Amendment to the 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

The City of Brainerd

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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.

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

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.

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).

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

MnDOT - Minnesota Department of Transportation

MnGEO - Minnesota Geospatial Information Office

MPCA - Minnesota Pollution Control Agency

SWCD - Soil and Water Conservation District

USDA - United States Department of Agriculture

NRCS - Natural Resource Conservation Service

UMN - University of Minnesota

USGS - United States Geological Survey

1. Introduction

The Minnesota Department of Health (MDH) amended Part I of the wellhead protection (WHP) plan at the request of the city of Brainerd (public water supply identification number 1180002). The work was performed in accordance with the Minnesota Wellhead Protection Rule, parts 4720.5100 to 4720.5590.

This report presents the delineation of the wellhead protection area (WHPA), the 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 1-year time of travel. Definitions of rule-specific terms that are used are provided in the "Glossary of Terms."

This report also documents the technical information that was required to prepare this portion of the WHP plan in accordance with the Minnesota Wellhead Protection Rule. Additional technical information is available from the MDH.

The wells included in the WHP plan are listed in Table 2.

2. Assessment of the Data Elements

MDH staff met with representatives of the public water supplier on July 22, 2010, for a scoping meeting that identified the data elements required to amend Part I of the WHP plan. Table 1 presents the assessment of these data elements relative to the present and future implications of planning items that are specified in Minnesota Rules, part 4720.5210.

Table 1 - 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	M	M	M	M	MN Climatology Office
Geology					
Maps and geologic descriptions	H	H	H	H	MGS, DNR, USGS,
Subsurface data	H	H	H	H	MGS, MDH, MPCA, DNR,
Borehole geophysics	M	H	H	H	
Surface geophysics	H	H	H	H	
Maps and soil descriptions	M	M	L	M	NRCS
Eroding lands					
Water Resources					
Watershed units	L	M	M	M	DNR, USGS
List of public waters	M	M	M	M	DNR
Shoreland classifications					
Wetlands map	M	H	M	M	DNR
Floodplain map					

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	
Land Use					
Parcel boundaries map	L	H	L	L	City, Crow Wing county
Political boundaries map	L	H	L	L	MnGEO, City
PLS 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	H	L	NA	MnGEO
Storm/sanitary sewers and PWS system map	M	M	M	NA	City
Oil and gas pipelines map					
Public drainage systems map or list	H	H	H	H	City, SWCD
Records of well construction, maintenance, and use	H	H	H	H	City, CWI, MDH files
Surface Water Quantity					
Stream flow data	L	H	M	L	DNR, USGS
Ordinary high water mark data	L	H	L	L	DNR, USGS
Permitted withdrawals	L	L	L	L	DNR
Protected levels/flows	L	L	L	L	DNR
Water use conflicts	L	L	L	L	DNR
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, MDH, City
Surface Water Quality					
Stream and lake water quality management classification					
Monitoring data summary	L	L	L	L	MPCA, MDH
Groundwater Quality					
Monitoring data	H	H	H	H	MPCA, MDH
Isotopic data	M	M	M	M	MDH
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	L	L	L	L	MPCA, MDA

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

3. General Descriptions

3.1 Description of the Water Supply System

The public water supply obtains its drinking water supply from six primary wells; Table 2 summarizes information regarding them.

Table 2 - 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	Well Vulnerability
3	232347	P	16	73	125	1939	Sand & Gravel	Vulnerable
4	232348	P	16	73	123	1944	Sand & Gravel	Vulnerable
5	232349	P	16	105	145	1947	Sand & Gravel	Vulnerable
6	232350	P	16	107	156	1947	Sand & Gravel	Vulnerable
7	232352	P	20	88	157	1955	Sand & Gravel	Vulnerable
8	403973	P	16	144	187	1984	Sand & Gravel	Vulnerable

Note: 1. Primary (P) Well

3.2 Description of the Hydrogeologic Setting

The description of the hydrologic setting for the aquifer that is used to supply drinking water is presented in Table 3.

Table 3 - Description of the Hydrogeologic Setting

Attribute	Descriptor	Data Source
Aquifer Material	Sand and Gravel	Interpreted from well records found in the CWI database.
Porosity (type and value)	25%	Conservative estimate for glacial materials (Fetter, 1988; Freeze and Cherry, 1979).
Aquifer Thickness	At the Brainerd Wellfield – Ranges of 107 to 140 feet	Interpreted from well records, and inferred from information contained in the county geologic atlas (Setterholm, 2004; Peterson, 2007).
Stratigraphic Top Elevation	Wells 3, 4, 5, 6 & 7: 1155 ft average Well 8: 1203 ft	Interpreted from well records, and inferred from information contained in the county geologic atlas (Setterholm, 2004; Peterson, 2007).

Table 3 - Continued

Attribute	Descriptor	Data Source
Stratigraphic Bottom Elevation	1013 feet at the wellfield (see original Part I WHP Plan, p. 11) 1050 feet generally	Estimated from well records and information contained in the county geologic atlas (Setterholm, 2004; Peterson, 2007). The representative values are weighted toward the base elevation at the wellfield and within the contribution area to the wells.
Hydraulic Confinement	At Wellfield - Unconfined Upgradient - Confined	Aquifer tests, well records, and information contained in the county geologic atlas (Setterholm, 2004; Peterson, 2007).
Transmissivity (T)	Reference Value: 61,000 ft^2/day (see original Part I WHP Plan, p. 9)	The aquifer test plan was approved on July 22, 2010. T was estimated from an aquifer test conducted at the wellfield.
Hydraulic Conductivity	Reference Value: 545 ft/day (see original Part I WHP Plan, p. 10)	The reference value was obtained from the reference transmissivity value and using a conservative estimate of aquifer thickness of 112 feet.
Groundwater Flow Field	Figure 2 - Local Groundwater Flow Field Estimated from Well Records	Defined by using static water level elevations from well records in the CWI database and information contained in the county geologic atlas (Peterson, 2007).

Figures 4, 5 and 6 show the distribution of the sand and gravel aquifer and its stratigraphic relationships with adjacent geologic materials. They were prepared using well record data that is contained in the CWI database. The geological maps and studies that were used to further define local hydrogeologic conditions are provided in the "Selected References" section of this report.

4. Delineation of the Wellhead Protection Area

4.1 Delineation Criteria

The boundaries of the WHPA for the public water supplier are shown in Figure 1. Table 4 describes how the delineation criteria that are 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	Surface Water Features	The major features of regional discharge were included in the groundwater flow model. The Mississippi River was represented with curvilinear linesinks and resistance varels. Rice Lake, Whiteley Creek, Buffalo Creek, and Buffalo Lake were simulated using resistance varel elements. Lakes located west of the Mississippi River were simulated using linesinks. Vertical recharge to the confined aquifer was represented using given varel elements.
Flow Boundary	Geologic Boundaries - See Figure 3	The unconfined glacial sand and gravel aquifer was simulated using inhomogenieties and doublet elements. The boundaries of the aquifer serving the city wells were mapped using information from the records of existing wells and interpreted from information contained in the county geologic atlas (Setterholm, 2004; Peterson, 2007). The bedrock surface was used to define the no-flow boundary beneath the aquifer. New information since the original Part I Plan indicates the presence of a buried bedrock valley beneath the wellfield, trending southwest-northeast. Also, new information indicates that the sand and gravel aquifer becomes confined and thins in the upgradient direction of the wellfield. This new information was incorporated into the model.
Flow Boundary	Other High-Capacity Wells	There are no other existing high-capacity wells, other than the city wells, located in the 10-year WHPA. However, three high-capacity wells located north of the wellfield were included in several simulations to assess any possible impact on the wellhead protection area boundaries.
Daily Volume of Water Pumped	See Table 5	Pumping information was obtained from the city and DNR Appropriations Permit PA 1977-3523. This was converted to a daily volume pumped by a well.
Groundwater Flow Field	See Figure 2	The model calibration process addressed the relationship between the calculated versus observed groundwater flow field.
Aquifer Transmissivity	See Table 3	A range of transmissivity values was used to reflect changes in aquifer composition and thickness as well as uncertainties related to the quality of existing aquifer test data.
Time of Travel	10 years	The public water supplier selected a 10 year time of travel.

Previous pumping values have been reported to the DNR, as required by the city's Groundwater Appropriation Permit PA 1977-3523. This information was used to identify the maximum volume of water pumped annually by each well over the previous five-year period, as shown in Table 5. During the first three years of the five-year record, Brainerd public utilities was supplying a significant volume of water to the city of Baxter. During this time, the city of Baxter constructed several new water supply wells and a treatment plant. By 2008, the city of Baxter's water plant was fully functioning and the city no longer needed assistance from Brainerd. For the purposes of the delineation, it was determined not to assess or use pumping volumes for 2005-2007, since Brainerd no longer serves the city of Baxter and does not foresee the need to do so in the future. The estimated future pumping amounts for the next five years are also shown in Table 5. 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. For comparison purposes, the pumping rates used in the 1997 delineation are also provided in Table 5.

Table 5
Annual Volume of Water Discharged from Water Supply Wells (million gallons)

Well Name	Unique No.	Water Supplied to Baxter			2008	2009	Future Pumping	2010 Daily Volume (gal/day)	1997 Daily Volume (gal/day)
		2005	2006	2007					
3	232347	141.327	161.38	131.119	106.318	102.024	**107.0**	293,151	644,277
4	232348	22.695	69.151	71.719	47.559	59.275	**61.0**	167,123	501,362
5	232349	28.31775	1.978	7.456	3.711	154.03	**158.0**	432,877	280,411
6	232350	68.6235	57.786	37.782	71.104	70.319	**73.0**	200,000	735,816
7	232352	360.9195	362.85585	396.213	272.179	**295.085**	280.0	808,452	439,690
8	403973	181.195	264.384	214.92	154.156	4.205	**158.0**	432,877	369,830
System Total		803.07775	917.53485	859.209	655.027	684.938	837.0	2,334,480	2,971,386

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

4.2 Method Used to Delineate the Wellhead Protection Area

The WHPA for the public water supplier was determined using an analytic element computer model called MLAEM (Version 5.1.08). The MLAEM Code was selected because it is capable of simulating the influence of 1) surface-water features, 2) spatial variability of geologic materials, 3) vertical infiltration, and 4) the pumping influence of multiple high-capacity wells. All of these conditions were considered for the delineation. In general, the model input parameters were determined from information 1) obtained from the existing flow model used to determine the original WHPA, 2) provided by the public water supplier, 3) interpreted from local well logs and pumping test data, and 4) obtained from existing published reports and maps (see “Selected References”). Another model code, called SLAEM (Version 2.21), was used to delineate the original WHPA in 1997. The SLAEM model code was basically the precursor to the MLAEM model code that was used for this delineation.

New information published since the original WHPA delineation shows that the city wells are situated directly over a buried bedrock valley that trends southwest to the northeast. In general, the thickness and base elevation of the sand aquifer serving the city’s wells is controlled by the topography of the underlying bedrock surface. The aquifer is thickest at the immediate location of the wellfield where the bedrock surface occurs at an elevation that is 100 to 150 feet lower than surrounding areas. At this location, the valley materials are comprised of interbedded layers of sand and gravel from the land surface to the top of the bedrock surface. Information from the records of wells within the valley structure to the northwest and the southeast indicate that the thicker sequence of sand and gravel materials that make up the aquifer occurs in a fairly limited geographic area. It is likely that this was the location of a former outwash drainage channel that flowed toward the larger meltwater channel that is occupied by the present day Mississippi River. Upgradient (east) of the wellfield and beyond the bedrock valley boundaries, the aquifer significantly thins, consists primarily of sand, and is overlain by clay-rich till. Figures 5 and 6 show cross-section views of the aquifer at the location of the wellfield and in the upgradient direction. The variable nature of aquifer transmissivity was simulated in the flow model by changing 1) the base elevation of the aquifer to reflect the bedrock valley feature, 2) aquifer thickness, and 3) hydraulic conductivity. This was accomplished using a set of nested aquifer inhomogeneity elements.

Similar to the previous model, surface water features located far afield and west of the Mississippi River were represented using linesink elements. All surface water features east of the Mississippi River, however, were simulated using varel resistance elements. These features included Buffalo Creek, Little Buffalo Creek, Whitely Creek, Rice Lake and Boon Lake. Varel elements were chosen in order to simulate the geometry of these features, particularly the features that are in close proximity to the wellfield. The Mississippi River was modeled as a regional discharge feature using varel elements (with relatively low resistance) along an eight mile stretch through the city of Brainerd. Global infiltration was simulated using a given varel element. Table 6 summarizes the model parameters. Table 7 summarizes other high-capacity wells that were assessed as part of the delineation. Additional information regarding the model parameters and element layout are available from MDH.

Table 6 - MLAEM Model Input Parameters

Model Parameters	Value	Source
Base Elevation	Global: 320 meters Inhomogeneity 1: 314.5 meters Inhomogeneity 2 (Wellfield): 309 meters	Estimated from local well records and the county geologic atlas (Setterholm, 2004; Peterson, 2007).
Aquifer Permeability	Global: 11.6 meters/day Inhomogeneity 1: 30.5 meters/day Inhomogeneity 2 (Wellfield): 61 meters/day	Estimated from previous pumping tests and WHPA model, specific capacity data, and calibration.
Aquifer Thickness	Global: 6 meters --- Inhomogeneity 1: 85 meters Inhomogeneity 2 (Wellfield): 85 meters	Estimated from local well records and the county geologic atlas (Setterholm, 2004; Peterson, 2007). Thickness is exaggerated within the boundaries of the inhomogeneities to maintain unconfined conditions.
Far Field Lakes and the Mississippi River (far field) - Head Specified Line Sinks	Head = River or Lake Elevation	Linesinks from previous model. River elevations originally derived from USGS topographic quadrangles.
Mississippi River, Rice Lake, Whitely Creek, Boon Lake, Buffalo Lake, Little Buffalo Creek, Buffalo Creek – Varel Elements with Specified Head and Resistance	Head = Water Level Elevation Resistance = 1 to100 Days	Water level elevations derived from USGS topographic quadrangles. Resistance values derived from professional judgement and calibration exercises.
Vertical Infiltration	7 inches/year	Published value (Delin et.al., 2007).
Porosity	0.25	Conservative estimate for outwash sand (Fetter, 1988).

Table 7 - Other Permitted High-Capacity Wells

Unique Number	Well Name	DNR Permit Number	Aquifer	Use	Annual Volume of Water Pumped (million gallons)	Daily Volume
116527	Independent School District 181	1976-3015	QBAA	Irrigation	14.0905	146.2 m^3/d
150830	Independent School District 181	1976-3015	QBAA	Irrigation	15.7839	163.85 m^3/d
437425	Atek Manufacturing LLC	1990-3026	QWTA	Air Conditioning	5.0	51.87 m^3/d

4.3 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.

The flow model was calibrated to water level information from the CWI database. Calibration was performed using a manual trial-and-error procedure that involved changing hydraulic conductivities and recharge rates and comparing simulated heads to about 35 water level observations from wells completed in glacial drift materials. All of the calibration observations are located east of the Mississippi River and within a distance of three-miles of the wellfield. The residual root mean square (RMS) error of the calibration well set from early model runs was approximately 18 feet (5.5 meters). The main model elements that were adjusted or changed as part of the calibration process were: 1) the geometry and permeabilities of the nested doublets; 2) the resistances of varels representing nearby surface water features, such as Little Buffalo Creek and the Mississippi River; and 3) infiltration. With respect to infiltration, several given polygons were added to represent the expected decreased infiltration that occurs in the area upgradient of the wellfield where the aquifer is overlain by clay till. Over the course of several calibration exercises, vertical infiltration was eventually lowered 50 percent, from an initial global rate of about 7 inches/year to 3.5 inches/year in the discrete elements (respectively, 4.9E-4 m/d and 2.45E-4 m/d). The resulting RMS error of the calibrated model was 2.3 meters (7.6 feet), representing about eight percent of the total head change across the contribution area of the city's wells.

As part of the calibration exercise, model baseflows to the Mississippi River were also assessed and determined to be acceptable. Under low flow conditions, groundwater baseflow has been estimated to be as low as 1 cubic foot per second per river mile (Payne, 1995). For the most part, simulated flux to the river (or baseflow) was generally very low, and along the order of less than 1 cfs to 10 cfs. Along a couple of river stretches, the net flux was essentially zero because there were discrete lengths along the river element where flow was going into the aquifer from the river (i.e., baseflow was reversed so that the aquifer was being recharged). Information to estimate baseflows to the creeks, such as Little Buffalo Creek, is not available at this time; this type of information would be useful to evaluate model calibration in the future. Additional information regarding model calibration and results is available from MDH.

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

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. However, the pumping rate is based on the results presented in Table 5 and, therefore, is not a variable factor that will influence the delineation of the WHPA.
- The aquifer thickness, permeability, 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 permeability defines the relative proportions of the capture zone width to length. A decrease in permeability 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 around the well.
- The bed resistance and hydraulic heads of the surface water discharge features affect aquifer flux and the potential for surface water contribution to the public wells. The location and strength of the modeled surface water features also have an influence on the simulated groundwater flow field and the orientation of the well capture zones.
- Vertical aquifer infiltration (or aquifer recharge) directly affects the volume of the aquifer that contributes water to the public wells. An increase in vertical infiltration within the boundaries of the recharge area of the wells potentially leads to a decrease in the aquifer contribution area.

The Brained model was most sensitive to vertical infiltration and global hydraulic conductivity. With respect to well capture zones, the model also proved to be sensitive to localized changes in bed resistances of the Mississippi River and Little Buffalo Creek.

4.4 Addressing Model Uncertainty

Performing an uncertainty analyses is a common approach used to evaluate uncertainties in the hydrogeologic data that may affect the size and shape of the capture zones. Assumptions were made regarding the location of the aquifer boundaries, especially with respect to the aquifer inhomogeneities. The lateral boundaries of the thick sequence of unconfined sand and gravel that are represented by the inhomogeneities were estimated and weighted toward known information from existing wells and the bedrock topography. There were only a couple of wells in the area aside from the city wells that extended to similar depths; therefore, it was the information from these wells that largely determined the lateral extent. Although the exact boundaries of the unconfined aquifer are uncertain, it was decided that there is not enough information at this time to warrant alternate model scenarios. Information from future borings or wells that are constructed in the area will help to confirm or perhaps modify our present understanding of the location of the aquifer boundaries.

A degree of uncertainty is also assumed with respect to the amount of interaction between local surface water features and the aquifer. In late September 2010, water samples were collected at several of the municipal wells, the nearby filter backwash basin, Little Buffalo Creek and the Mississippi River in an effort to gain a better understanding of the degree of connection, if any. The water samples were submitted to an MDH contract lab in Waterloo, Ontario, for the analysis of the stable isotopes of hydrogen and oxygen. At the time of this report, the results have not been received from the lab.

Water samples were also collected and submitted to the MDH Lab for total organic carbon, chloride and bromide. These parameters can also be helpful for evaluating the amount of surface-groundwater interaction. Three of the four municipal wells indicated elevated chloride/bromide ratios. In addition, the total organic carbon result from one well indicated the possibility of a significant surface-groundwater connection with respect to this well. Future monitoring at the wells, the basin and nearby wetland, Little Buffalo Creek and the Mississippi River is planned and the results should lead to a better understanding of the degree of connection. However, because of the possibility of a strong connection with surface waters, bed resistances in the model were varied to allow for more or less surface water contribution with respect to Little Buffalo Creek and the Mississippi River. The resulting wellhead protection area shown in Figure 1 is a composite of capture zones produced when model resistances ranged from 1 day to 100 days.

4.5 Addressing Changes to the Surface Water Contribution Area (Conjunctive Delineation)

Similar to the previous model, the land surface watershed area for Little Buffalo Creek was included as part of the WHPA. Surface runoff from this area can potentially drain to Little Buffalo Creek and recharge the unconfined aquifer serving the city wells. For the most part, the surface water contribution area remained unchanged relative to the previous delineation along the north and east boundaries. The only notable change to the boundary occurs along an approximate three-quarter-mile stretch along the southern boundary. The expanded area of the new 10-year capture zones and the availability of updated drainage maps accounted for this small revision. Figure 7 shows a comparison between the previous boundaries and the new boundaries of the combined 10-year WHPA and the surface water contribution area.

5. Delineation of the Drinking Water Supply Management Area

Figure 1 shows the boundaries of the Drinking Water Supply Management Area (DWSMA) and were defined by the public water supplier using the following features:

- Highways, streets, roads, or railroad rights-of-ways;
- Public Land Survey coordinates; and
- Property parcel boundaries.

In July 2010, the city of Brained provided MDH with geographic information system (GIS) shape files of updated parcel boundaries. This information was very useful in delineating the DWSMA boundaries. A comparison between the old and new DWSMA is shown in Figure 7.

6. Summary of Comparisons Between Previous (1997) and Current WHPA and DWSMA Delineations

Overall the new DWSMA is larger in size compared to the previous delineation. This is primarily due to the change in the shape of the 10-year capture zone boundaries, as discussed above. The original WHPA for Brainerd was delineated using the analytic model code called SLAEM, Version 2.21. For this delineation, the next generation of the model code called MLAEM (Version 5.1.08) was used. Most of the far field elements of the original model, such as the linesinks west of the Mississippi River, were preserved and projected to the UTM NAD83 Zone 15 coordinate system.

Additional modifications that were made to the previous model are as follows:

1) The discharge rates for the Brainerd public wells were adjusted to reflect current and projected pumping conditions (Table 5).

2) Global recharge was reduced from a rate of 7.4 inches/year in the original model to about 7 inches/year in this amendment. The new value corresponds to estimates published by the United States Geological Survey since the time of the original delineation (Lorenz and Delin, 2007). In addition, the recharge rate was reduced 50 percent, to 3.5 inches/year, in areas where the aquifer is overlain by fairly thick sequences of till.

3) The variable nature of the base elevation of the aquifer, aquifer thickness, and transmissivity was simulated using nested inhomogeneity elements. The aquifer was modeled as a thick unconfined sand and gravel unit at the location of the wellfield, roughly corresponding to the boundaries of the buried bedrock valley. Globally and upgradient from the bedrock valley, the aquifer was modeled as a relatively thin confined sand unit.

4) Little Buffalo Creek and several other small-scale surface water features were included in this model; these features were not included in the original model.

5) The pumping volumes at three non-municipal high-capacity wells (Table 7) were assessed and included in the model.

The resulting WHPA primarily differs from the previous version in terms of its overall shape. In the previous model, the shape of the combined 10-year WHPA zones was elongate and narrow, trending to the southeast. In comparison, the new 10-year WHPA zone is wider and more circular in appearance. This is primarily due to simulating the thick unconfined aquifer at a discrete location near the river rather than as a global feature.

There was only a minor revision to the previous boundaries representing the surface water contribution area of Little Buffalo Creek. This change occurs along the south boundary of the WHPA.

7. Vulnerability Assessments

The Part I wellhead protection plan includes the vulnerability assessments for the public water supply wells and the DWSMA. These vulnerability assessments are used to help select appropriate measures for reducing the potential contaminant source threat to the public water supply.

7.1 Assessment of Well Vulnerability

The vulnerability assessment for each well used by the public water supplier is listed in Table 2 and is based upon the following conditions:

1) The geologic sensitivity of the aquifer at the well sites is considered high because of the lack of a significant thickness of clay-rich geologic materials over the aquifer.
2) Isotopic results from two of the Brainerd wells indicate that the aquifer used by the wells is recharged by surface water over a time span of weeks to years. Tritium was detected in Well 3 (232347) at 10.3 tritium units and in Well 6 (232350) at 8.5 tritium units in 2010. Therefore, the wells have the potential to be impacted by human activities and are considered potentially vulnerable to contamination.
3) The chloride/bromide ratio results from water samples collected from three of the four wells (September 2010) indicates impact by human activities occurring on the land surface.

7.2 Assessment of Drinking Water Supply Management Area Vulnerability

The vulnerability of the aquifer used by the city of Brainerd has been determined to be low in the eastern part of the DWSMA and high in the western part of the DWSMA (Figure 8). The DWSMA vulnerability map was based on the following:

1) Well geologic sensitivity ratings and the surficial geology map (Figures 3 and 8) were used to delineate the boundaries between the low and high vulnerability areas. As shown in Figure 8, the geologic sensitivities of wells located in the DWSMA are variable, ranging from low to high. Wells with low ratings indicate the presence of at least 10 feet of clay between the land surface and the sand and gravel aquifer serving the city wells. The low sensitivity wells also correspond to areas where surficial geologic materials are comprised of clayey till materials (Figures 3 and 8). Wells with high sensitivity ratings indicate the absence of any significant till layer between the land surface and the aquifer. The high vulnerability area corresponds to where the aquifer was determined to be comprised of interbedded layers of sand and gravel from the land surface to the base and is unconfined.

   There are a few wells within the high vulnerability area that have low sensitivity ratings (Figure 8). Rather than map isolated patches of low vulnerable areas, it was decided to place more weight on the till boundaries shown on the surficial geology map.

2) Isotopic and water chemistry data from Brainerd Wells 3 and 6 (232347 and 232350, respectively) indicate that the aquifer used by the city wells is recharged by surface water over a time span of years, at most.

8. Selected References

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Setterholm, D.R., and Meyer, G.N. (2004), Bedrock topography, depth to bedrock, and quaternary subsurface geology, in *Geologic atlas of Crow Wing County, Minnesota,* Setterholm, D.R., (Project mgr.), County Atlas Series, C-16, Part A, Plate 5, Minnesota Geological Survey, St. Paul, Minn., scale 1:200,000.

9. Figures

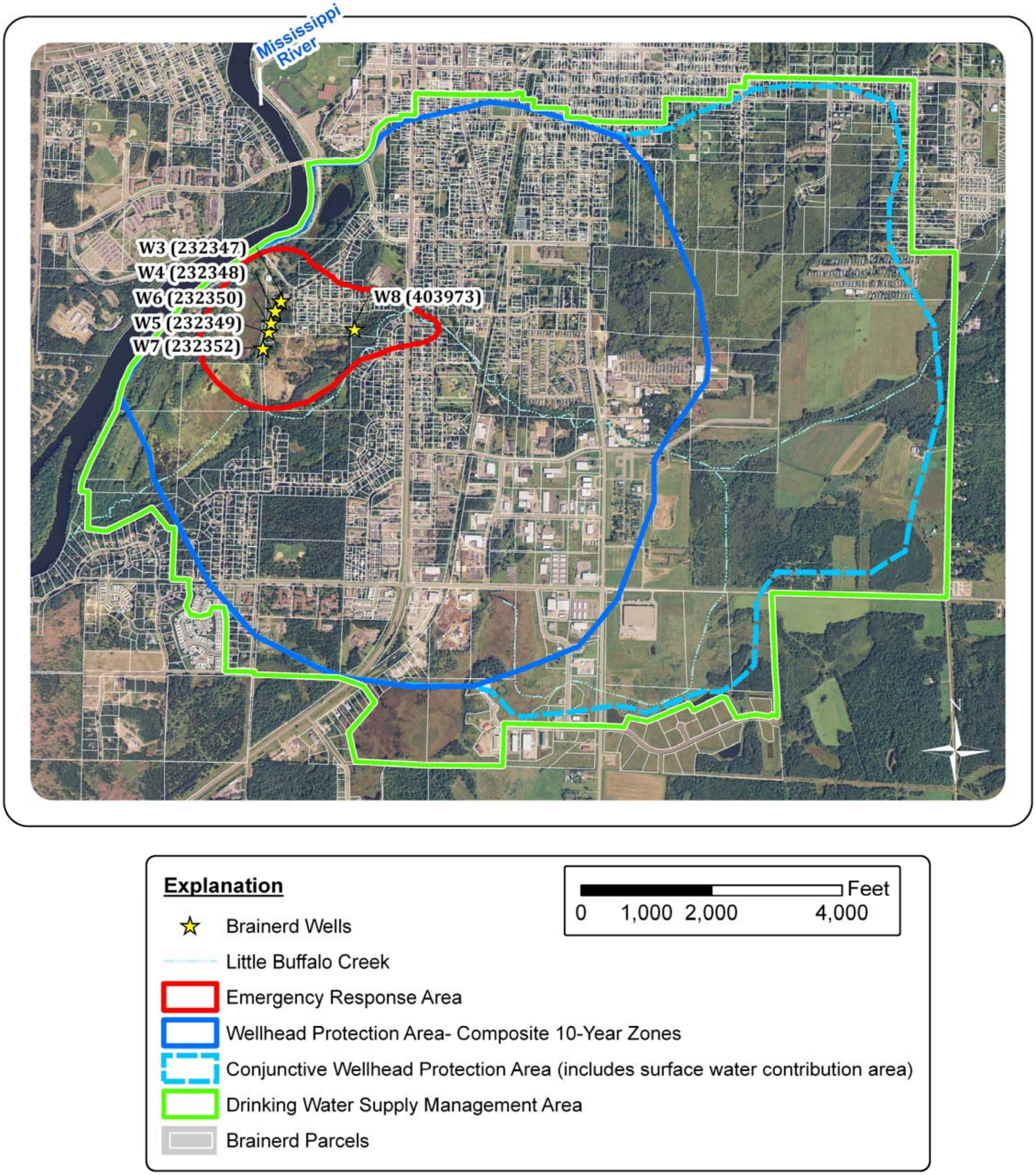


Figure 1. Wellhead Protection Area and Drinking Water Supply Management Area, Brainerd, Minnesota

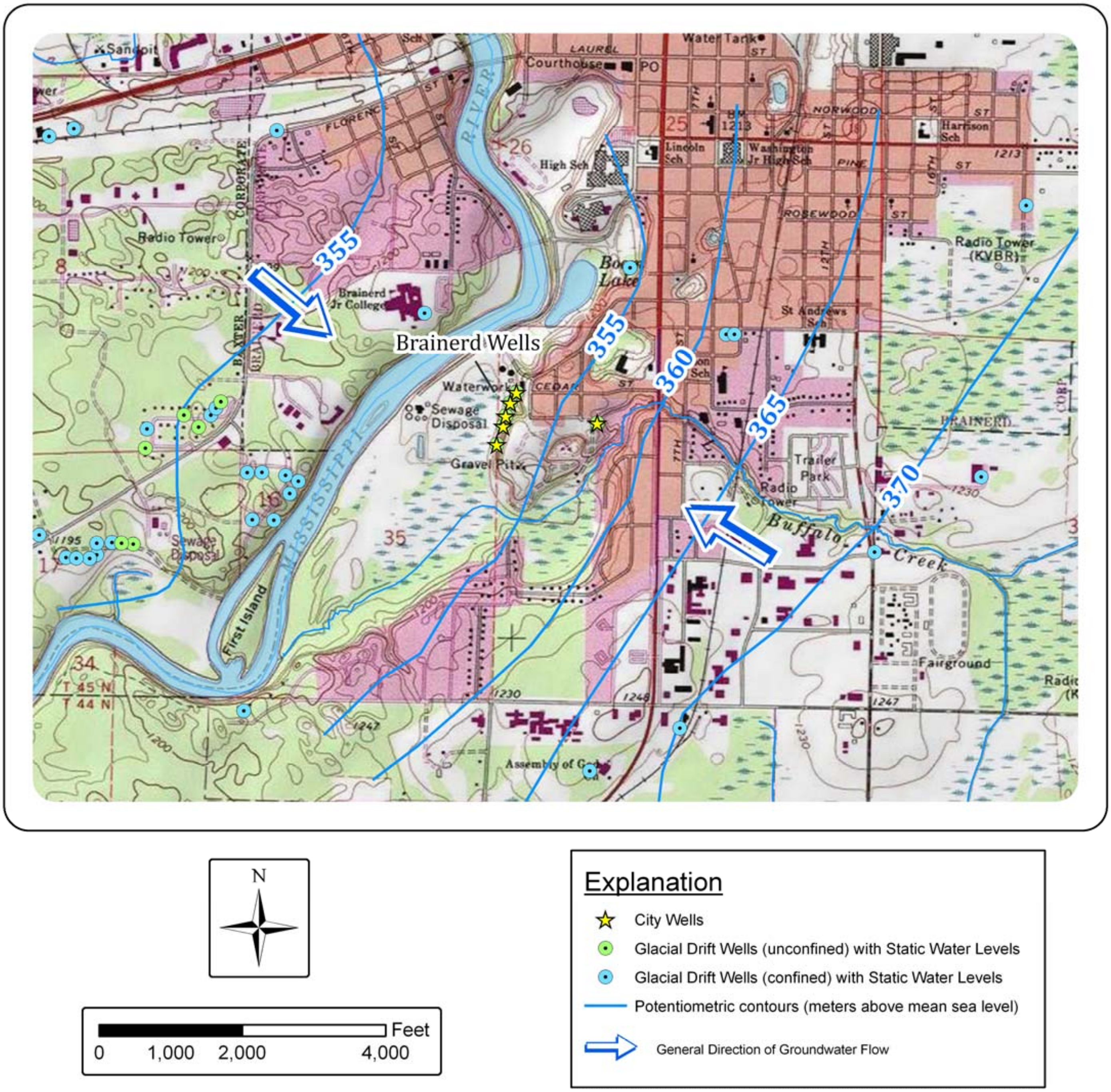
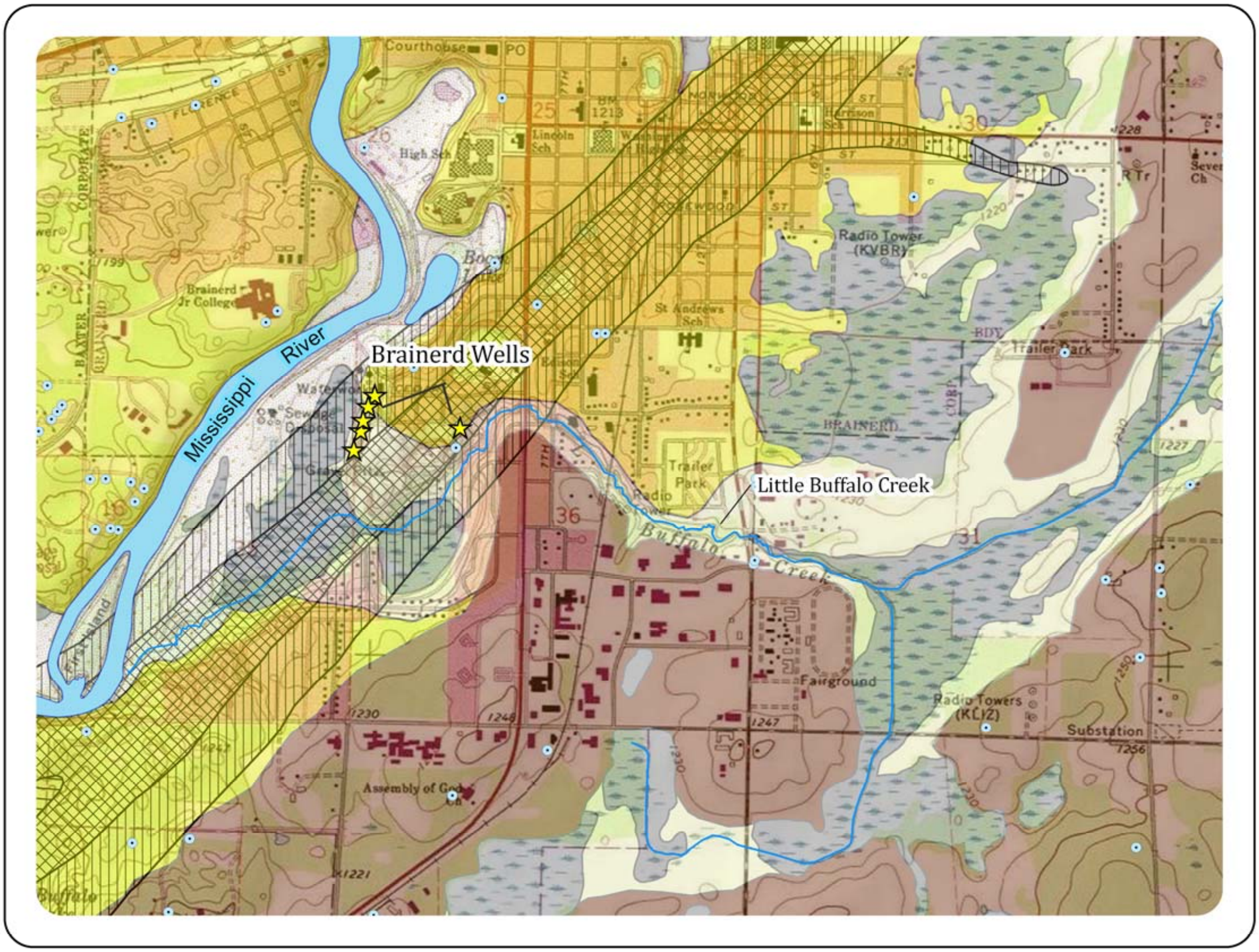
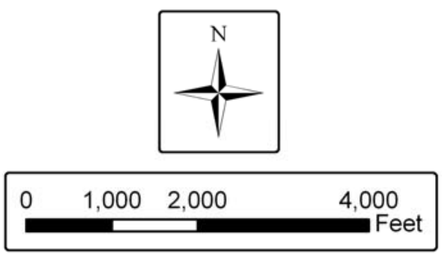


Figure 2. Local Groundwater Flow Field Estimated from Well Records



Modified from "Geologic Atlas of Crow Wing County, Minnesota, County Atlas Series, C-16, Part A, Plate 3;" D. Setterholm, 2004.



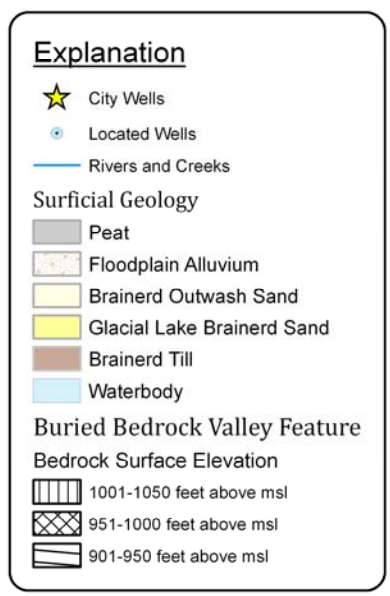


Figure 3. Buried Bedrock Valley Feature and Surficial Geology in the Brainerd Area

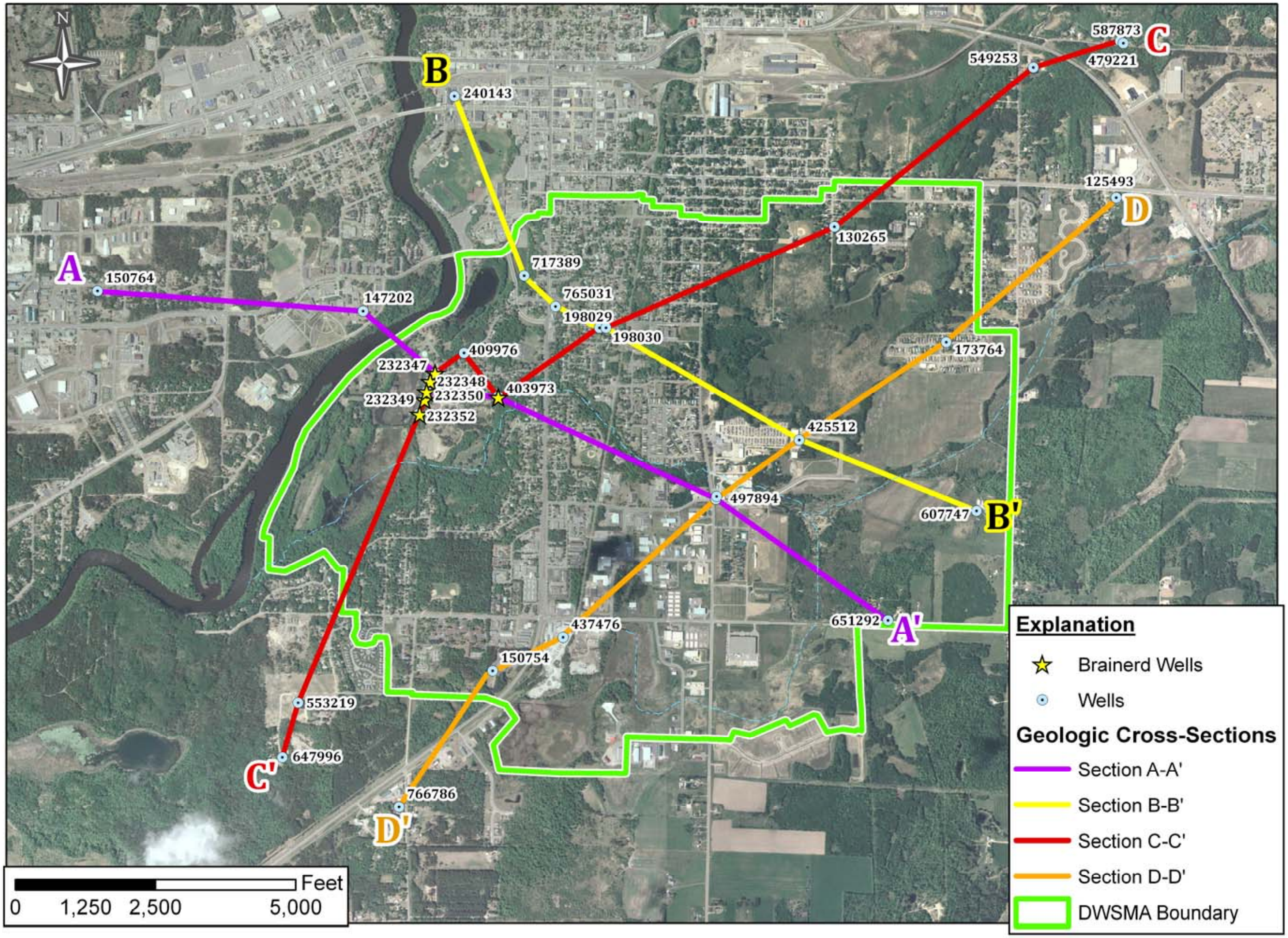


Figure 4. Database Map and Trends of Cross Sections

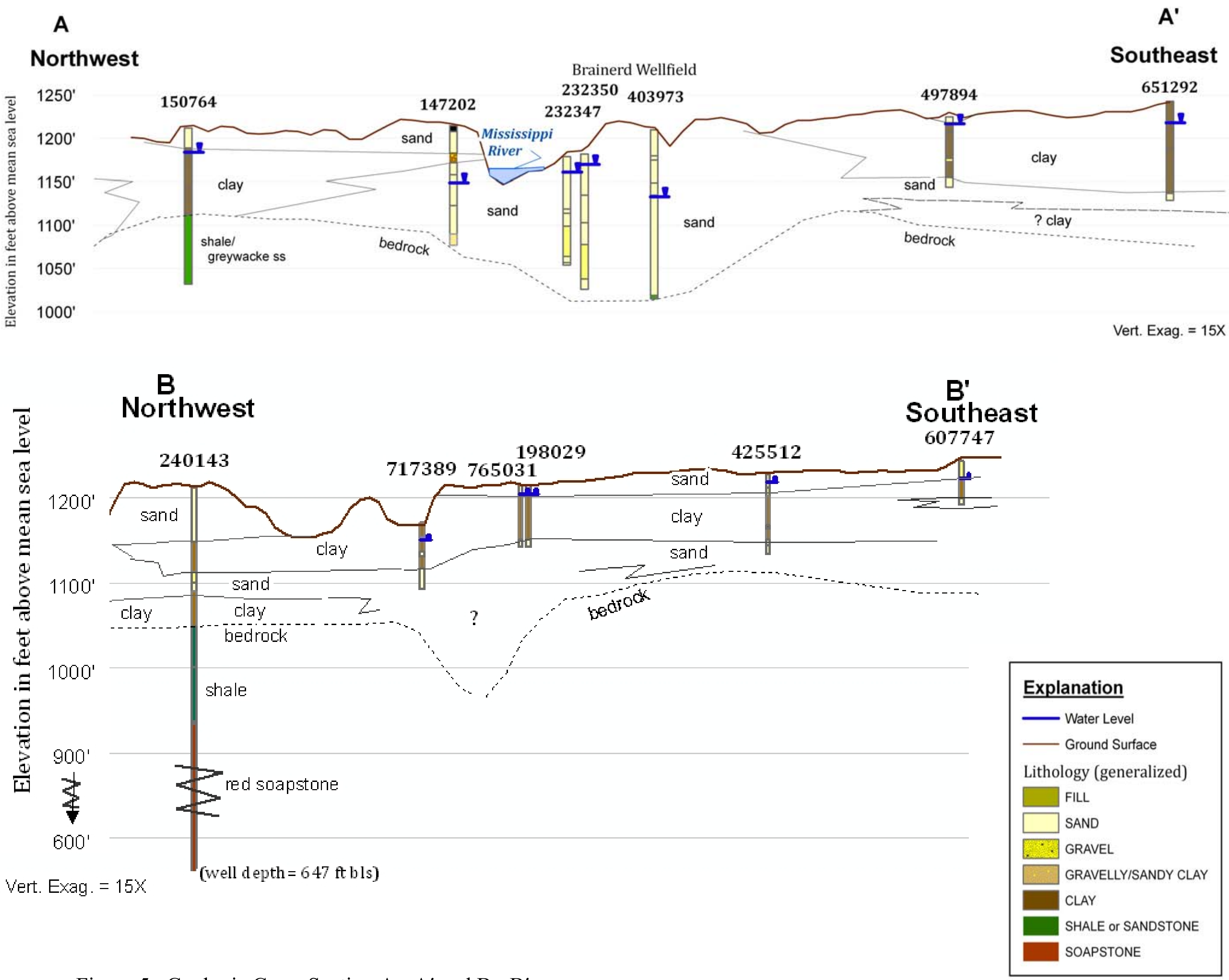
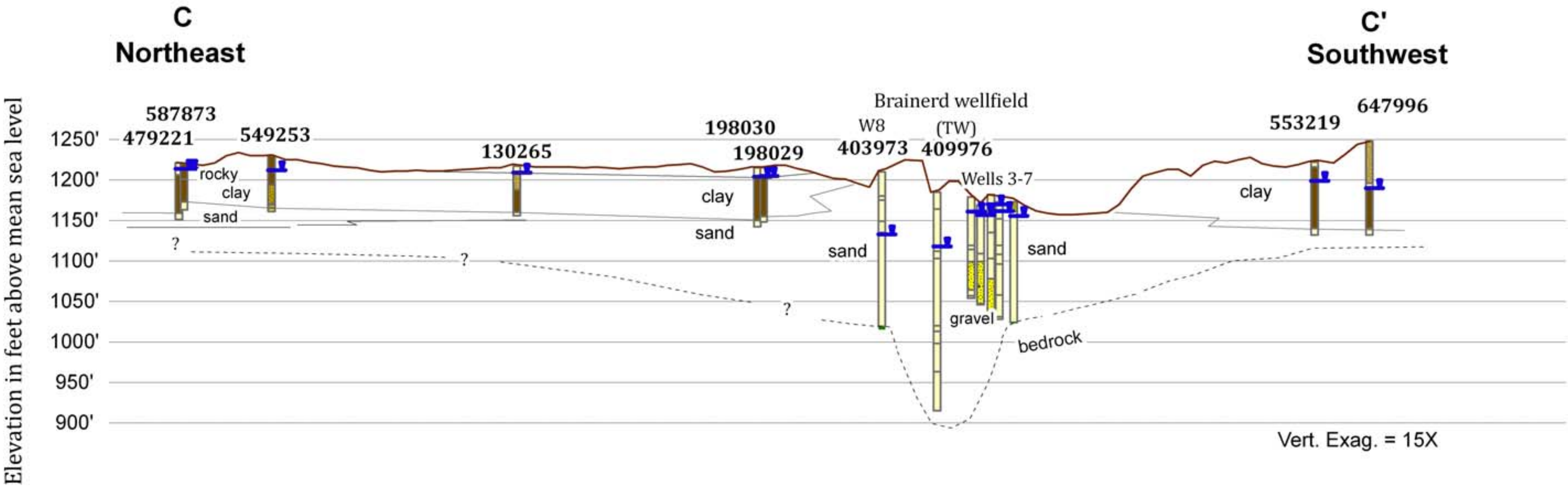
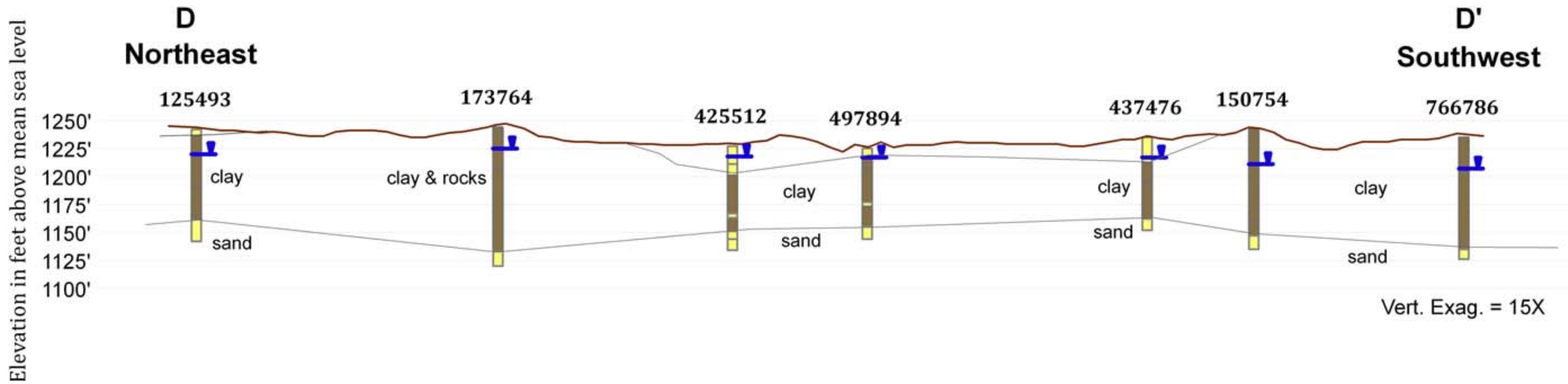


Figure 5. Geologic Cross Section A - A′ and B - B′





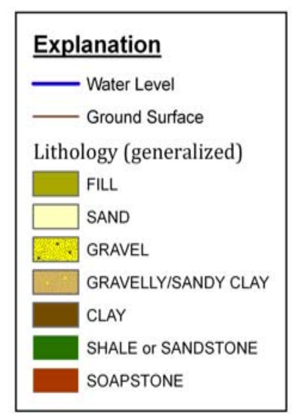


Figure 6. Geologic Cross Section C - C′ and D - D′

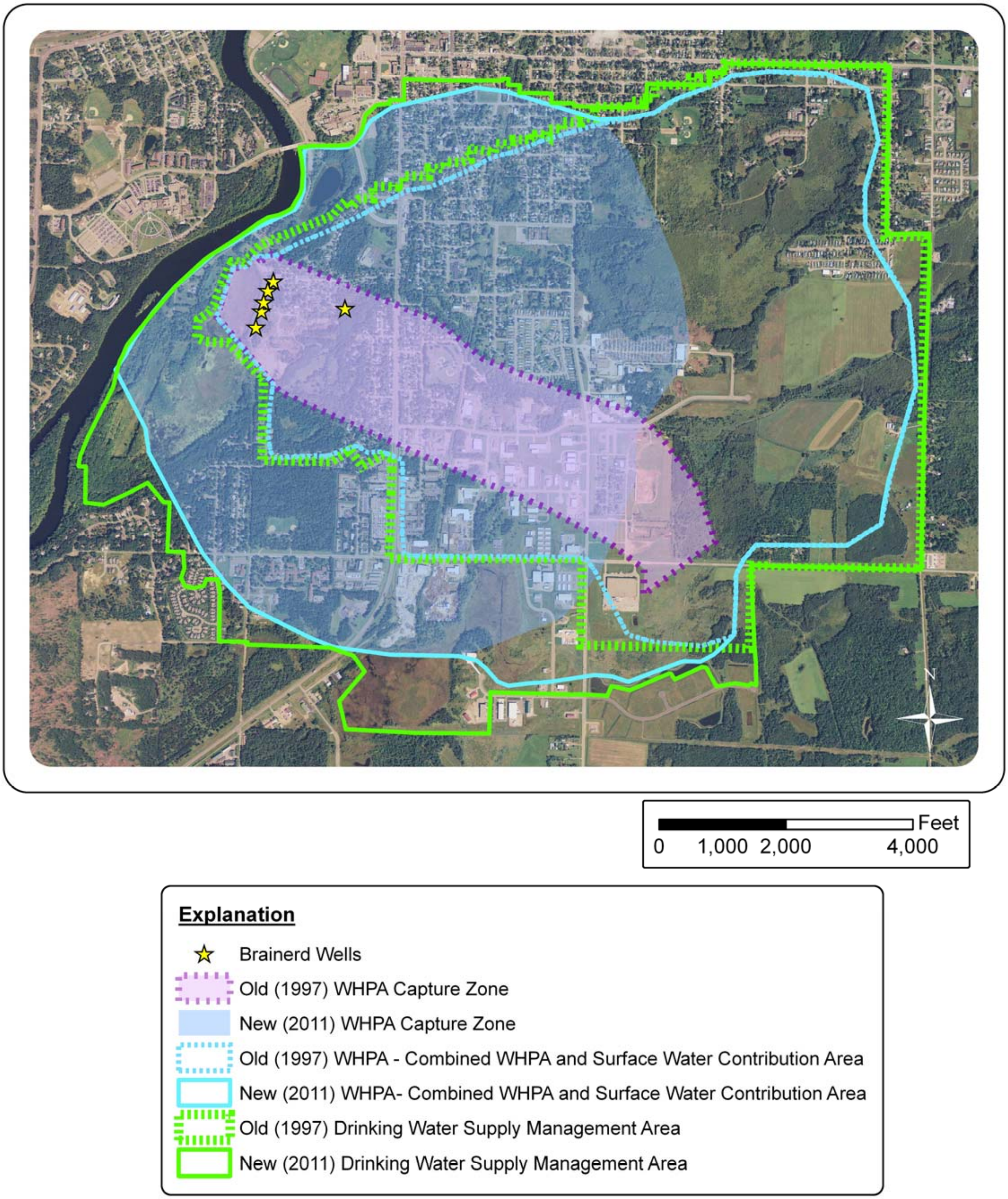


Figure 7. Comparison Between New and Old WHPAs and DWSMAs

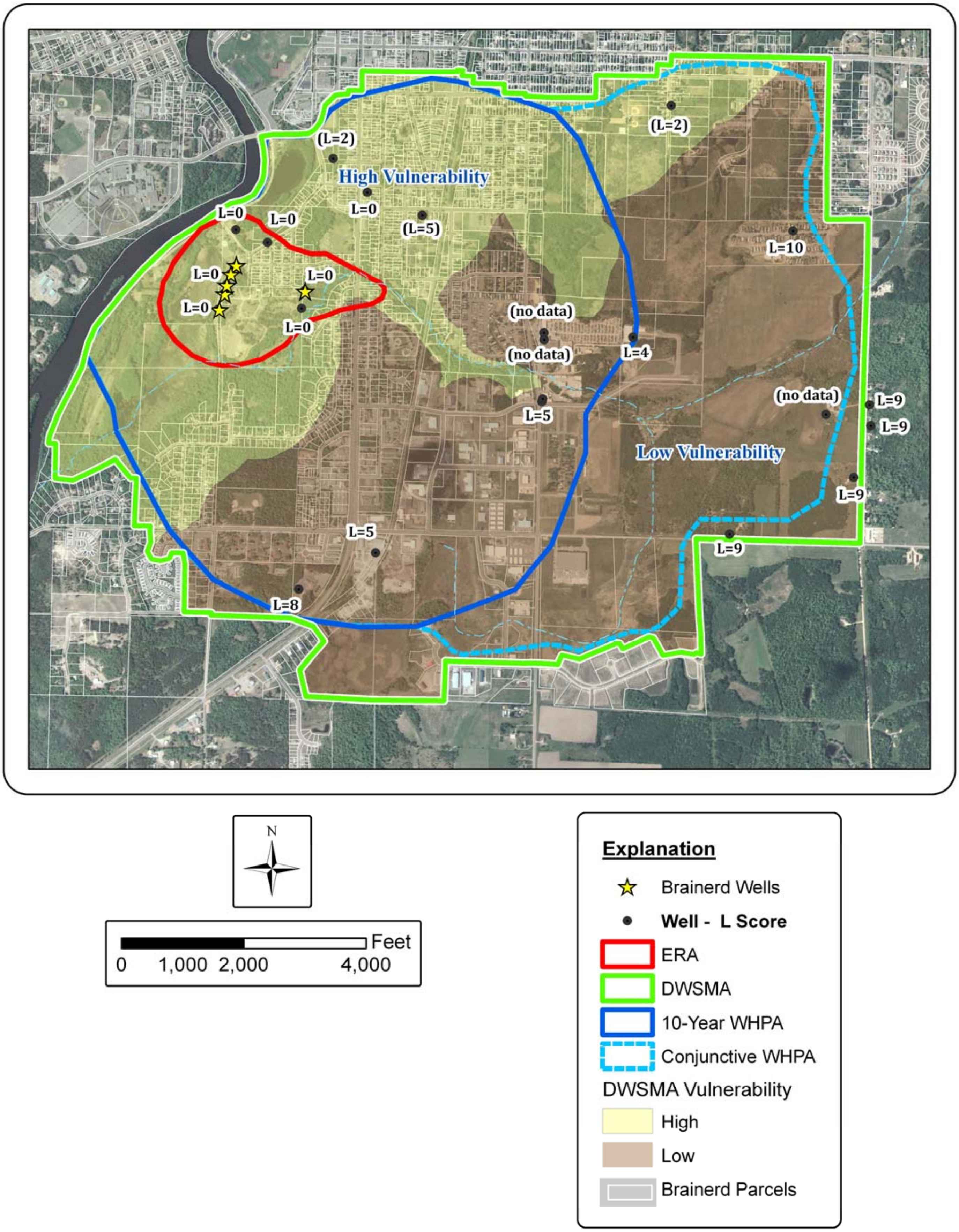


Figure 8. DWSMA Vulnerability, Brainerd, Minnesota