PART I WELLHEAD PROTECTION AMENDMENT

CITY OF WHITE BEAR LAKE, MINNESOTA

CITY OF WHITE BEAR LAKE

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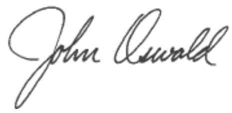

6/24/2021

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1 EXECUTIVE SUMMARY

WSP USA Inc. (WSP) developed a Part 1 Wellhead Protection Plan (WHP) Amendment for the City of White Bear Lake, Minnesota (City). The work was performed in accordance with the Minnesota WHP Minnesota Rule (MR), parts 4720.5100 to 4720.5590.

The results of the development of this WHP Plan Amendment are presented in the following text, Tables 1 through 6, Figures 1 through 11, and Appendices A through C.

This report presents delineations of the wellhead protection area (WHPA) and drinking water supply management area (DWSMA), as well as the vulnerability assessments for the public water supply wells and DWSMA. Figure 9 shows the boundaries of the WHPA and the DWSMA. These are based on WHPAs for the City's four wells that are defined by a 10-year time of travel. Figure 9 also shows the emergency response areas (ERA), which are defined by a 1-year time of travel. Definitions of rule-specific terms that are used are provided in the "Glossary of Terms".

This report also lists the technical information that was used to prepare this portion of the WHP Plan in accordance with the MR. Information pertaining to the Determination of Aquifer Properties - Aquifer Test Plan (DAP-ATP) and the well vulnerability sheets can be obtained from the Minnesota Department of Health (MDH).

Information about the City's wells and the hydrogeology in the area were obtained from the City or from other studies in the area. This information and the numerical groundwater modeling code, MODFLOW, were used to complete the delineation of the recommended WHPA, which was determined by combining the modeled or simulated groundwater capture zones for a 10-year time of travel over several sets of model boundary conditions and combining those with capture zones representing the fracture-flow capture area for each well. All completed work inside the model domain, referred to hereafter as the study area, resulted in the creation of composite capture zones, which are the boundaries of the recommended WHPA.

The City gets its water from the Prairie du Chien (OPDC), Jordan (CJDN), Wonewoc (CWOC), and Mt. Simon (CMTS) aquifers. Well No. 1 is completed solely in the CJDN aquifer, Well No. 2 is completed in the CWON and CMTS aquifers and Wells No. 3 and 4 are competed in both the OPDC and CJDN aquifers. In the model area, the flow direction is generally from east northeast toward west southwest.

The City Wells are in an area where the long-term direction of groundwater flow is unlikely to change significantly. Groundwater flow across the area is primarily from recharge areas northeast of the study area toward the Mississippi River. Even under extreme conditions, this general flow direction would likely remain the same. The capture zones produced in this study substantially agree with those from the earlier Part 1 wellhead protection model. The primary uncertainties associated with the water supply are related to the amount of fracture flow within the OPDC aquifer and the variability in the hydraulic conductivity of OPDC and CJDN of the aquifers.

To help understand these uncertainties, a sensitivity and uncertainly assessment was also completed and is included in this report. The vulnerability of the aquifers, as determined by the geologic sensitivity analysis, is low to moderate near the City. The presence of low conductivity layers near the surface in the area of the City Wells provides some protection, but relatively high tritium detections at Wells 1, 3, and 4 indicate higher vulnerability than would be expected. Well No.2, in the much deeper Mt. Simon aquifer, has many more protective barriers between the aquifer and the surface and vulnerability of that aquifer is considered very low.

It is recommended that the City continue to sample all of their wells for tritium. This will indicate the relative age of the water each of the wells is producing and provide information as to its source.

2 INTRODUCTION AND BACKGROUND

WSP USA Inc. (WSP) has developed a Part 1 Wellhead Protection (WHP) Plan Amendment for the City of White Bear Lake (City), public water supply identification number 1620024). The work was performed in accordance with the Minnesota WHP Minnesota Rule (MR), parts 4720.5100 to 4720.5590.

The City's wells included in the WHP Plan are listed in Table 1. Only wells listed as primary are required to be included in the WHP Plan.

Table 1 - Water Supply Well Information

Local Well Name	Unique Number	Type	Casing Diameter (inches)	Casing Depth (feet)	Well Depth (feet)	Date Constructed/ Reconstructed	Well Vulnerability	Aquifer
Well No. 1	14005	Primary	22 x 16	390	490	1959	Vulnerable	CJDN
Well No. 2	222880	Primary	30 x24 x16	700	970	1962	Not Vulnerable	CWMS
Well No. 3	205733	Primary	30 x 20	289	513	1966	Vulnerable	OPCJ
Well No. 4	226566	Primary	30 x 20	267	476	1969	Vulnerable	OPCJ
Well No. 5	226567	Emergency	20 x 16 x 12	371	463	1956	Not Vulnerable	CJDN

CJDN – Jordan Sandstone.
CWMS – Wonewoc- Mt. Simon.
OPCJ – Prairie du Chien-Jordan Group.

3 ASSESSMENT OF THE DATA ELEMENTS

Table 2 presents the assessment of the data elements as outlined in the Minnesota Department of Health's (MDH's) scoping letter relative to the present and future implications of planning items that are specified in MR, 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	H	H	H	H	MN Climatology Office, Metropolitan Council (Metromodel)
Geology					
Maps and geologic descriptions	M	H	H	H	MGS, DNR, USGS
Subsurface data	M	H	H	H	MGS, MDH, MPCA, USGS
Borehole geophysics	M	H	H	H	No relevant data available
Surface geophysics					No relevant data available
Maps and soil descriptions	L	H	M	L	No relevant data available
Eroding lands					
Water Resources					
Watershed units	L	H	L	L	National Hydrography Dataset (USGS)
List of public waters	L	H	L	L	DNR, National Hydrography Dataset (USGS)
Shoreland classifications					
Wetlands map					
Floodplain map					
Land Use					
Parcel boundaries map	L	H	L	L	County GIS Data
Political boundaries map	L	H	L	L	ESRI Data
Public Land Survey map	L	H	L	L	ESRI Data
Land use map and inventory					
Comprehensive land use map					
Zoning map					
Public Utility Services					
Transportation routes and corridors	L	H	L	L	ESRI Data

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	
Storm/sanitary sewers and PWS system map	L	L	L	L	City, County
Oil and gas pipelines map					
Public drainage systems map or list	L	M	L	L	City, County, DNR
Records of well construction, maintenance, and use	H	H	H	H	City, Minnesota Well Index (MWI)
Surface Water Quantity					
Stream flow data	L	M	M	M	DNR, USGS
Ordinary high-water mark data	L	M	L	L	No relevant data available
Permitted withdrawals	L	M	L	L	DNR
Protected levels/flows	L	H	L	L	No relevant data available
Water use conflicts	L	H	L	L	DNR
Groundwater Quantity					
Permitted withdrawals	H	H	H	H	DNR
Groundwater use conflicts	H	H	H	H	No relevant data available
Water levels	H	H	H	H	DNR, MPCA, MDH, City
Surface Water Quality					
Stream and lake water quality management classification					
Monitoring data summary	L	H	L	L	MDH, USGS
Groundwater Quality					
Monitoring data	H	H	H	H	MPCA, MDH
Isotopic data	H	H	H	H	MDH
Tracer studies					No relevant data available
Contamination site data	M	M	M	M	MPCA, MDA
Property audit data from contamination sites					
MPCA and MDA spills/release reports	H	H	H	H	No relevant data available

Definitions Used for Assessing Data Elements:

High (H) – The element has a direct impact.

Moderate (M) – The element has an indirect or marginal impact.

Low (L) – The element has little if any impact.

Shaded – The element was not required by MDH for preparing the WHP Part 1 Amendment

4 GENERAL DESCRIPTIONS

4.1 DESCRIPTION OF THE WATER SUPPLY SYSTEM

The City obtains its drinking water supply from Wells No. 1 through 4 with an additional well, Well No. 5, designated only for emergency backup use. The wells are shown on Figure 1 and Table 1 summarizes their construction details.

4.2 DESCRIPTION OF THE HYDROGEOLOGIC SETTING

The hydrogeologic settings for the bedrock aquifers pumped by the City's wells are described in detail in the previous Part 1 Wellhead Protection Plan (Champion, 2009).

The geology in the vicinity of the City consists of Quaternary-age glacial and post-glacial deposits that are underlain by Paleozoic-aged bedrock. Overburden in the area surrounding White Bear Lake consists of glacial deposits associated with the Superior Lobe overlying Wisconsinan Lobe till. The Superior Lobe deposits consist primarily of till with large areas of outwash sands and gravels. The Wisconsinan deposits are primarily glacial till. The City's wells are bedrock wells completed primarily in the Prairie du Chien Formation (OPDC) and the Jordan Sandstone (CJDN). The OPDC and CJDN bedrock units are underlain by the St. Lawrence Formation, which is a low-conductivity layer and is considered an aquitard. Appendix C includes a surficial bedrock map and shows the distribution of bedrock units in the area of the City and also includes hydrogeologic cross sections A-A' and B-B' from Champion, 2009.

Table 3a - Description of the Hydrogeologic Setting in Prairie du Chien Aquifer

Aquifer	Attribute	Descriptor	Data Source
Prairie du Chien Group (OPDC)	Aquifer Material	Shale, Dolomite	City Well Logs
	Primary Porosity	0.056	MDH (2012)
	Aquifer Thickness	124 - 129 feet	City Well Logs
	Stratigraphic Top Elevation	722 - 737 feet AMSL	City Well Logs
	Stratigraphic Bottom Elevation	596 - 613 feet AMSL	City Well Logs
	Hydraulic Confinement	Confined	City Well Logs
	Transmissivity (T)	Reference Value 9,324 ft^2/day	The reference value for the transmissivity of the Prairie du Chien Aquifer was determined by multiplying the reference hydraulic conductivity, discussed below, by the aquifer thickness.
	Hydraulic Conductivity (K)	Reference Value/Range 74 ft/day Range: 30 – 500 ft/day	The reference value for the hydraulic conductivity of the Prairie du Chien Aquifer was determined from pumping tests at White Bear Township Well No. 3 and City Well No. 4, as well as specific capacity data from wells in the area as listed in the DAP-ATP.
	Groundwater Flow Field	Flow generally to the southwest. Hydraulic Gradient: 0.0014	Based on mathematical analysis of measured heads. Flow west and south toward the Mississippi River.

Table 3b - Description of the Hydrogeologic Setting in Jordan Aquifer

Aquifer	Attribute	Descriptor	Data Source
Jordan Sandstone (CJDN)	Aquifer Material	Sandstone	City Well Logs
	Primary Porosity	0.2	MDH (2012)
	Aquifer Thickness	97 ft	City Well Logs
	Stratigraphic Top Elevation	596-614 feet AMSL	City Well Logs
	Stratigraphic Bottom Elevation	500-520 feet AMSL	City Well Logs
	Hydraulic Confinement	Confined	City Well Logs
	Transmissivity (T)	Reference Value 2,436 ft^2/day	The reference value for the transmissivity of the Jordan Aquifer was determined by multiplying the reference hydraulic conductivity, discussed below, by the aquifer thickness.
	Hydraulic Conductivity (K)	Reference Value: 28 ft/day Range: 10 – 63 ft/day	The reference value for the hydraulic conductivity of the Jordan Aquifer was determined from pumping tests at White Bear Township Wells No. 1 and 4, as well as specific capacity data from wells in the area as listed in the DAP&ATP.
	Groundwater Flow Field	Flow generally to the west and southwest. Hydraulic Gradient: 0.0014	Based on mathematical analysis of measured heads. Flow west and south toward the Mississippi River.

Table 3c - Description of the Hydrogeologic Setting in Mt. Simon Aquifer

Aquifer	Attribute	Descriptor	Data Source
Mt. Simon Sandstone (CMTS)	Aquifer Material	Sandstone	City Well Logs
	Primary Porosity	0.2	MDH (2012)
	Aquifer Thickness	165 ft	City Well Logs
	Stratigraphic Top Elevation	180 feet AMSL	City Well Logs
	Stratigraphic Bottom Elevation	15 feet AMSL	City Well Logs
	Hydraulic Confinement	Confined	City Well Logs
	Transmissivity (T)	Reference Value 2,359 ft^2/day	The reference value for the transmissivity of the Mt. Simon Aquifer was determined by multiplying the reference hydraulic conductivity, discussed below, by the aquifer thickness.
	Hydraulic Conductivity (K)	Reference Value: 15 ft/day Range: 4.5 – 20.3 ft/day	The reference value for the hydraulic conductivity of the Mount Simon Aquifer was determined from specific capacity data from City Well No. 2 and other wells in the region as listed in the DAP&ATP.
	Groundwater Flow Field	Flow generally to the west and southwest. Hydraulic Gradient: 0.0014	Based on mathematical analysis of measured heads. Flow west and south toward the Mississippi River.

Annual precipitation for the area is approximately 32.42 inches per year (in/yr) (National Oceanic and Atmospheric Administration Resources ([NOAA] 2020). Recharge to the surficial layers in the model is approximately 6 in/yr.

Groundwater flow in the area of the City is generally to the southwest toward the Mississippi River. The Mississippi River is the primary discharge location for local groundwater. White Bear Lake and other water bodies are also included in the model.

5 DELINEATION OF THE WELLHEAD PROTECTION AREA

5.1 DELINEATION CRITERIA

Table 4 provides descriptions of how the delineation criteria that are specified under MR, part 4720.5510 were included in the model.

Table 4 - Description of WHPA Delineation Criteria

Criterion	Descriptor	How the Criterion was Addressed
Flow Boundary	Mississippi River; White Bear and Bald Eagle Lakes, and smaller streams and lakes	These features are used to define the flow field. Surface water features are represented using the MODFLOW river package.
Flow Boundary	Other High-Capacity Wells	The pumping amounts at wells within two miles were determined based on the averaged 2015-2019 pumped volumes. The pumping amounts of the other wells in the Metro Model were not modified.
Daily Volume of Water Pumped	See Table 5	Pumping information was obtained from DNR Appropriations Permits 1969-0174 and the City. The annual pumped volumes were converted to an average daily volume pumped by a well.
Groundwater Flow Field	See Figure 6	The model calibration process addressed the relationship between the calculated versus observed groundwater flow field.
Aquifer Transmissivity	9,324 ft^2/day-OPDC 2,436 ft^2/day-CJDN 2,359 ft^2/day-CMTS	The reference values for transmissivity were calculated using the hydraulic conductivity values determined in the DAP-ATP and multiplied by the average thickness of each aquifer in the area of the City's wells.
Time of Travel	10 years	The public water supplier selected a 10-year time of travel.

Information provided by the City and from the Minnesota Department of Natural Resources (DNR) Permit and Reporting System (MPARS) database was used to identify the maximum volume of water pumped annually by each well over the previous 5-year period. The volumes pumped from the wells over the previous 5 years are summarized in Table 5. Summing the highest pumping value from each of the City wells totaled over 1,319 million gallons per year (MGY). The value used in the model is the highest value for each well over the past 5 years or the projected value for 5 years in the future. Since the City has had stable to decreasing water use over the recent past, and the City does not expect any significant increase in future use, the total volume pumped from the City's wells used in the model is high-5 value of 1,319 MGY. This value is significantly higher than any individual year and is the same value that was used in the previous Part 1. These pumping rates represent conservative values. The daily volume of discharge used as an input parameter in the model was calculated by dividing the annual withdrawal volume by 365 days.

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

Well Name	**Unique Number**	**Total Annual Withdrawal (million gallons/year [MGY])**					**Withdrawal used in Previous WHP Plan (MGY)**	**Withdrawal used in Current WHP Plan (MGY)**	**Withdrawal used in Current WHP Plan (m^3/d)**
		2015	**2016**	**2017**	**2018**	**2019**			
Well No. 1	14005	18.2	86.1	11.4	**87.2**	63.6	156.1	87.2	904.4
Well No. 2	222880	**2.9**	0.6	0.5	0.6	0.02	111.0	2.9	30.1
Well No. 3	205733	359.3	**393.5**	362.4	210.8	374.3	445.7	393.5	4081.0
Well No. 4	226566	397.6	334.8	**438.7**	432.5	279.8	606.7	428.7	4549.8
Well No. 5	226567	0.0	0.0	0.0	0.0	0.0	0	0	0.0
Totals		778.0	815.1	813.1	731.1	717.1	922.3	1,319.5	9,565.2

Sources: DNR MPARS Permit Numbers 1969-0174 and City
Bolding indicates greatest annual pumping volume of the last five years

Table 6 – High Capacity Wells within 2.0 Miles

Well Number	Name	Permit Number	Aquifer	Use Category	2015-2019 Average Use (MGY)	Average Daily Use (m^3/d)
151596	White Bear Township	1984-6121	OPDCCJDN	Municipal/Public Water Supply	135.3	1,403.1
676446	White Bear Township	1984-6120	CJDN	Municipal/Public Water Supply	24.4	253.0
226570	White Bear Township	1984-6120	CJDN	Municipal/Public Water Supply	5.7	59.1
205744	City of North St. Paul	1977-6176	CJDN	Municipal/Public Water Supply	61.3	635.7
208223	City of North St. Paul	1977-6176	OPDCCJDN	Municipal/Public Water Supply	46.3	480.1
208222	City of North St. Paul	1977-6176	OPDCCJDN	Municipal/Public Water Supply	41.8	433.5
112222	Vadnais Heights, City Of	1980-6153	OPCJ	Municipal/Public Water Supply	0.1	1.0
233149	Saputo Dairy Foods USA, LLC	1986-6316	CJDN	Agricultural/Food Processing	151.115	1,567.1
753675	Mahtomedi, City of	1969-0163	CJDN	Municipal/Public Water Supply	62.845	651.7
433255	Mahtomedi, City of	1969-0163	OPDCCSTL	Municipal/Public Water Supply	20.761	215.3
655934	Ind School District 624	2004-3020	OPDC	Landscaping/Athletic Field Irrigation	3.1	32.1
127293	RAMSEY COUNTY PARKS and RECREATION	1987-6205	OPDC	Golf Course Irrigation	14.008	145.3
151584	Gem Lake Hills Inc	1986-6211	OPDCCJDN	Golf Course Irrigation	12.844	133.2
151575	Oakdale Public Works	1978-6197	CJDNCSTL	Municipal/Public Water Supply	0.02	0.2

- Source: DNR MPARS

5.2 METHOD USED TO DELINEATE THE WELLHEAD PROTECTION AREA

The final WHPA consists of areas determined through a porous media delineation, a fracture flow delineation, and, if necessary, a conjunctive area delineation. The WHPA is a composite of all the areas identified using methods described in this report that potentially contribute recharge to the aquifer used by the City’s wells within a 10-year time of travel.

5.2.1 POROUS MEDIA DELINEATIONS

The porous media delineations of the WHPA for the City's wells were completed using an existing regional MODFLOW-NWT model, Metromodel 3.0, which was provided by the Metropolitan Council (Metropolitan Council, 2014). MODFLOW-NWT is a 3D, cell-centered, finite difference, saturated flow model developed by the USGS (Niswonger et al., 2011).

The regional Metromodel consists of nine layers that represent the major aquifers and aquitards within the seven-county metropolitan area. These layers represent, from top to bottom, the following units: (1) surficial aquifer of glacial deposits; (2) St. Peter Sandstone or Quaternary Buried Artesian Aquifer; (3) Prairie du Chien Group; (4) Jordan Sandstone; (5) St. Lawrence Formation (aquitard); (6) Tunnel City Group; (7) Wonewoc Sandstone; (8) Eau Claire Formation (aquitard); and, (9) Mt. Simon Sandstone. The regional groundwater model was calibrated to steady-state water levels and river base flows.

A local-scale model, limited to the northeastern portion of the Metromodel, was extracted from the regional model and is shown on Figure 1. The local model and all of the modeling for this amendment was completed using GMS (Aquaveo, 2016), a pre- and post-processor for MODFLOW. The local model was created using the technique of local grid refinement where a smaller, more refined grid is used within the regional model. The heads computed from the regional model then provide some of the boundary conditions for the local model as specified heads. The size of the domain and the general flow-field characteristics of the model were based on the Metromodel and the results of the original delineation.

The local model domain was divided into a three-dimensional, non-uniform grid with nine layers. The details of the Metromodel were translated to the local-scale model using GMS. Finer grid spacing was applied around the in the local model with telescopic mesh refinement used in the area of the site where the City's wells are located. This grid spacing (1.5 meters in the area of the City's wells) provides better definition in the area of the flow field where simulating the influence of pumping from the wells is critical. The base of the model is variable at an elevation of approximately 5 meters above mean sea level in the area of the City's wells. The nine layers in the local model represent the bedrock units and unconsolidated materials just as in the Metromodel. These layers correspond to the approximate vertical extent of the various stratigraphic units observed in the vicinity of the City. Layer 1 represents the unconsolidated materials, primarily clay till and sand units. Layer 2 represents unconsolidated materials in some areas and St. Peter Sandstone, where present. Layers 3 and 4 are comprised primarily of either unconsolidated material or the Prairie du Chien Group and Jordan Sandstone, respectively. Layer 5 is the St. Lawrence Formation, which is an aquitard that effectively eliminates any influence from the lower layers on the upper four layers of the model in the area of interest. Layers 6 and 7 represent the Tunnel City Group and Wonewoc aquifers, respectively. Layer 8 is the Eau Claire confining unit and the base layer, Layer 9, represents the Mt. Simon aquifer.

Changes were made to the original Metromodel defined characteristics in the area of interest around the City's wells. Site specific information allowed for more accurate definition of aquifer characteristics and to alter defined properties in the Metromodel. The alterations were to the bed conductance of several lakes in the southeastern portion of the local model. Excessive and unrealistic infiltration from these lakes was producing an area of artificially increased head. The remaining changes were confined primarily to the OPDC, CJDN, and CMTS aquifers in the area of the City. The conductivity of the CJDN, OPDC, and CMTS were modified to align with the values reported in the DAP-ATP for each aquifer. Zones were created in Layers 3, 4. and 9 of the model for modifying the horizontal conductivity of the aquifer in the vicinity of the City's wells and their capture zones. These conductivities replaced those defined in the Metromodel for that area.

In addition to the previously mentioned changes, the following modifications were incorporated in the refined model:

- The pumping rates from Table 5 were assigned to the City's wells.
- The pumping rates from Table 6 were assigned to the permitted high-capacity wells located within approximately 2 miles of the City's wells (Figure 2).

The model is used to determine the groundwater head and flow direction throughout the domain (Figure 3). As part of the delineation, groundwater pathline analyses were performed to determine the 1-, 5- and 10-year capture zones and ultimately the WHPA. The pathline analysis consisted of using MODPATH, a flowpath calculation program (Pollack, 1994), to determine the capture zone for each of the City's wells. This was completed by tracing 36 flow paths from each cell for a 10-year travel time. A porosity of 20 percent was used for CJDN and CMTS, and a value of 5.6 percent was applied to the OPDC, consistent with the MDH guidelines and slightly conservative for the aquifers (MDH, 2012).

As part of the uncertainty analysis, additional groundwater pathline analyses, each consisting of 36 pathlines per cell containing a well for a 10-year time-of-travel, were performed to delineate the 1-, 5- and 10-year capture zones and ultimately porous media portion of the WHPA.

The resulting area is a composite of the 10-year time of travel capture zones calculated using this model for the base case parameters and the parameter values used in the uncertainty analysis that is discussed in the following section. The model input files are available upon request from the MDH.

5.2.2 RESULTS OF MODEL CALIBRATION AND SENSITIVITY ANALYSIS

The goal of numerical model calibration is to obtain a reasonable correlation between the simulated model results and observed field data. The calibration process is generally completed by running a series of steady-state simulations (simulations where the flow magnitude and direction are constant with time), comparing calculated heads to the measured heads at wells within the model domain while changing the model parameters until the best match between the two is achieved. After a model is reasonably calibrated, a sensitivity analysis is used to determine the impact that changes to an input parameter have on the output of the model. In areas where there is a great deal of uncertainty in the physical parameters, either as a consequence of lack of data or based on the uncertainty associated with the interpretation of available data (i.e. pumping test analyses), a number of models are generally run to observe the effect on the model results over the range of potential values for each of the significant parameters. While none of the individual capture zones delineated as part of this analysis should be considered the “correct” one, it is assumed that the actual capture zone is encompassed by the resulting concatenation of the zones created during the uncertainty analysis.

5.2.3 CALIBRATION

The calibration plots, showing measured versus simulated hydraulic head values, for the model are illustrated on Figures 4, 5, and 6. The plots show that the simulated values and measured head values generally compare quite favorably and have a normalized root mean squared (NRMS) error of approximately 4.8 percent for observation points in layer 3, 5.1 percent for points in layer 4, and 6.6 percent in layer 9 of the model representing the OPDC, CJDN, and CMTS aquifers, respectively. The calibration data sets are subsets of the one created for Metromodel 3 corresponding to each layer.

The groundwater hydraulic head in the area of the City, simulated in the calibrated model, is shown on Figure 3. The 1-, 5-, and 10-year capture zones, predicted using the calibrated model, are shown on Figure 7. However, due to the amount of variability associated with the physical characteristics of the aquifer, sensitivity and uncertainty analyses were completed as part of the modeling effort.

5.2.4 SENSITIVITY ANALYSIS

Sensitivity is the amount of change in model results caused by the variation of a particular input parameter. For example, changing the hydraulic conductivity of an area can change the calculated head values in and around the area of the modified model as compared to the heads in unmodified model. Because of the relative complexity of the area of interest in this model, the size and orientation of the modeled capture zone may be sensitive to any of the input parameters:

The **pumping rate** determines the volume of the aquifer that donates water to the well. Increasing the pumping rate will expand the capture zone, for a given thickness, and decreasing it will make the capture zone smaller.

- **Results –** The pumping rates for the City’s wells were defined by the Minnesota Rules are not considered variables for this analysis.

The **direction of groundwater flow** and gradient can often be variable and change significantly with changing conditions such as fluctuations in local surface water elevations or the pumping rates in local wells.

- **Results** – The regional flow direction and gradient were determined through the modeling process and resemble the flow direction and gradient determined through mathematical analysis of the measured heads in the area. The model was calibrated to hydraulic heads, and the calibration mirrored regional head data. Based on the regional observation data, the characteristics of the flow field, and the use of the aquifers of interest, there is not likely to be a significant change to the flow field.

The **hydraulic conductivity** influences the size and shape of the capture zone. In the presence of a gradient, higher conductivities will result in long, narrow capture zones extending upgradient. Lower conductivities will result in shorter, wider capture zones. As there is nearly always a large amount of uncertainty associated with this parameter, most analyses will consider a range of conductivities. All of the transmissivity and conductivity data and analyses can be found in the DAP-ATP documentation from the MDH.

- **Results** – The representative conductivities as well as the range for each aquifer were determined by analyzing data from pumping tests on City and other municipal wells in the area as well as specific capacity data from high-capacity wells in the study area. The analysis indicates that the range of potential conductivities for the CJDN aquifer is 10.1 to 63 feet per day (ft/d) with a geometric mean of 28.6 ft/d. The model was completed using a representative value of 28 ft/d and a range of 10-63 ft/d. The results also indicate that the range of potential conductivities for the OPDC aquifer is from 12 to over 1,200 ft/d with a mean value of 115 ft/d. The model was completed with a representative value of 74 ft/d. Since 12 ft/d is anomalously low and 1,200 ft/d is anomalously high, an uncertainty range of 30 to 500 ft/d was used for the OPDC aquifer. The range used for the Mt. Simon aquifer was 2.3 to 20.3 ft/d with a representative value of 15 ft/d.

  The Metromodel also employs what are known as "quasi 3-d" confining layers between some of the layers in the model. These are used to represent thin layers that act as confining units between the aquifer layers without actually having to define another layer in the model. The Oneota portion of the Prairie du Chien Group, which directly overlies the Jordan Sandstone, is represented using one of these quasi layers. The vertical hydraulic conductivity of this layer was increased two orders of magnitude in the uncertainty analysis and showed no discernable effect.

The aquifer **thickness** and **porosity** influence the size and shape of the capture zone by limiting the water-bearing volume within a given area of aquifer. Decreasing or increasing either thickness or porosity forces a proportional decrease or increase in the areal extent of the capture zone.

- **Results** - The thicknesses of the CJDN and OPDC aquifers within the model vary. The thickness values for the aquifers in the area of the City's wells were similar to be the thickness as specified in the stratigraphy database of the well log information. Therefore, aquifer thickness is not considered a variable for this study. The porosity for the CJDN and CWMS aquifers was chosen to be 0.2 based on MDH recommendations. The porosity of the OPDC aquifer was defined to be 0.056, also consistent with the value in MDH, 2012. The porosity is also not considered a variable.

5.2.5 ADDRESSING MODEL UNCERTAINTY

Using computer models to simulate groundwater flow always requires that simplifying assumptions be made. Local geology can be highly variable and information from well logs and pumping tests indicates that this is likely the case near the City. Unfortunately, existing information is not detailed enough to define this degree of variability, and interpretation of log and test data is often inconsistent. For models of the scale used in this study, the information and computational ability does not exist to precisely delineate the WHPA. To account for this, a number of models are run to examine the various potential WHPAs for the well, given the range of the input data mentioned previously.

MODFLOW models were used to delineate capture zones for the aquifers that supply water to the City's wells. As described previously, the hydraulic conductivity was the primary variable identified that would potentially cause the greatest change in the WHPAs for the City's wells. Capture areas were delineated for the assessed range of conductivities for a time-of-travel period of 10 years and the resulting concatenated capture zones define the WHPAs, shown on Figure 7.

The WHPAs for the City's wells (Figure 7) consist of composites of the porous media aquifer delineations for the different hydraulic conductivity values used in the sensitivity analyses. To complete the DWSMA delineation, the results of the fracture flow delineation described in the following section were concatenated with these results. This provides a conservative approach to addressing porous media model uncertainty and produces a WHPA that is protective of public health.

5.3 FRACTURE FLOW DELINEATION

The second WHPA delineation (the first is the Porous Media Delineation discussed in section 5.2) for the City's wells was determined using the "Guidance for Delineating Wellhead Protection Areas in Fractured and Solution-Weathered Bedrock in Minnesota" (MDH, 2012). This guidance was developed by MDH to address the increased variability in flow velocities and directions in geologic settings with secondary porosity. The OPDC aquifer is considered to have secondary porosity while the CJDN does not. The guidance is a modified volumetric analysis and does not use a model based on flow equations.

In accordance with the guidance, Delineation Techniques 3 and 4 were used to delineate the WHPA. These techniques were chosen, in part, because it is recommended for aquifers characterized by locally confined conditions where the ratio of the well discharge to the discharge vector is less than 3,000. Wells No. 3 and 4 are open to both the OPDC and CJDN aquifers, and Well No. 1 is completed exclusively in the CJDN aquifer. Parameters used in the fracture flow analysis are summarized in Appendix A. The flow rates used for the wells were determined from the rates calculated for well conditions in layer 3 of the model. The amount of groundwater flow that moved across the boundary from layer 3 to layer 4 within the capture zone of each well was then added to the layer 3 flow quantity to get the total daily flow for each well. As Wells No. 1, 3, and 4 are all in the vicinity of each other, the flow from the OPDC into the CJDN aquifer near Well No. 1 was split between Wells No. 3 and 4 and the 2-well GIS tool was used to encompass all three wells.

The fracture-flow analysis is a method that establishes a calculated fixed-radius (CFR) capture zone based on the 5-year volume of water pumped for a given well. The CFRs were calculated using the MDH Arcmap Add-In tool for creating one- and two-well capture areas. Special consideration had to be made due to significant overlap of between the Wells No. 3 and 6 CFRs. The final resulting combined upgradient fracture flow delineation accounts for the initial CFR overlapping areas. The flow direction was determined by reviewing the upgradient capture direction determined from the 10-year capture zones in the groundwater flow model.

Appendix A presents the input and output from the tool used to determine the fracture flow delineation. Figure 8 shows the fracture flow WHPA delineations and the 6-month fracture zones with 6-month upgradient extensions used in delineating the emergency response area (ERA) for each well.

5.4 CONJUNCTIVE DELINEATION

A conjunctive delineation involving the consideration of surface waters in making the final wellhead protection area delineation was not considered necessary for the City. Guidance from the MDH states that a conjunctive delineation is required if the 1-year capture zone of a well intersects an area of high vulnerability. That area can be increased to the 3-year capture zone at the discretion of the project hydrogeologist. As discussed in the following section, there are no high vulnerability areas within the 1- or 3-year capture zones of the wells.

6 DELINEATION OF THE WELLHEAD PROTECTION AND DRINKING WATER SUPPLY MANAGEMENT AREAS

After the porous media flow, uncertainty analyses, and fracture flow analysis, the capture zones delineated for each of them were plotted together. The outline of this concatenation created the final 10-Year composite WHPA capture zone, shown on Figure 9, for use in delineating the DWSMA.

The boundary of the DWSMA was defined by WSP using roads and Public Land Survey System (MDH, 2020) coordinates (Figure 9).

6.1 VULNERABILITY ASSESSMENTS

The Part 1 Wellhead Protection Plan includes the vulnerability assessments for the public water supply well and DWSMA. These vulnerability assessments are used to help define potential contamination sources within the DWSMA and to select appropriate measures for reducing the risk that they present to the public water supply.

6.1.1 ASSESSMENT OF WELL VULNERABILITY

The City's well vulnerability assessment was conducted in accordance with the MDH guidance document, *Assessing Well Vulnerability for Wellhead Protection* (MDH, 1997). Vulnerability assessment rating sheets and vulnerability scores for City Wells No. 1 through 4 were obtained from the MDH and reviewed by WSP. The vulnerability of a well is scored based on the following six categories: DNR geologic sensitivity rating, casing integrity, casing depth, pumping rate, isolation distance from contaminant sources, and chemical and isotopic information.

The DNR geologic sensitivity rating is an empirical value determined by dividing the cumulative thickness of low permeability units (e.g. clay) above the aquifer by 10 (DNR, 1991). The resulting score is termed the "L-score". A higher L-score indicates more low-permeability material above the aquifer, and therefore a lower vulnerability. A low L-score represents higher vulnerability. For example, a rating of L-1 has a higher vulnerability than L-9, because there is less low-permeability material present above the aquifer. This type of assessment is defined by the DNR as Level 3. A Level 3 assessment was conducted for the City wells since the aquifer is overlain by varying thicknesses of clay. As mentioned above, points are also assigned to casing integrity and depth, pumping rate, isolation distance to contaminant sources, and chemical data, in addition to the geologic sensitivity.

Vulnerability assessment worksheets and the total score of the six vulnerability categories for Wells No. 1 through 5 are presented in Appendix B. Per MDH guidance, any well that receives an assessment rating of 45 points or greater is considered a vulnerable well. Wells No. 1 and 3 had vulnerability scores or 45 and Well No. 4 had a score of 50. Well No. 2, being in the deeper, more protected Mt. Simon aquifer had a vulnerability score of 0. Wells No. 1, 3, and 4 are considered vulnerable due to the tritium detections in area groundwater. Tritium has been detected in Wells No. 1, 3, and 4. Tritium in ground water is a result of nuclear testing and is used as an indicator of post-1953 recharge. Nitrate was detected at low concentration in Wells No. 3 and 4 and tested for but not detected in the remaining wells.

6.1.2 ASSESSMENT OF DRINKING WATER SUPPLY MANAGEMENT AREA SENSITIVITY

The assessment of geologic sensitivity is a useful metric when estimating the relative vertical downward travel time of contaminants from grade level to the water table or source aquifer. A Level-2 DNR geologic sensitivity assessment was used for the City's wells. The Level-3 DNR geologic sensitivity rating is an empirical value determined by dividing the cumulative thickness of low permeability units above the aquifer by 10 (DNR, 1991). A Level-3 assessment was conducted since the aquifers utilized by the City's wells are confined.

The geologic sensitivity within the Washington County portion of the DWSMA was determined by examining the ratings of the geologic sensitivity of the bedrock surface as defined by the DNR (Berg, 2019) within each PLSS-defined 40-acre parcel and assigning the parcel the majority sensitivity value. This value was then upgraded in areas where bedrock confining layers (the Basal St. Peter Sandstone and Oneota member of the OPDC) provide additional protection. In the portion of the DWSMA in Ramsey County, MDH applied a GIS tool to MWI lithology log data to calculate L-scores for each well extending at least to bedrock within the DWSMA. Areas were also upgraded to account for bedrock confining layers where they were present, for example in the southwest portion of the DWSMA where the aquifers are overlain by a shale confining unit as shown on the geologic data in Appendix C. Zones containing wells with generally similar ratings within the DWSMA were then delineated. The geologic sensitivity delineations and ratings within the DWSMA are illustrated on Figure 10.

6.1.3 ASSESSMENT OF THE DRINKING WATER SUPPLY MANAGEMENT AREA VULNERABILITY

In the DWSMA, the ground water that supplies the City Wells is from the OPDC, CJDN, CWON, and CMTS aquifers that underlie glacial deposits (Ramsey and Washington County Atlas Series, Atlas C-7 and C-5, respectively). The glacial deposits are composed of Superior Lobe sand and silt lacustrine deposits, till, and outwash. Deposits also consist of Pre-Late Wisconsinan Keewatin and Grantsburg Sublobe till, outwash and sandy lacustrine sediment. The Superior Lobe, due to its higher sand content, is generally not considered an effective barrier to the downward migration of contaminants from grade. Underlain deposits, however, do act as effective barriers where till is present or where Glenwood or basal St. Peter shales are present (Appendix C).

As discussed in Section 6.1.2 the DNR geologic sensitivity rating is an empirical value determined by dividing the cumulative thickness of low permeability units (e.g. clay) above the aquifer by 10 (DNR, 1991). The L-score results ranged from 0 to 21. This indicates much of the DWSMA is underlain by low-permeable material creating hydraulic separation from grade.

For the DWSMA vulnerability assessment, and pursuant to MDH guidance (MDH, 1997), geologic sensitivity classifications of low to very low sensitivity would be automatically increased to a classification of moderate vulnerability due to the presence of tritium, which has been detected at all of the City Wells except Well No. 2 (Figure 11). However, the area around the City Wells has retained a vulnerability rating of low due to the presence of the Glenwood Formation, that can be seen on Figure C1 in Appendix C, that is known to be an effective barrier to downward migration in those areas.

7 COMPARISON OF AMENDED PART 1 TO ORIGINAL PART 1

The primary changes between the original Part 1 and this Amendment are a better understanding of the geology, an improved regional model providing better boundary conditions to the local model, and updated pumping rates from the original model rates.

The Amendment model incorporates updated pumping rates, as well as simulating the influence of the low vertical conductivity layer at the base of the Prairie du Chien Group that limits flow between it and the Jordan Sandstone. The current model uses a larger range for conductivities in the OPDC aquifer which results in the capture zones extending further upgradient than the previous model. The use of 5-year pumping volume calculated fixed radius (CFR) and a 5-year upgradient extension, as opposed to 10-year rates used in the previous model reduced the size of the fracture flow zone. In general, however, the previous and currently delineated DWSMAs are much the same.

8 RECOMMENDATIONS

The WHPA delineations for the City Wells were created using maximum pumping rates and conservative assumptions in the fracture flow delineation. These factors combine to 'build in' a safety factor, which is necessary when attempting to simulate natural systems and their inherent heterogeneity.

While the delineations are considered to be conservative and are based on the best available data, there is some information that could improve the quality of any future re-evaluations. The standard assessment monitoring package (Chloride + Bromide, Nitrate + nitrite N, Tritium) should be analyzed during year six for Well No. 1 (14005), Well No. 2 (222880), Well No. 3 (205733), and Well No. 4 (226566), contingent on funding assistance from MDH for sampling and analysis. The city may need to collect the samples and ship them to MDH. Information generated by this sampling will be used to refine vulnerability assessments for the next amendment

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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, part 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

CFR - Calculated Fixed Radius

DAP-ATP – Determination of Aquifer Properties - Aquifer Test Plan

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

MnDOT - Minnesota Department of Transportation

MnGEO - Minnesota Geospatial Information Office

MPARS – Minnesota DNR Permitting and Reporting System

MWI – Minnesota Well Index

MPCA - Minnesota Pollution Control Agency

NRCS - Natural Resource Conservation Service

SWCD - Soil and Water Conservation District

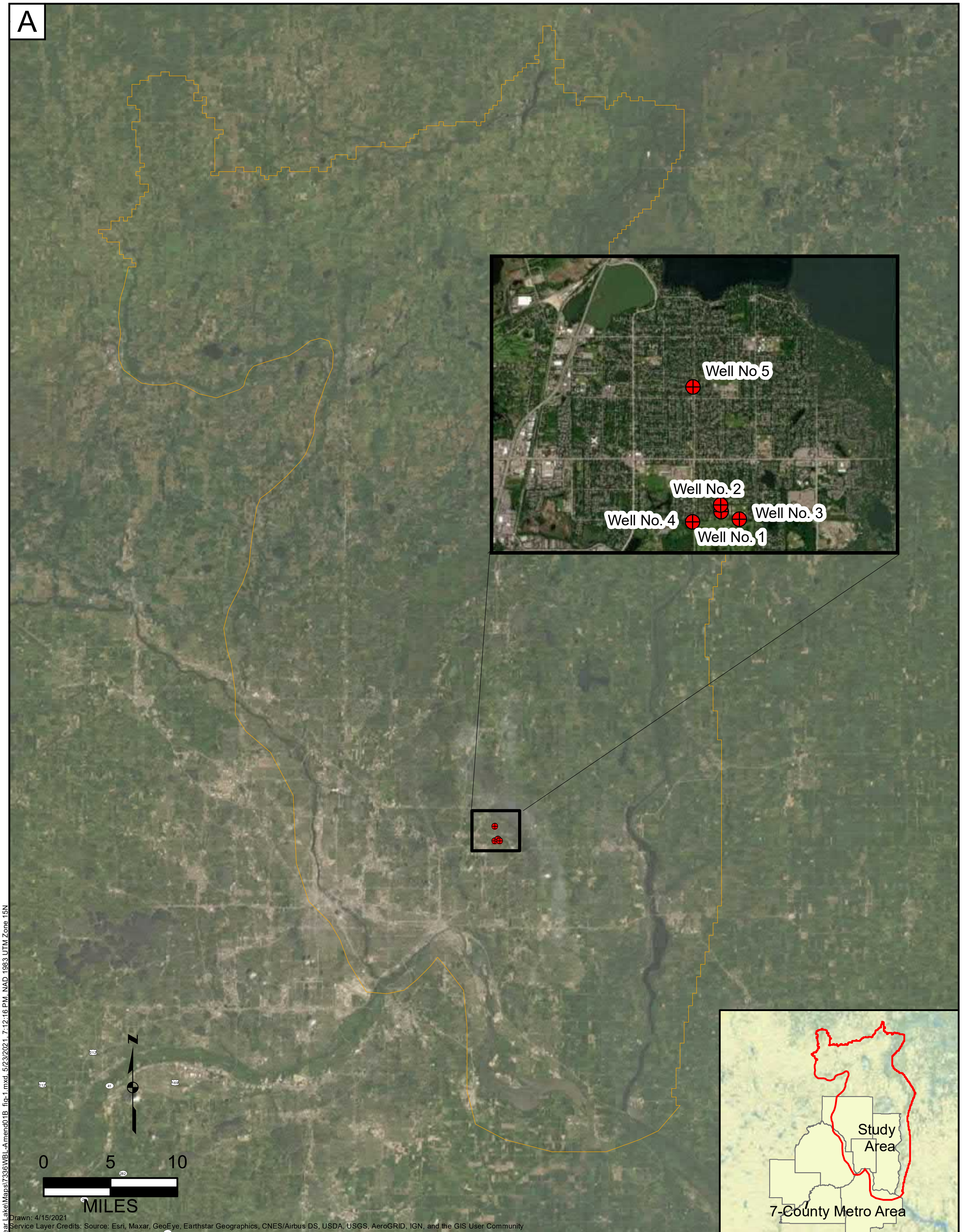
UGE - Upgradient Extensions

UMN - University of Minnesota

USDA - United States Department of Agriculture

USGS - United States Geological Survey

FIGURES



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WBL_City_Wells_pts

Local Model Boundary

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PART 1 WELLHEAD PROTECTION AMENDMENT
WHITE BEAR LAKE, MINNESOTA

PREPARED FOR

City of White Bear Lake, Minnesota

FIGURE 1

SITE LOCATION AND MODEL BOUNDARY

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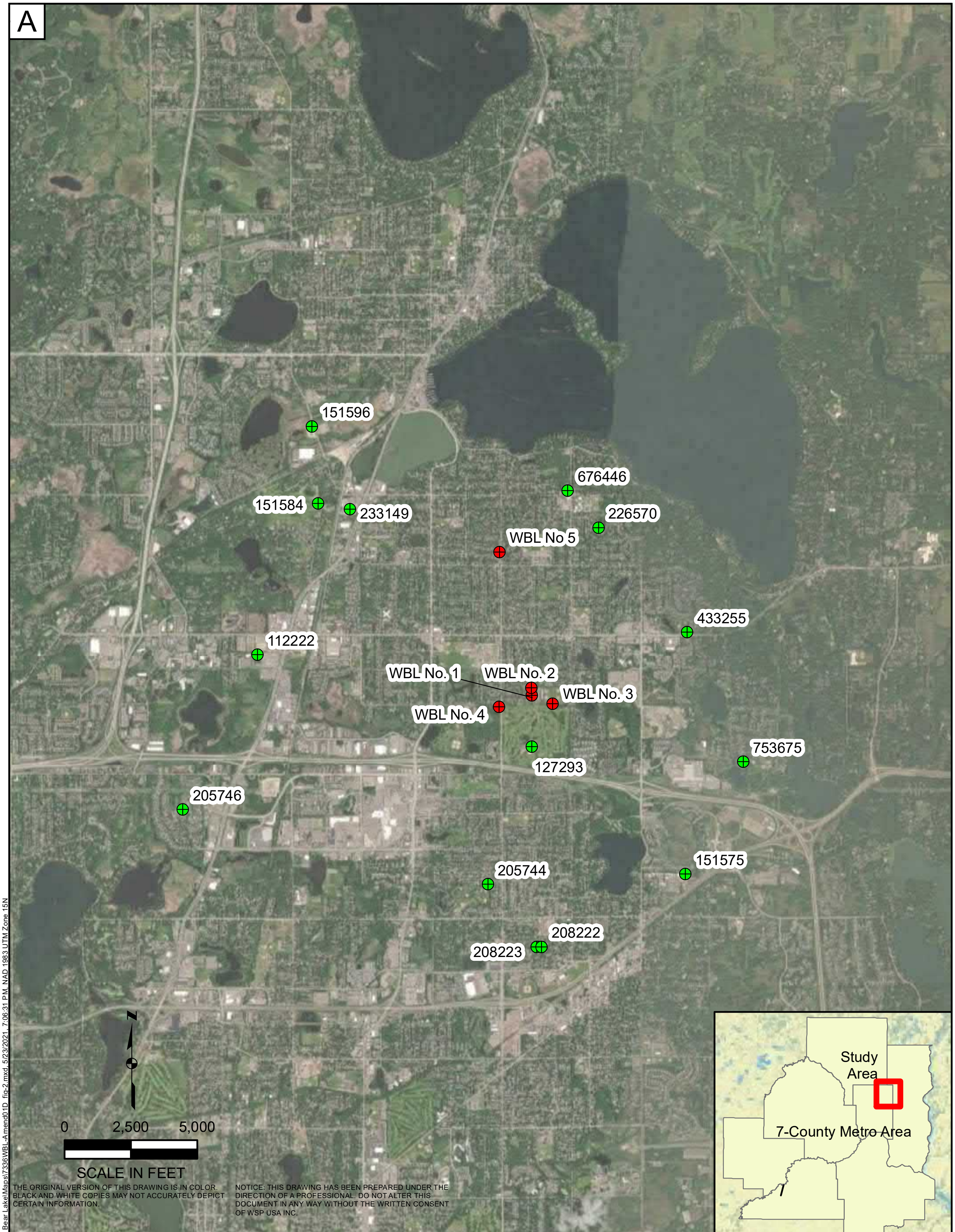

High Capacity Wells (Unique ID Num)

City Wells

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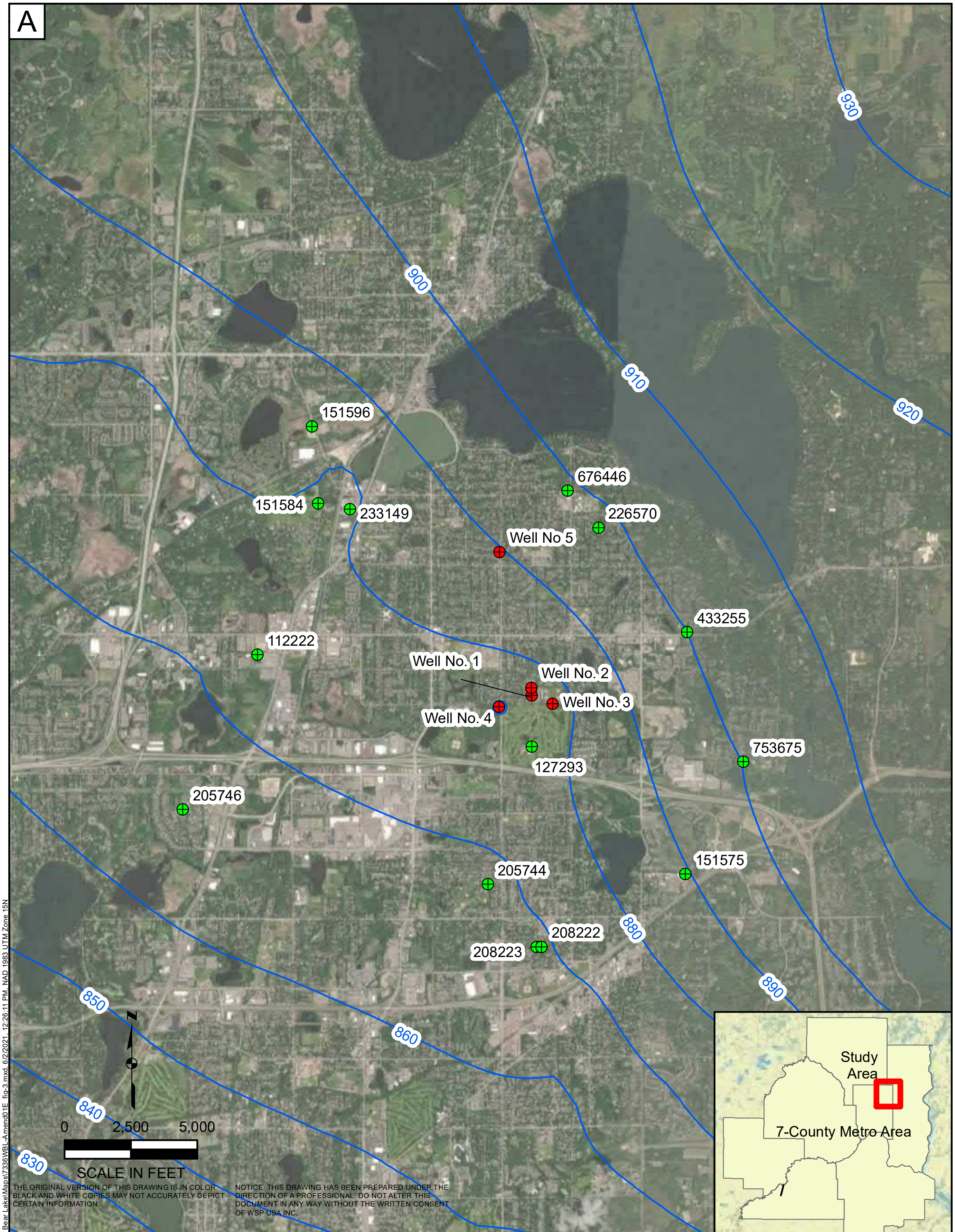
FIGURE 2

LOCATION OF CITY AND SURROUNDING HIGH CAPACITY WELLS MODIFIED IN THE GROUNDWATER FLOW MODEL

WSP Office: Minneapolis, MN | Source: G:\GIS\White Bear Lake\Maps\7336WBL-Amend01D_fig-2.mxd, 5/23/2021, 7:06:31 PM, NAD 1983 UTM Zone 15N



City Wells

Jordan Aquifer Head (ft-amsl)

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FIGURE 3

SIMULATED JORDAN GROUNDWATER EQUIPOTENTIAL CONTOURS

WSP Office: Minneapolis, MN | Source: G:\GIS\White Bear Lake\Maps\7336WBL-Amend01E_fig-3.mxd, 6/2/2021 12:26:11 PM, NAD 1983 UTM Zone 15N

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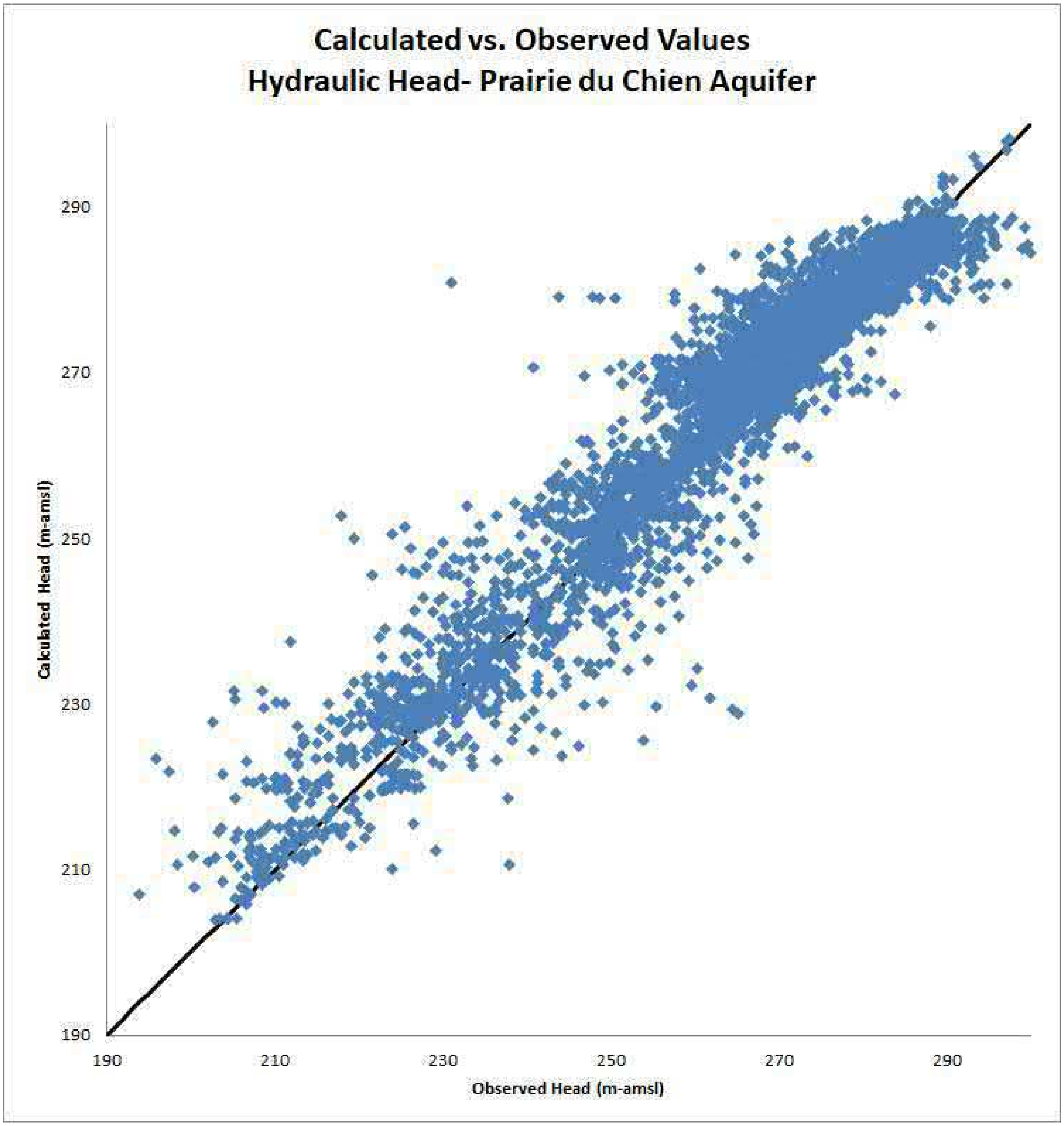

MEAN RESIDUAL = -2.06 m
MEAN ABSOLUTE RESIDUAL = 3.75 m
ROOT MEAN SQUARED ERROR = 5.22 m
NORMALIZED RMS = 4.8%

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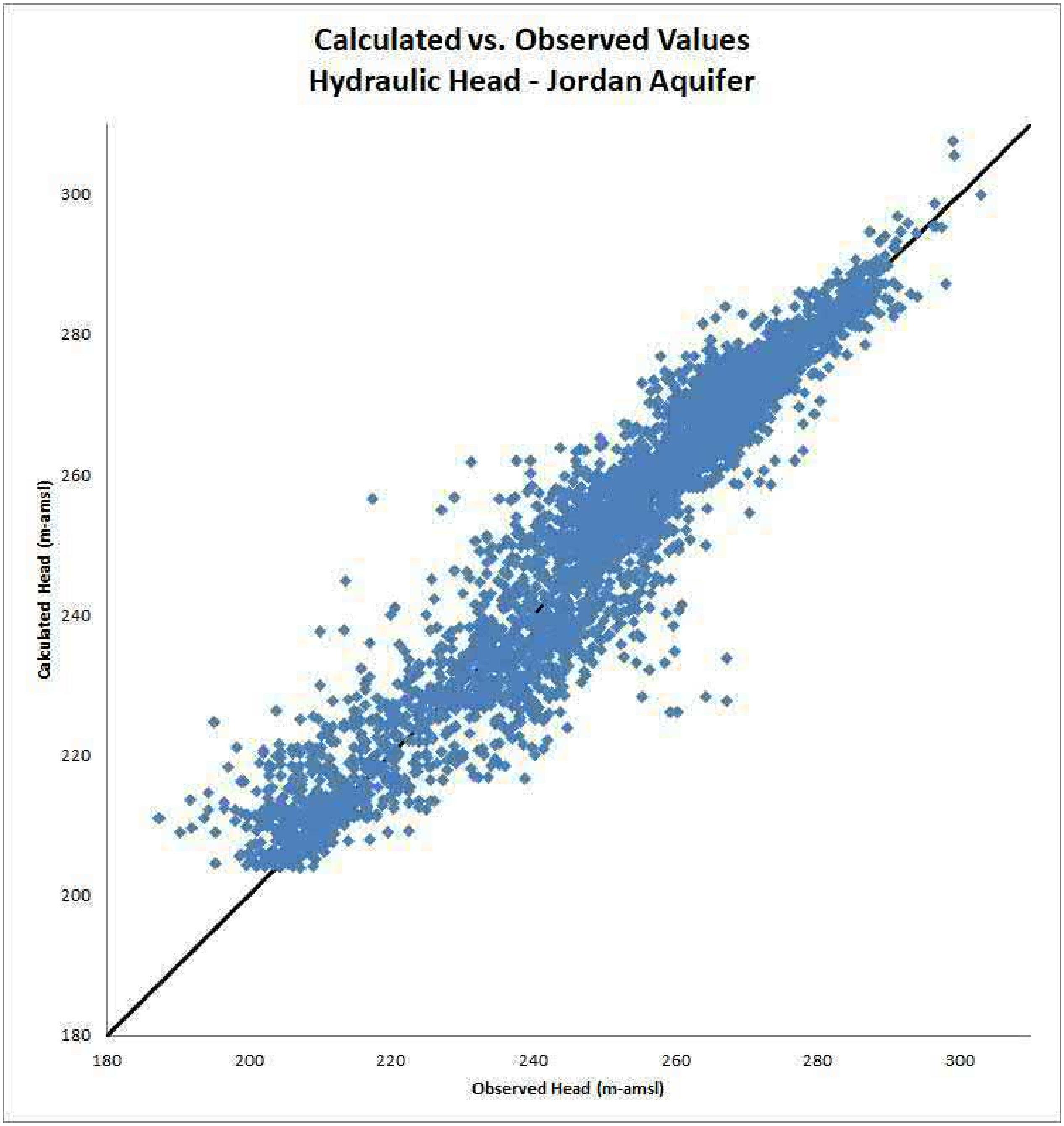
FIGURE 4

STEADY-STATE MODEL CALIBRATION DATA AND MODEL STATISTICS - OPDC

A



MEAN RESIDUAL = -1.69 m
MEAN ABSOLUTE RESIDUAL = 4.23 m
ROOT MEAN SQUARED ERROR = 5.87 m
NORMALIZED RMS = 5.1%

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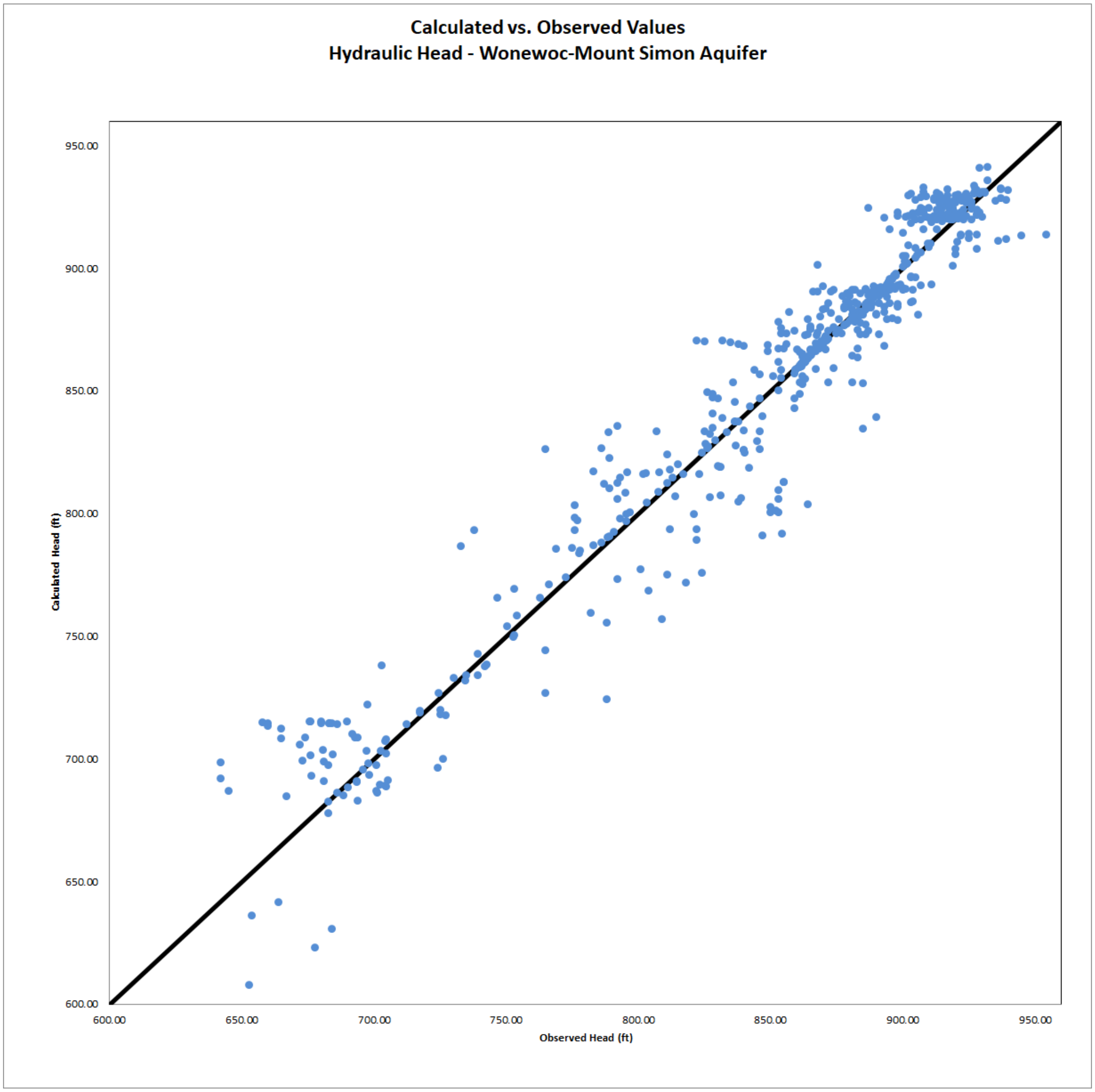
FIGURE 5

STEADY-STATE MODEL CALIBRATION DATA AND MODEL STATISTICS - CJDN

A



MEAN RESIDUAL = -1.53 ft
MEAN ABSOLUTE RESIDUAL = 10.73 ft
ROOT MEAN SQUARED ERROR = 17.41 ft
NORMALIZED RMS = 4.75%

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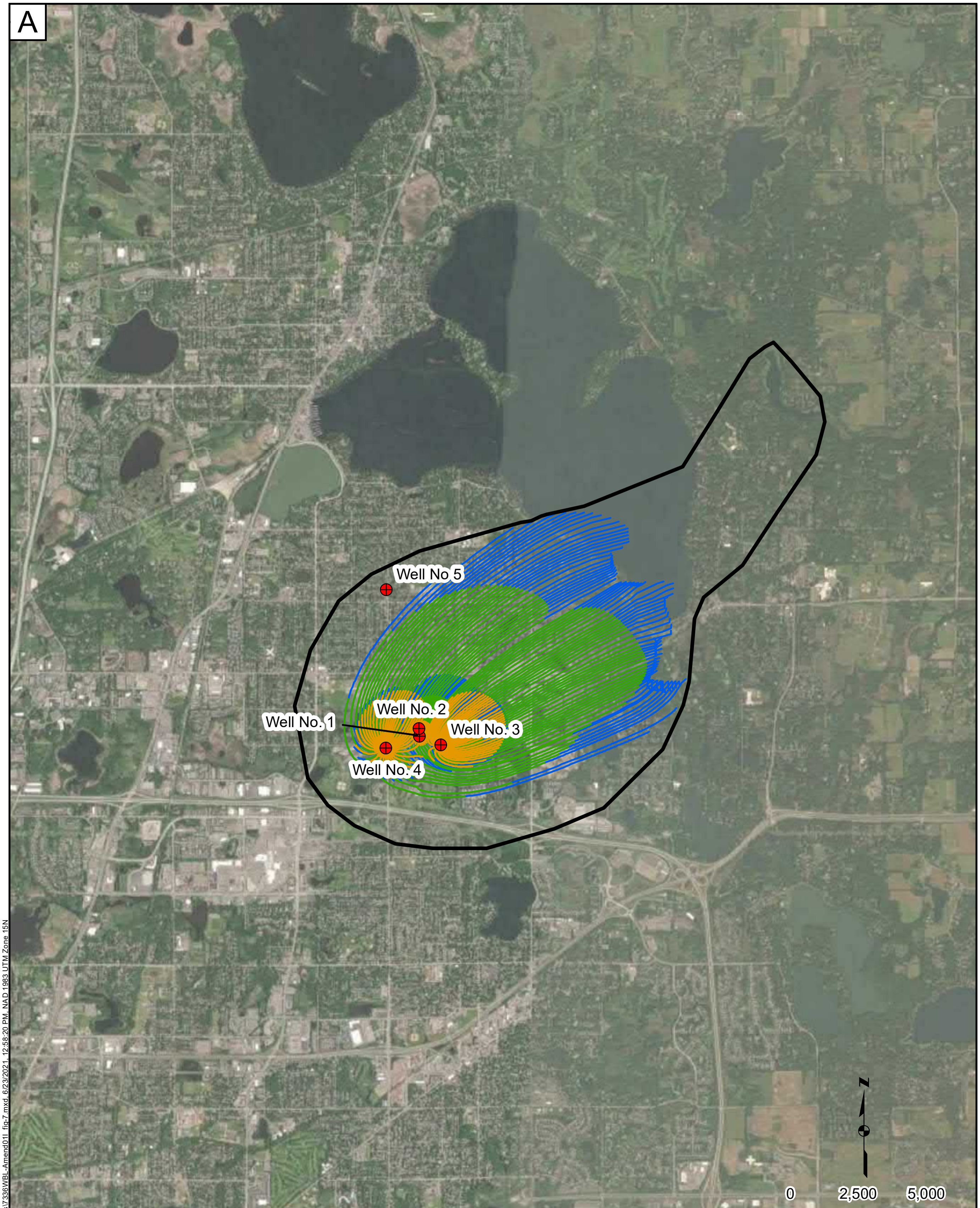
FIGURE 6

STEADY-STATE MODEL CALIBRATION DATA AND MODEL STATISTICS - CWMS



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1-Year Pathlines
5-Year Pathlines
10-Year Pathlines
Composite 10-Year Capture Zone
City Wells

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FIGURE 7

1-, 5-, AND 10-YEAR FLOWPATHS AND 10-YEAR COMPOSITE CAPTURE ZONE (POROUS FLOW)

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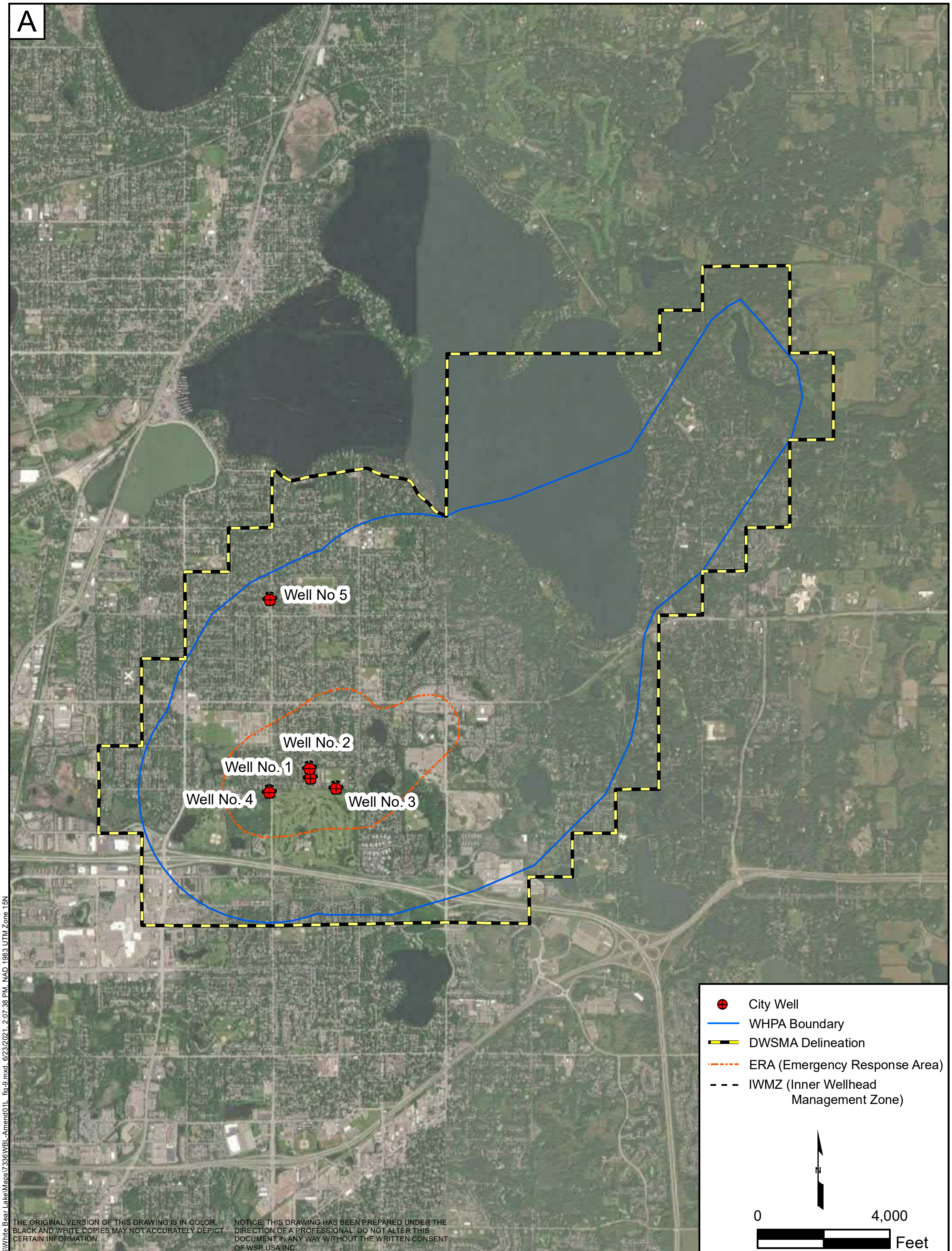
FIGURE 8

FRACTURE FLOW DELINEATION BOUNDARIES



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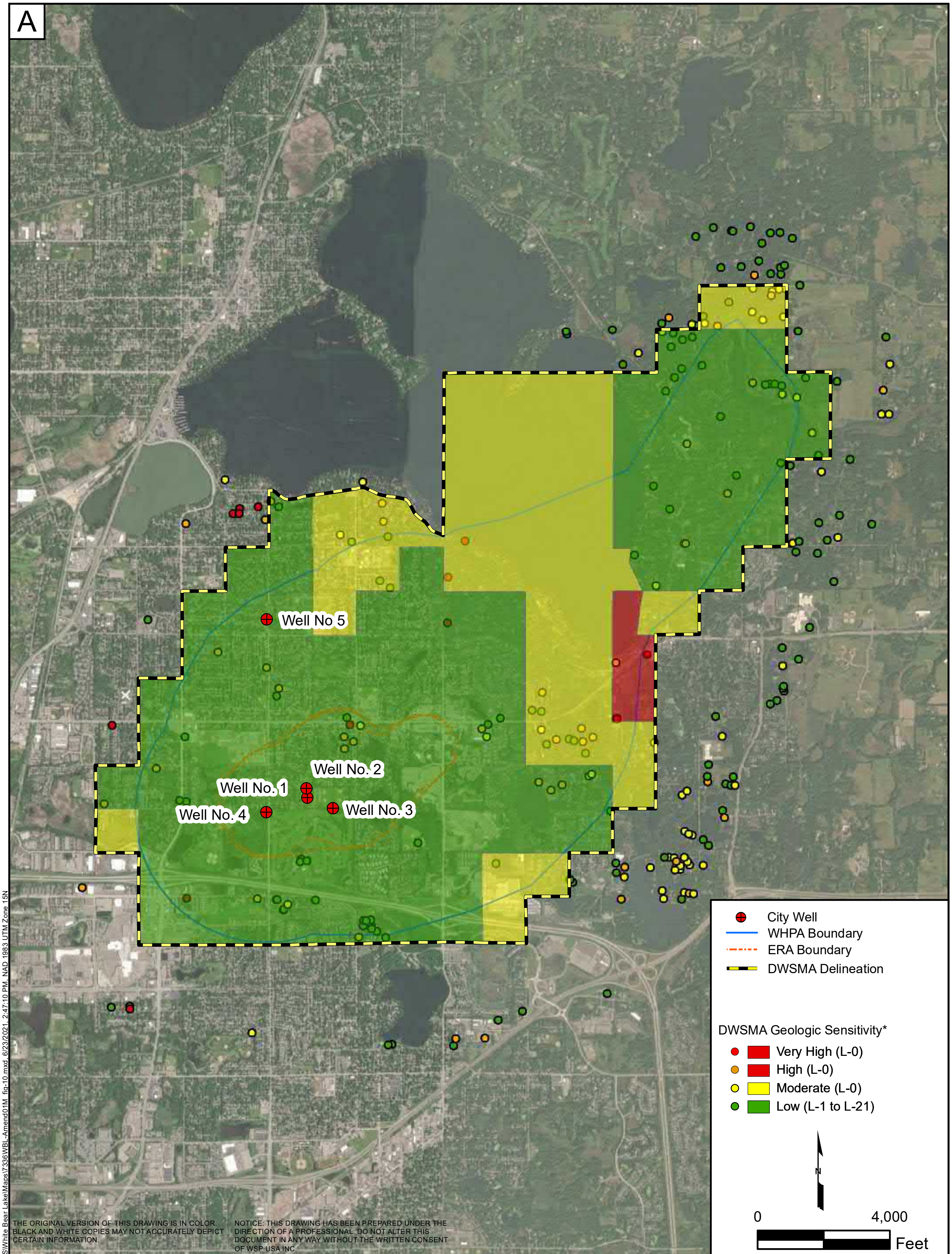
PART 1 WELLHEAD PROTECTION AMENDMENT
WHITE BEAR LAKE, MINNESOTA

PREPARED FOR

City of White Bear Lake

FIGURE 9

COMBINED WELLHEAD PROTECTION AREA BOUNDARIES AND DRINKING WATER SUPPLY MANAGEMENT AREA BOUNDARY



Source: Centerville, Hugo, White Bear Lake East and White Bear Lake West 7.5-Minute USGS Quadrangles, and Ramsey and Washington County Pollution Sensitivity maps (County Atlas Series).
*: DWSMA geologic sensitivity (L-scores) as determined by MDH using MN CWI data.

Drawn: 6/23/2021
Service Layer Credits: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

WSP Office: Minneapolis, MN | Source: G:\GIS\White Bear Lake\Maps\7336WBL-Amend01M_fig-10.mxd, 6/23/2021 2:47:10 PM, NAD 1983 UTM Zone 15N

WSP USA Inc.
520 NICOLLET MALL
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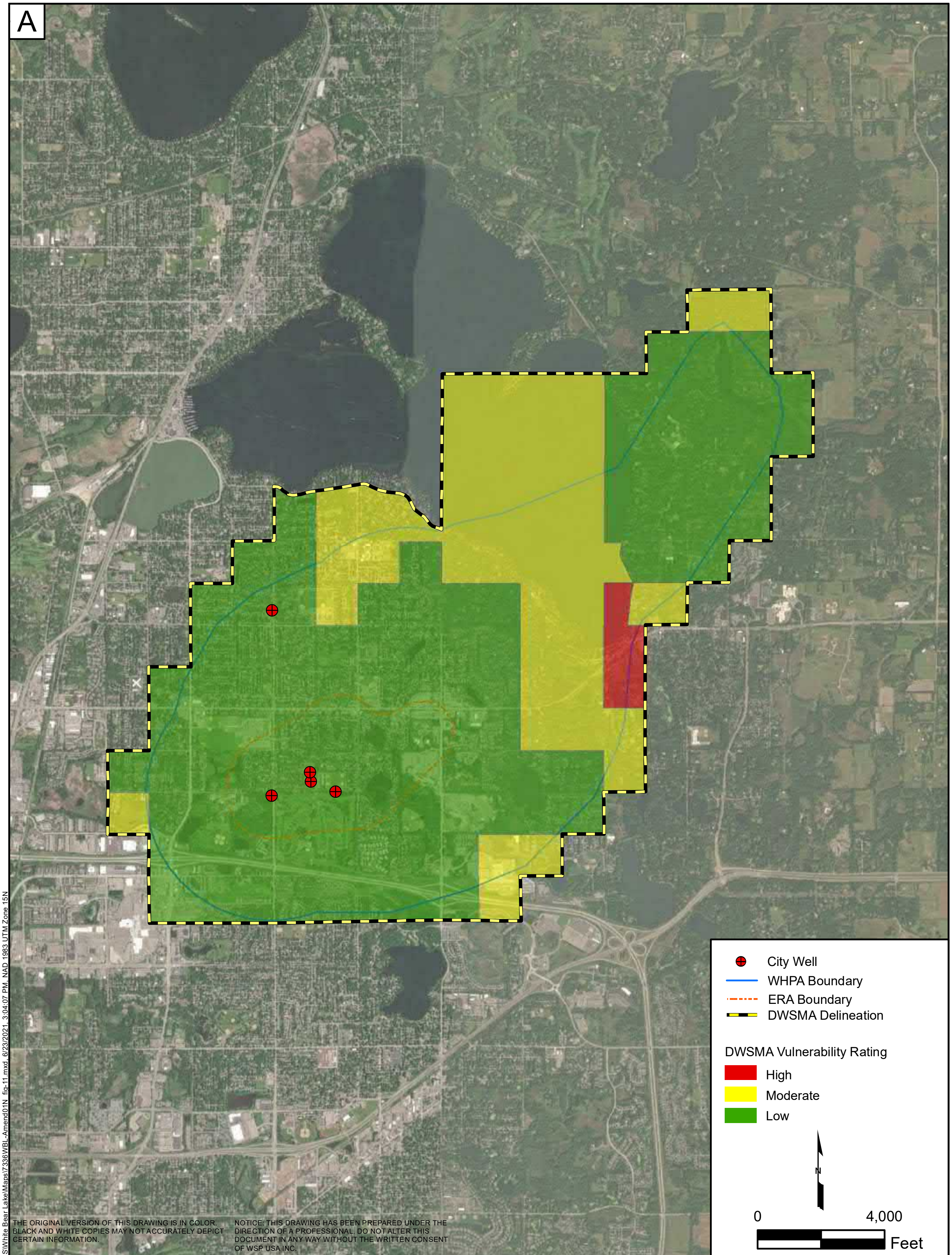
PART 1 WELLHEAD PROTECTION AMENDMENT
WHITE BEAR LAKE, MINNESOTA

PREPARED FOR

City of White Bear Lake

FIGURE 10

DRINKING WATER SUPPLY MANAGEMENT AREA GEOLOGIC SENSITIVITY ASSESSMENT



Drawn: 6/23/2021
Service Layer Credits: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

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PART 1 WELLHEAD PROTECTION AMENDMENT
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FIGURE 11

DRINKING WATER SUPPLY MANAGEMENT AREA VULNERABILITY ASSESSMENT

WSP Office: Minneapolis, MN | Source: G:\GIS\White Bear Lake\Maps\7336WBL-Amend01N_fig-11.mxd, 6/23/2021, 3:04:07 PM, NAD 1983 UTM Zone 15N

APPENDIX

A

FRACTURE FLOW DELINEATION INFORMATION

Unique Well# =
Well No. 4
X = 499,567.000, Y = 4,987,709.000

5 Year Pumping Volume (1825 days)				
Pumping Volume (Q):	3,653.00 m3/day	129,004.48 cu.ft./day	670.153 gal./min.	965,020.50 gal./day
Water Producing Zone Thickness (L):	38.4 m	125.984 ft.		
Effective Porosity (n):	0.05			
Original (CFR) Radius:	1,051.31 m	3,449.18 ft.		
New Radius:	1,203.99 m	3,950.10 ft.		
New Pumping Volume (Q): *	4,791.09 m3/day	169,195.61 cu.ft./day	878.938 gal./min.	1,265,671.06 gal./day

Unique Well# =
Well No. 3
X = 500,180.000, Y = 4,987,745.000

5 Year Pumping Volume (1825 days)				
Pumping Volume (Q):	3,294.00 m3/day	116,326.51 cu.ft./day	604.294 gal./min.	870,182.74 gal./day
Water Producing Zone Thickness (L):	38.4 m	125.984 ft.		
Effective Porosity (n):	0.05			
Original (CFR) Radius:	998.315 m	3,275.31 ft.		
New Radius:	1,143.30 m	3,750.98 ft.		
New Pumping Volume (Q): *	4,320.24 m3/day	152,567.84 cu.ft./day	792.56 gal./min.	1,141,286.74 gal./day

OVERLAP SUMMARY INFORMATION

Original (CFR) Area for Well# :	3,472,252.60 m2	37,374,979.81 sq.ft.
New (CFR) Area for Well# :	4,554,027.22 m2	49,019,093.54 sq.ft.
Original (CFR) Area for Well# :	3,131,015.63 m2	33,701,939.09 sq.ft.
New (CFR) Area for Well# :	4,106,478.41 m2	44,201,723.00 sq.ft.
Overlap Area to Well# :	1,081,774.61 m2	11,644,113.73 sq.ft.
Overlap Area to Well# :	975,462.79 m2	10,499,783.91 sq.ft.
Total Overlap Area:	2,057,237.40 m2	22,143,897.65 sq.ft.

* = New Pumping Volumes (Q) if needed for additional
overlap computations with another well.

UP-GRADIENT EXTENSION (UGE)
(area beyond the New Areas of both Wells)
(area beyond the New Areas of both Wells)
Bearing from Well# = 54° from North +/- 10°.
Bearing from Well# = 54° from North +/- 10°.

Up-Gradient Extension Area:	3,408,190.13 m2	36,685,417.74 sq.ft.
Up-Gradient Intersection Area:	2,598,929.40 m2	27,974,616.12 sq.ft.

Unique Well# =
Well No. 4
X = 499,567.000, Y = 4,987,709.000

6 Month Pumping Volume (182 days)

Pumping Volume (Q):	3,653.00 m3/day	129,004.48 cu.ft./day	670.153 gal./min.	965,020.50 gal./day
Water Producing Zone Thickness (L)	38.4 m	125.984 ft.		
Effective Porosity (n):	0.05			
Original (CFR) Radius:	331.998 m	1,089.23 ft.		
New Radius:	333.143 m	1,092.99 ft.		
New Pumping Volume (Q): *	3,678.25 m3/day	129,896.25 cu.ft./day	674.786 gal./min.	971,691.43 gal./day

Unique Well# =
Well No. 3
X = 500,180.000, Y = 4,987,745.000

6 Month Pumping Volume (182 days)

Pumping Volume (Q):	3,294.00 m3/day	116,326.51 cu.ft./day	604.294 gal./min.	870,182.74 gal./day
Water Producing Zone Thickness (L)	38.4 m	125.984 ft.		
Effective Porosity (n):	0.05			
Original (CFR) Radius:	315.262 m	1,034.33 ft.		
New Radius:	316.35 m	1,037.89 ft.		
New Pumping Volume (Q): *	3,316.77 m3/day	117,130.65 cu.ft./day	608.471 gal./min.	876,198.08 gal./day

OVERLAP SUMMARY INFORMATION

Original (CFR) Area for Well# :	346,273.96 m2	3,727,258.26 sq.ft.
New (CFR) Area for Well# :	348,667.66 m2	3,753,023.80 sq.ft.
Original (CFR) Area for Well# :	312,243.75 m2	3,360,960.50 sq.ft.
New (CFR) Area for Well# :	314,402.21 m2	3,384,193.92 sq.ft.
Overlap Area to Well# :	2,393.70 m2	25,765.54 sq.ft.
Overlap Area to Well# :	2,158.46 m2	23,233.42 sq.ft.
Total Overlap Area:	4,552.16 m2	48,998.96 sq.ft.

* = New Pumping Volumes (Q) if needed for additional
overlap computations with another well.

UP-GRADIENT EXTENSION (UGE)
(area beyond the New Areas of both Wells)
(area beyond the New Areas of both Wells)
Bearing from Well# = 54° from North +/- 10°.
Bearing from Well# = 54° from North +/- 10°.

Up-Gradient Extension Area:	644,424.34 m2	6,936,519.18 sq.ft.
Up-Gradient Intersection Area:	4,444.68 m2	47,842.08 sq.ft.

APPENDIX

B

CITY WELL VULNERABILITY WORKSHEETS

MINNESOTA DEPARTMENT OF HEALTH
SECTION OF DRINKING WATER PROTECTION
SWP Vulnerability Rating

625 Robert St. N. St. Paul MN 55155
P.O. Box 64975 St. Paul MN 55164 - 0975

PWSID: 1620024 — TIER: 2
SYSTEM NAME: White Bear Lake — WHP RANK:
WELL NAME: Well #1 — UNIQUE WELL #: 00014005

COUNTY: Ramsey — TOWNSHIP NUMBER: 30 — RANGE: 22 W — SECTION: 36 — QUARTERS: BCDA

CRITERIA		DESCRIPTION	POINTS
Aquifer Name(s)	:	Jordan	
DNR Geologic Sensitivity Rating	:	Low	20
L Score	:	0	
Geologic Data From	:	Well Record	
Year Constructed	:	1959	
Construction Method	:	Cable Tool/Bored	0
Casing Depth	:	390	5
Well Depth	:	490	
Casing grouted into borehole?		Unknown	0
Cement grout between casings?		Yes	0
All casings extend to land surface?		Yes	0
Gravel - packed casings?		No	0
Wood or masonry casing?		No	0
Holes or cracks in casing?		Unknown	0
Isolation distance violations?			0
Pumping Rate	:	1100	20
Pathogen Detected?			0
Surface Water Characteristics?			0
Maximum nitrate detected	:	<.4	0
Maximum tritium detected	:	7.87 04/06/2015	VULNERABLE
Non-THMS VOCs detected?			0
Pesticides detected?			0
Carbon 14 age	:	Unknown	0
Wellhead Protection Score	:		45
Wellhead Protection Vulnerability Rating	:		VULNERABLE
Vulnerability Overridden	:		

COMMENTS

Very low rating was determined by the presence of the Glenwood and basal St. Peter shale beds, Previous tritium result 14.2 TU on 07/29/1991.

MINNESOTA DEPARTMENT OF HEALTH
SECTION OF DRINKING WATER PROTECTION
SWP Vulnerability Rating

625 Robert St. N. St. Paul MN 55155
P.O. Box 64975 St. Paul MN 55164 - 0975

PWSID: 1620024 | TIER: 2
SYSTEM NAME: White Bear Lake | WHP RANK:
WELL NAME: Well #2 | UNIQUE WELL #: 00222880

COUNTY: Ramsey | TOWNSHIP NUMBER: 30 | RANGE: 22 W | SECTION: 36 | QUARTERS: BCDA

CRITERIA		DESCRIPTION	POINTS
Aquifer Name(s)	:	Wonewoc-Mt.Simon	
DNR Geologic Sensitivity Rating	:	Very low	0
L Score	:	0	
Geologic Data From	:	Well Record	
Year Constructed	:	1962	
Construction Method	:	Cable Tool/Bored	0
Casing Depth	:	700	0
Well Depth	:	970	
Casing grouted into borehole?		Unknown	0
Cement grout between casings?		Yes	0
All casings extend to land surface?		Yes	0
Gravel - packed casings?		No	0
Wood or masonry casing?		No	0
Holes or cracks in casing?		Unknown	0
Isolation distance violations?			0
Pumping Rate	:	1650	20
Pathogen Detected?			0
Surface Water Characteristics?			0
Maximum nitrate detected	:	<.4	0
Maximum tritium detected	:	Unknown	0
Non-THMS VOCs detected?			0
Pesticides detected?			0
Carbon 14 age	:	A	-20
Wellhead Protection Score	:		0
Wellhead Protection Vulnerability Rating	:		NOT VULNERABLE
Vulnerability Overridden	:		

COMMENTS

Very low rating was determined by the presence of the Glenwood, basal St. Peter shale beds, and the St. Lawrence confining layers.

625 Robert St. N. St. Paul MN 55155
P.O. Box 64975 St. Paul MN 55164 - 0975

MINNESOTA DEPARTMENT OF HEALTH
SECTION OF DRINKING WATER PROTECTION
SWP Vulnerability Rating

PWSID: 1620024
SYSTEM NAME: White Bear Lake
WELL NAME: Well #3

TIER: 2
WHP RANK:
UNIQUE WELL #: 00205733

COUNTY: Ramsey | TOWNSHIP NUMBER: 30 | RANGE: 22 W | SECTION: 36 | QUARTERS: BDCD

CRITERIA		DESCRIPTION	POINTS
Aquifer Name(s)	:	Prairie Du Chien-Jordan	
DNR Geologic Sensitivity Rating	:	Low	20
L Score	:	2	
Geologic Data From	:	Well Record	
Year Constructed	:	1966	
Construction Method	:	Cable Tool/Bored	0
Casing Depth	:	289	5
Well Depth	:	513	
Casing grouted into borehole?		Unknown	0
Cement grout between casings?		Yes	0
All casings extend to land surface?		Yes	0
Gravel - packed casings?		No	0
Wood or masonry casing?		No	0
Holes or cracks in casing?		Unknown	0
Isolation distance violations?			0
Pumping Rate	:	2400	20
Pathogen Detected?			0
Surface Water Characteristics?			0
Maximum nitrate detected	:	.4 08/05/2014	0
Maximum tritium detected	:	7.5 02/19/2013	VULNERABLE
Non-THMS VOCs detected?			0
Pesticides detected?			0
Carbon 14 age	:	Unknown	0
Wellhead Protection Score	:		45
Wellhead Protection Vulnerability Rating	:		VULNERABLE
Vulnerability Overridden	:		

COMMENTS

vulnerable based on tritium result from well 014005.

625 Robert St. N. St. Paul MN 55155
P.O. Box 64975 St. Paul MN 55164 - 0975

MINNESOTA DEPARTMENT OF HEALTH
SECTION OF DRINKING WATER PROTECTION
SWP Vulnerability Rating

PWSID: 1620024 TIER: 2
SYSTEM NAME: White Bear Lake WHP RANK:
WELL NAME: Well #4 UNIQUE WELL #: 00226566

COUNTY: Ramsey TOWNSHIP NUMBER: 30 RANGE: 22 W SECTION: 35 QUARTERS: ADDD

CRITERIA		DESCRIPTION	POINTS
Aquifer Name(s)	:	Prairie Du Chien-Jordan	
DNR Geologic Sensitivity Rating	:	Low	20
L Score	:	0	
Geologic Data From	:	Well Record	
Year Constructed	:	1969	
Construction Method	:	Cable Tool/Bored	0
Casing Depth	:	267	5
Well Depth	:	476	
Casing grouted into borehole?		Unknown	0
Cement grout between casings?		Unknown	5
All casings extend to land surface?		Yes	0
Gravel - packed casings?		No	0
Wood or masonry casing?		No	0
Holes or cracks in casing?		Unknown	0
Isolation distance violations?			0
Pumping Rate	:	2400	20
Pathogen Detected?			0
Surface Water Characteristics?			0
Maximum nitrate detected	:	.17 08/05/2014	0
Maximum tritium detected	:	7.32 03/24/2014	VULNERABLE
Non-THMS VOCs detected?			0
Pesticides detected?			0
Carbon 14 age	:	Unknown	0
Wellhead Protection Score	:		50
Wellhead Protection Vulnerability Rating	:		VULNERABLE
Vulnerability Overridden	:		

COMMENTS

Low rating was determined by the presence of the Glenwood andl basal St. Peter shale layers
VULNERABLE BASED ON TRITIUM RESULT FROM WELL 014005.

APPENDIX

C GEOLOGIC CROSS-SECTIONS

Figure C1

Figure Bedrock Geology

City of White Bear Lake
Phase I Wellhead Protection Plan

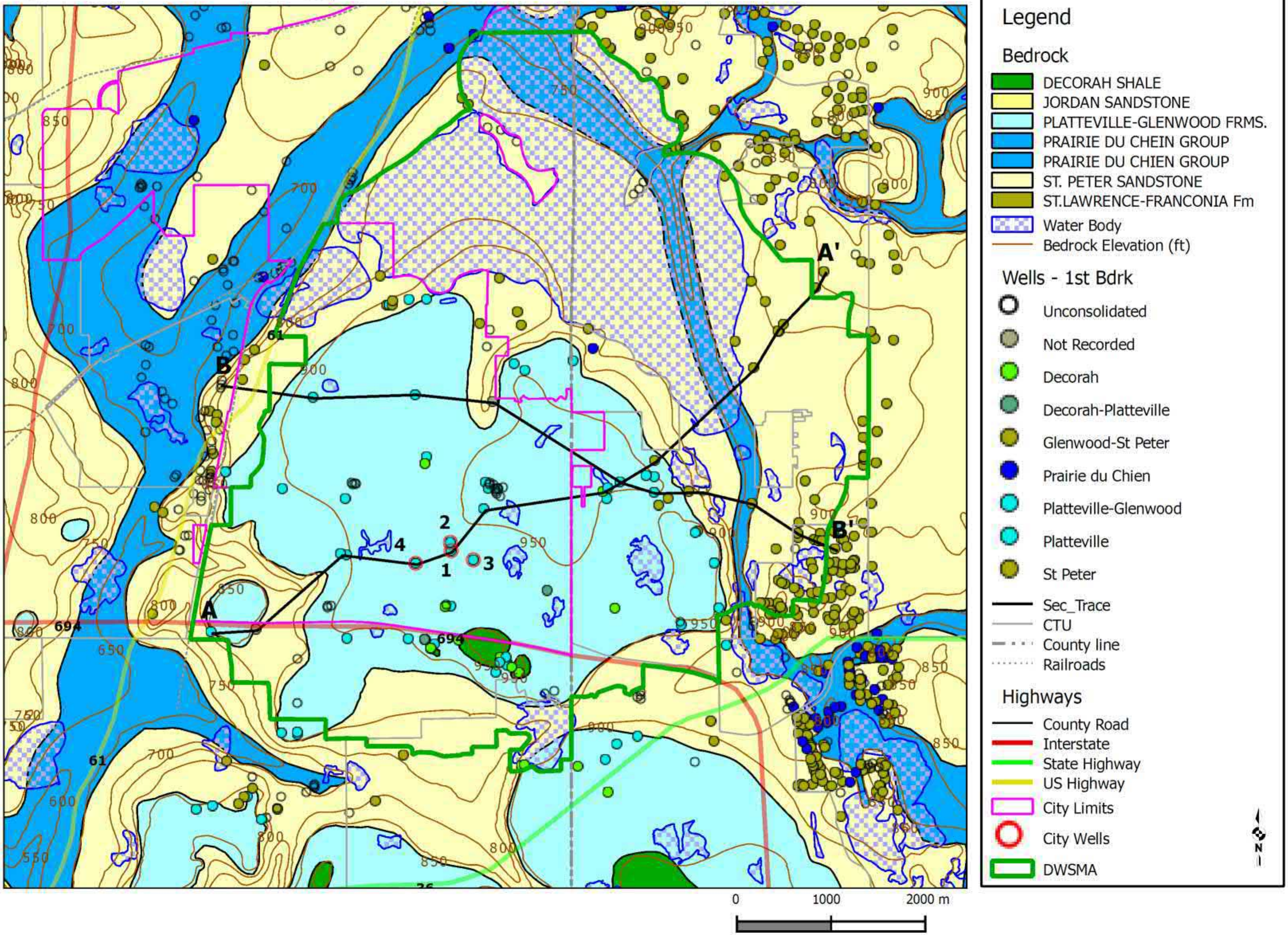

Figure C2 - Geologic Cross Section A – A' (a) stratigraphic codes and (b) cross section (*on next page*)

(a)

<u>Surficial Geology</u>

Qno	New Ulm Formation outwash
Qna	New Ulm Formation sandy till
Qnd	Twin Cities Member of New Ulm Formation (diamicton of mixed provenance)
Qcl	Cromwell Formation lake sand and clay
Qco	Cromwell Formation ouwash
Qcs	Cromwell Formation complex of sand and gravel and till
Qct	Cromwell Formation till

<u>Well Log Stratigraphic Units</u>

The four letter codes applied in CWI are used.

The first letter indicates the geological period: Q – Quaternary, O – Ordovician, and C – Cambrian.

Quaternary Deposits

The second letter indicates lithology:

C	Clay
F	Sand
G	Gravel
L	Sandy clay
P	Pebbly clay or pebbly, sandy clay
T	Till (diamicton)
U	Unknown / not recorded

The third letter isn't used, and the fourth letter indicates color

B	Brown
G	Gray
R	Red
Y	Yellow

Bedrock

PVL	Platteville Formation
GWD	Glenwood Formation
STP	St. Peter Sandstone
PDC	Prairie du Chien Group
JDN	Jordan Sandstone
STL	St. Lawrence Formation

City of White Bear Lake

Phase I Wellhead Protection Plan

Figure C2 - Cross Section A - A'

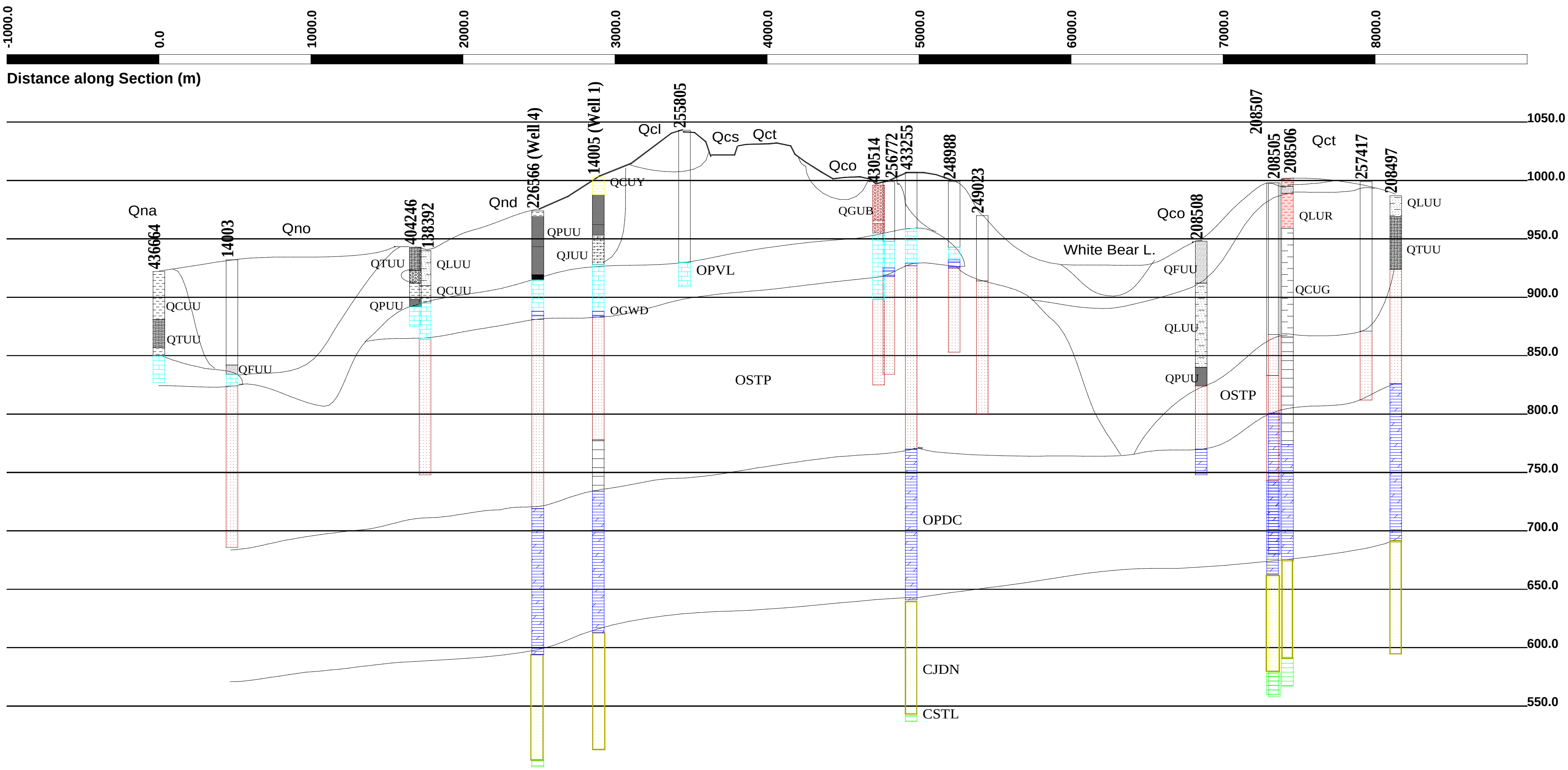

Figure C3 - Geologic Cross Section B – B' (a) stratigraphic codes and (b) cross section (*on next page*)
(a)

Surficial Geology

Qno	New Ulm Formation outwash
Qnd	Twin Cities Member of New Ulm Formation (diamicton of mixed provenance)
Qco	Cromwell Formation ouwash
Qct	Cromwell Formation till

Well Log Lithologic Units

The four letter codes applied in CWI are used.

The first letter indicates the geological period: Q – Quaternary, O – Ordovician, and C – Cambrian.

Quaternary Deposits

The second letter indicates lithology:

C	Clay
F	Sand
G	Gravel
H	Sand, gravel, and larger
L	Sandy clay
P	Pebbly clay or pebbly, sandy clay
U	Unknown / not recorded

The third letter isn't used, and the fourth letter indicates color

B	Brown
G	Gray
R	Red
Y	Yellow

Bedrock

PVL	Platteville Formation
GWD	Glenwood Formation
STP	St. Peter Sandstone
PDC	Prairie du Chien Group
JDN	Jordan Sandstone
STL	St. Lawrence Formation

City of White Bear Lake
Phase I Wellhead Protection Plan
Figure C3 - Cross Section B - B'