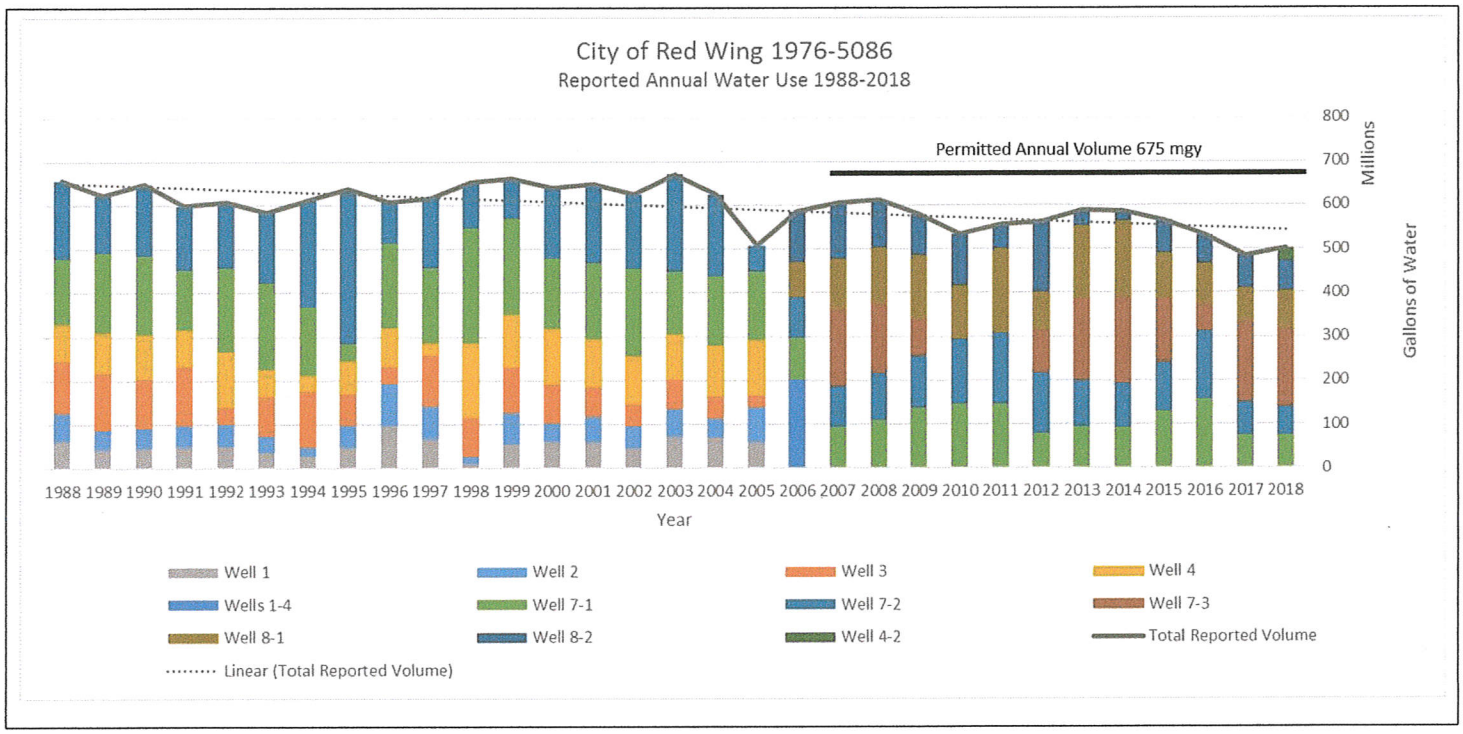


Figure 1. Red Wing reported annual water use from 1988 to 2018 (DNR, 2019a).

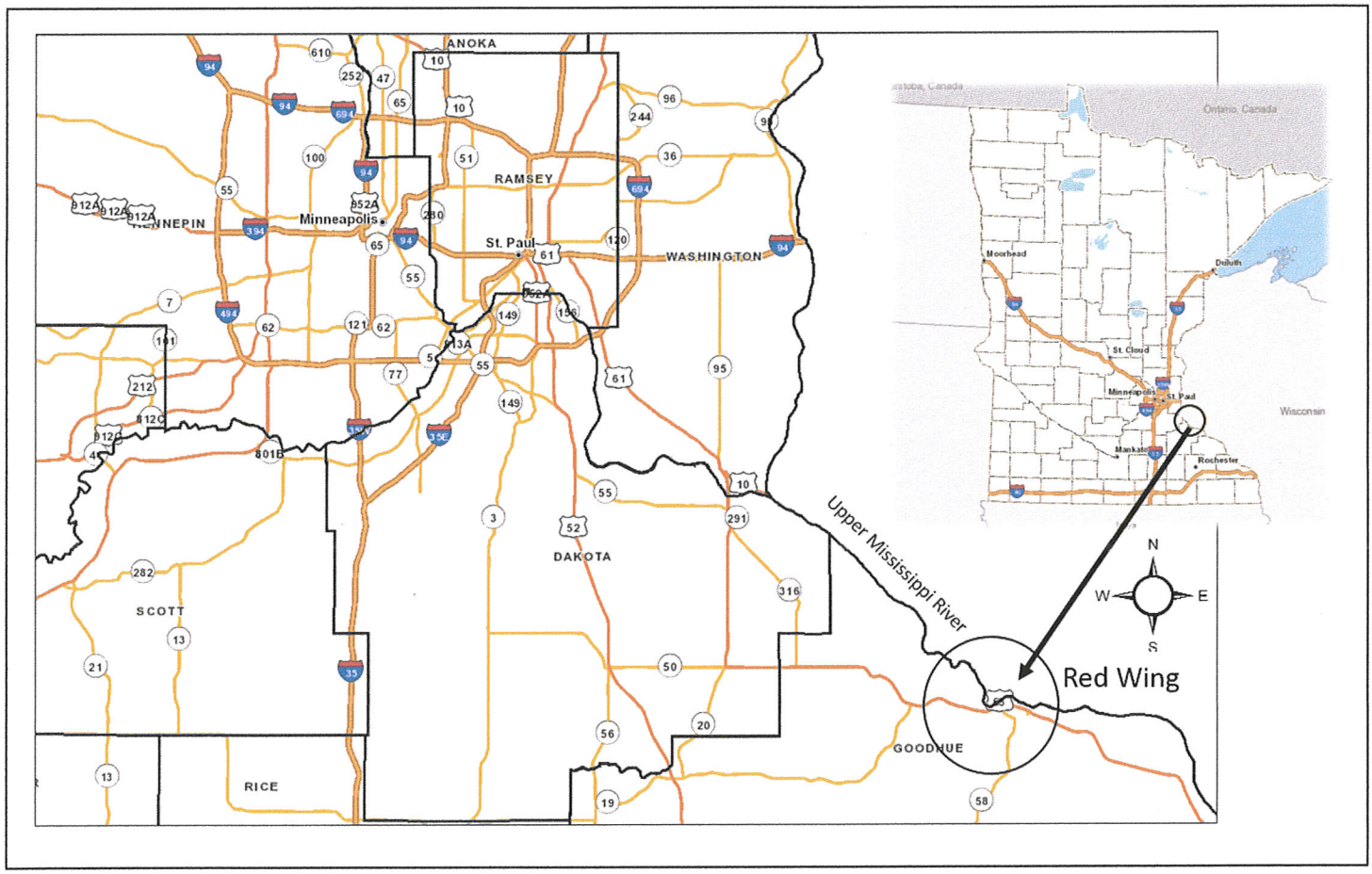


Figure 2. Red Wing location map (DNR, 2019b).

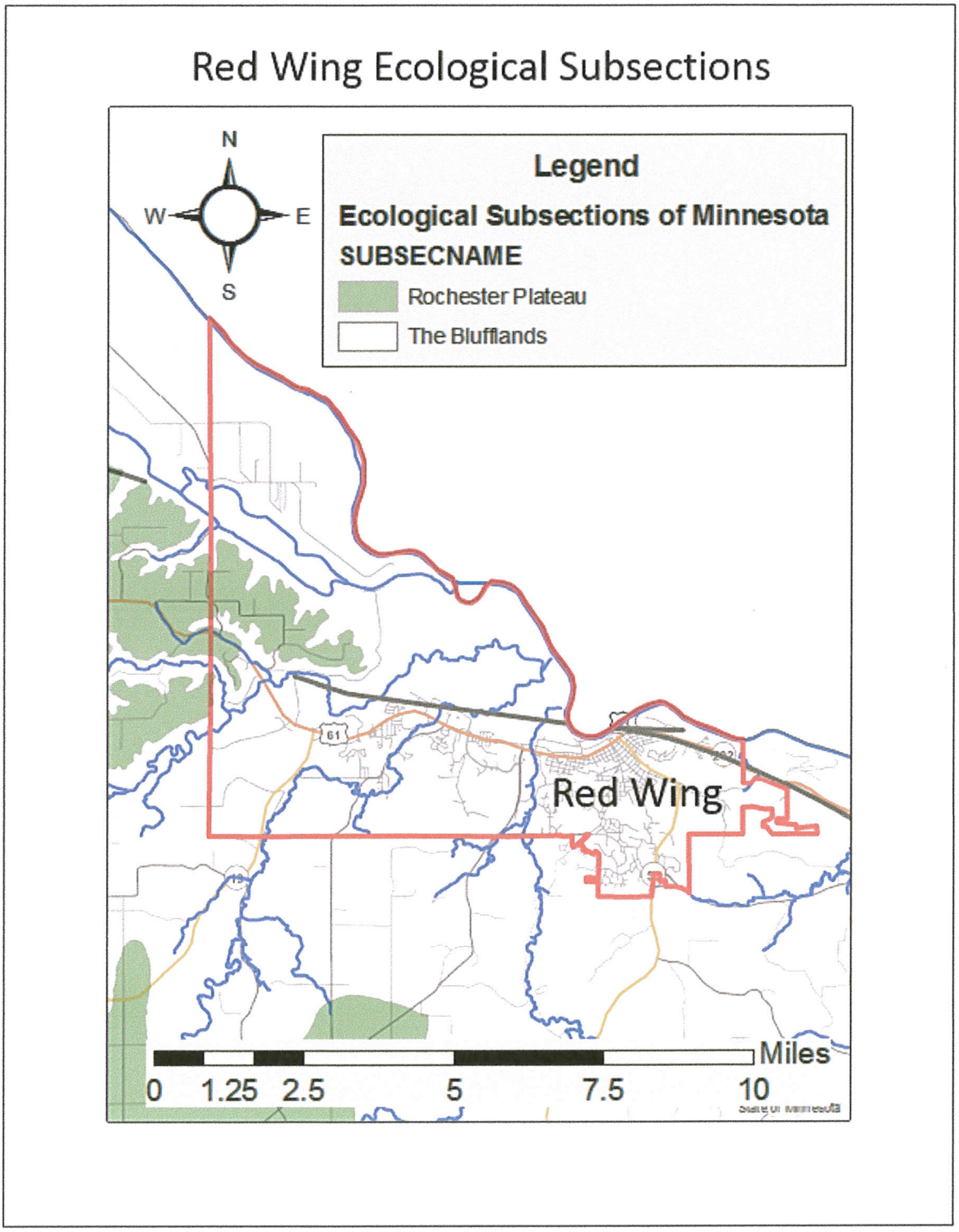


Figure 3. Mapped ecological subsections in the Red Wing area (DNR, 2019b).

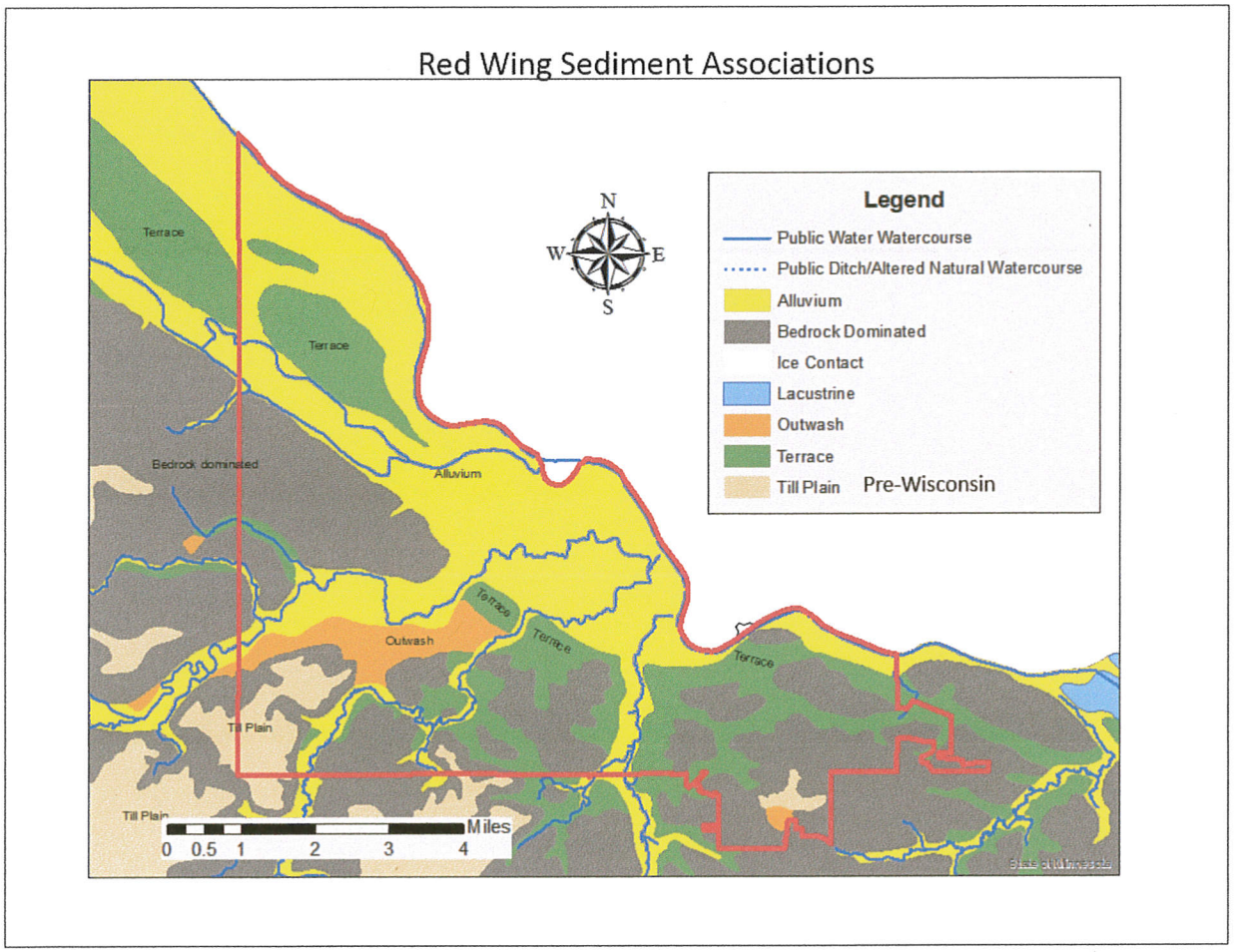


Figure 4. Mapped sediment associations in the Red Wing area (DNR, 2019b).

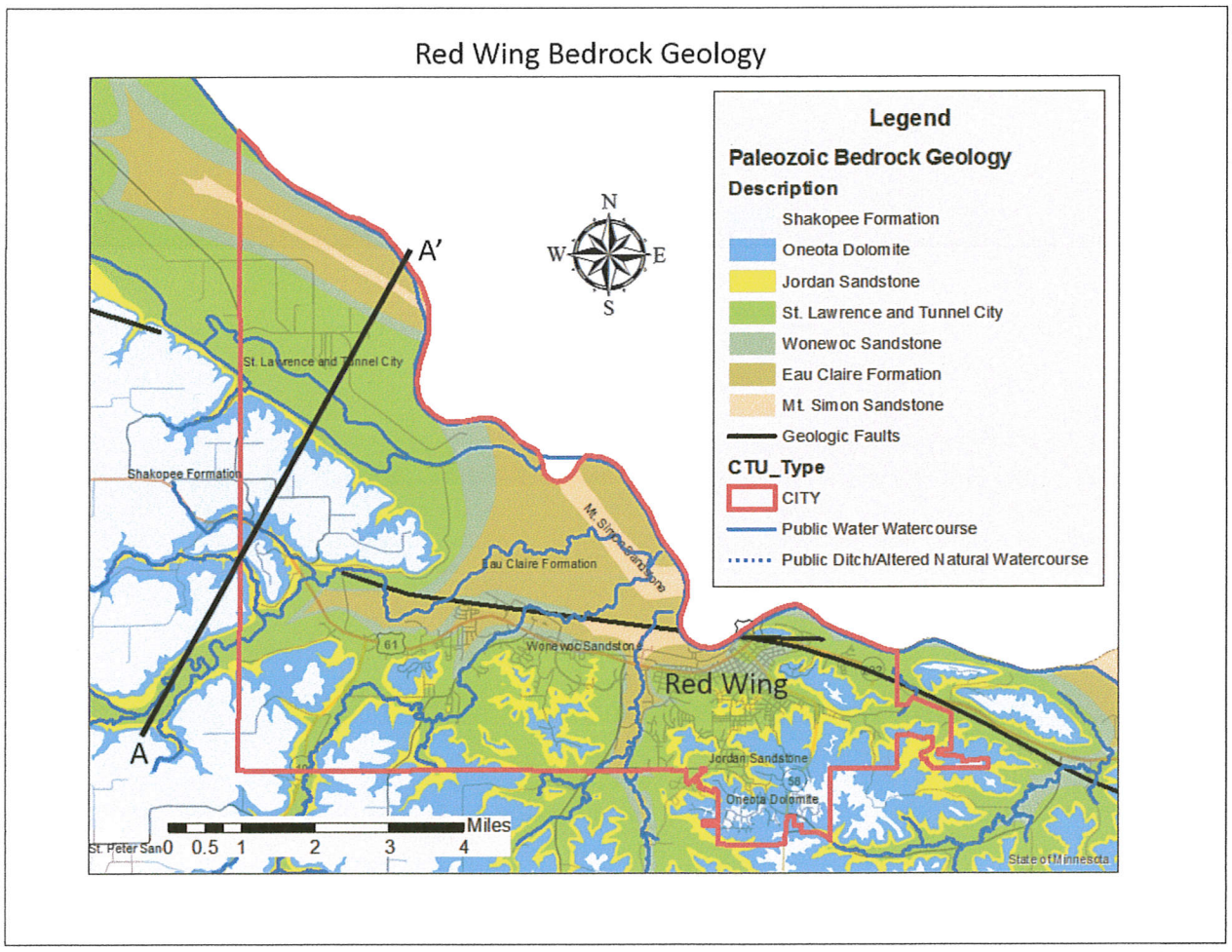


Figure 5. Mapped Paleozoic bedrock in the Red Wing area (Runkel et al, 2014).

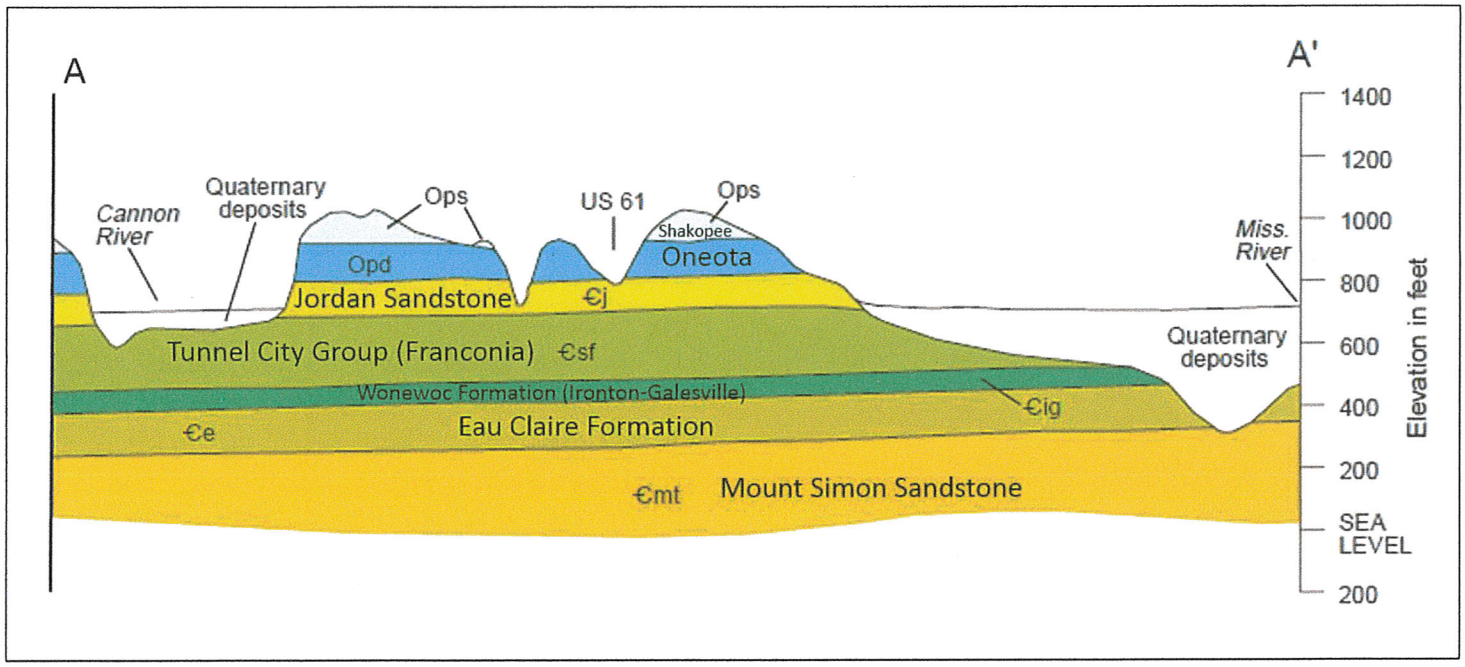


Figure 6. Geologic cross section A to A' in the Red Wing area (Setterholm, 1998).

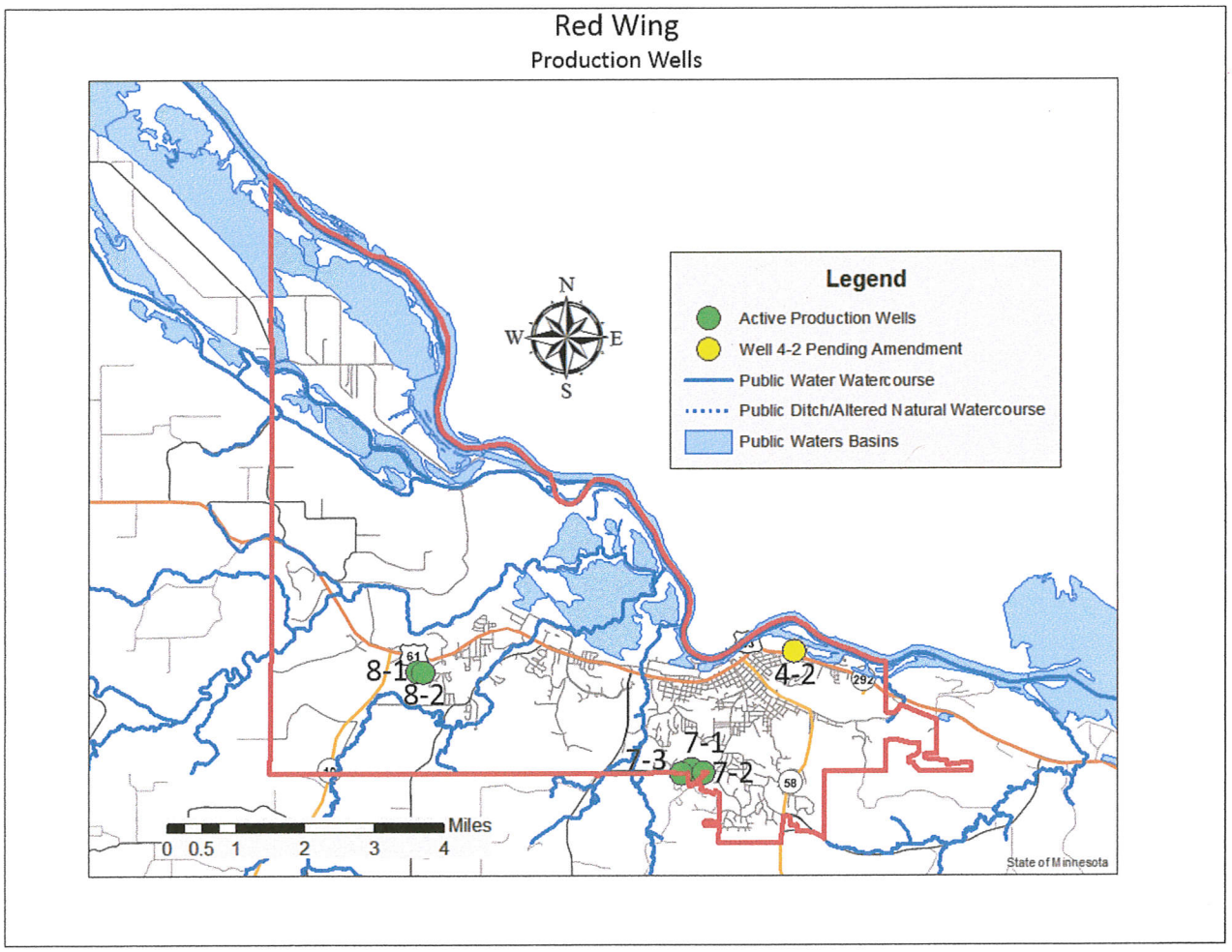


Figure 7. Red Wing active municipal wells (DNR, 2019a) (DNR, 2019b).

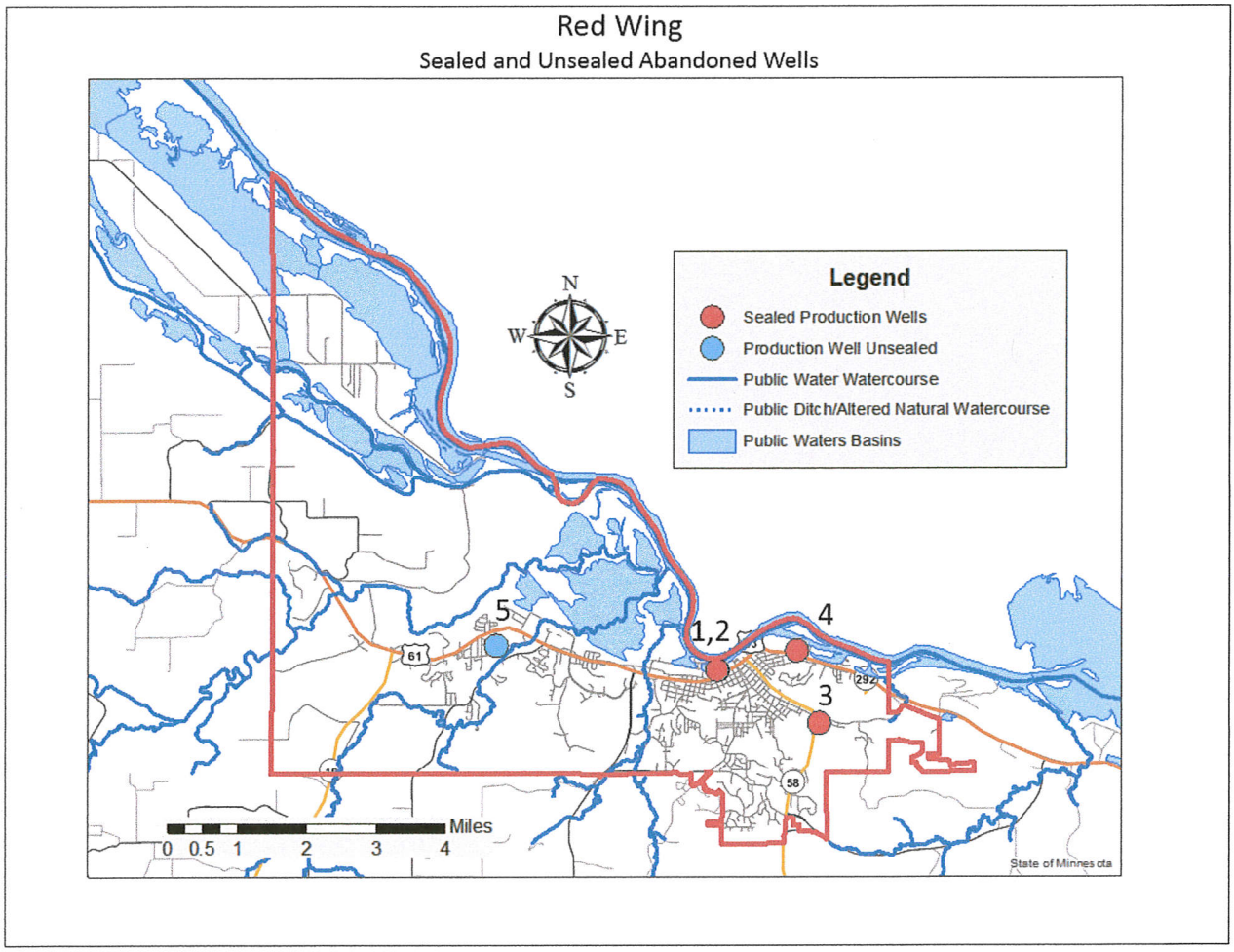


Figure 8. Red Wing sealed and abandoned municipal wells (DNR, 2019a) (DNR, 2019b).

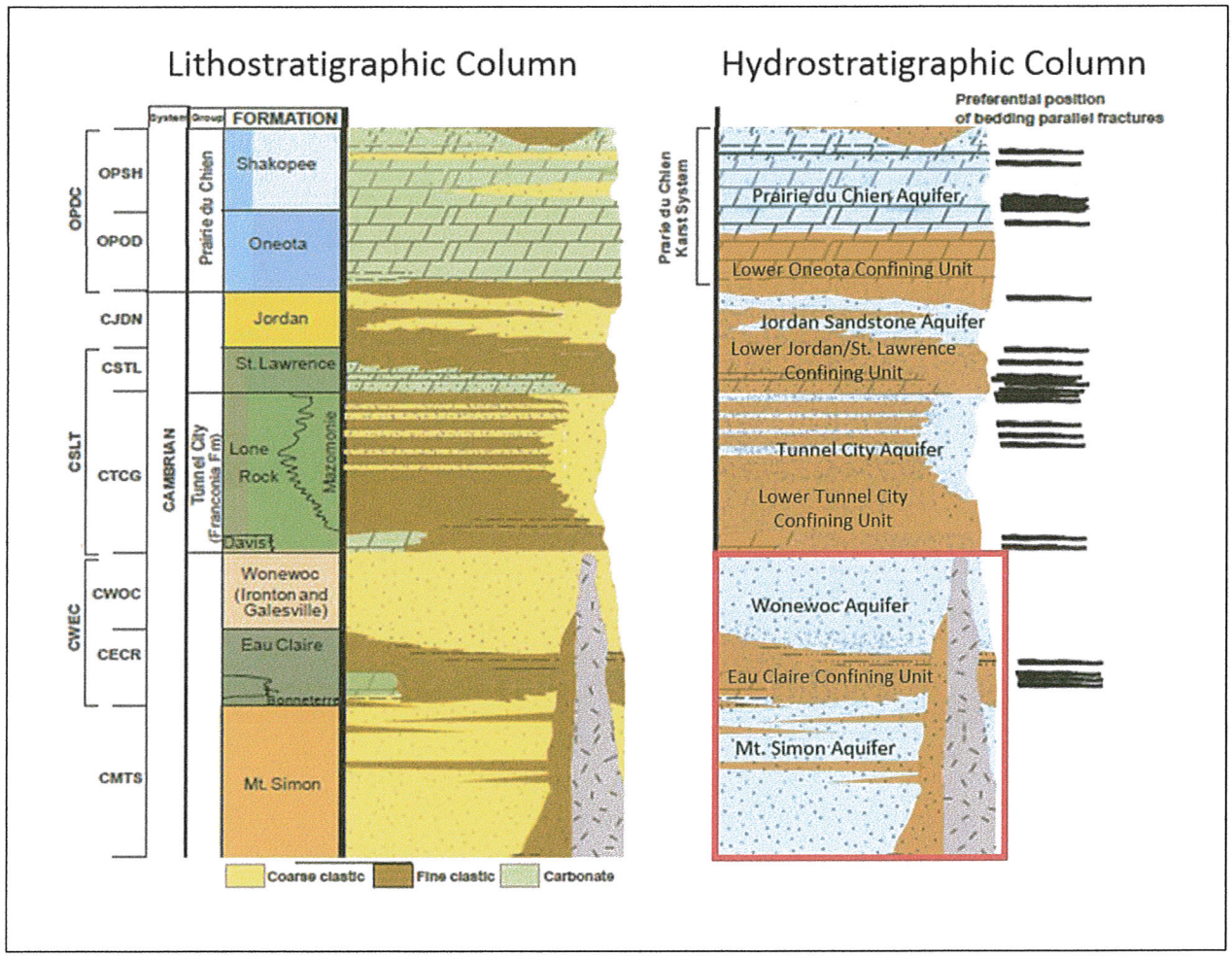


Figure 9. Lithostratigraphic and hydrostratigraphic columns (Runkel et al, 2014 as modified).

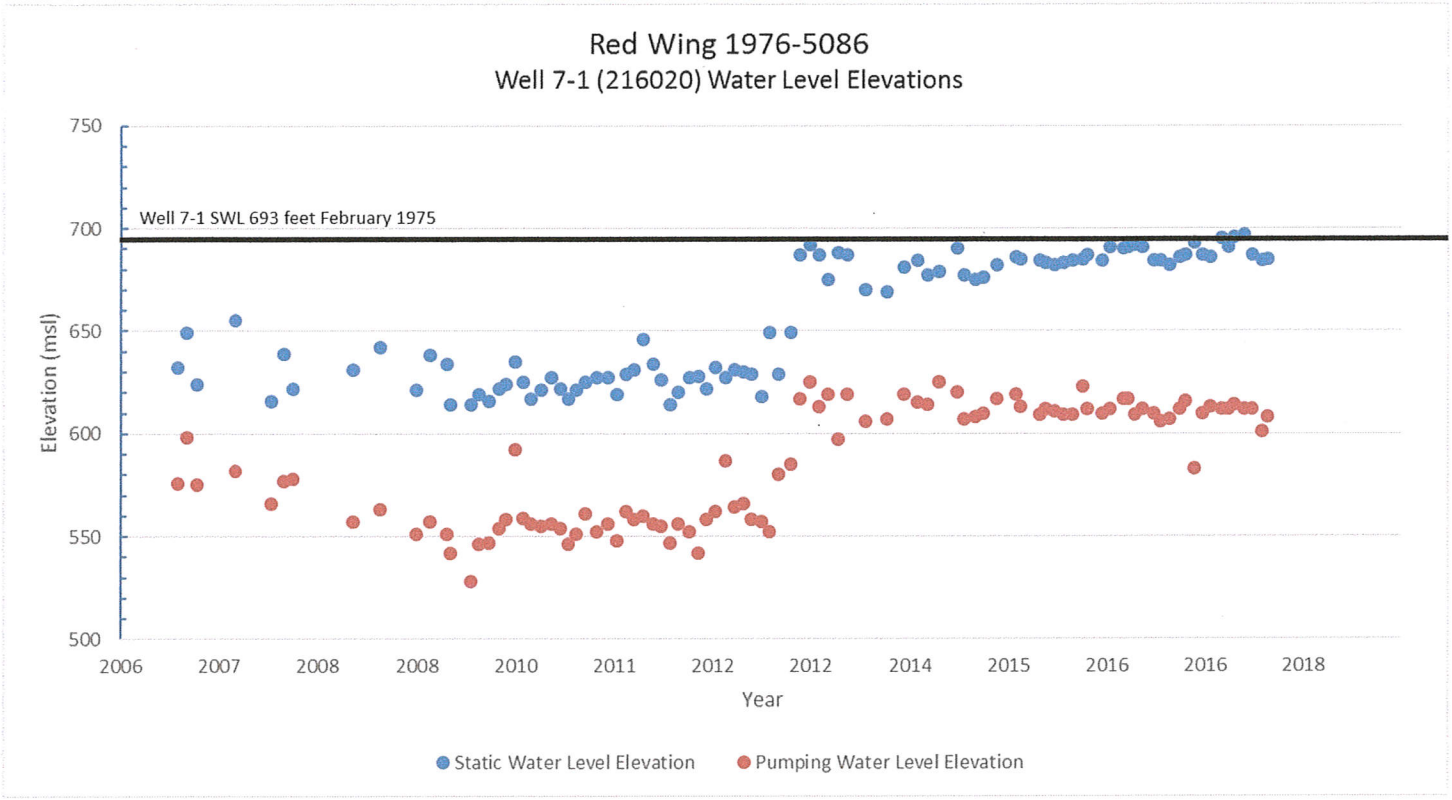


Figure 10. Red Wing static and pumping estimated water level elevations for the Twin Bluff Well 7-1 (Red Wing, 2017).

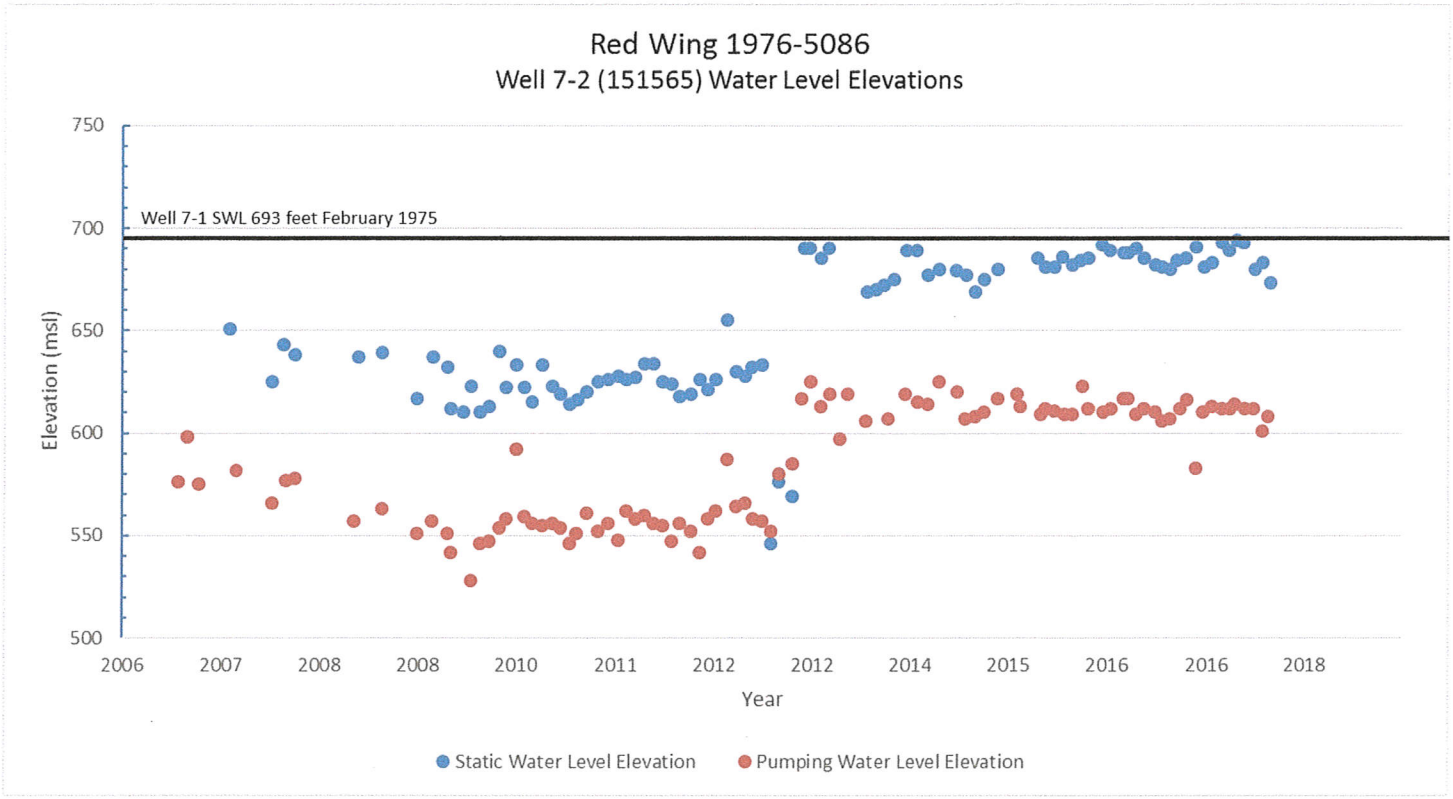


Figure 11. Red Wing static and pumping estimated water level elevations for the Twin Bluff Well 7-2 (Red Wing, 2017).

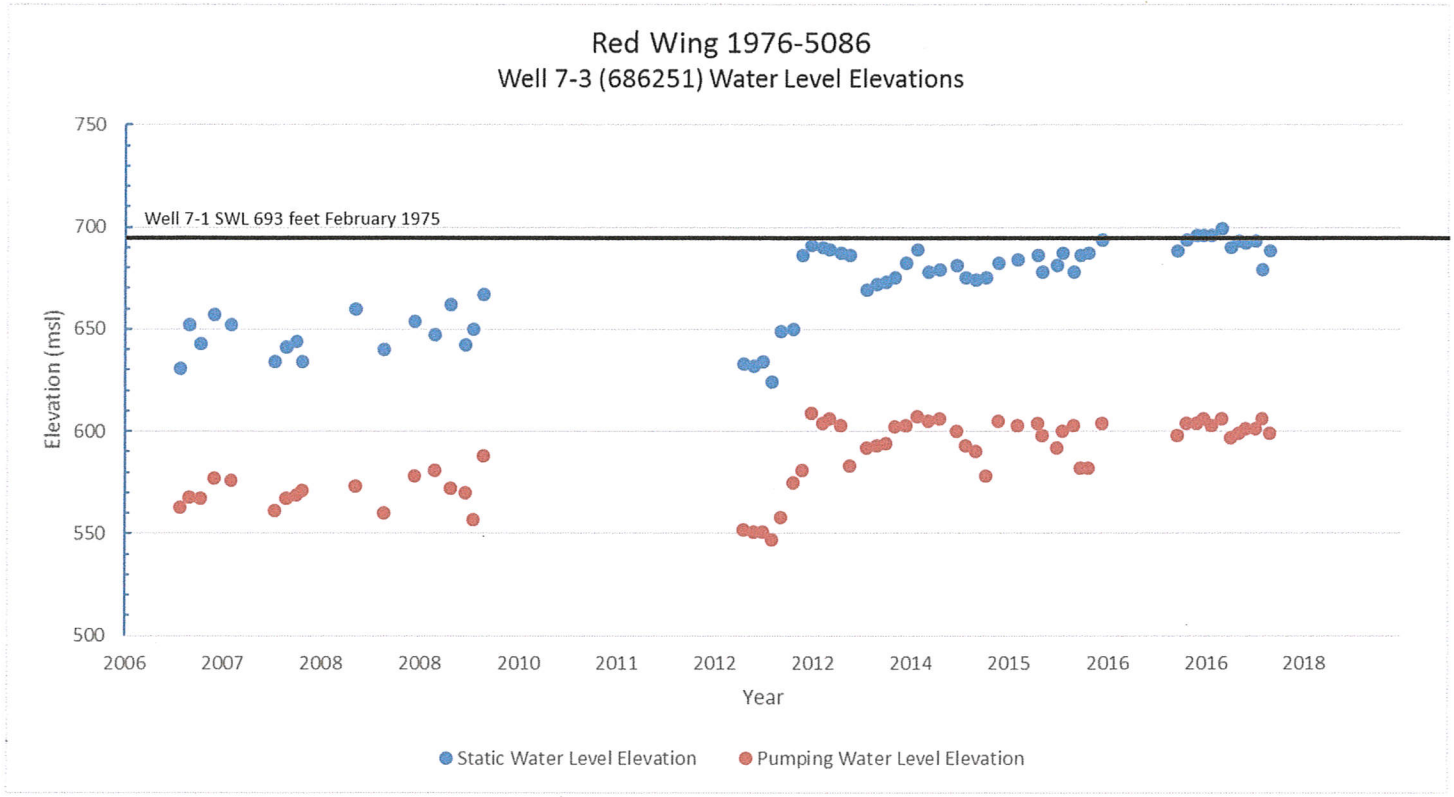


Figure 12. Red Wing static and pumping estimated water level elevations for the Twin Bluff Well 7-3 (Red Wing, 2017).

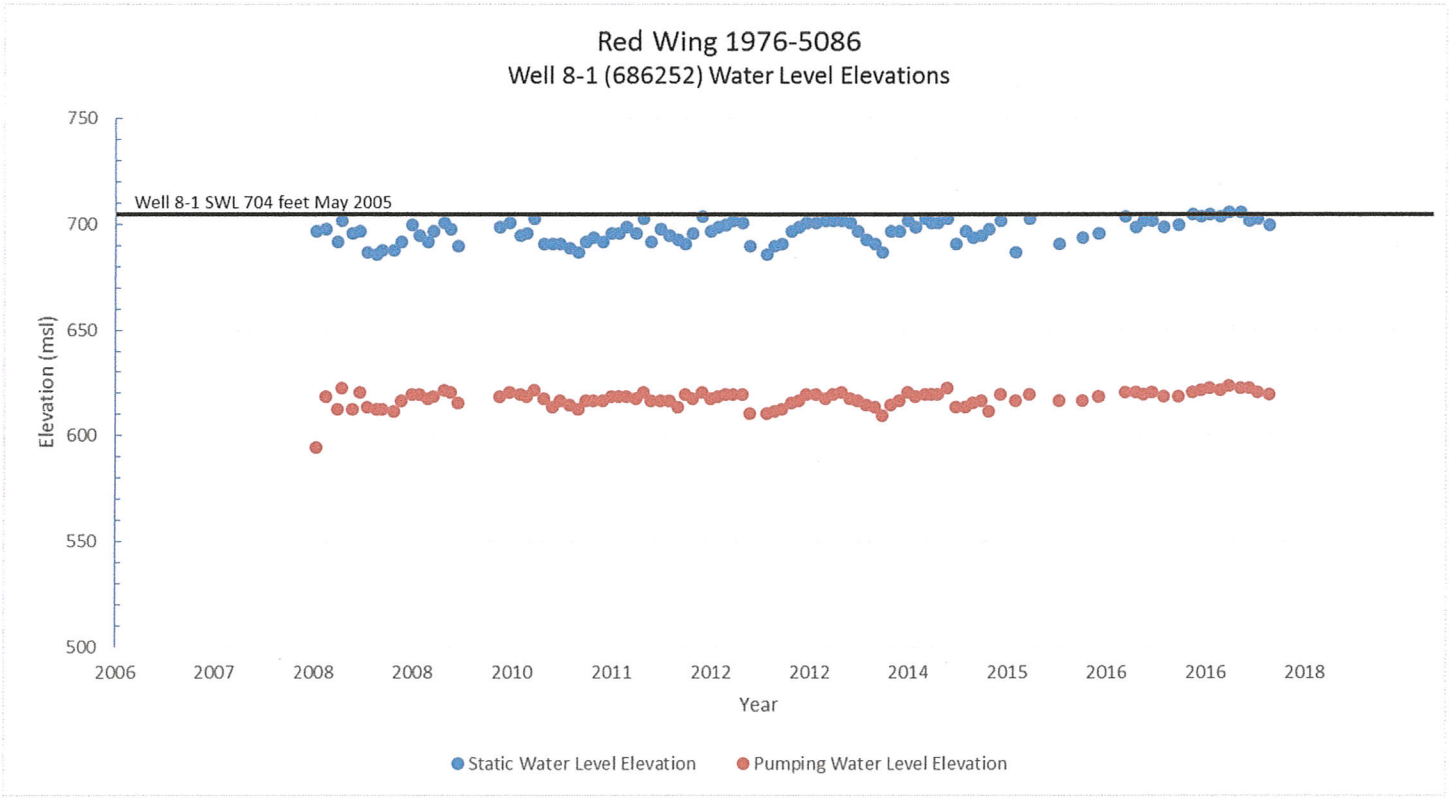


Figure 13. Red Wing static and pumping estimated water level elevations for the Burnside Well 8-1 (Red Wing, 2017).

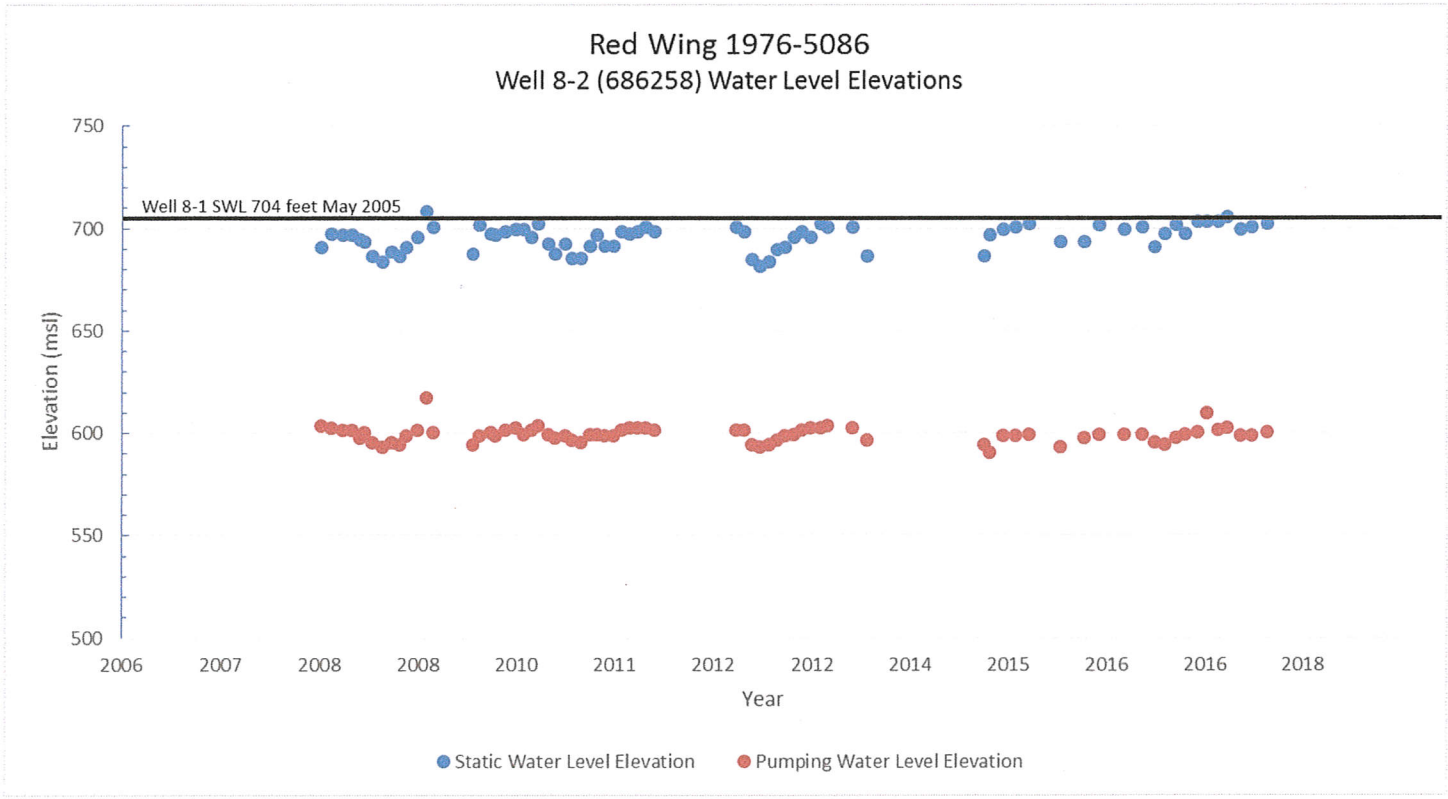
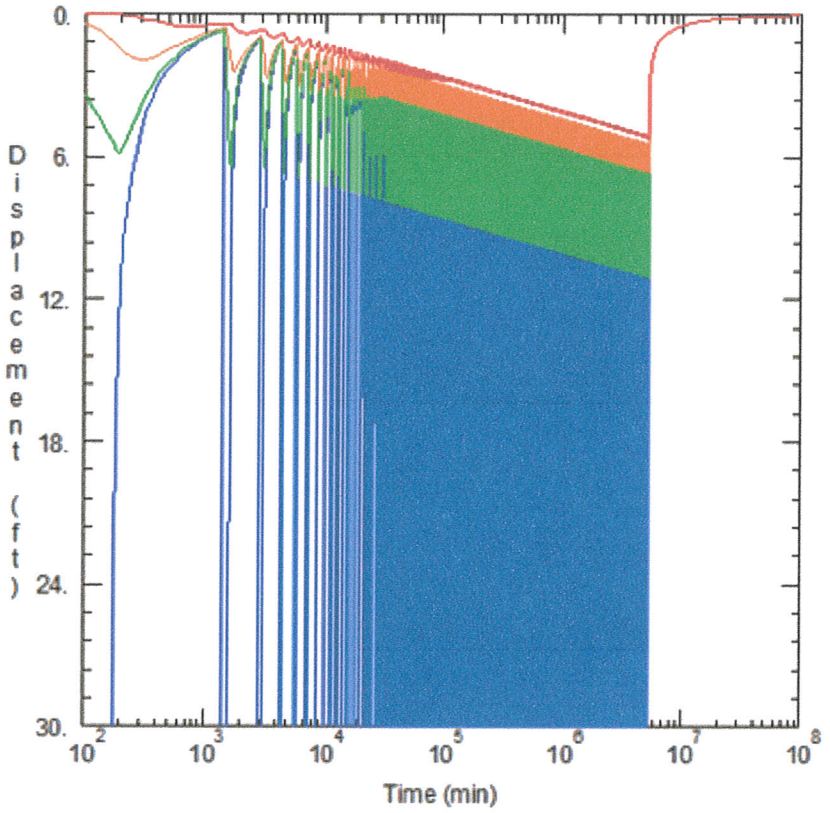


Figure 14. Red Wing static and pumping estimated water level elevations for the Burnside Well 8-2 (Red Wing, 2017).



WELL TEST ANALYSIS

Data Set: C:\...\FSTheisObWellDistance.aqt
Date: 03/18/19 Time: 13:15:27

PROJECT INFORMATION

Company: Red Wing
Project: 1976-5086
Location: Red Wing
Test Well: Ob Well Recommendation
Test Date: 2005

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
Production Well	0	0

Observation Wells

Well Name	X (ft)	Y (ft)
Production Well	0	0
ObWell 1320	1320	0
ObWell2640	2640	0
ObWell5280	5280	0

SOLUTION

Aquifer Model: Confined
Solution Method: Theis

T = 4560. ft^2/day
S = 0.0003
Kz/Kr = 1.
b = 240. ft

Figure 15. AQTESOLV forward solution model for siting observation well.

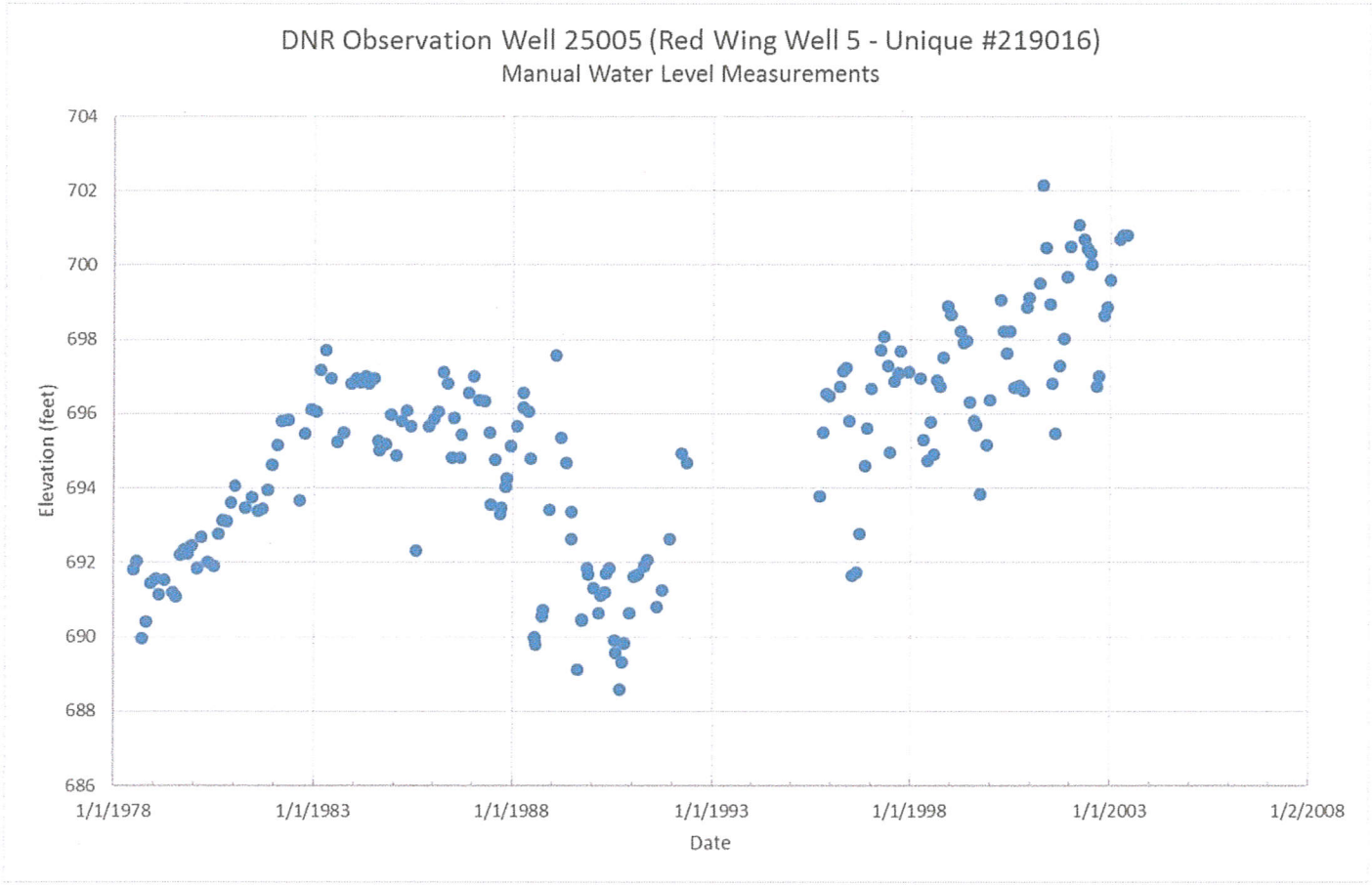


Figure 16. DNR Observation Well 25005 water level elevation measurements from 1978 to 2003 (DNR and MPCA, 2019). This well has not been sealed yet.

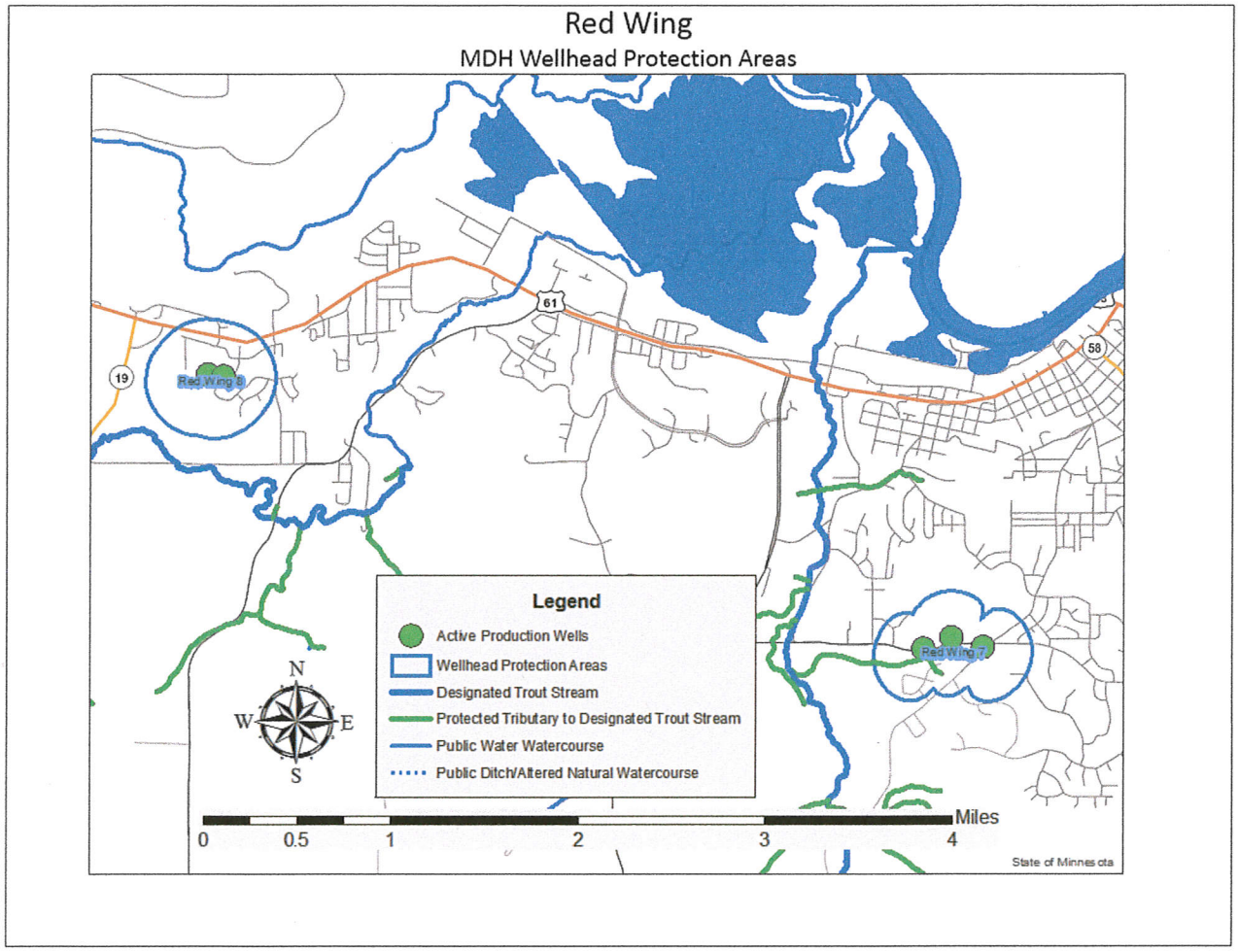


Figure 17. Wellhead protection areas for Red Wing's two well fields (Red Wing, 2016).

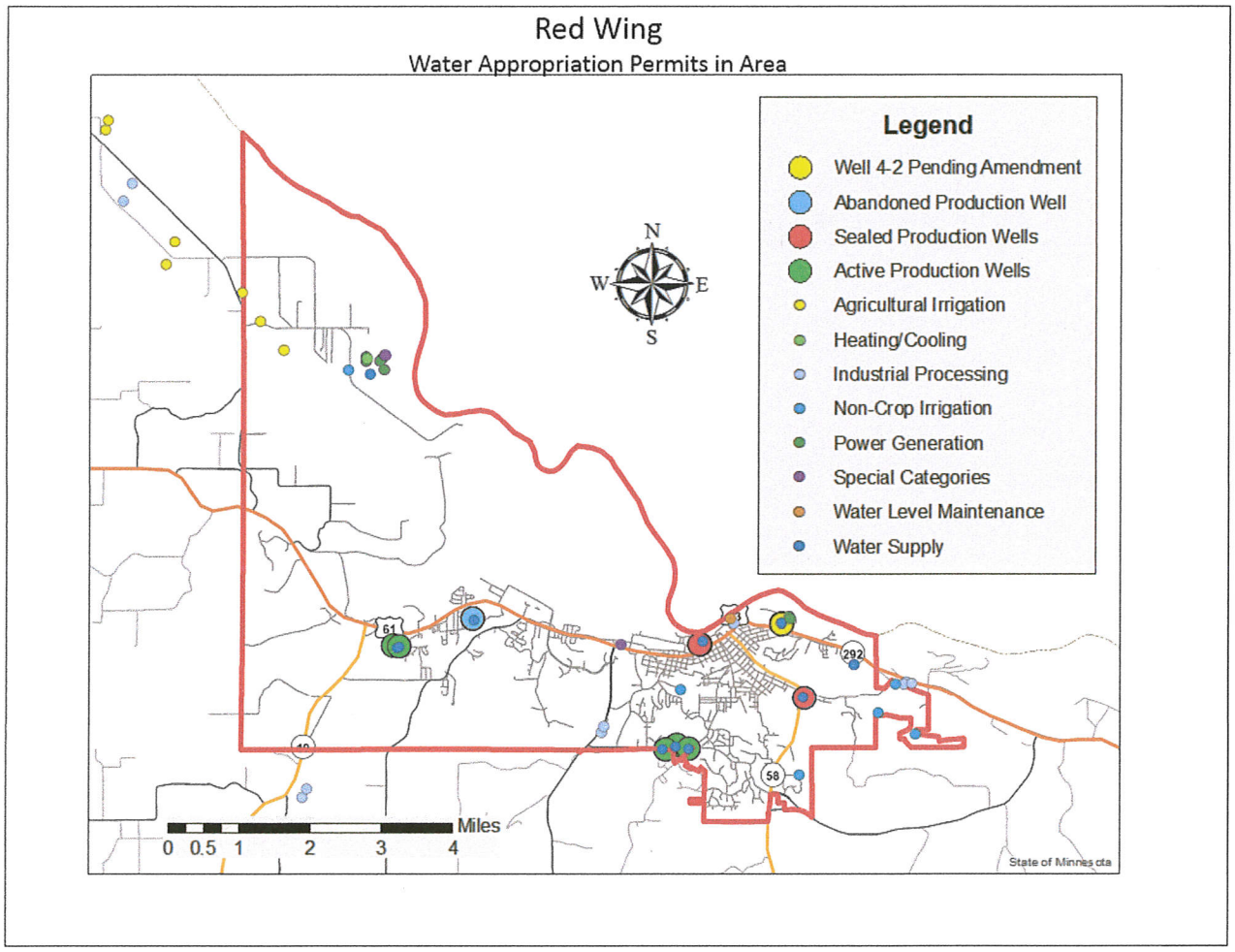


Figure 18. Water appropriation permits in the Red Wing area (DNR, 2019a) (DNR, 2019b).

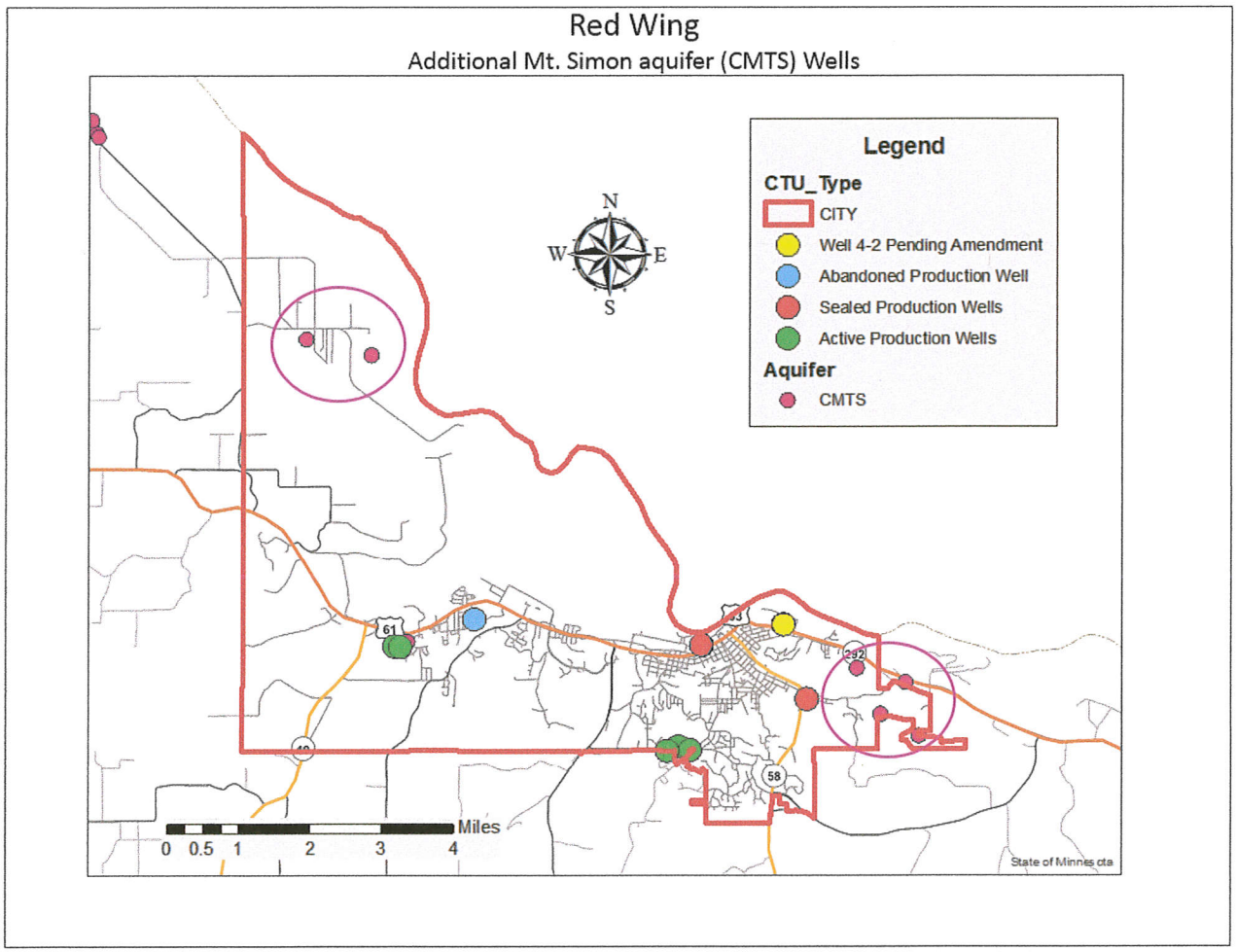


Figure 19. Additional Mt. Simon (CMTS) aquifer wells in the Red Wing area (MGS and MDH, 2019) (DNR, 2019a) (DNR, 2019b).

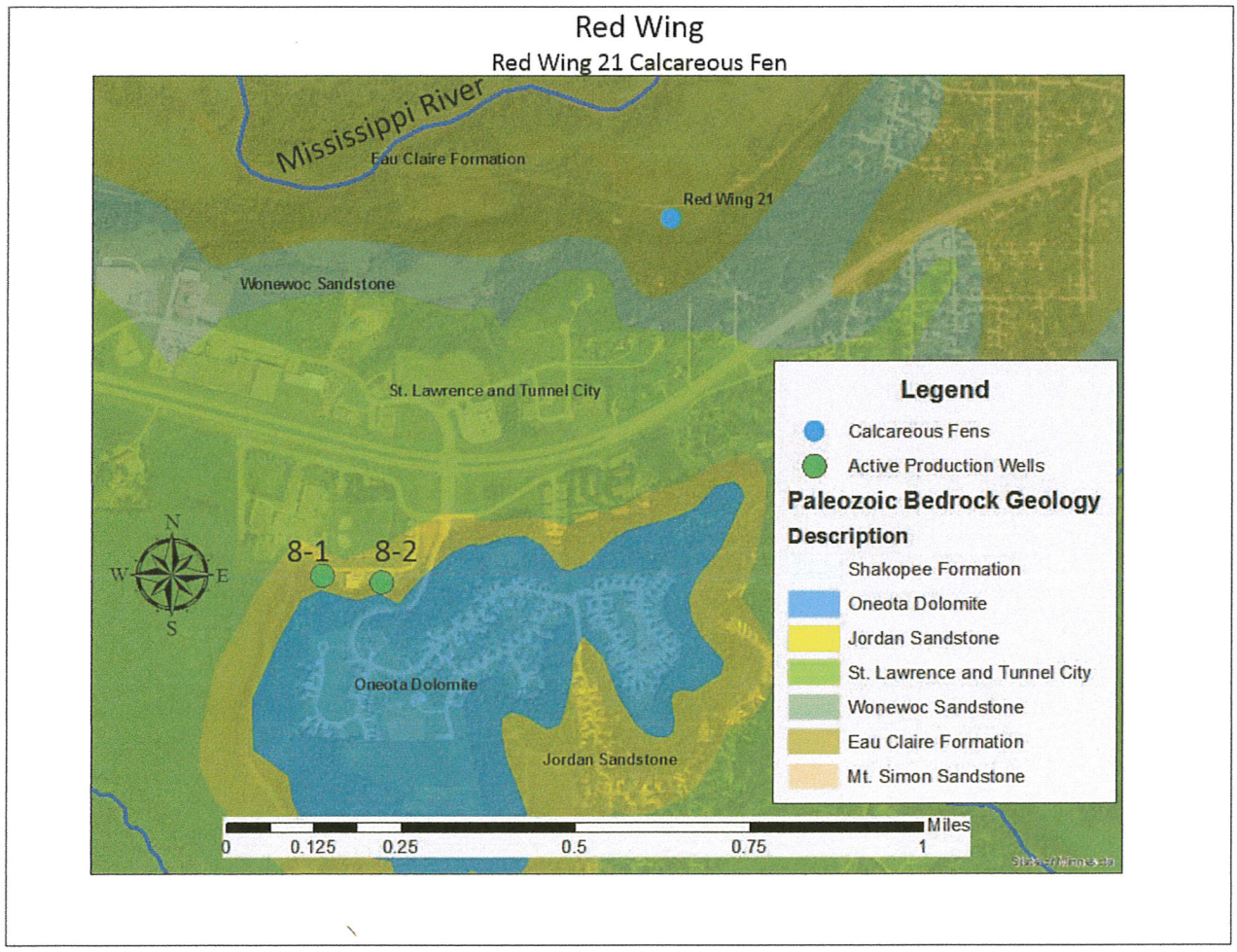


Figure 20. Red Wing 21 calcareous fen location map (Runkel et al, 2014) (DNR, 2019a) (DNR, 2019b).

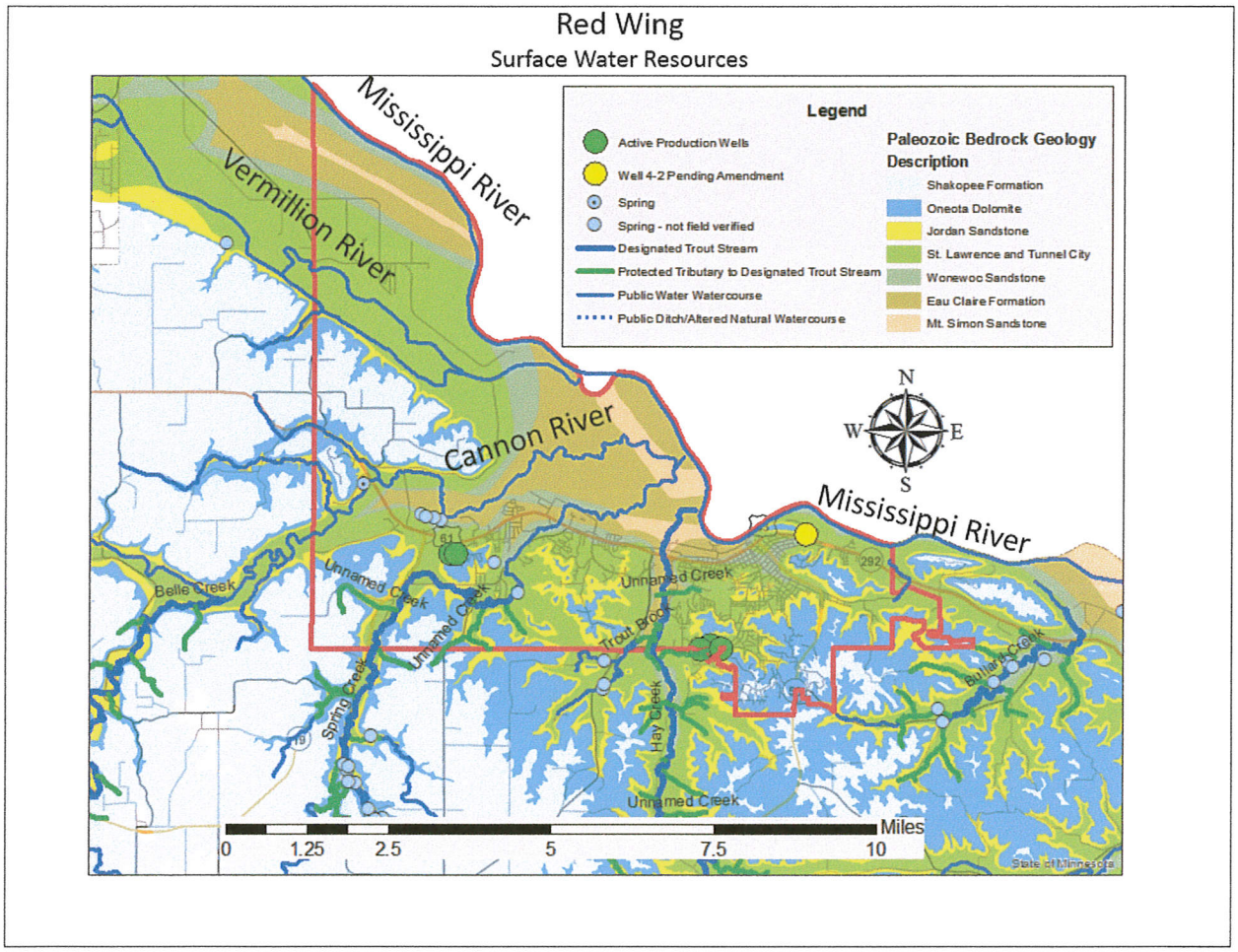


Figure 21. Surface water resources in the Red Wing area (Runkel et al, 2014) (DNR, 2019a) (DNR, 2019b).