Wellhead Protection Plan

Part I

Wellhead Protection Area Delineation
Drinking Water Supply Management Area Delineation
Well and Drinking Water Supply Management Area Vulnerability Assessments

For

City of Mantorville

August 2015

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Glossary of Terms

Data Element. A specific type of information required by the Minnesota Department of Health to prepare a wellhead protection plan.

Drinking Water Supply Management Area (DWSMA). The area delineated using identifiable land marks that reflects the scientifically calculated wellhead protection area boundaries as closely as possible (Minnesota Rules, part 4720.5100, subpart 13).

Drinking Water Supply Management Area Vulnerability. An assessment of the likelihood that the aquifer within the DWSMA is subject to impact from land and water uses within the wellhead protection area. It is based upon criteria that are specified under Minnesota Rules, part 4720.5210, subpart 3.

Emergency Response Area (ERA). The part of the wellhead protection area that is defined by a one-year time of travel within the aquifer that is used by the public water supply well (Minnesota Rules, part 4720.5250, subpart 3). It is used to set priorities for managing potential contamination sources within the DWSMA.

Inner Wellhead Management Zone (IWMZ). The land that is within 200 feet of a public water supply well (Minnesota Rules, part 4720.5100, subpart 19). The public water supplier must manage the IWMZ to help protect it from sources of pathogen or chemical contamination that may cause an acute health effect.

Wellhead Protection (WHP). A method of preventing well contamination by effectively managing potential contamination sources in all or a portion of the well's recharge area.

Wellhead Protection Area (WHPA). The surface and subsurface area surrounding a well or well field that supplies a public water system, through which contaminants are likely to move toward and reach the well or well field (Minnesota Statutes, section 103I.005, subdivision 24).

Well Vulnerability. An assessment of the likelihood that a well is at risk to human-caused contamination, either due to its construction or indicated by criteria that are specified under Minnesota Rules, part 4720.5550, subpart 2.

Acronyms

CWI - County Well Index

DNR - Minnesota Department of Natural Resources

EPA - United States Environmental Protection Agency

FSA - Farm Security Administration

MDA - Minnesota Department of Agriculture

MDH - Minnesota Department of Health

MGS - Minnesota Geological Survey

MLAEM - Multi Layer Analytic Element Model

MnDOT - Minnesota Department of Transportation

MnGEO - Minnesota Geospatial Information Office

MODFLOW - Three-Dimensional Finite-Difference Groundwater Model

MPCA - Minnesota Pollution Control Agency

NRCS - Natural Resource Conservation Service

SWCD - Soil and Water Conservation District

UMN - University of Minnesota

USDA - United States Department of Agriculture

USGS - United States Geological Survey

1. Executive Summary

This summary documents the delineation of the protection areas for the public water supply wells used by the city of Mantorville and includes an assessment of their vulnerability to contamination. The recharge area for the well is known as the wellhead protection area, or WHPA, and represents the area that contributes a 10 year pumping volume to the city's well. The area represented by a one-year volume is known as the emergency response area, or ERA. Practical reasons require the designation of a management area that fully envelops the wellhead protection area, called the drinking water supply management area, or DWSMA. Each of these areas is shown in Figure 1.

The wells used by the city of Mantorville are sufficiently deep, well-constructed, and are considered to have a low vulnerability to contamination. One of the principal considerations for this determination is that there is significant natural geologic protection between the ground surface and the depth from which the water is pumped. Available data suggest that the low vulnerability observed at the city wells is consistent throughout the DWSMA. At present, none of the contaminants of concern for which the Safe Drinking Water Act has established standards are present in the city's water supply.

The low vulnerability of the DWSMA means that the chief contamination threats to the city of Mantorville's aquifer are other wells that reach or penetrate it. Old and unused wells may provide a conduit for contaminants to short circuit the natural geologic protection and are considered a principal threat to the city's drinking water source.

The following report outlines the steps taken to delineate the city of Mantorville's WHPA, DWSMA and ERA.

2. Introduction

The Minnesota Department of Health (MDH) developed Part I of the wellhead protection (WHP) plan at the request of the city of Mantorville (PWSID 1200006). The work was performed in accordance with the Minnesota Wellhead Protection Rule, parts 4720.5100 to 4720.5590.

This report presents delineations of the wellhead protection area (WHPA) and drinking water supply management area (DWSMA), and the vulnerability assessments for the public water supply wells and DWSMA. Figure 1 shows the boundaries for the WHPA and the DWSMA. The WHPA is defined by a 10-year time of travel. Figure 1 also shows the emergency response area (ERA), which is defined by a one-year time of travel. An inner wellhead management zone (IWMZ), which is the area within a 200-foot radius around the well, serves as the wellhead protection area for emergency wells and is not displayed in this report. Definitions of rule-specific terms used are provided in the "Glossary of Terms."

In addition, this report documents the technical information required to prepare this portion of the WHP plan in accordance with the Minnesota Wellhead Protection Rule. Additional technical information is available from MDH.

Table 1 lists all the wells in the public water supply system. Only wells listed as primary are required to be included in the WHP plan.

Table 1 - Water Supply Well Information

Local Well ID	Unique Number	Use/ Status[1]	Casing Diameter (inches)	Casing Depth (feet)	Well Depth (feet)	Date Constructed/ Reconstructed	Aquifer[2]	Well Vulnerability
Well 1	241008	E	12 x 8	155	215	1959	OSTP - St. Peter	Vulnerable
Well 2	217550	P	18 x 10	670	750	10/28/1970	CJDN - Jordan	Not Vulnerable

Note: 1. Primary (P), Emergency Backup (E), Seasonal Use (S)
2. St. Peter-Prairie du Chien-Jordan Aquifer System

3. Assessment of the Data Elements

MDH staff met with representatives of the city of Mantorville on October 29, 2013, for a scoping meeting that identified the data elements required to prepare Part I of the WHP plan. Table 2 presents the assessment of these data elements relative to the present and future implications of planning items specified in Minnesota Rules, part 4720.5210.

Table 2 - Assessment of Data Elements

Data Element	Present and Future Implications				Data Source
	Use of the Well (s)	Delineation Criteria	Quality and Quantity of Well Water	Land and Groundwater Use in DWSMA	
Precipitation					
Geology					
Maps and geologic descriptions	M	H	H	H	MGS, DNR, USGS, Consultant Reports
Subsurface data	M	H	H	H	MGS, MDH, MPCA, DNR, MDA
Borehole geophysics	M	H	H	H	MGS, Consultant Reports
Surface geophysics	L	L	L	L	DNR, MPCA, Consultant Reports
Maps and soil descriptions					
Eroding lands					
Water Resources					
Watershed units					
List of public waters					
Shoreland classifications					
Wetlands map					
Floodplain map					
Land Use					
Parcel boundaries map	L	H	L	L	Dodge County
Political boundaries map	L	H	L	L	MnGEO, City
Public Land Survey map	L	H	L	L	MnGEO
Land use map and inventory					
Comprehensive land use map					
Zoning map					
Public Utility Services					
Transportation routes and corridors	L	L	L	L	MnDOT, MnGEO
Storm/sanitary sewers and PWS system map					
Oil and gas pipelines map					
Public drainage systems map or list					
Records of well construction, maintenance, and use	H	H	H	H	City, CWI, MDH
Surface Water Quantity					
Stream flow data					
Ordinary high water mark data					
Permitted withdrawals					
Protected levels/flows					
Water use conflicts					
Groundwater Quantity					
Permitted withdrawals	H	H	H	H	DNR
Groundwater use conflicts	H	H	H	H	DNR
Water levels	H	H	H	H	DNR, MPCA, MDA, MDH, City

Data Element	Present and Future Implications				Data Source
	Use of the Well (s)	Delineation Criteria	Quality and Quantity of Well Water	Land and Groundwater Use in DWSMA	
Surface Water Quality					
Stream and lake water quality management classification					
Monitoring data summary					
Groundwater Quality					
Monitoring data	H	H	H	H	MPCA, MDH, MDA, USGS
Isotopic data	H	H	H	H	MPCA, MDH, MDA, USGS, Dodge County, UMN
Tracer studies	H	H	H	H	DNR, MPCA
Contamination site data	M	M	M	M	MPCA, MDA
Property audit data from contamination sites					
MPCA and MDA spills/release reports	M	M	M	M	MPCA

Definitions Used for Assessing Data Elements:

High (H) - the data element has a direct impact

Moderate (M) - the data element has an indirect or marginal impact

Low (L) - the data element has little if any impact

Shaded - the data element was not required by MDH for preparing the WHP plan

Acronyms used in this report are listed on page ii, after the "Glossary of Terms."

4. General Descriptions

4.1 Description of the Water Supply System

The city of Mantorville obtains its drinking water supply from one primary well. Table 1 summarizes information regarding them.

4.2 Description of the Hydrogeologic Setting

The city of Mantorville draws groundwater from the St. Peter-Prairie Du Chien-Jordan Aquifer System. The distribution of the aquifer system and its stratigraphic relationships with adjacent geologic materials are shown in Figures 3, 4, and 5. These figures were prepared using well record data contained in the CWI database. The geological maps and studies used to further define local hydrogeologic conditions are provided in the "Selected References" section of this report. The local hydrogeologic properties for the aquifer materials used to supply drinking water are presented in Table 3.

Table 3 - Local Properties of Aquifer Materials

Attribute	Descriptor	Data Source
Material St. Peter Sandstone Prairie du Chien Group Jordan Sandstone	 Sandstone Dolomite and Sandstone Sandstone	Well record 217550
Porosity Type and Value	St. Peter Sandstone: 0.25 Prairie du Chien Group: 0.05 Jordan Sandstone: 0.25	Well record 217550, geologic cross-sections (Figures 4 and 5)
Aquifer Thickness	St. Peter Sandstone: 113 ft. Prairie du Chien Group: 316 ft. Jordan Sandstone: 107 ft.	
Stratigraphic Top Elevation	St. Peter Sandstone: 994 ft. Prairie du Chien Group: 881 ft. Jordan Sandstone: 565 ft.	
Stratigraphic Bottom Elevation	St. Peter Sandstone: 881 ft. Prairie du Chien Group: 565 ft. Jordan Sandstone: 458 ft.	
Hydraulic Confinement	Confined	
Transmissivity	Range of Values: St. Peter Sandstone: 1,000 ft^2/day Prairie du Chien Group: 9,360 ft^2/day Jordan Sandstone: 1,030 ft^2/day	Blum (2012). See Table 4 for the reference value.
Hydraulic Conductivity	Range of Values: St. Peter Sandstone: 8.8 ft/day Prairie du Chien Group: 19 ft/day Jordan Sandstone: 9.8 ft/day	Blum (2013). Determined by dividing Transmissivity by aquifer thickness
Groundwater Flow Field	Groundwater flow is from the northeast, with an approximate compass direction of N 55° E and gradient of 0.002 (Figure 2).	Defined by using static water level elevations from well records in the CWI database and documents listed in the "Selected References" section of this report.

The geologic cross-sections show glacial-fluvial sediments that are 10 to 60 feet thick in Mantorville. The clay-rich till is not consistent across the area and large areas are composed of more permeable silty sand and sandy alluvium. Below the glacial-fluvial sediments, sedimentary bedrock of the Galena Group form continuous layers composed of dolomite. The shale content of the bedrock increases with depth in the Decorah, Platteville, and Glenwood Formations found between 1000 and 1100 feet elevation. These shaley rocks provide geological protection to the St. Peter-Prairie Du Chien-Jordan Aquifer System that supplies the city wells.

The hydraulic interconnection between the St. Peter Sandstone, Prairie du Chien Group, and Jordan Sandstone is such that they are considered to be one aquifer on a regional basis. Beneath the Jordan Sandstone is the St. Lawrence Formation, composed of dolomitic shale. This unit is considered to be a regional confining layer that strongly retards the vertical movement of ground water and forms the base of the aquifer system.

5. Delineation of the Wellhead Protection Area

5.1 Delineation Criteria

The boundaries of the WHPA for the city of Mantorville are shown in Figure 1. Table 4 describes how the delineation criteria specified under Minnesota Rules, part 4720.5510, were addressed.

Table 4 - Description of WHPA Delineation Criteria

Criterion	Descriptor	How the Criterion was Addressed
Flow Boundary	None	There are no flow boundaries close enough to the public water supply well(s) that may have an impact on their capture areas.
Daily Volume of Water Pumped	See Table 5	Pumping information was obtained from the DNR, Appropriations Permit No. 1984-5050, and was converted to a daily volume pumped by a well.
Groundwater Flow Field	Groundwater flow is from the northeast, with an approximate compass direction of N 55° E and gradient of 0.002 (Figure 2).	Defined by using static water level elevations from well records in the CWI database and documents listed in the "Selected References" section of this report.
Aquifer Transmissivity (T)	Reference Value: 2,865 ft^2/day	The aquifer test plan was approved on July 25, 2014, and T was determined from specify the methods used. Uncertainty regarding aquifer transmissivity was addressed as described in Section 4.4.
Time of Travel	10 years	The public water supplier selected a 10-year time of travel.

Pumping data was obtained from the DNR Permit and Reporting System (MPARS) for the public water supply's Appropriation Permit No. 1984-5050. These values, confirmed by the public water supplier, were used to identify the maximum volume of water pumped annually by each well over the previous five-year period, as shown in Table 5. An estimate of the pumping for the next five years is also shown. The maximum daily volume of discharge used as an input parameter in the model was calculated by dividing the greatest annual pumping volume by 365 days.

Table 5 - Annual Volume of Water Discharged from Water Supply Wells

Well Name (Unique No.)	2010	2011	2012	2013	2014	2019 Pumping	Daily Volume (cubic meters)
Well 1 (241008)	**108,647**	33,250	21,000	100,500		No change	Not modeled
Well 2 (217550)	31,673,000	**35,593,000**	32,360,000	31,539,000		No change	369

(Expressed as gallons. Bolding indicates greatest annual pumping volume.)

In addition to the wells used by the city of Mantorville, the DNR MPARS database was queried to find other high capacity wells which may influence the public water supply wells. No other permitted high-capacity wells were found.

5.2 Method Used to Delineate the Wellhead Protection Area

The WHPA for the city of Mantorville's well was determined using a combination of two methods, a porous media flow model and a fractured rock delineation procedure. The first method used representative aquifer parameters that were input into MLAEM, a groundwater modeling code (Strack, 1989). The well is also hydraulically connected to a fractured and solution weathered bedrock, the Prairie du Chien Group, which requires a different approach to account for the unpredictability of flow through aquifer materials with secondary porosity (MDH, 2011). The resulting WHPA boundaries are a composite of the capture zones calculated using these two approaches (Figure 1). The fracture flow analysis is described in Section 4.2.2.

5.2.1. Porous Media Delineation

A porous media groundwater model was used to generate capture zones in the St. Peter-Prairie du Chien-Jordan Aquifer system that meets the delineation criteria specified under Minnesota Rules, part 4720.5510. The MLAEM code (Strack, 1989) was selected for the delineation because it is capable of simulating the leaky connections between aquifer layers and the pumping influence of multiple high-capacity wells. A regional model developed in MLAEM, Blum (2013), is the basis of the Mantorville delineation. Three parameters in this regional data set; thickness, hydraulic conductivity, and base elevation of the aquifer layers, were adjusted to reflect local conditions, as shown in Table 6. All other parameters and boundary conditions remained the same as in the calibrated regional model. Figure 6 shows the resulting 10-year time of travel capture zones provided by the MLAEM. The input files for the model are available at MDH upon request.

Table 6 – Modeled Hydraulic Properties

Geologic Unit	Aquifer Layer	Base Elevation (meters)	Aquifer Thickness (meters)	Transmissivity (m^2/day)	Hydraulic Conductivity (m/day)	Hydraulic Resistance (day)	Porosity
		Glacial-fluvial sediments are modeled as a constant infiltration where younger bedrock has been removed by erosion					
St. Peter Sandstone	1	269	29	92.8	3.2	--	0.25
Basal St. Peter Sandstone	-		1			1,000	0.25
Prairie du Chien Group	2	173	95	870	5.8	-	0.05
Jordan Sandstone – Top[1]	-		1			1250	0.25
Jordan Sandstone	3	140	32	96	3	--	0.25
St. Lawrence Formation		Bottom of Jordan Sandstone is a no-flow boundary					

Note[1]: Confining Layers are shaded.

5.2.2. Fracture Flow Delineation

The fracture flow delineation procedure was developed to address the increased variability in flow velocities and directions in geologic settings with secondary porosity, (MDH, 2011). This guidance describes a modified volumetric analysis and does not use a model based on flow equations. The area that is calculated by this procedure is called a calculated-fixed-radius, CFR, capture zone.

Appendix A of this report documents the steps and results of the fracture flow analysis. Because the wells are constructed to be open to the Prairie du Chien Group, a CFR capture zone must be included. Input parameters used for CFR calculation are summarized in Table 7.

Table 7 - Fracture Flow Delineation Parameters

Fracture Flow Delineation Parameter	Value	Source
Well Discharge	369 m^3/day	Table 5
Aquifer Thickness	61 m	The average thickness of the Prairie du Chien Group is 95 m. The maximum thickness used in the procedure is 61 m.
Direction for Upgradient Extension of Groundwater Flow (plus and minus 22°)	N 55° E	Water elevation information in the CWI dataset.
Gradient	0.002	Regional water level information in the CWI dataset. The St. Peter-Prairie du Chien-Jordan aquifer system near Mantorville has a high gradient (> 0.001)
Bulk Porosity	0.05	Conservative estimate for carbonate bedrock (Fetter, 2001)

5.3 Results of Model Calibration and Sensitivity Analysis

Model calibration is a procedure that compares the results of a model based on estimated input values to measured or known values. This procedure can be used to define model validity over a range of input values, or it helps determine the level of confidence with which model results may be used. As a matter of practice, groundwater flow models are usually calibrated using water elevation or flux.

A regional calibration was performed on the total discharge from the model. In this model, the given or known values were hydraulic conductivity and water elevation. Infiltration is only roughly estimated and discharge to the rivers is the unknown to be solved. Therefore, comparison of the discharge calculated versus that observed was the critical measure for the quality of the model, both regionally and locally.

Calculated river discharges were compared to the observed discharges from USGS stream gauging stations. Daily and monthly statistical data were obtained for all years of record from the USGS web site. Additional baseflow measurements were obtained from published USGS Hydrologic Atlas reports, Blum (2013).

For gauge stations with daily data, the base flow for each gauging station was estimated at about 10 percent of the daily observed flow. Meaning, 10 percent of the observed flows were below and 90 percent of the daily readings were above the value. Where data permitted, a mean value for January's monthly flow was also calculated. These two values, the 10 percent low flow and the January monthly average flow, represent a reasonable range for the portion of groundwater in the observed stream flow. If the sum of the discharges for line elements above the gauge site location is bracketed by these flow rates, then the model discharge is considered to be well-calibrated.

Given that the boundary conditions were not changed from the regional model (infiltration and discharge were unchanged), then the calibration of the local model depends on the match of calculated to observed water elevations. Model calibration is difficult because of the variability of reported water elevations near Mantorville, ranging from 990 to 1015 feet within one mile of the water supply wells. The overall comparison between modeled versus observed water elevations yields an average root mean square error of 13 feet. This error is partly the result of the quality of regional water level data and the changing hydraulic confining conditions to the east of Mantorville.

Model sensitivity is the amount of change in model results caused by the variation of a particular input parameter. Because of the simplicity of the MLAEM, the direction and extent of the modeled capture zone may be very sensitive to any of the input parameters:

- The pumping rate directly affects the volume of the aquifer that contributes water to the well. An increase in pumping rate leads to an equivalent increase in the volume of aquifer within the capture zone, proportional to the porosity of the aquifer materials. The modeled pumping rate is based the on the largest annual pumping in the last five years of record, Table 5. Therefore, the sensitivity of this parameter is minimized for the WHPA delineation.
- The direction of groundwater flow determines the orientation of the capture area. Variations in the direction of groundwater flow will not affect the size of the capture zone but are important for defining the areas that are the source of water to the well. The ambient groundwater flow field that is defined in Figure 2 provides the basis for determining the extent to which the orientation of the modeled capture area corresponds to the observed direction of flow.
- A hydraulic gradient of zero produces a circular capture zone, centered on the well. As the hydraulic gradient increases, the capture zone changes into an elliptical shape, with the well centered on the down-gradient focal point. The hydraulic gradient was determined by using water level elevations that were taken from wells that have verified locations (Figure 2). Generally, the accuracy of the hydraulic gradient determination is directly proportional to the amount of available data that describes the distribution of hydraulic head in the aquifer.
- The aquifer thickness, hydraulic conductivity, and porosity influence the size and shape of the capture zone. A decrease in either thickness or porosity causes a linear, proportional increase in the areal extent of the capture zone; whereas hydraulic conductivity defines the relative proportions of the capture zone width to length. A decrease in hydraulic conductivity decreases the length of the capture zone and increases the distance to the stagnation point, making the capture zone more circular in shape and centered on the well.

5.4 Addressing Model Uncertainty

Using computer models to simulate groundwater flow involves representing a complicated natural system in a simplified manner. Local geologic conditions may vary within the capture area of the public water supply well, but the amount of existing information that is needed to accurately define this degree of variability is often not available for portions of the WHPA. In addition, the current capabilities of groundwater flow models may not be sufficient to represent the natural flow system exactly. However, the results are valid within a range defined by the reasonable variation of input parameters for this delineation setting.

Uncertainty related to water levels reported on well records is based on the accuracy of the ground elevation assigned to the well using topographic maps and the transient variability of the water levels in the aquifer over time. Water levels that are probably inaccurate were identified using data from 1) the CWI database, and 2) DNR observation well measurements. Only water levels that fit the flow field (Figure 2) were used for MLAEM calibration and the fractured rock delineation procedure.

The steps employed for this delineation to address model uncertainty were:

1) Pumping Rate - For each well, a maximum historical (five-year) pumping rate or an engineering estimate of future pumping, whichever is greater (Minnesota Rules, part 4720.5510, subpart 4).
2) Aquifer Thickness - The smaller maximum thickness of 200 feet was used in the fractured rock delineation procedure, as per the guidance.
3) Groundwater flow field – The directions of groundwater flow were expanded by +/- 10 degrees in the fractured rock delineation procedure, as per the guidance.

In confined settings the capture area from the fractured rock delineation procedure is invariably larger than the area based on porous media assumptions. Therefore, the fractured rock delineation is sufficient to encompass any variation in capture area that may result from the uncertainty in model input parameters. Capture areas were developed for a range of groundwater flow directions and times of travel of one and ten years (Figure 6).

6. Delineation of the Drinking Water Supply Management Area

The boundaries of the Drinking Water Supply Management Area (DWSMA) were defined by the city of Public Water Supplier using the following features (Figure 1):

- Center-lines of highways, streets, roads, or railroad rights-of-ways
- Property or fence lines

7. Vulnerability Assessments

The Part I wellhead protection plan includes the vulnerability assessments for the city of Mantorville's wells and DWSMA. These vulnerability assessments are used to help define potential contamination sources within the DWSMA and select appropriate measures for reducing the risk that they present to the public water supply.

7.1 Assessment of Well Vulnerability

The vulnerability assessment for the well used by the city of Mantorville is listed in Table 1 and is based upon the following conditions:

1) Well construction meets current State Well Code specifications (Minnesota Rules, part 4725), meaning that the well itself should not provide a pathway for contaminants to enter the aquifer used by the public water supplier.
2) The geologic conditions at the well site include a cover of clay-rich geologic materials over the aquifer that is sufficient to retard or prevent the vertical movement of contaminants.

3) None of the human-caused contaminants regulated under the federal Safe Drinking Water Act have been detected at levels indicating that the well itself serves to draw contaminants into the aquifer as a result of pumping (Alexander and Alexander, 1989).

Table 8 - Water Quality Results

Well	Sample Date	Nitrate (mg/L)	Chloride/Bromide ratio	Chloride (mg/L)	Bromide (mg/L)
Well 2 (217550)	7/15/2013	< 0.05	--	< 0.5	0.01

7.2 Assessment of Drinking Water Supply Management Area Vulnerability

The vulnerability of the DWSMA is low based upon review of the geologic logs contained in the CWI database and geological maps and reports indicate that the aquifer exhibits a low geologic sensitivity throughout the DWSMA and is isolated from the direct vertical recharge of surface water.

8. Recommendations

The following recommendations have been generated to inform the next amendment of the city of Mantorville's Wellhead Protection Plan.

1) Well Locating: This delineation is based on very little well data. If wells are constructed within two-miles of the city or one mile of the DWSMA, their locations should be verified.
2) Well Inventory: Wells that are within the aquifer that supplies the city's well will need to be inventoried. The criteria to be included in the inventory are that the well has an open hole or screened interval between 1050 feet and 400 feet MSL elevation or are completed in the St. Peter Sandstone, Prairie du Chien Group, or Jordan Sandstone geologic formations.
3) Water Quality Monitoring: The standard assessment monitoring package should be analyzed during year 5, including the primary wells and river. MDH can provide sample bottles and cover analytical costs. The city may need to collect the samples and ship them to MDH.

9. Selected References

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Figures

MINNESOTA MDH DEPARTMENT of HEALTH

Figure 1
Wellhead Protection and
Drinking Water Supply Management Area
City of Mantorville

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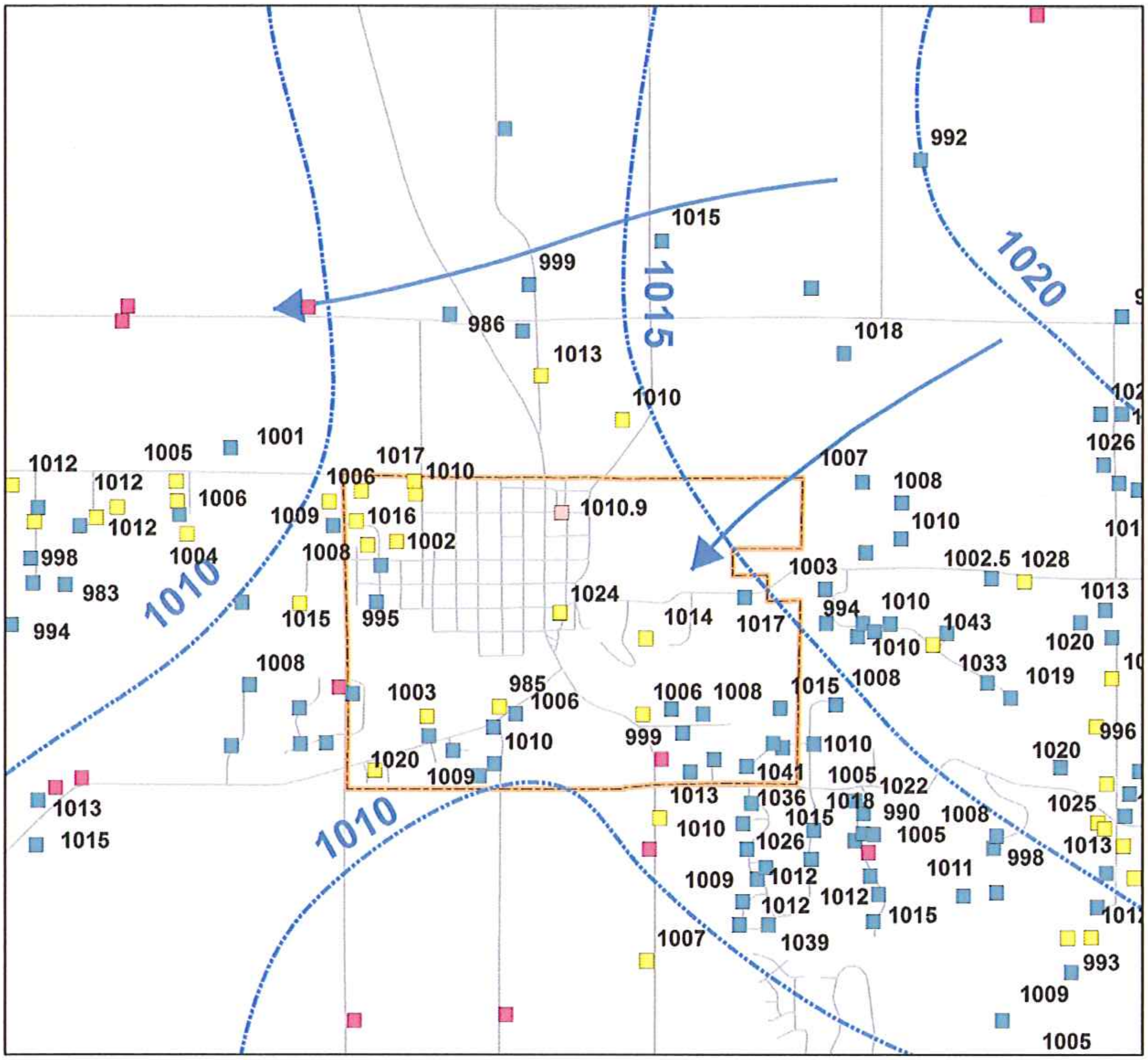


Directions of Groundwater Flow

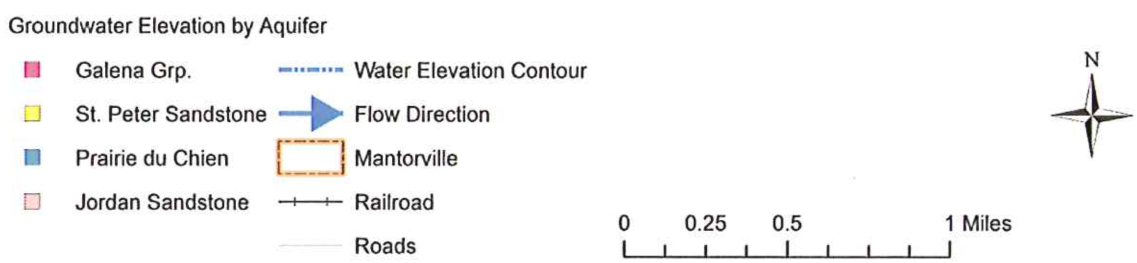
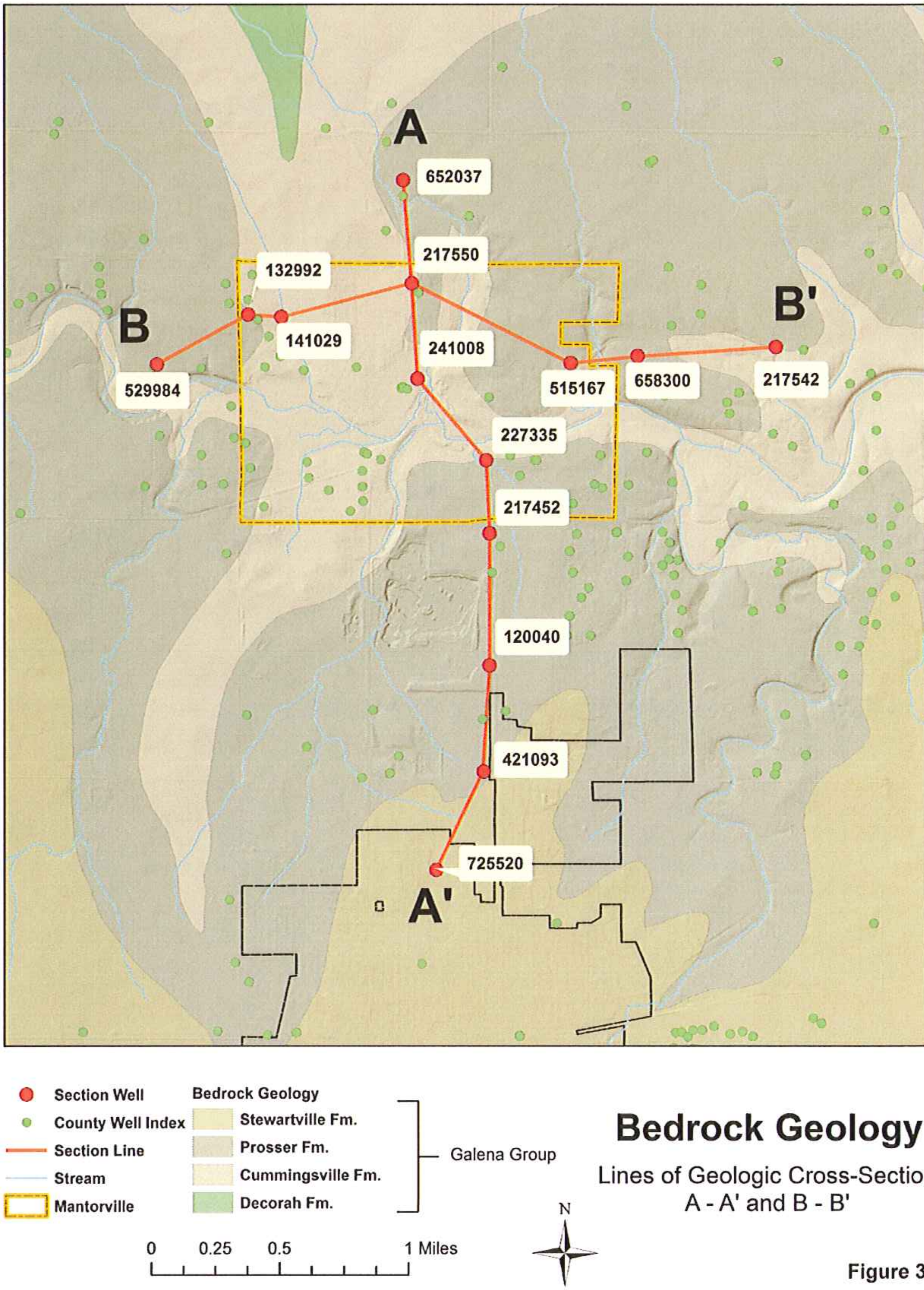


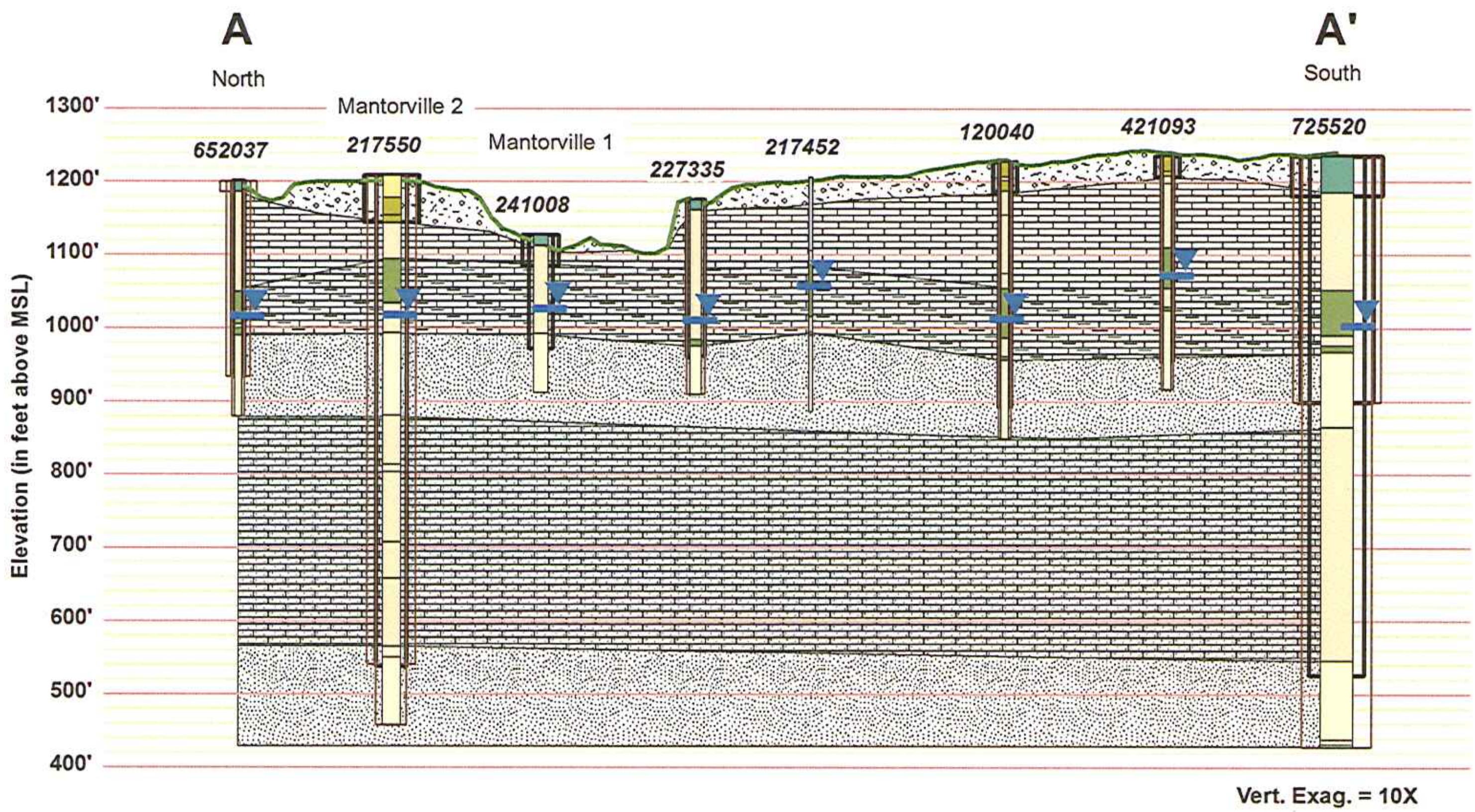
Figure 2



Bedrock Geology

Lines of Geologic Cross-Section
A - A' and B - B'

Figure 3



Geologic Interpretation
- Glacial-Fluvial Deposits
- Galena Grp.
- Decorah-Platteville-Glenwood Fms.
- St. Peter Sandstone
- Prairie du Chien Grp.
- Jordan Sandstone

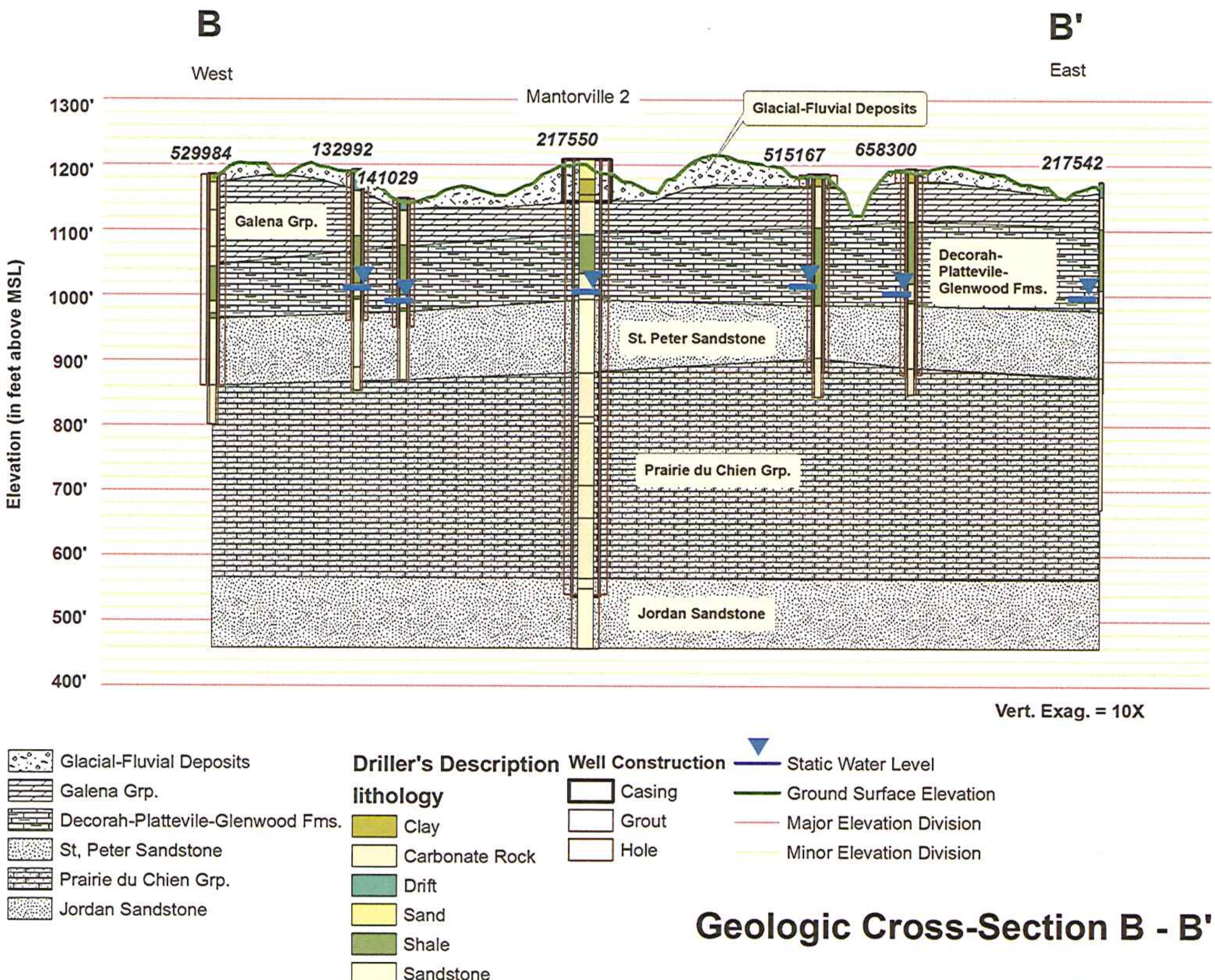
Driller's Description lithology
- Clay
- Carbonate Rock
- Drift
- No record
- Sand
- Shale
- Sandstone

Well Construction
- Casing
- Grout
- Hole

- Static Water Level
- Ground Surface Elevation
- Major Elevation Division
- Minor Elevation Division

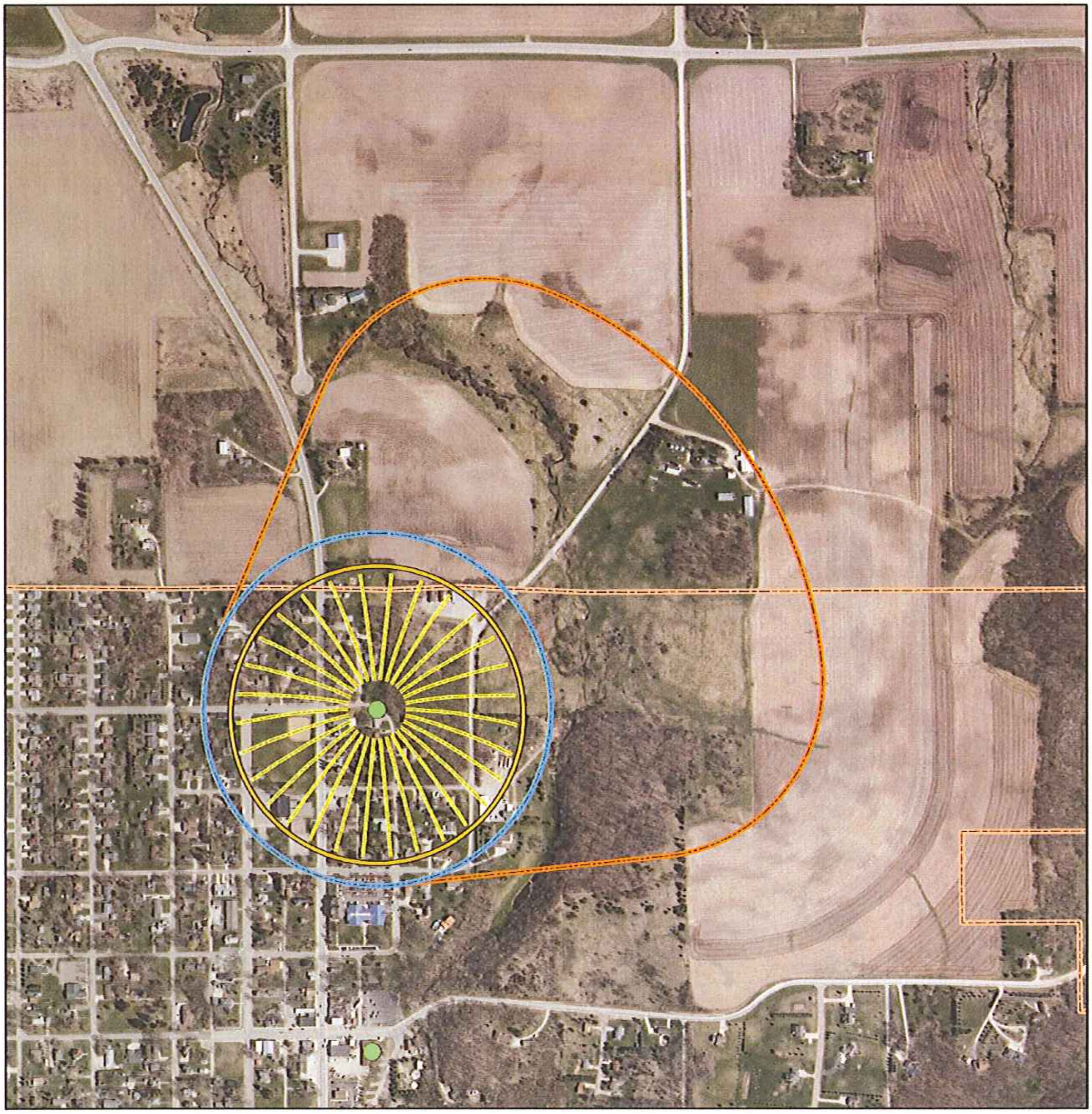
Geologic Cross-Section A - A'

Figure 4



Geologic Cross-Section B - B'

Figure 5



Porous Media Model and Fractured Rock Delineation Capture Areas

Fractured Rock Delineation

- Five-year Capture Area
- Ten-year Capture Area
- Porous Media Capture Pathlines
- Porous Media Capture Area
- PWS Well
- Mantorville

N

0 500 1,000 2,000 Feet

Figure 6

Appendix A

Fractured Rock Delineation Procedure

Fractured Rock Delineation Procedure

A fracture flow analysis is required where flow through fractures or solution weathered features exists. Mantorville Well 2 (217550) is completed in the Jordan Sandstone which is hydraulically connected to the Prairie du Chien Group. Specific to the setting in Mantorville, Delineation Technique 3 of *The Guidance* (MDH, 2011) applies to the fractured rock capture zone for Well 2 (217550). This technique is a composite calculated fixed-radius (CFR) and porous media capture zone that reflects the flow regimes of the two hydrogeologic units providing water to the well. Table A-1 contains the quantities used for the delineation calculations, converted to consistent units.

The CFR is a simple volumetric calculation for a cylinder that would supply the discharge amount for the well, based on 1) the highest pumping rate in the last five years, 2) the thickness of the saturated portion of the aquifer open to the well, and 3) the effective porosity of the aquifer. The equation for this cylinder is:

$$R = \sqrt{\frac{Q}{nL\pi}}$$

Where: R = radius of the capture area

Q = well discharge = (well pumping rate)(pumping time period)

n = effective porosity

L = thickness of saturated portion of the aquifer or open hole length of the well

π = 3.14159

Step 1. Define inputs for CFR calculation and determine if an upgradient extension is required

1.1 Aquifer thickness
The aquifer thickness is the sum of the transmissive zone thicknesses for a fractured rock aquifer, not to exceed 200 feet (61 meters).

1.2 Aquifer porosity
Geologic-unit-specific porosity values for the Prairie du Chien Dolomite and Jordan Sandstone were not available for this specific well; regional unit-specific values of 0.05 and 0.25, respectively, are provided by *The Guidance* (MDH, 2011).

1.3 Pumping Time
The standard 5-year period was used for the base CFR.

1.4 Define (apportion) Pumping Rate
The pumping rate of Well 1 is determined from the fivce-high annual pumping volume, Table 5. This rate is apportioned by the contrast in transmissivities between the Jordan and Prairie du Chien Aquifer layers. As there is no possibility of an upgradient contribution in the Jordan Sandstone itself, all of the water is assumed to be coming from the Prairie du Chien Group.

1.5 Calculate the ratio of the specific discharge to the discharge vector, Table A-1
The transmissivity used is that of the Prairie du Chien Group from the calibrated regional model. The well discharge is the average annualized rate used in the model.

Table A-1: Ratio of the Specific Discharge to the Discharge Vector

Description	Quantity	
T (ft^2/dy)	5900	OPDC
T (m^2/d)	548.1234	
gradient	0.002	
	=========	
specific discharge	1.096247	
(b) • (K) • (i), or (T) • (i)		
(discharge vector)		
Discharge (m^3/d)	369	
Ratio of well discharge to discharge vector	**337**	

Step 2: Calculate Five-Year CFR, Table A-2.

Table A-2: Five-Year Aquifer Volume Calculation

Calculated Fixed Radius Worksheet for Fractured Rock WHPA Delineation

Equation

$$R = \sqrt{\frac{Q}{nL\pi}}$$

Discharge	Q	=	369 m^3/day
Efffective Porosity	n	=	0.05
Open Hole Length	L	=	61 m
π	pi	=	3.14159

Radius of 10-year capture zone = (Q * 1826.25 (days/5-years) / (n * L * pi))^0.5

R = 265 meters (870 feet)

According to these calculations (Table A-2), the five-year radius is 870 feet.

Step 3: Calculate Upgradient CFR Extension, Table A-3.

The upgradient extension is calculated for settings where the ratio from Table A-1 is less than 3,000. The CFR is then projected this distance from the well in the direction of groundwater flow. The upgradient extension then is broadened to include the uncertainty in the direction of groundwater flow by a minimum of +/- 10°.

Table A-3: Upgradient Extension Calculation

Upgradient Extension Calculation for Fractured Rock WHPA Delineation

Equation

$$R = \sqrt{\frac{Q}{nL\pi}}$$

Discharge	Q	=	369 m^3/day
Efffective Porosity	n	=	0.05
Open Hole Length	L	=	61 m
π	pi	=	3.14159

Upgradient Extension from Well = ((Q * 1826.25 (days/5-years) / (n * L * pi))^0.5) * 2.57

UGE = 682 meters (2236 feet)

Step 4: Calculate Overlapping (Interfering) CFRs

No other wells exist in the area to interfere with Mantorville Well 2 (217550).

Step 5: Lineament Analysis

As the St. Peter-Prairie du Chien-Jordan fractured rock aquifer has more than 100 feet of younger bedrock and glacial-fluvial materials over the aquifer in this area, a lineament extension is not required.