

Part I Wellhead Protection Plan Update

WHPA Delineation, DWSMA Delineation, Well and
DWSMA Vulnerability Assessments

Worthington, Minnesota

Public Water Supplier No. 1530011
SEH No. WORTC 126958 14.00

December 29, 2015



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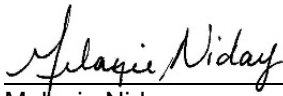
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Worthington, Minnesota

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I hereby certify that this report was prepared by me or under my direct supervision,
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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.

Surface Water Contribution Area (SWCA). In a conjunctive delineation, the geographic area that may provide recharge to the aquifer within the well capture zone, attributed to: 1) the presence of a surface hydraulic feature; and 2) the runoff of precipitation or meltwater.

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

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

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

Acronyms

CWI	County Well Index
DNR	Minnesota Department of Natural Resources
EPA	United States Environmental Protection Agency
IWMZ	Inner Wellhead Protection Management Zone
MDA	Minnesota Department of Agriculture
MDH	Minnesota Department of Health
MGS	Minnesota Geological Survey
MNDNR	Minnesota Department of Natural Resources
MnDOT	Minnesota Department of Transportation
MPARS	MNDNR Permitting and Reporting System (formerly known as SWUDS)
MPCA	Minnesota Pollution Control Agency
PLS	Public Land Survey
SWCA	Surface Water Contributing Area
SWCD	Soil and Water Conservation District
UMN	University of Minnesota
USGS	United States Geological Survey

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Part I Wellhead Protection Plan Update

WHPA Delineation, DWSMA Delineation, Well and DWSMA Vulnerability Assessments

Prepared for the City of Worthington, Minnesota

1.0 Introduction

The City of Worthington and Worthington Public Utilities (PWSID 1530011) has completed an update to the City's wellhead protection (WHP) plan. 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 DWSMAs. Figure 1 shows the boundaries for the WHPAs and DWSMAs. The WHPAs are defined by a 10-year time of travel for the Okabena Wellfield and a combination of 10-year travel times and SWCAs for the Malcolm and Lake Bella Wellfields. Figure 1 and Figure 2 also show the emergency response areas (ERA), which are defined by a 1-year time of travel. The Inner Wellhead Protection Management Zone (IWMZ) is the area within a 200-foot radius around each well (not shown in the figures due to scale). 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 Minnesota Department of Health (MDH). The municipal water supply wells included in the WHP Plan are listed in Table 1.

Table 1
Water Supply Well Information

Well No.	Unique Well No.	Date Constructed/ Reconstructed	Aquifer	Total Depth (ft)	Casing Depth (ft)	Casing Diameter (in)	Capacity (gpm)	Vulnerability
19	223617	1957	Buried Sand and Gravel	63	58	24-12	116	Not Vulnerable
20	633531	2000	Water Table	44	28	20	103	Vulnerable
22	169892	1980	Buried Sand and Gravel	64	45	8	125	Vulnerable
24	197476	1984	Water Table	76	56	12	385	Vulnerable
25	195163	1985	Water Table	80	65	12	499	Vulnerable
26	654756	1989/2001	Water Table	69/91	41/62	12/20	480	Vulnerable
27	240094	Unk/2001	Water Table	57/73	46/57	Unk/20	421	Vulnerable
28	455791	1989	Water Table	75	50	12	456	Vulnerable
29	455790	1988	Water Table	102	77	12	487	Vulnerable
31	760572	2008	Water Table	90	66	16	635	Vulnerable

Note: All wells are Primary status

2.0 Assessment of the Data Elements

MDH staff met with representatives of the public water supplier in September 2013 for a scoping meeting that identified the data elements required to prepare Part I of the WHP Plan Update. Table 2 presents the assessment of these data elements, relative to the present and future implications of planning items, as specified in Minnesota Rules, part 4720.5210. The Scoping Decision Notice is provided as Appendix A.

Table 2
Assessment of Data Elements

	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					
Average monthly and annual precipitation	L	M	L	M	Midwestern Regional Climate Center, USGS
Geology					
Maps and geologic descriptions	M	H	H	H	MGS, MNDNR, USGS, Consultant Reports
Subsurface data	M	H	H	H	MGS, MDH, MNDNR
Borehole geophysics	M	H	H	H	MGS, Consultant Reports
Surface geophysics	L	L	L	L	DNR, MPCA, Consultant Reports
Maps and soil descriptions	L	M	L	M	USDA SURGGO
Water Resources					
Watershed units	L	H	M	M	DNR
List of public waters	L	M	L	M	DNR
Land Use					
Parcel boundaries map	L	H	L	M	Nobles County
Political boundaries map	L	H	L	M	DNR
PLS map	L	H	L	L	DNR
Public Utility Services					
Transportation routes and corridors	L	H	M	M	MnDOT, City of Worthington
Storm/sanitary sewers and PWS system map	L	L	M	M	City of Worthington
Public drainage systems map or list	L	L	M	M	DNR, City of Worthington
Records of well construction, maintenance, and use	H	H	H	H	City of Worthington, CWI, MDH files
Surface Water Quantity					
Stream flow data	L	L	M	L	USGS, MPCA, MNDNR
Ordinary high water mark data	L	L	L	M	DNR
Permitted withdrawals	M	L	M	M	DNR, City of Worthington
Protected levels/flows	M	L	M	M	DNR, MPCA
Water use conflicts	M	M	M	M	DNR, MPCA

Table 2
Assessment of Data Elements

	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	
Groundwater Quantity					
Permitted withdrawals	H	H	H	H	DNR
Groundwater use conflicts	H	H	H	H	DNR
Water levels	H	H	H	H	DNR, MPCA, MDA, MDH, City
Surface Water Quality					
Monitoring data summary	L	L	M	M	MPCA
Groundwater Quality					
Monitoring data	H	M	H	H	MPCA, MDH, MDA, USGS
Isotopic data	H	H	H	H	MPCA, MDH, MDA, USGS, Nobles County, UMN
Tracer studies	L	L	L	L	Not Available
Contamination site data	L	L	L	L	MPCA, MDA
MPCA and MDA spills/release reports	H	L	H	H	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 Acronyms used in this report are listed on page ii, after the "Glossary of Terms."					

2.1 Geological Information

The local and regional geologic and hydrogeologic conditions influence the delineation of the WHPAs for the public water supply wells. By characterizing these conditions, the geometry, location and magnitude of groundwater recharge and discharge areas, and the groundwater flow direction of the source water aquifer could be determined or estimated. The ambient groundwater flow field is shown in Figure 3.

Existing geological maps, reports, and studies that were used are listed in the References section of the plan. Through the use of public-domain well records and local and regional geologic studies and publications, the geology and hydrogeology of the area have been evaluated and reviewed to aid in the WHPA delineations and vulnerability assessments. These resources were provided by the City, the MDH, the Minnesota Geological Survey (MGS), and the United States Geological Survey (USGS). These resources provided the basis for defining local geologic and hydrologic conditions but this interpretation was refined using the records of wells, borings, exploration test holes, and excavations. The City has no additional geologic information from logs or borehole geophysical records of wells, borings, or exploration test holes, nor additional information from surface geophysical studies. A surficial geology map is presented as Figure 4. Geologic cross-sections were created through the

study area and are provided as Figures 5, 6, 7, and 8. The cross-section locations are depicted on Figure 4.

2.1.1 Regional and Local Geology

Glacial ice advanced into and receded from southwestern Minnesota many times and from a similar source area during the last two million years. The resulting glacial sediments and deposits are typically 400 to 450 feet thick in the Worthington area and are the difficult to distinguish. In the vicinity of the Worthington public water supply wells there are four types of glacial deposits near the land surface. Figure 4 depicts the surficial geology of the Worthington area. Regionally, the Quaternary glacial deposits consist of supraglacial hummocky till comprised of discontinuous lenses of clay, silt, sand, and gravel. The matrix texture of this complex is loam to clay loam. Within this till mass and in the vicinity of most of the Worthington public water supply wells are stream sediments of sand, gravel, and silt, organic deposits of peat, marshes, and shallow lakes, and till with stream-modified surfaces where thin sand and gravel deposits overlie clayey till. Two locally prominent, north to south channels of these deposits extend from the southwestern and southeastern corners of Okabena Lake in southwestern Worthington to Lake Bella.

Depth to bedrock in the Worthington area is estimated to be 400 to 450 feet below the land surface (elevation of approximately 1,200 feet above mean sea level [MSL]). The uppermost bedrock is Cretaceous rock comprised primarily of shale and siltstone with some fine-grained, quartzose sandstone. The total thickness of the formation is likely 300 to 350 feet, and the beds of sandstone within it range in thickness from 0 to 100 feet and are most common near the base of the formation. The Sioux Quartzite underlies the Cretaceous rocks. It is interbedded with hard red claystone (“pipestone”). The upper 200 to 300 feet of the quartzite may contain sand zones, joints, and fractures. The maximum thickness of the Sioux Quartzite is more than 1,000 feet and it is underlain by undifferentiated crystalline rock.

2.1.2 Regional and Local Hydrogeology

Four aquifers are in the Worthington, Minnesota area: the unconfined sand and gravel (“water table”) aquifer, the semi-confined or confined buried drift aquifer(s), the Cretaceous bedrock aquifer, and the Sioux Quartzite aquifer. The water table and buried drift aquifers are present within the Quaternary glacial deposits and are the source water aquifers currently used by WPU for public water supplies. Till in the area has a low permeability and is generally considered a confining unit locally where the horizontal and vertical extent is widespread. Yields for aquifers in the Quaternary glacial deposits are highly variable, and higher yields are generally associated with surficial sand and gravel outwash deposits that can be as high as 1,000 gallons per minute (gpm).

The water table aquifer is the primary source water aquifer utilized by WPU and provides adequate yield and good recharge, but could easily be contaminated by land surface activities due to little or no fine-grained materials overlying the top of the aquifer. The buried drift aquifer provides a fair yield and adequate supply of water locally, and is not as susceptible to contamination, but is high in dissolved solids and iron. The Cretaceous bedrock aquifer generally provides poor yields, is deeply buried, and has high concentrations of sulfate, dissolved solids, and iron. The deepest aquifer, the Sioux Quartzite only provides low yield water where it is heavily fractured or jointed, is also deeply buried, and has a variable water quality.

The water table in the Worthington area generally exists within loam to clay loam till not typically considered suitable as an aquifer. Regionally, the water table is evident and directly connected hydrologically to surface waters including lakes and streams (Magner and Regan,

1994). Typically the water table is within 50 feet of the land surface and approximates a subdued surface topography. Locally, groundwater in this upper water-bearing unit discharges toward topographically low areas and surface waters. Regionally, groundwater movement in the water table aquifer and buried drift aquifers in the Quaternary glacial deposits is south and west or north and east away from the surface water divide that trends northwest to southeast through the City of Worthington (Figure 3).

In the areas of the Worthington public water supply wells, groundwater flow in the source water aquifers is west to east at an estimated gradient of 0.0012 to 0.0016 feet per foot (0.00037 to 0.00049 m/m). Locally, the groundwater elevations generally range from 1,600 feet above mean sea level (MSL) to 1,550 feet above MSL (487.68 to 472.44 meters above MSL). Groundwater flow in the bedrock aquifers in the Worthington area is generally south-southwesterly at elevations of 1,500 to 1,200 feet AMSL

Generally, the groundwater in the area is very hard with total dissolved solids ranging from 270 milligrams per liter (mg/L) to 2,749 mg/L with most samples exceeding 500 mg/L. Water from confined buried drift aquifers is usually more highly mineralized than water from unconfined aquifers. The higher concentrations of chemical constituents in the confined aquifers are due primarily to longer residence times, compared to the generally shorter residence times in the unconfined surficial sand and gravel aquifer. The degree of mineralization of the surficial aquifer most likely reflects the proportion of more mineralized recharge from the till and other buried drift aquifers, and less mineralized contributions from precipitation and surface runoff. Locally, the average concentrations of iron, manganese, sulfate, chloride, dissolved solids, and hardness in the surficial sand and gravel aquifer are 2.8, 0.33, 390, 16, 1,000, and 560 mg/L, respectively. The average concentrations of iron, manganese, sulfate, chloride, dissolved solids, and hardness in the buried drift aquifer are 4.5, 1.2, 812, 15, 1,480, and 1,040 mg/L, respectively.

Isotopic studies have been conducted for the Worthington public water supply wells and source water aquifers to characterize the local hydrogeologic conditions. Samples from select wells were collected in 1991 by the MDH and analyzed for tritium. The concentrations of tritium in Wells 25, 26, 28, and 30 were 15.7, 13.6, 14.8, and 16.4 tritium units (TU), respectively. Reportedly, wells open to the buried drift aquifer (Wells 19 and 22) showed no to minor detectable concentrations of tritium. Well 22 had tritium detected at 3.1 TU, a level insufficient to require the use of a SWCA for WHPA delineation. Also in 1992, an oxygen isotope study was conducted by the MPCA. Results of this study suggested that at least 80 percent of the groundwater obtained from wells near Lake Bella was derived from surface waters (Magner and Regan, 1994). The most recent isotopic analyses were completed in wells 19, 22, 27, 29, 31 in September 2013.

2.1.3 Hydrologic Conditions

The local surface waters and hydrologic features in the vicinity of the Worthington public water supply wells can be seen on Figure 1 and Figure 2. Three lakes and several small streams and ditches are present within this area. The three lakes are Okabena Lake in the southern part of the city, Ocheda Lake located 2.5 miles south of the city, and Lake Bella, approximately 6.5 miles south of the city. Lake Bella was recently created by restricting the flow of the Ochededan River that flows south from Ocheda Lake. Most of the streams, creeks, and ditches in the area are intermittent and seasonal. No major rivers are present locally, and the area is divided between the Little Sioux River, the West Fork of the Des Moines River and the Rock River major watersheds. The Little Rock River is located approximately 7 miles southwest of Worthington.

A regional surface water divide trends through Worthington from northwest to southeast. A groundwater divide for the surficial sand and gravel water table aquifer is present north to south, southwest of Worthington and west of the public water supply wells.

2.2 Land Use Information

Parcel boundaries, road centerlines, and U.S. Public Land Survey coordinates were used to define the boundaries of the DWSMA. This information was primarily used to delineate the DWSMA and determine whether the limits of the DWSMA cross political boundaries. Specific land uses and zoning within and adjacent to the DWSMA will be reviewed, evaluated, assessed, and presented in Part II of the Plan. Sanitary and storm sewer coverage and presence of large-scale pipelines within the DWSMA will be examined in Part II of the Plan.

2.3 Water Quantity Information

Information on groundwater pumping information from high capacity wells was obtained from water appropriation permits records provided in the MNDNR Permitting and Reporting System (MPARS) database and the County Well Index (CWI) managed by the MDH. No other active high capacity wells were identified within two miles of the City of Worthington's wells.

The annual pumping reported by the Public Water Supplier was used in determining the daily volume of water that is discussed in Section 4 of this document (Table 5). The Worthington public water supply system appears to utilize two different source water aquifers: An unconfined, sand and gravel channel deposit, water table aquifer utilized by Wells 20, 24, 25, 26, 27, 28, 29, and 31 located south and southwest of the city, and a buried drift, semi-confined aquifer for Wells 19 and 22 in the southern part of the city. Well logs are included as Appendix B.

The City has provided the 2009-2013 water use and pumping volume records presented in this plan to determine an appropriate discharge rate for the wells in delineating the WHPAs. In addition, the City has estimated a projected increase in groundwater use for 2018. These records are provided in Table 5. The City has no immediate plans to replace or add municipal wells. While the City continues to seek additional sources of water to meet future demands, the existing groundwater wells will continue to serve as the primary water source and, with normal precipitation, are anticipated to be adequate to meet the City's current demand.

The CWI and the MPARS were utilized to identify and quantify wells and local groundwater uses that could influence and affect the groundwater flow fields and related WHPA delineations. In addition, studies completed by the USGS, the MGS, and the MNDNR have been reviewed, and the information from these studies used, in delineating the WHPAs and performing the vulnerability assessments. Currently, there are no known, significant groundwater-use conflicts between the City and other parties

2.4 Water Quality Information

Groundwater quality information was used to update well vulnerability. The quality of the groundwater in the source water aquifers, and in the Worthington area specifically, must be evaluated and assessed for this Plan. Groundwater contamination and undesirable groundwater quality will directly impact the public water supply system. Certain naturally-occurring constituents in the groundwater also provide information that can be used to determine the vulnerability of the source water aquifer. The City publishes an annual consumer confidence report (Worthington Drinking Water Report) that contains water quality data collected over the course of the year.

Generally, the quality of the source water aquifers utilized for the Worthington public water supply is good and free of harmful contaminants and pollutants. The public water supply system has always remained in full compliance with all state and federal drinking water regulations.

Samples from the Worthington public water supply system are routinely collected and analyzed by the MDH as required under the Minnesota Public Water Supply Program and the federal *Safe Drinking Water Act*. The samples are tested for microorganisms, inorganic compounds, organic chemicals, pesticides and herbicides, and radioactive contaminants. No contaminants were detected at levels that violated federal drinking water standards; however copper was in exceedance of the federal action level. Some constituents were detected in trace amounts that were below legal limits such as arsenic, barium, fluoride, TTHM and HAA5 (byproducts of drinking water disinfection), chlorine, and lead. The 2014 Worthington Drinking Water Consumer Confidence Report is available on the Worthington Public Utilities website. There are currently no issues related to the quality of the water obtained by the public water supply wells.

The Worthington public water supply is treated for aesthetic problems through the addition of chlorine and potassium permanganate. Fluoride is also added to the water as mandated by the State of Minnesota, and a phosphate product is added to inhibit corrosion. Groundwater quality studies completed by the Minnesota Pollution Control Agency (MPCA), the USGS, the MGS, and the MNDNR have been reviewed, and the information from these studies used, in delineating the WHPAs and performing the vulnerability assessments.

3.0 General Descriptions

3.1 Description of the Water Supply System

The public water supplier currently obtains its drinking water supply from 10 primary groundwater wells. Table 1 summarizes information regarding the City wells.

3.2 Description of the Hydrogeologic Setting

The description of the hydrologic setting for the aquifer used to supply drinking water is presented in Table 3a and Table 3b and discussed in further detail below.

Figures 5, 6, 7, and 8 show the distribution of the aquifers and their stratigraphic relationships with adjacent geologic materials. They were prepared using well record data that is contained in the CWI database and topographic information from the LiDAR database available from the MNDNR. The geological maps and studies that were used to further define local hydrogeologic conditions are provided in the “Selected References” section of this report

Table 3a
Description of the Hydrogeologic Setting in the Buried Sand and Gravel Aquifer (Okabena Wellfield)

Attribute	Descriptor	Data Source
Aquifer Material	Glacial till and stream deposits	Well Logs, MGS
Porosity	0.3	MGS
Aquifer Thickness	15 ft	City Well Logs
Stratigraphic Top Elevation	1527 ft AMSL	City Well Logs
Stratigraphic Bottom Elevation	1510 ft AMSL	City Well Logs
Hydraulic Confinement	Semi-confined	City Well Logs
Transmissivity	3708 ft ² /day	The reference value was determined from pumping tests on Wells 19 (223617) and 22 (169892) in June 1988 by the MDH.
Hydraulic Conductivity	75 ft/day	See above.
Groundwater Flow Field	0.0014 ft/ft	Defined by using static water level elevations from well records in the CWI database and documents listed in the "Selected References" section of this report.

Table 3b

Description of the Hydrogeologic Setting in the Water Table Aquifer (Malcolm and Lake Bella Wellfields)

Attribute	Descriptor	Data Source
Aquifer Material	Glacial till and stream deposits	Well Logs, MGS
Porosity	0.3	MGS
Aquifer Thickness	400-450	MGS
Stratigraphic Top Elevation	Surficial (1550-1600 ft AMSL)	City Well Logs
Stratigraphic Bottom Elevation	1200 ft AMSL	MGS
Hydraulic Confinement	Unconfined	City Well Logs
Transmissivity	Range of 9,114-78,870 ft ² /day	Determined from pumping tests performed by Liesch & Assoc. in 1989 on Wells 25 (195163), 26 (654756), 28 (455791), 29 (455790) and in 2000 on Well 20 (633531) and by Banner Assoc., Inc in 2008/2009 on Well 31 (760572).
Hydraulic Conductivity	287-1,200 ft/day	Obtained from Transmissivity
Groundwater Flow Field	0.0014 ft/ft	Defined by using static water level elevations from well records in the CWI database and documents listed in the "Selected References" section of this report.

4.0 Delineation of the Wellhead Protection Area

4.1 Delineation Criteria

The boundaries for each of the City's WHPAs are shown in Figure 1 and Figure 2. Delineation criteria are presented in Tables 4a, 4b, and 5 below.

Table 4a and Table 4b describes how the delineation criteria that are specified under Minnesota Rules, part 4720.5510, were addressed for each hydrogeologic setting.

Table 4a
Description of WHPA Delineation Criteria for the Buried Sand and Gravel Aquifer

Criterion	Descriptor	How the Criterion was Addressed
Flow Boundary	Surface Water Features	The major regional and local discharge features were included in the groundwater flow model. Vertical recharge to the aquifer was represented using given varel elements
Flow Boundary	Geologic Boundaries	The boundaries of the buried sand and gravel aquifer were mapped using information from records of existing wells and information published as part of the Quaternary Geology of Southwestern Minnesota (Setterholm, 1995)
Flow Boundary	Other High-Capacity Wells	The pumping of wells other than the public water supply wells may influence the groundwater flow field(s). No high capacity wells were identified within a 2-mile radius that could significantly impact or influence the public water supply wells.
Daily Volume of Water Pumped	See Table 5	Pumping information was obtained from the Minnesota Department of Natural Resources Appropriations Permit 1979-6207. The annual pumped volumes were converted to a daily volume pumped by a well.
Groundwater Flow Field	See Figure 3	The model calibration process addressed the relationship between the calculated versus observed groundwater flow field.
Aquifer Transmissivity	Reference Value: 3,708 ft ² /day	The reference value for the transmissivity were determined from pumping tests and other data collected for the City of Worthington's WHP Plan.
Time of Travel	10 years	The public water supplier selected a 10 year time of travel.

Table 4b
Description of WHPA Delineation Criteria for the Water Table Aquifer

Criterion	Descriptor	How the Criterion was Addressed
Flow Boundary	Local Lakes and Rivers: Okabena Lake, Ocheda Lake, and Lake Bella	The rivers and lakes provided boundary conditions to the model that extended to and included these natural boundaries. They were included in the model and helped set the regional groundwater flow and water balance.
Flow Boundary	Other High-Capacity Wells	The pumping of wells other than the public water supply wells may influence the groundwater flow field(s). No high capacity wells were identified within a 2-mile radius that could significantly impact or influence the public water supply wells.
Daily Volume of Water Pumped	See Table 5	Pumping information was obtained from the Minnesota Department of Natural Resources Appropriations Permit 1979-6207. The annual pumped volumes were converted to a daily volume pumped by a well.
Groundwater Flow Field	See Figure 3	The model calibration process addressed the relationship between the calculated versus observed groundwater flow field.
Aquifer Hydraulic Transmissivity	See Table 3b Reference Values: 16,042 - 78,870 ft ² /day	The reference value for the transmissivity were determined from pumping tests and other data collected for the City of Worthington's WHP Plan. A range of transmissivity values was used to reflect changed 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.

Information provided by the public water supplier 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. Also, the projected 2018 pumping rate is shown. Previous pumping values have been reported to the MNDNR, as required by the public water supply's Groundwater Appropriation Permit No. (1979-6207). Maximum daily volume of discharge, used as an input parameter in the model, was calculated by dividing the greatest annual pumping volume by 365 days.

Table 5
Annual Volume of Water Discharged from Water Supply Wells

Well No.	Unique Well No.	2009 (MGY)	2010 (MGY)	2011 (MGY)	2012 (MGY)	2013 (MGY)	Avg. (MGY)	2018 Projected* (MGY)	Highest (gal/day)	Highest** (m ³ /day)
19	223617	45.10	62.10	41.40	43.08	41.55	46.65	50.14	170,137	644
20	633531	50.60	54.00	5.20	22.47	20.75	30.60	32.90	147,945	560
22	169892	15.30	0.00	0.00	0.00	0.00	3.06	3.29	41,918	159
24	197476	26.70	33.30	32.80	37.20	4.56	26.91	28.93	101,918	386
25	195163	204.00	220.40	194.30	212.54	177.87	201.82	216.96	603,836	2,286
26	654756	165.00	152.50	175.40	165.08	84.88	148.57	159.71	480,548	1,819
27	240094	177.10	214.80	186.30	163.68	106.67	169.71	182.44	588,493	2,228
28	455791	188.00	213.10	208.50	197.03	161.59	193.64	208.17	583,836	2,210
29	455790	64.50	32.90	86.30	91.90	110.95	77.31	83.11	303,973	1,151
31	760572	59.30	81.30	150.90	154.01	150.91	119.28	128.23	421,945	1,597
Total Volume Pumped (MGY)		995.60	1,064.40	1,081.10	1,086.99	859.73	1,017.56	1,093.88		
Notes: * Projections assume 1.5% increase in water production per year ** Pumping rate used in groundwater flow modeling MGY - million gallons per year										
Annual volumes expressed as gallons. Bold indicates greatest annual pumping volume. * Total annual volume calculated from Worthington Comprehensive Plan projections. Well volume ratio was calculated based upon 2013 pumping.										

4.2 Method Used to Delineate the Wellhead Protection Area

The WHPA for Worthington 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 surface-water features, spatial variability of geologic materials, vertical infiltration, and 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 References below). For this WHP Plan Part 1 amendment, the original conceptual model and parameters were compared to new information since 2004. New information assessed included Well 31 construction and pump test data, the removal of Wells 16, 17, and 30 from use, water chemistry results, and recharge estimates.

4.2.1 Conceptual Model

The hydrogeological conceptual model for the water table aquifer is a single layer unconfined system with channelized areas where sand and gravel deposits are concentrated within the till. The Malcolm and Lake Bella Wellfields are located in these sand and gravel channels. Regionally, groundwater flow is from the west to the east. Recharge to the aquifer primarily occurs via precipitation infiltration and is significantly higher in areas of sand and gravel deposits than in the areas of clayey till.

The sand and gravel deposits, bordered and bounded by the till, are presumed to have much higher permeabilities, be relatively thin, and have larger porosities than the till. Overall, the

aquifer is assumed to be laterally continuous with a base elevation of 1,200 feet (365 meters) above MSL corresponding to the uppermost bedrock elevation, and has a consistent thickness. Groundwater leakage from the aquifer into the bedrock is assumed to be insignificant. Figures 5-8 show cross-section views of the aquifer at the location of the wellfields.

The buried sand and gravel aquifer a relatively thin, semi-confined aquifer. The wells in the Okabena Wellfield (19 and 22) are completed to this aquifer. The source of recharge to the aquifer is primarily via leakage from the surrounding water table aquifer. A review of static water levels of wells utilizing the buried sand and gravel aquifer, as found in the CWI, shows that and local groundwater flow is northeasterly in the aquifer.

It is assumed that the three local lakes (Okabena, Ocheda, and Lake Bella) and the Ochedan River contribute a substantial amount of recharge to the water table aquifer (Magner and Regan, 1994). The presence of clay-rich geologic deposits noted in drillers' logs may prevent the direct hydraulic connection of wells in the Malcolm and Okabena Wellfields.

4.2.2 Numerical Model

Steady-state, single-layer groundwater flow models were developed to delineate the groundwater capture areas for the public supply wells. The variable nature of aquifer transmissivity was simulated in the model by changing the base elevation of the aquifer, the aquifer thickness, and hydraulic conductivity using nested inhomogeneity elements

Transmissivity values were calculated based the analysis of well pump tests conducted on wells completed in each aquifer. An aquifer test plan was submitted to and approved by the MDH. The transmissivity values indicated in the ATP and included in Appendix C were used as a starting point for refining the model. Those values are referenced above in Table 4a and Table 4b.

The model inputs for the buried sand and gravel aquifer are summarized in Table 6a. Surface water features were represented using linesink elements. Global infiltration was simulated using a given varel element. The buried aquifer was represented as an inhomogeneity with an increased porosity and permeability and decreased thickness relative to global values based off pumping test data and public supply well logs. The recharge to the buried aquifer was increased slightly to represent the likely higher infiltration rates through the stream modified till in the vicinity of the Okabena Wellfield.

The model inputs for the water table aquifer are summarized in Table 6b. Surface water features located in the far field were represented using linesink elements and nearfield surface water features were represented using both linesink elements and varel resistance elements. Resistance elements were utilized in areas where well logs indicate clay-rich geologic deposits that would likely prevent a direct hydraulic connection between surface waters and groundwater. The sand and gravel channel deposits that the public supply wells are located in were represented as inhomogeneities where the porosities and permeabilities were increased, the base elevation was raised, and the layer thickness was decreased to represent the thin, more permeable sand and gravel deposits surrounded by thick, less permeable clay till. The thicknesses of the inhomogeneities were based on data from the logs of wells in the immediate area. In addition, these same areas were assigned higher aquifer recharge values to represent the likely higher precipitation infiltration rates through these deposits

Table 6a
MLAEM Model Input Parameters for the Buried Sand and Gravel Aquifer

Model Parameter	Value	Source
Base Elevation	Global:365 m Inhomogeneity: 480 m	Estimated from local well records and geologic atlas
Aquifer Permeability	Global: 3 m/d Inhomogeneity: 23 m/d	Estimated from previous pumping tests and 2004 WHPA model
Aquifer Thickness	Global:500 m Inhomogeneity: 15 m	Estimated from local well records
Far Field Lakes and Streams and Lake Okabena	Head = lake or river elevation	Linesinks from previous model (elevations originally derived from USGS topographic quads)
Vertical Infiltration	Global: 0.000226 m/d Inhomogeneity: 0.0004 m/d	Global: published value (Smith and Westenbroek, 2015) Inhomogeneity: Estimated to represent higher infiltration through sand and gravel deposits
Porosity	Global: 0.1 Inhomogeneity: 0.3	Conservative estimates for glacial tills and sand and gravels

Table 6b
MLAEM Model Input Parameters for the Water Table Aquifer

Model Parameter	Value	Source
Base Elevation	Global:365 m Inhomogeneity 1 (Malcolm Wellfield): 475 m Inhomogeneity 2 (Lake Bella Wellfield): 460 m	Estimated from local well records and geologic atlas
Aquifer Permeability	Global: 3 m/d Inhomogeneity 1 (Malcolm Wellfield): 185 m/d Inhomogeneity 2 (Lake Bella Wellfield): 90 m/d	Estimated from previous pumping tests and 2004 WHPA model
Aquifer Thickness	Global:500 m Inhomogeneity 1 (Malcolm Wellfield): 20 m Inhomogeneity 2 (Lake Bella Wellfield): 30 m	Estimated from local well records and geologic atlas
Far Field Lakes and Streams	Head = lake or river elevation	Linesinks from previous model (elevations originally derived from USGS topographic quads)
Near Field Ponds and Lake Bella	Head = elevation Pond Resistance: 30 days Lake Resistance: 3 days	Estimated from previous WHPA model calibration
Vertical Infiltration	Global: 0.000226 m/d Inhomogeneities: 0.0007 m/d	Global: published value (Smith and Westenbroek, 2015) Channel Deposits: Estimated to represent higher infiltration through sand and gravel deposits
Porosity	Global: 0.1 Inhomogeneities: 0.3	Conservative estimates for glacial tills and sand and gravels

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.

After several iterations the solutions to the MLAEM code were within acceptable variances. The models present a generally west to east flow field influenced by local and regional surface water bodies. Groundwater elevation contours calculated by the models are depicted in Figure 3. The head elevations and groundwater flow field generated by the models generally agree with the groundwater contours depicted in Plate 3 of the 1997 *Regional Hydrogeologic Assessment of Southwestern Minnesota* (included as Appendix G of this report) and with water level information from the CWI database.

Model sensitivity is the amount of change in model results caused by the variation of a particular input parameter. Input parameters include:

- 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 *direction of groundwater flow* determines the orientation of the capture area. Variations in the direction of groundwater flow will not affect the size of the capture zone but are important for defining the areas that are the source of water to the well. The calibrated potentiometric map that is produced by the Worthington WHPP model closely matches that generated by contouring static water level data. Therefore, the direction of groundwater flow should not have a significant effect on WHPA delineation given the current knowledge of hydraulic head distribution in the aquifer.
- A *hydraulic gradient* of zero produces a circular capture zone, centered on the well. As the hydraulic gradient increases, the capture zone changes into an elliptical shape, with the well centered on the down-gradient focal point. The hydraulic gradient was determined by using water level elevations that were taken from wells that have verified locations. Generally, the accuracy of the hydraulic gradient determination is directly proportional to the amount of available data that describes the distribution of hydraulic head in the aquifer.
- The *aquifer thickness 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. Aquifer thickness was verified in the area of study based upon boring and geophysical log data. The aquifer thickness in the area of study is relatively well defined, therefore is not a variable that will change to influence the WHPA delineation. A change in porosity will affect the delineation of the WHPA, however, the value used in the model for the aquifers are relatively accepted, and therefore is not a variable that will change to influence the WHPA delineation.
- Aquifer *permeability* will influence the size and shape of the capture zone. 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, centered at the well.

4.4 Addressing Model Uncertainty

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

- Pumping Rate - For each well, a maximum historical (five-year) pumping rate or an engineering estimate of future pumping, whichever is greater (Minnesota Rules, part 4720.5510, subpart 4). The maximum historical rate was greater than projected rates and therefore used for all wells.
- To incorporate the potential hydrologic contribution of water to the aquifer from surface water bodies and runoff, the local topography and minor watersheds were used to define the SWCA for each ten-year groundwater contributing area. These boundaries were used to define the final WHPAs. The process is described in further detail in Section 4.5 below.
- A range of permeabilities were used in the areas where the channelized sand and gravel deposits are concentrated. This approach was used to account for the varying aquifer characteristics resulting suggested from the several different aquifer pumping test conducted. The range of permeabilities used included 25 to 185 meters per day in the vicinity of the Malcolm Wellfield and 90 to 380 meters per day in the vicinity of the Lake Bella Wellfield.
- The resistances used in modeling the ponds near the Malcolm and Lake Bella Wellfields were varied to account for not knowing the exact properties, resistance, thickness, or hydrologic interaction with the aquifer of the materials at the bottom of these surface water bodies. The resistance values ranged from 3 to 30 days.

Capture areas were developed by compositing flow paths for a range of aquifer thicknesses and permeabilities for times of travel of one and ten years.

4.5 Conjunctive Delineation

Based upon the sensitivity of the aquifer, the likelihood of a hydraulic connection between the surface water features and the aquifer, and the evaluation criteria outlined in the MDH Guidance for Preparing a Conjunctive Delineation dated September 7, 2006, a conjunctive delineation was required for the wells in the Malcolm and Lake Bella Wellfields. This delineation is provided in Figure 1 and Figure 2. This additional area of potential surficial contribution is identified as the Surface Water Contribution Area (SWCA). The land surface watershed area was delineated from the MN MNDNR level 08 and level 09 catchments with assistance from MDH personnel. The approach for determining the surface water contribution area was modified to include till areas which provide surface runoff to area of exposed outwash and alluvium materials that could potentially recharge the channel aquifer serving the city well. The NRCS inundation classification map for the area was used in the process.

5.0 Delineation of the Drinking Water Supply Management Area

Boundaries used to delineate the Drinking Water Supply Management Area (DWSMA) are described above in Section 3.2. The DWSMA boundaries were defined using the following features:

- public land surveys (including township, range, and section boundaries),
- roadway centerlines, and
- property parcel lines (Nobles County parcel data).

A GIS shapefile of the DWSMA is provided in Appendix D.

6.0 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 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 Assessment of Well Vulnerability

The vulnerability assessment for each well used by the public water supplier is listed in Table 1 and is based upon the following conditions:

1. Well construction meets current state Well Code specifications (Minnesota Rules, part 4725) and each well itself does not provide a pathway for contaminants to enter the aquifer used by the public water supplier.
2. None of the human-caused contaminants regulated under the federal Safe Drinking Water Act have been detected at levels indicating that any of the wells serve to draw contaminants into the aquifer as a result of pumping.
3. The geologic conditions at the Okabena Wellfield include a cover of geologic materials over the aquifer that is sufficient to retard or prevent the vertical movement of contaminants.
4. Tritium analysis, when it exists, of water from each well at levels high enough to indicate the presence of “young” water. Tritium levels indicate wells in the Malcolm and Lake Bella Wellfields are drawing water of a relatively young age.

Well vulnerability for each public supply well is identified in Table 1 above. The L-scores and geologic sensitivity ratings used in determining well vulnerability are based upon the overlying surficial geology and the presence of any protective confining units. The wells determined to be vulnerable had a low to very high geologic sensitivity to pollution. The presence of tritium in wells open to the same aquifer overrode the “not vulnerable” rating for those with low geologic sensitivities. The MDH scoring sheets can be found in Appendix F.

6.2 Assessment of Drinking Water Supply Management Area Vulnerability

The vulnerability of the DWSMAs shown in Figure 9 and Figure 10 are based upon the following information:

- Boring logs available for wells within the DWSMA were reviewed for the presence of clay as potential confining units. Geologic cross-sections were developed and are included as Figures 5 through 8.
- The MDH guidance (MDH, 1997) was followed in determining the DWSMA vulnerability. L-scores were calculated based upon MNDNR geologic sensitivity guidelines for wells within the DWSMA by the MDH. In addition, the following criteria were determined with

correspondence with MDH staff, incorporating tritium and water quality data with the hydrogeologic setting:

1. For the Malcolm and Lake Bella Wellfields, areas with tritium present indicating a surface water connection: groundwater contributing area should be very high vulnerability and surface water contributing area should be of high vulnerability
2. For the Okabena Wellfield, areas with low or no tritium present and moderate to low geologic sensitivity should be of high vulnerability.

Figures 9 and 10 show the DWSMA Vulnerability and Appendix F includes the public supply well vulnerability assessments and geologic sensitivity of wells within the DWSMAs.

7.0 Recommendations

The following plan implementation action item recommendation has been made for the Public Water Supplier to consider. The recommendation will be further evaluated during the preparation of the Part II WHP Plan Update.

Plan Implementation Category – Data Collection

Item 1 – Address deficiencies in understanding of surface water and groundwater interactions by sampling isotopes in Okabena Lake and Wells 19 and 22 (Okabena Wellfield). Quarterly sampling should be performed in year 2 of implementation. Contact the MDH Source Water Hydrologist to develop a sampling strategy.

8.0 Standard of Care

The interpretations presented in this report are based on local data collected during this study and previous studies, such as current and historical pumping tests and regional data collected from governmental agencies. Data collected and analyzed by others and used in this report may not be precise or accurate. This Plan does not account for any variations that may occur between points of exploration; geologic and hydrogeologic conditions likely differ across the study area. Also, it must be noted that seasonal and cyclical fluctuations in the hydrogeologic characteristics and properties of the aquifers will occur.

The scope of this report and the corresponding groundwater flow model and calculations is limited to the delineation of capture zones for the Worthington municipal wells. Use of the groundwater flow model by other parties or for other purposes is not advised. Use or modification of the model for purposes other than the delineation of capture zones must be done with caution and a full understanding of the inherent assumptions and limitations of the data.

This Plan represents our understanding of the significant aspects of the local geologic and hydrogeologic conditions; the conclusions are based on our hydrogeologic and engineering judgment, understanding and perspective, and represent our professional opinions. These opinions were arrived at in accordance with the currently accepted standard of care for geologic and engineering practices at this time and location. No warranty is implied or intended.

9.0 Selected References

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Figures

Figure 1 – WHPA and DWSMA, Okabena and Malcolm Wellfields

Figure 2 – WHPA and DWSMA, Lake Bella Wellfield

Figure 3 – Ambient Groundwater Flow Field

Figure 4 – Surficial Geology and Cross Section Locations

Figure 5 – Geologic Cross Section A-A'

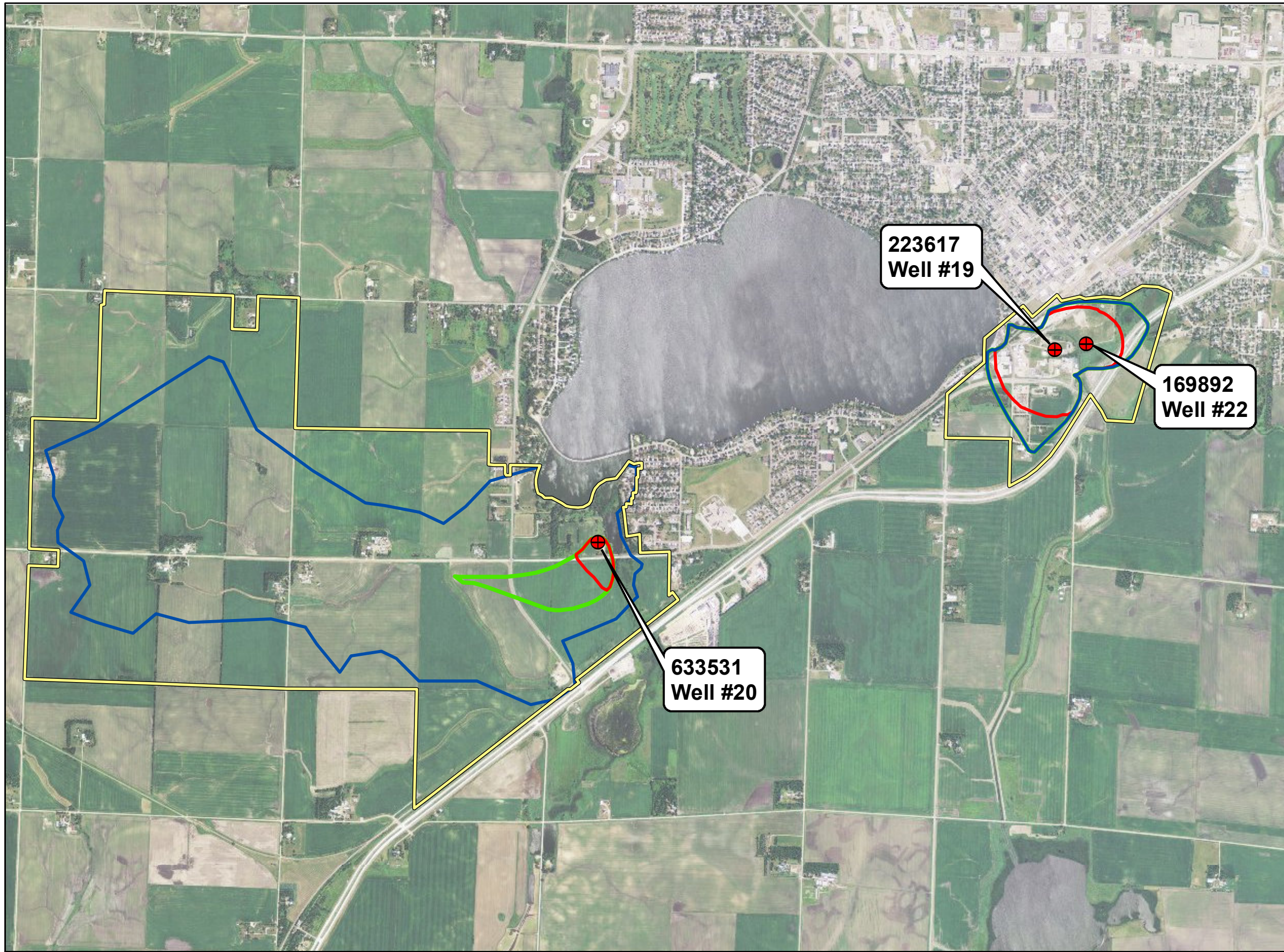
Figure 6 – Geologic Cross Section B-B'

Figure 7 – Geologic Cross Section C-C'

Figure 8 – Geologic Cross Section D-D'

Figure 9 – DWSMA Vulnerability, Okabena and Malcolm Wellfields

Figure 10 – DWSMA Vulnerability, Lake Bella Wellfield

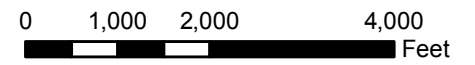


- Legend**
- Public Supply Wells
 - ERA: 1-year time of travel
 - Groundwater 10-year Capture Zone
 - WHPA
 - DWSMA

223617
Well #19

169892
Well #22

633531
Well #20



Projection: UTM Zone 15N, NAD 83 (m)
Source: USDA NAIP
Map By: jam




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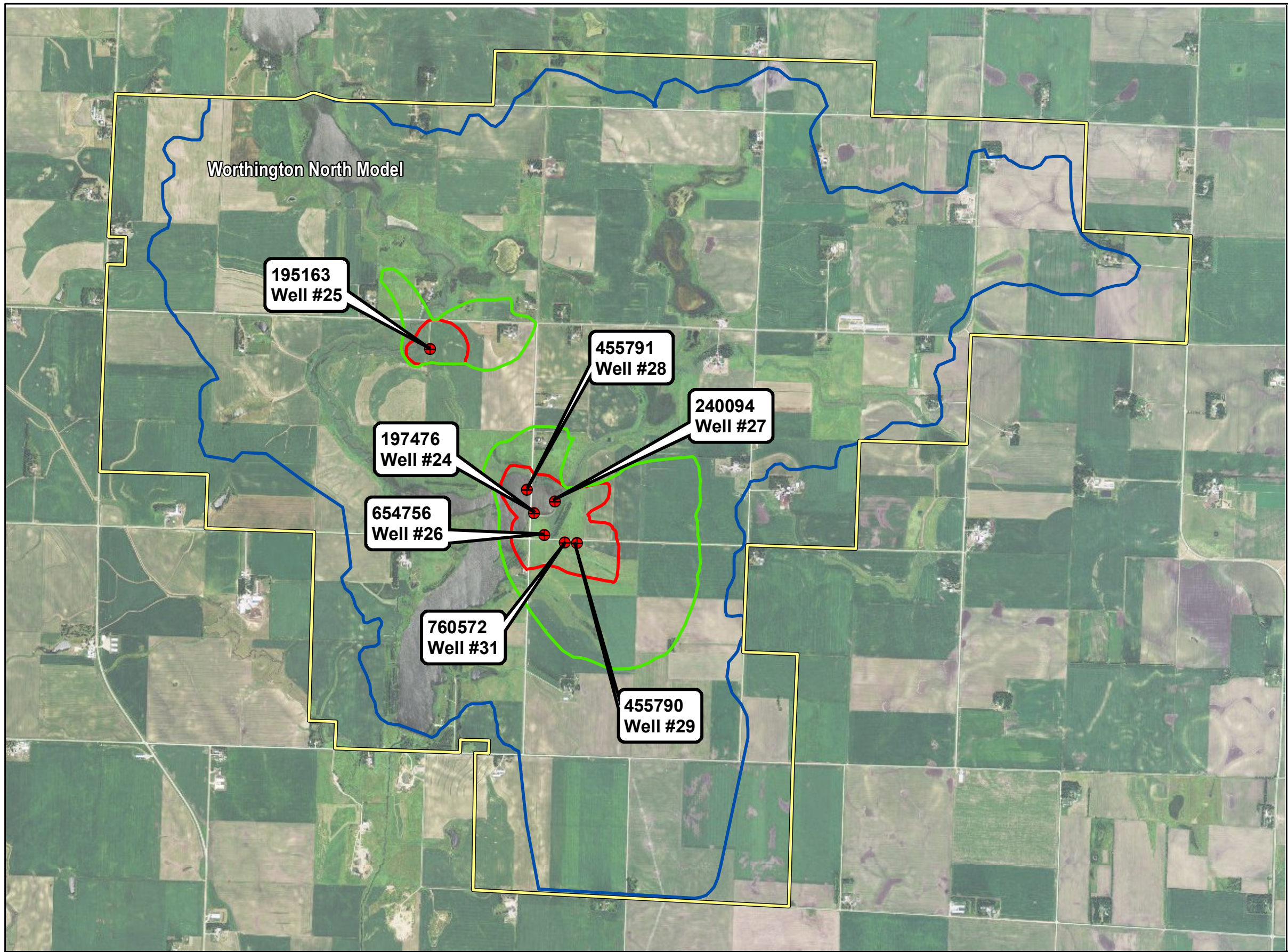
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WELLHEAD PROTECTION PLAN

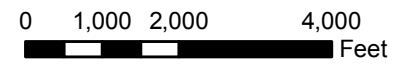
Worthington, Minnesota

**Wellhead Protection
Areas - Okabena
and Malcolm Wellfields**

**Figure
1**



- Legend**
- Public Supply Wells
 - ERA: 1-year time of travel
 - Groundwater 10-year Capture Zone
 - WHPA
 - DWSMA



Projection: UTM Zone 15N, NAD 83 (m)
 Source: USDA NAIP
 Map By: jam



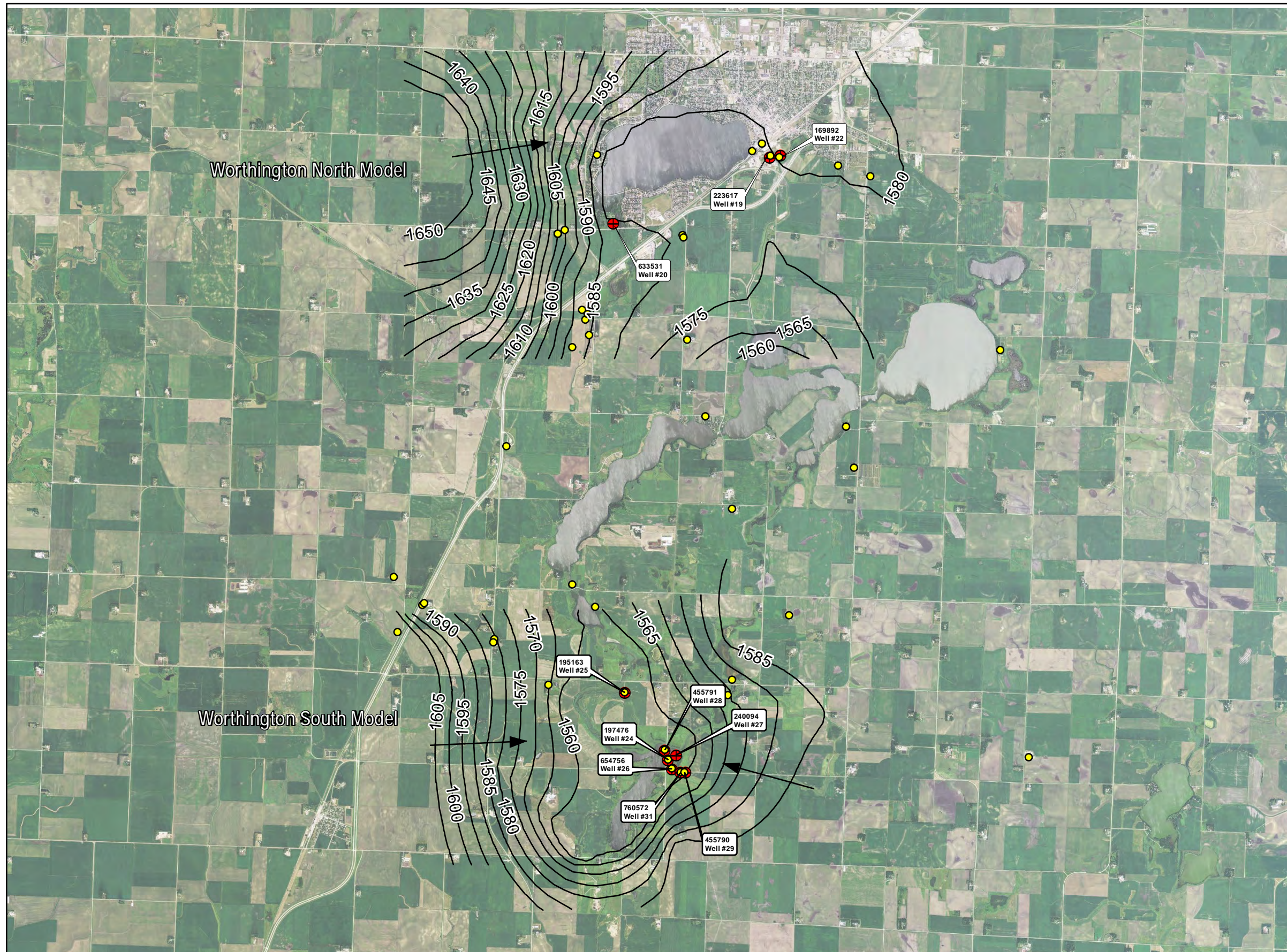

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WELLHEAD PROTECTION PLAN Worthington, Minnesota

**Wellhead Protection
 Areas - Lake Bella
 Wellfield**

**Figure
 2**



Legend

- Public Supply Wells
- Model Calibration Wells
- Calculated Ambient Groundwater Flow Field (ft. AMSL)



Projection: UTM Zone 15N, NAD 83 (m)
 Source: USDA NAIP
 Map By: jam





Project Number
 WORTC 126958

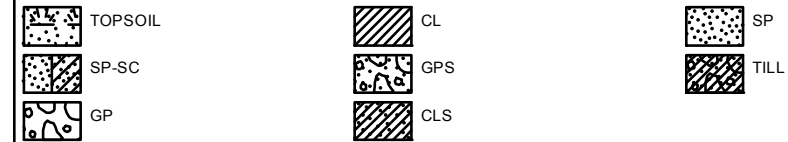
WELLHEAD PROTECTION PLAN Worthington, Minnesota

Lines of Cross-Section
 and Surficial Geology

Figure
 4

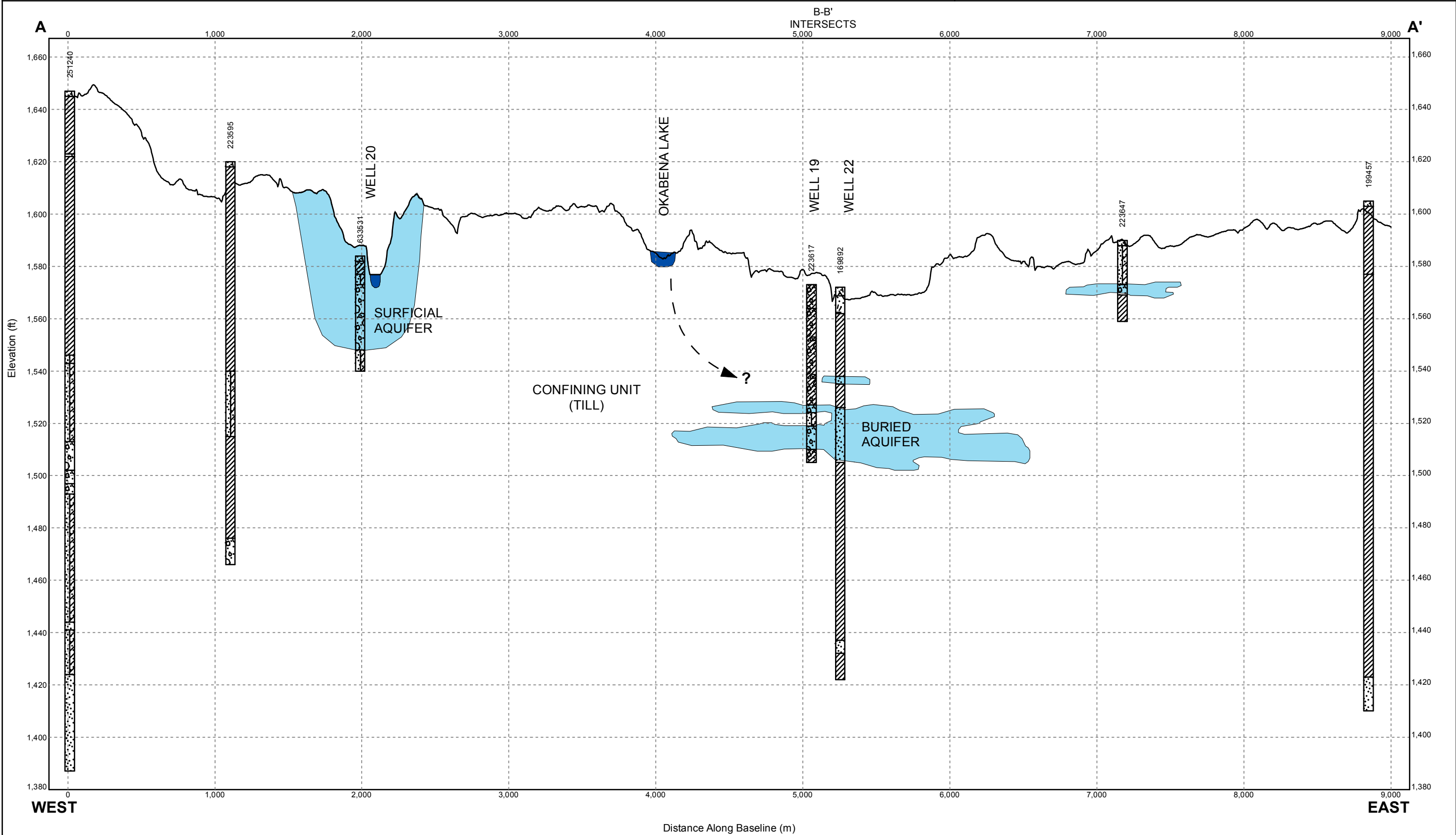
**FIGURE 5
 CROSS-SECTION A—A'**

SUBSURFACE DIAGRAM



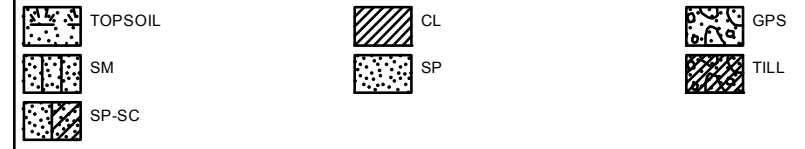
CLIENT City of Worthington
 PROJECT NUMBER 126598

PROJECT NAME WHP Plan Part 1 Amendment
 PROJECT LOCATION _____



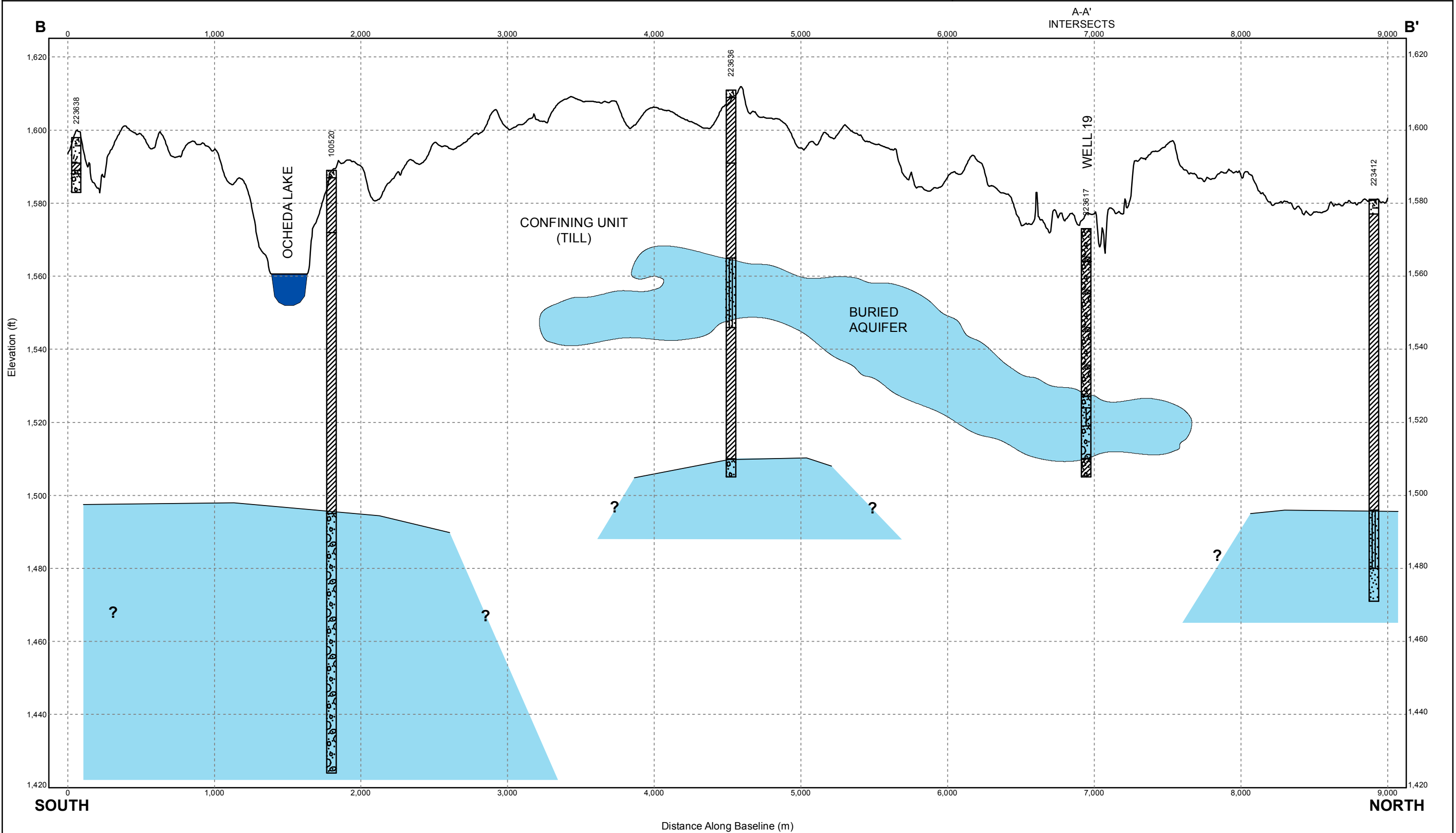
**FIGURE 6
 CROSS-SECTION B—B'**

SUBSURFACE DIAGRAM



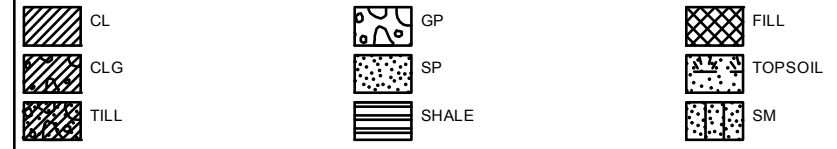
CLIENT City of Worthington
 PROJECT NUMBER 126598

PROJECT NAME WHP Plan Part 1 Amendment
 PROJECT LOCATION _____



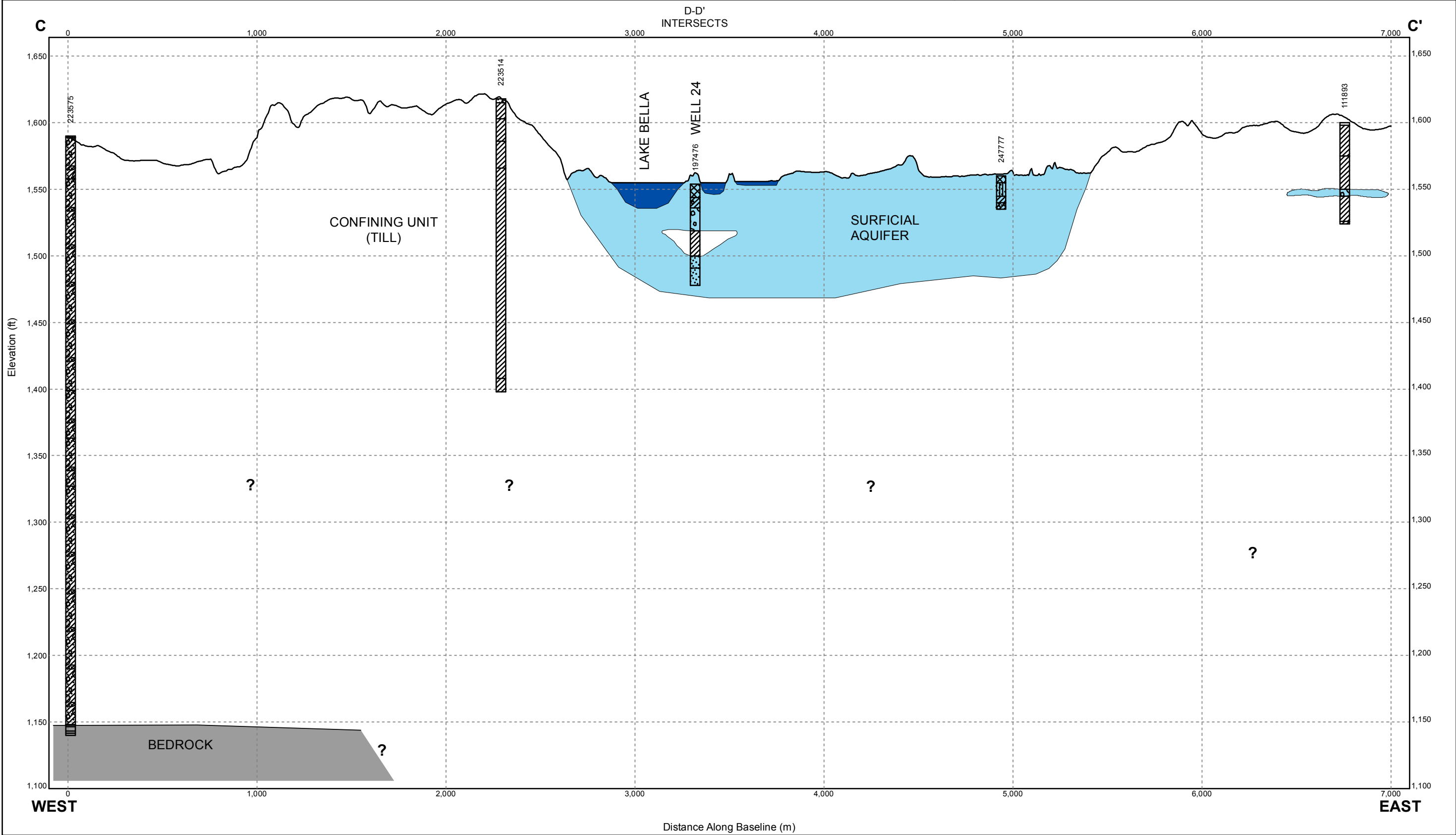
**FIGURE 7
 CROSS-SECTION C—C'**

SUBSURFACE DIAGRAM



CLIENT City of Worthington
 PROJECT NUMBER 126598

PROJECT NAME WHP Plan Part 1 Amendment
 PROJECT LOCATION _____



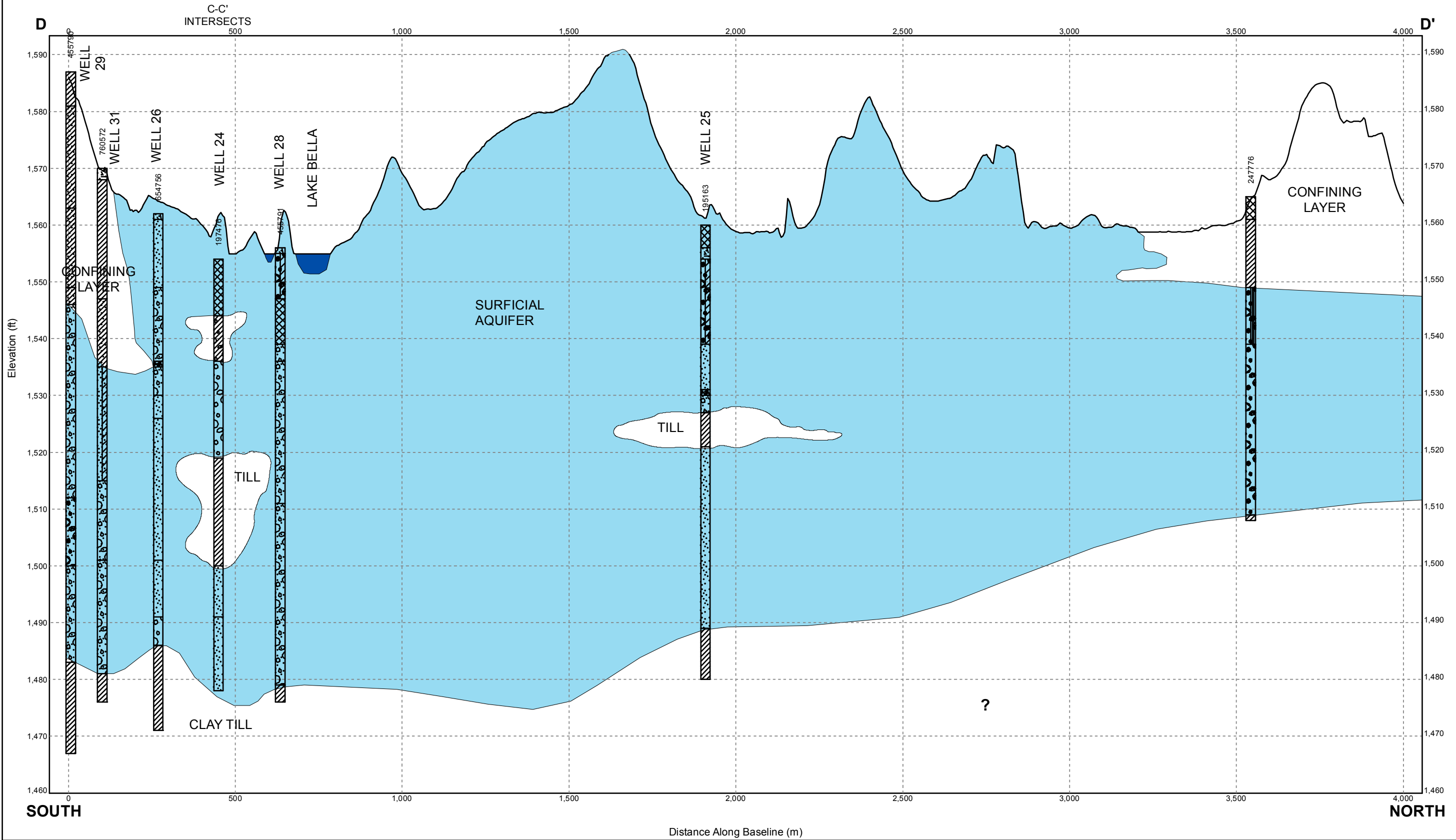
**FIGURE 8
 CROSS-SECTION D—D'**

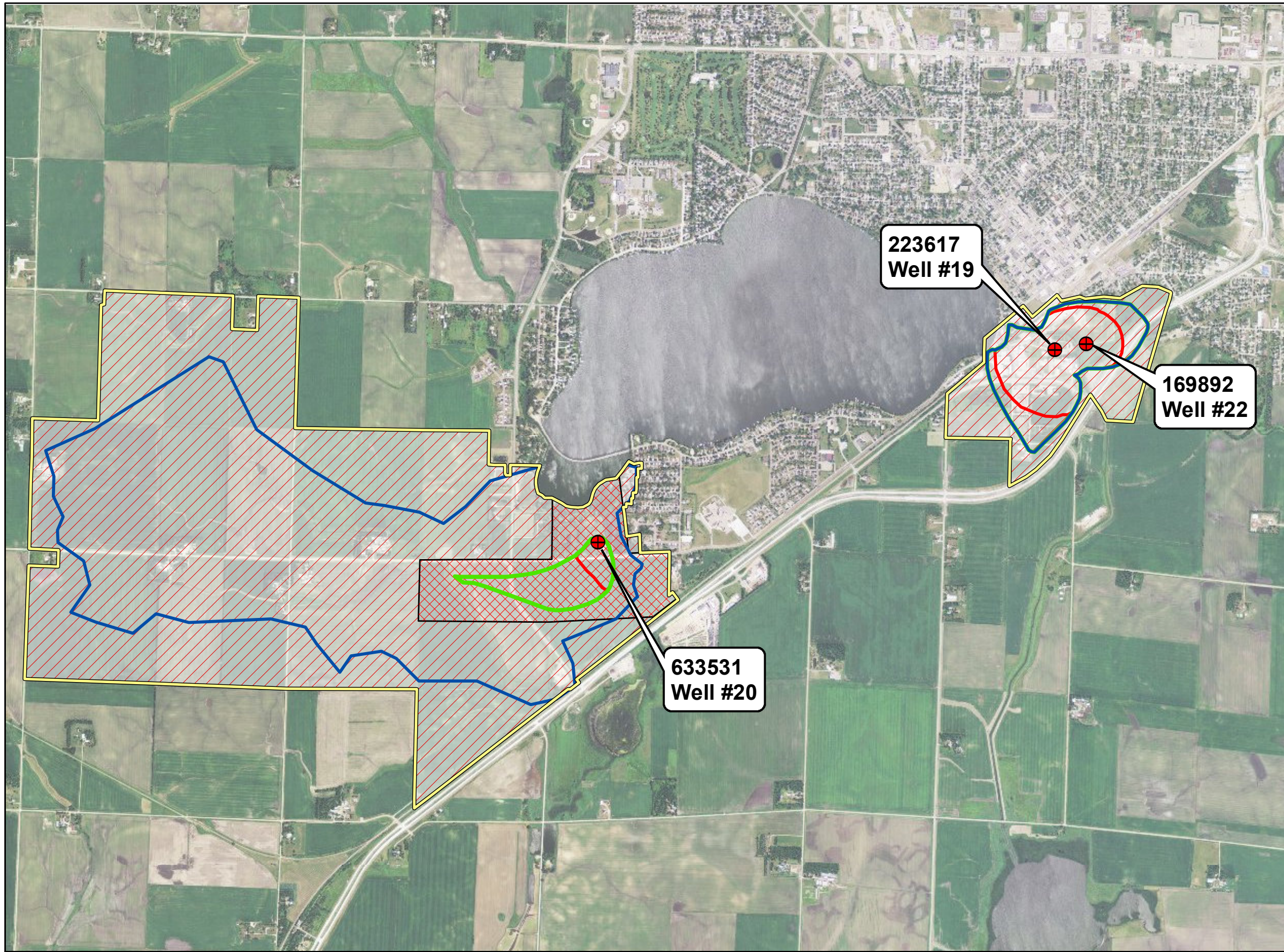
SUBSURFACE DIAGRAM

- | | | | | | |
|--|-------|--|----------|--|-------|
| | FILL | | TOPSOIL | | GW-GC |
| | SP | | BLDRCBBL | | GPS |
| | CL | | CLG | | GP |
| | GW-GM | | GW | | CLS |

CLIENT City of Worthington
 PROJECT NUMBER 126598

PROJECT NAME WHP Plan Part 1 Amendment
 PROJECT LOCATION _____





Legend

- Public Supply Wells
- ERA: 1-year time of travel
- Groundwater 10-year Capture Zone
- WHPA
- DWSMA

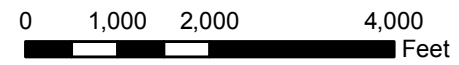
DWSMA Vulnerability

- High
- Very High

223617
Well #19

169892
Well #22

633531
Well #20



Projection: UTM Zone 15N, NAD 83 (m)
Source: USDA NAIP
Map By: jam



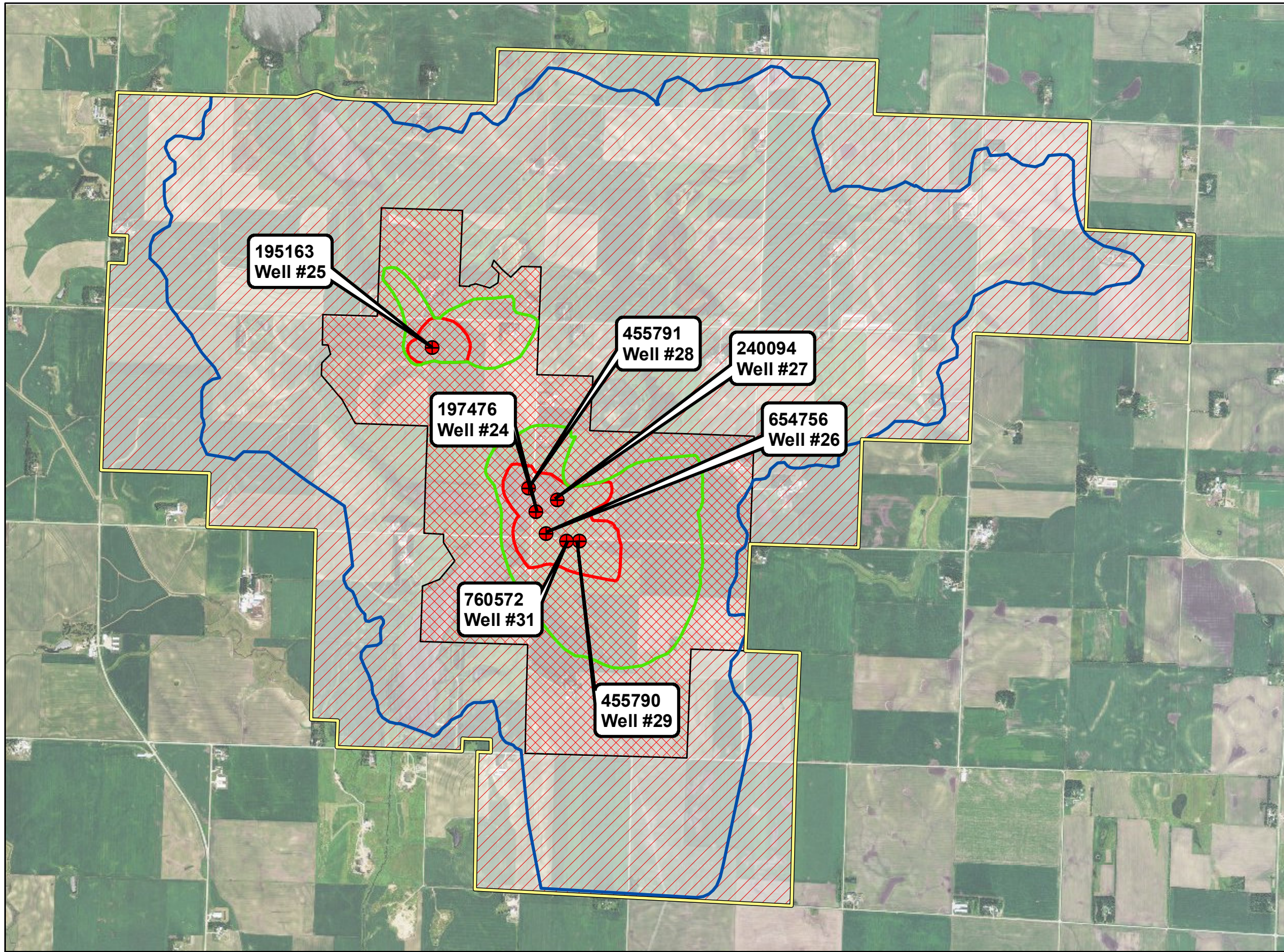

3535 VADNAIS CENTER DR.
ST. PAUL, MN 55110
PHONE: (651) 490-2000
FAX: (651) 490-2150
WATTS: 800-325-2055
www.sehinc.com

Project Number
WORTC 126958






WELLHEAD PROTECTION PLAN Worthington, Minnesota

**DWSMA Vulnerability
Okabena and
Malcolm Wellfields**



**Figure
9**

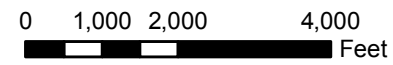


Legend

-  Public Supply Wells
-  ERA: 1-year time of travel
-  Groundwater 10-year Capture Zone
-  WHPA
-  DWSMA

DWSMA Vulnerability

-  High - Surface Water Contribution Area
-  Very High - Groundwater Capture Area



Projection: UTM Zone 15N, NAD 83 (m)
 Source: USDA NAIP
 Map By: jam




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WELLHEAD PROTECTION PLAN

Worthington, Minnesota

DWSMA Vulnerability
Lake Bella Wellfield

Figure
10

Appendix A

Scoping Decision Notice



Protecting, maintaining and improving the health of all Minnesotans

October 4, 2013

Mr. Eric Roos, Water Superintendent
Worthington Public Utilities
P.O. Box 458
Worthington, Minnesota 56187-0458

Dear Mr. Roos:

Subject: Scoping Decision Notice No. 1 for Worthington Public Utilities, PWSID 1530011, for Amending the Wellhead Protection Plan

This letter provides notice of the results of the Scoping 1 meeting that Terry Bovee and I (Minnesota Department of Health) held with you on September 16, 2013, to amend your wellhead protection plan. During the meeting, we discussed the preparation of Part I of a Wellhead Protection Plan that will document the 1) delineation of a wellhead protection area, 2) delineation of a drinking water supply management area, and 3) assessments of well and aquifer vulnerability related to these areas for the primary water supply wells that are used by Worthington Public Utilities (WPU). As you may remember, the wellhead protection area is the surface and subsurface area surrounding your public water supply wells through which contaminants are likely to move and affect your drinking water supply. The drinking water supply management area is the area delineated using identifiable landmarks that reflect the wellhead protection area boundaries as closely as possible.

The system will have until June 15, 2016, to complete the amendment of its entire Wellhead Protection Plan, Part I and Part II. The Minnesota Department of Health (MDH) highly recommends that half of the time allotted be dedicated to completing Part II of the plan.

It is our understanding that you will be contracting a consultant to prepare the delineations and vulnerability assessments for the system for amending its Wellhead Protection Plan. MDH has a draft Request for Proposal (RFP) that can be used to help select a competent consultant that has experience in wellhead protection planning and, in particular, with preparing a Part I report. Please contact me at the phone number below if you want to discuss using the draft RFP.

Mr. Eric Roos
Page 2
October 4, 2013

At our meeting, we discussed rule requirements and the types of information needed to amend the Part I report. The Wellhead Protection Plan must be prepared in accordance with Minnesota Rules, parts 4720.5100 to 4720.5590. General wellhead protection requirements and criteria for delineating the wellhead protection area and data reporting are presented in Minnesota Rules, parts 4720.5500 to 4720.5510.

The enclosed Scoping Decision Notice No. 1 formally identifies the information the system must provide to MDH to meet rule requirements for amending and preparing Part I of the Wellhead Protection Plan. The wellhead rule refers to the existing information required for wellhead planning as data elements. Much of this information is available in the public domain, as described in the Scoping Decision Notice No. 1 form. You only need to provide the information that is not in the public domain and, therefore, not available to MDH. The Scoping Decision Notice No. 1 form also 1) lists the Minnesota unique well number and well construction for each well that will be included in the Wellhead Protection Plan [Table 1]; 2) lists the pumping volumes for each well [Table 2]; and 3) includes a map of the well locations. A summary of the information the PWS needs to provide is included at the end of the Scoping Decision Notice No. 1 form.

After your consultant has had an opportunity to develop a conceptual model of the local hydrogeologic setting, we would like to meet with your consultant to discuss the proposed delineation approach. This pre-delineation meeting may be accomplished by a conference call if 1) MDH approves, and 2) the consultant provides figures for the discussion beforehand.

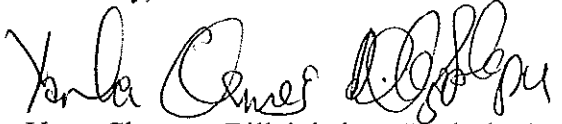
Prior to finalizing the wellhead protection area boundaries, we highly recommend that MDH informally review preliminary model results and assess whether any changes are needed to meet rule requirements. Model input and solution files should be submitted in electronic form. The same applies to geographical data, such as the wellhead protection area and drinking water supply management area. When geographic data are submitted electronically, ArcInfo export or ArcView shapefile formats are preferred. It will greatly accelerate our review if these geographic data use the 1983 North American Datum (NAD83), Universal Transverse Mercator, Zone 15 North (UTM, Z15N) projection, with meter distance units. Other datum and projection systems are acceptable as long as they are documented. Specific questions regarding electronic geographic data can be directed to Michael Baker, Source Water Protection Unit, at 651/201-4651.

Finally, it is our understanding that you will serve officially as the wellhead protection manager on behalf of the system. You are responsible for providing written notice to local units of government of the city's intent to amend the Wellhead Protection Plan, as required by the wellhead protection rule (part 4720.5300, subpart 3). A copy of this notice should be forwarded to MDH and must include a list of the city wells, their unique well numbers, and contact information for you as Wellhead Protection manager. If you do not have a copy of your original notice from your previous WHP Plan, Terry Bovee, your Source Water Protection Unit Planner can provide you with some examples of the notification of intent that other communities have used. Please contact him at 507/344-2744.

Mr. Eric Roos
Page 3
October 4, 2013

In closing, we look forward to working with you on amending your Wellhead Protection Plan. If you have any questions regarding our comments, please contact me at 651/201-4686 or at yarta.clemens-billaigbakpu@state.mn.us.

Sincerely,



Yarta Clemens-Billaigbakpu, Hydrologist
Source Water Protection Unit
Environmental Health Division
P.O. Box 64975
St. Paul, Minnesota 55164-0975

YC-B:ds-b

Enclosures: Scoping Decision Notice No. 1, Summary of Data Requested, Table 1 - Public Water Supply Well Information, Table 2 - Annual Volume of Water Pumped From PWS Wells, Map of Well Locations

cc: Terry Bovee, MDH, Mankato District Office
Aaron Myer, Minnesota Rural Water Association
Ron Struss, Minnesota Department of Agriculture

SCOPING DECISION NOTICE No. 1 (Vulnerable Setting)

The purpose for the first Scoping Meeting, as required by Minnesota Rules, part 4720.5310, is to discuss the information necessary for preparing the Part I Report of a Wellhead Protection Plan. The Part I Report identifies the area that provides the source of drinking water for the public water supply (PWS) so that the PWS can develop land use or management practices to protect their groundwater resource from contamination. Specifically, the Part I Report documents the delineation of the wellhead protection area (WHPA), the delineation of the drinking water supply management area (DWSMA), and assesses the vulnerability of the PWS well(s) and DWSMA.

The wellhead rule (Minnesota Rules, part 4720.5310) refers to the information required for wellhead planning as data elements. This form lists the data elements stated in Minnesota Rules, part 4750.5400. The Minnesota Department of Health (MDH) uses this form to designate which data elements are needed to prepare the Part I Report, based on the hydrogeological setting, vulnerability of the well(s), and aquifer information known at the time of the Scoping 1 Meeting.

Name of Public Water Supply		Date	
Worthington Public Utilities		October 4, 2013	
Name of the Wellhead Protection Manager			
Mr. Eric Roos, Water Superintendent			
Address		City and State	Zip
P.O. Box 458		Worthington, Minnesota	56187-0458
Unique Well Numbers		Phone	
223617(Well 19), 633531(Well 20), 169892(Well 22), 197476(Well 24), 195163(Well 25), 455788(Well 26), 240094(Well 27), 455791(Well 28), 455790 (Well 29), 760572 (Well 31)		507-372-8680	

Instructions for Completing the Scoping No. 1 Form

N	D	V	S	N = If this box is checked with an "X," this data element is NOT necessary for the Part I Report of your Wellhead Protection Plan. This data element may be identified later at the Scoping 2 Meeting and used for the Part 2 Report. Please go to the next data element.
<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	

N	D	V	S	D = If this box is checked with an "X," the preparer of the Part I Report is required to use this information for the DELINEATION of the WHPA or the DWSMA. If there is no check in the "S" box, this information is available in the public domain or is on file at MDH.
<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	

N	D	V	S	V = If this box is checked with an "X," the preparer of the Part I Report is required to use this information for the VULNERABILITY assessment of the PWS well(s) or the DWSMA. If there is no check in the "S" box, this information is available in the public domain or is on-file at MDH.
<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	

N	D	V	S	S = If this box is checked with an "X," the PWS must SUBMIT the information to the MDH.
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	

DATA ELEMENTS ABOUT THE PHYSICAL ENVIRONMENT

A. PRECIPITATION				
N	D	V	S	A.1: An existing map or list of local precipitation gauging stations.
	X			
Technical Assistance Comments: Precipitation values can be used to determine the local recharge in the groundwater model. The map can be used to determine the closest gauging station. The locations of the gauging stations are available in the public domain.				
N	D	V	S	A.2: An existing table showing the average monthly and annual precipitation, in inches, for the preceding five years.
	X		X	
Technical Assistance Comments: This information may be used for determining local recharge for the groundwater model. This information may be available in the public domain if there is a local gauging station, or may be obtained from the local wastewater treatment plant.				
B. GEOLOGY				
N	D	V	S	B.1: An existing geologic map and a description of the geology, including aquifers, confining layers, recharge areas, discharge areas, sensitive areas as defined in Minnesota Statutes, section 103H.005, subdivision 13, and groundwater flow characteristics.
	X	X	X	
Technical Assistance Comments: Information of this type is required to characterize the geologic and hydrogeologic setting of the PWS well field(s). This information is used to define aquifer geometry, location and magnitude of the recharge and discharge areas, and groundwater flow information. Aquifer tests or alternatives listed in MN Rules, part 4720.5510, subpart 6, can be used to help characterize flow in the aquifer. Reference all information used to develop the conceptual model of the geologic setting and submit to MDH only the information that is not available in the public domain.				
N	D	V	S	B.2: Existing records of the geologic materials penetrated by wells, borings, exploration test holes, or excavations, including those submitted to the department.
	X	X	X	
Technical Assistance Comments: Information of this type may be useful to refine the understanding of the geologic and hydrogeologic setting on a local basis. Submit only if the PWS or city has information of test drilling or site investigations conducted by the city that is not available in the public domain.				
N	D	V	S	B.3: Existing borehole geophysical records from wells, borings, and exploration test holes.
	X	X	X	
Technical Assistance Comments: Information from geophysical records may provide additional information about aquifer thickness, well construction, and water level information at a local scale. Submit only if the information is not available in the public domain.				
N	D	V	S	B.4: Existing surface geophysical studies.
	X	X	X	
Technical Assistance Comments: Information from geophysical studies may be useful to refine the understanding of the geology on a local basis. Submit only if the information is not available in the public domain.				
C. SOILS				
N	D	V	S	C.1: Existing maps of the soils and a description of soil infiltration characteristics.
	X	X		
Technical Assistance Comments: This information is in the public domain and can be used to delineate the WHPA and assess the vulnerability of the DWSMA because it indicates the underlying geology.				
N	D	V	S	C.2: A description or an existing map of known eroding lands that are causing sedimentation problems.
X				
Technical Assistance Comments:				

D. WATER RESOURCES

N	D	V	S	D.1: An existing map of the boundaries and flow directions of major watershed units and minor watershed units.
	X			
Technical Assistance Comments: This information is in the public domain and may be used to delineate the surface water contribution area of the WHPA.				
N	D	V	S	D.2: An existing map and a list of public waters as defined in Minnesota Statutes, section 103G.005, subdivision 15, and public drainage ditches.
	X	X		
Technical Assistance Comments: This information is in the public domain and may be used to delineate the surface water contribution area of the WHPA and determine the vulnerability of the DWSMA.				
N	D	V	S	D.3: The shoreland classifications of the public waters listed under sub-item (2), pursuant to part 6120.3000 and Minnesota Statutes, sections 103F.201 to 103F.221.
X				
Technical Assistance Comments:				
N	D	V	S	D.4: An existing map of wetlands regulated under Chapter 8420 and Minnesota Statutes, section 103G.221 to 103G.2373.
X				
Technical Assistance Comments:				
N	D	V	S	D.5: An existing map showing those areas delineated as floodplain by existing local ordinances.
X				
Technical Assistance Comments:				

DATA ELEMENTS ABOUT THE LAND USE

E. LAND USE

N	D	V	S	E.1: An existing map of parcel boundaries.
	X		X	
Technical Assistance Comments: This information may be helpful in delineating the DWSMA, if available. If this information is provided, identification numbers must be provided for each parcel. An electronic format for the map is preferable.				
N	D	V	S	E.2: An existing map of political boundaries.
	X		X	
Technical Assistance Comments: Please provide this information if the boundaries have been updated/changed. This information may be helpful in delineating the DWSMA. An electronic format for the map is preferable.				
N	D	V	S	E.3: An existing map of public land surveys, including township, range, and section.
	X			
Technical Assistance Comments: This information is available in the public domain and may be helpful in delineating the DWSMA.				
N	D	V	S	E.4: A map and an inventory of the current and historical agricultural, residential, commercial, industrial, recreational, and institutional land uses and potential contaminant sources.
X				
Technical Assistance Comments:				

N	D	V	S	E.5: An existing, comprehensive land-use map.
X				
Technical Assistance Comments:				
N	D	V	S	E.6: Existing zoning map.
X				
Technical Assistance Comments:				
F. PUBLIC UTILITY SERVICES				
N	D	V	S	F.1: An existing map of transportation routes or corridors.
	X			
Technical Assistance Comments: This information is available in the public domain and may be helpful in delineating the DWSMA.				
N	D	V	S	F.2: An existing map of storm sewers, sanitary sewers, and the public water supply systems.
	X		X	
Technical Assistance Comments: Do not submit a map of the storm sewers and sanitary sewers. Describe the difference in how much water is pumped and how much is sold. The difference is the leakage that may be used as recharge in the groundwater model.				
N	D	V	S	F.3: An existing map of gas and oil pipelines used by gas and oil suppliers.
X				
Technical Assistance Comments:				
N	D	V	S	F.4: An existing map or list of public drainage systems.
	X	X		
Technical Assistance Comments: This information is available in the public domain and may be helpful in delineating the DWSMA.				
N	D	V	S	F.5: An existing record of construction, maintenance, and use of the public water supply well(s) and other wells within the DWSMA.
	X	X	X	
Technical Assistance Comments: If the information is different from that on file with MDH, please provide 1) the pumping rates for the current and previous years, and the projected annual pumping rates for the next five years for each well in the PWS; and 2) well record(s) for the PWS well(s). Information about the PWS well(s) may affect the vulnerability assessment due to rehabilitation/reconstruction of a well or changes in pumping rates.				

DATA ELEMENTS ABOUT WATER QUANTITY

G. SURFACE WATER QUANTITY				
N	D	V	S	G.1: An existing description of high, mean, and low flows on streams.
	X	X		
Technical Assistance Comments: This information is available in the public domain and may be used to determine hydraulic connections between surface water bodies and the aquifer(s) of concern.				
N	D	V	S	G.2: An existing list of lakes where the state has established ordinary high water marks.
	X			
Technical Assistance Comments: This information is available in the public domain. The information may be used to determine the WHPA.				
N	D	V	S	G.3: An existing list of permitted withdrawals from lakes and streams, including source, use, and amounts withdrawn.
	X	X	X	
Technical Assistance Comments: Only required if different from the DNR database. Surface water bodies may be in direct hydraulic connection with the aquifer(s) of concern and withdrawals may affect water levels in both the surface water and adjacent groundwater systems.				
N	D	V	S	G.4: An existing list of lakes and streams for which state protected levels or flows have been established.
	X			
Technical Assistance Comments: This information is available in the public domain and may be used to determine hydraulic connections between surface water bodies and the aquifer(s) of concern.				
N	D	V	S	G.5: An existing description of known water-use conflicts, including those caused by groundwater pumping.
	X	X	X	
Technical Assistance Comments: Please notify MDH of surface water/well interference problems of which the PWS is aware. Conflicts between use of groundwater resources and surface water bodies would indicate a hydrologic boundary that would need to be considered in delineating the WHPA.				
H. GROUNDWATER QUANTITY				
N	D	V	S	H.1: An existing list of wells covered by state appropriation permits, including amounts of water appropriated, type of use, and aquifer source.
	X	X	X	
Technical Assistance Comments: Please submit this information for wells that are not permitted by the DNR because this information may be useful in identifying the hydrologic boundary conditions that could affect the size and shape of the WHPA boundaries.				
N	D	V	S	H.2: An existing description of known well interference problems and water-use conflicts.
	X	X	X	
Technical Assistance Comments: Please notify MDH of well interference problems of which the PWS is aware. Interference problems with other wells, if present, likely indicate a hydrologic boundary that would need to be considered in making the WHPA delineation.				
N	D	V	S	H.3: An existing list of state environmental boreholes, including unique well number, aquifer measured, years of record, and average monthly levels.
	X	X	X	
Technical Assistance Comments: Only submit monthly water level measurements (with unique well numbers and dates) that are not in the public domain.				

DATA ELEMENTS ABOUT WATER QUALITY

I. SURFACE WATER QUALITY				
N	D	V	S	I.1: An existing map or list of the state water quality management classification for each stream and lake.
X				
Technical Assistance Comments:				
N	D	V	S	I.2: An existing summary of lake and stream water quality monitoring data, including: 1. bacteriological contamination indicators; 4. sedimentation; 2. inorganic chemicals; 5. dissolved oxygen; and 3. organic chemicals; 6. excessive growth or deficiency of aquatic plants.
		X	X	
Technical Assistance Comments: This information can be used to evaluate surface water/groundwater interactions and aquifer water quality. Submit if the PWS has information that is not available in the public domain.				
J. GROUNDWATER QUALITY				
N	D	V	S	J.1: An existing summary of water quality data, including: 1) bacteriological contamination indicators; 2) inorganic chemicals; and 3) organic chemicals.
	X	X	X	
Technical Assistance Comments: Submit if the PWS has information that is not available in the public domain because the information may help explain groundwater flow paths.				
N	D	V	S	J.2: An existing list of water chemistry and isotopic data from wells, springs, or other groundwater sampling points.
	X	X	X	
Technical Assistance Comments: Submit if the PWS has information that is not available in the public domain because the information may help explain groundwater flow paths.				
N	D	V	S	J.3: An existing report of groundwater tracer studies.
	X	X	X	
Technical Assistance Comments: Submit if the PWS has information that is not available in the public domain because the information may help explain groundwater flow paths.				
N	D	V	S	J.4: An existing site study and well water analysis of known areas of groundwater contamination.
		X	X	
Technical Assistance Comments: Submit if the PWS has information on contaminant sources not available in the public domain because these reports may contain additional geologic or hydrogeologic information.				
N	D	V	S	J.5: An existing property audit identifying contamination.
X				
Technical Assistance Comments:				
N	D	V	S	J.6: An existing report to the Minnesota Department of Agriculture and the Minnesota Pollution Control Agency of contaminant spills and releases.
	X	X		
Technical Assistance Comments: Notify MDH of reports on spills or contaminant releases that are on file with the PWS or city but are not in the public domain. These reports do not need to be submitted but MDH staff would like to review reports.				

Summary of Data Request Specific Data to be Provided to MDH by PWS

As discussed during the first Scoping Meeting on September 16, 2013, the public water supply (PWS) will supply the following information for Part I of their Wellhead Protection Plan to the Minnesota Department of Health. The number of the data element that refers to the information needed to prepare the Part I Report is listed in the parenthesis at the end of each request.

- 1) PWS well information: Use Tables 1 and 2, the well records for the PWS wells, and a map showing the locations of all the PWS wells, to review the accuracy of 1) all PWS well construction, 2) well locations, and 3) pumping information. (F.5)

Table 1 lists well use and construction for each of the PWS wells. Have you reconstructed any wells? Are there well records for reconstructed wells?

The enclosed map shows the locations of the primary public water supply wells. Please let us know if you feel the wells are not correctly located. These locations must be used to delineate your wellhead protection areas.

Table 2 shows the available pumping information and indicates what information the PWS needs to provide for the delineation of the capture zone. Please provide 1) the pumping data for (NAME YEAR) that was sent to the Minnesota Department of Natural Resources, 2) whether this rate was measured or estimated, and 3) the projected annual pumping amounts for the next five years.

- 2) Please provide a copy of any aquifer test or specific capacity information for the PWS wells that was obtained during well construction, maintenance, or repair. (B.1)
- 3) Is there an existing map of parcel and/or political boundaries that could be used for defining the Drinking Water Supply Management Area (DWSMA)? If you wish to use parcel lines, please provide the parcel identification number for each parcel boundary along with the map. Have the city boundaries changed? If the city boundaries have changed, please provide the new boundaries. The boundaries of the DWSMA may be larger if political boundaries are used instead of the parcel boundaries. (E.1 and E.2)
- 4) If there are private well records, soil boring reports, geophysical studies, or water level measurements in your files that MDH staff did not identify at the scoping meeting, and that would be available for MDH staff to review and copy, please notify MDH. (B.2, B.3, B.4, and H.3)
- 5) Please identify reports that you have on file relating to leaks/contamination sites that may be a concern to your drinking water supply that MDH may review and copy. (J.4)
- 6) If your files contain water chemistry data, such as bacteria, virus, inorganic, organic, or isotopic results from wells or other groundwater sampling points, that are not currently available to MDH, that MDH may review and copy, please notify MDH. (J.1 and J.2)
- 7) Please identify reports that you have in your files relating to groundwater tracer studies that have been conducted. (J.3)

Summary of Data Request

Page 2

- 8) Please provide information about other high-capacity wells in your area that may not be permitted and are not listed on the attached Table 3. (H.1)
- 9) Please describe any conflicts over water use that the PWS has been involved with, such as
1) private wells that went dry (or well interference) or 2) springs or wetlands that were affected.
Was the Department of Natural Resources involved in resolving the conflict? (G.5 and H.2)
- 10) Please describe the annual amount of water that is lost due to leaks in the distribution system. Can you identify specific parts of the distribution system where this loss occurs? (F.2)
- 11) If local precipitation information is not available in the public domain within a couple of miles and in the same geomorphic setting, please provide average monthly precipitation values from the wastewater treatment facility during the preceding five years. (A.2)
- 12) Please identify any other reports about surface water withdrawals or surface water monitoring data from lakes, streams, or wetlands that are not in the public domain that MDH staff could review and copy. (G.3 and I.2)

**Table 1 - Public Water Supply Well Information
Worthington Public Utilities**

Local Well Name	Unique Number	Use/Status ¹	Casing Diameter (inches)	Casing Depth (feet)	Well Depth (feet)	Date Constructed/Reconstructed	Well Vulnerability	Aquifer
Well 19	223617	P	12	58	63	1957	Nonvulnerable	Quaternary Buried Artesian
Well 20	633531	P	20	28.5	49	2000	Vulnerable	Quaternary Water Table
Well 22	169892	P	8	45	64	1980	Nonvulnerable	Quaternary Buried Artesian
Well 24	197476	P	12	56	76	1984	Nonvulnerable	Quaternary Buried Artesian
Well 25	195163	P	12	56	71		Vulnerable	Quaternary Water Table
Well 26	455788	P	12	44	69	1989	Vulnerable	Quaternary Water Table
Well 27	240094	P	12	52	62	1963	Vulnerable	Quaternary Water Table
Well 28	455791	P	12	50	75	1989	Vulnerable	Quaternary Water Table
Well 29	455790	P	12	77	102	1988	Nonvulnerable	Quaternary Buried Artesian
Well 31	760572	P	16	66	90	2009	Nonvulnerable	Quaternary Buried Artesian

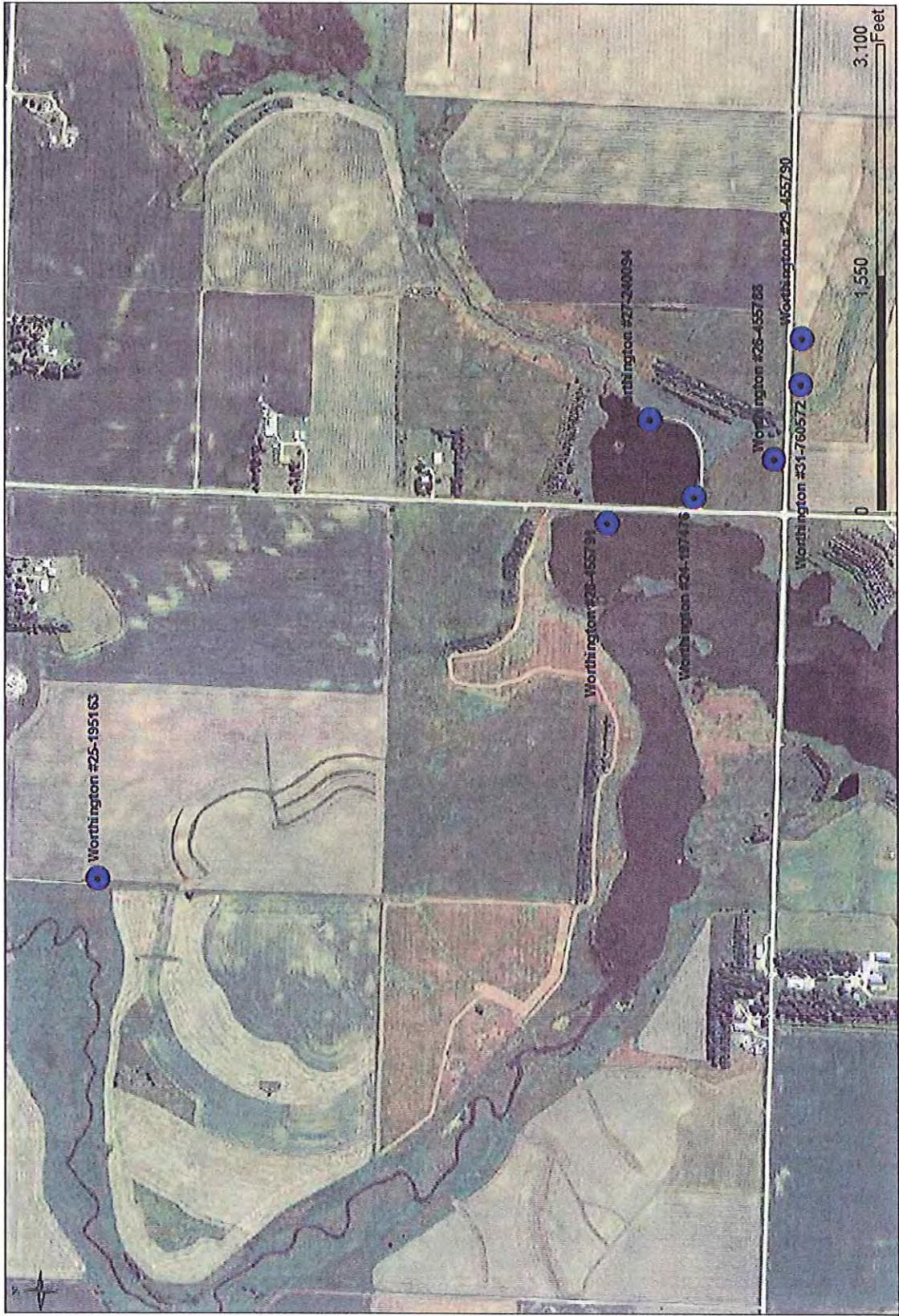
Note: 1. Primary (P) or Emergency Backup (E) Well

**Table 2 - Annual Volume of Water Pumped from PWS Wells
(gallons)**

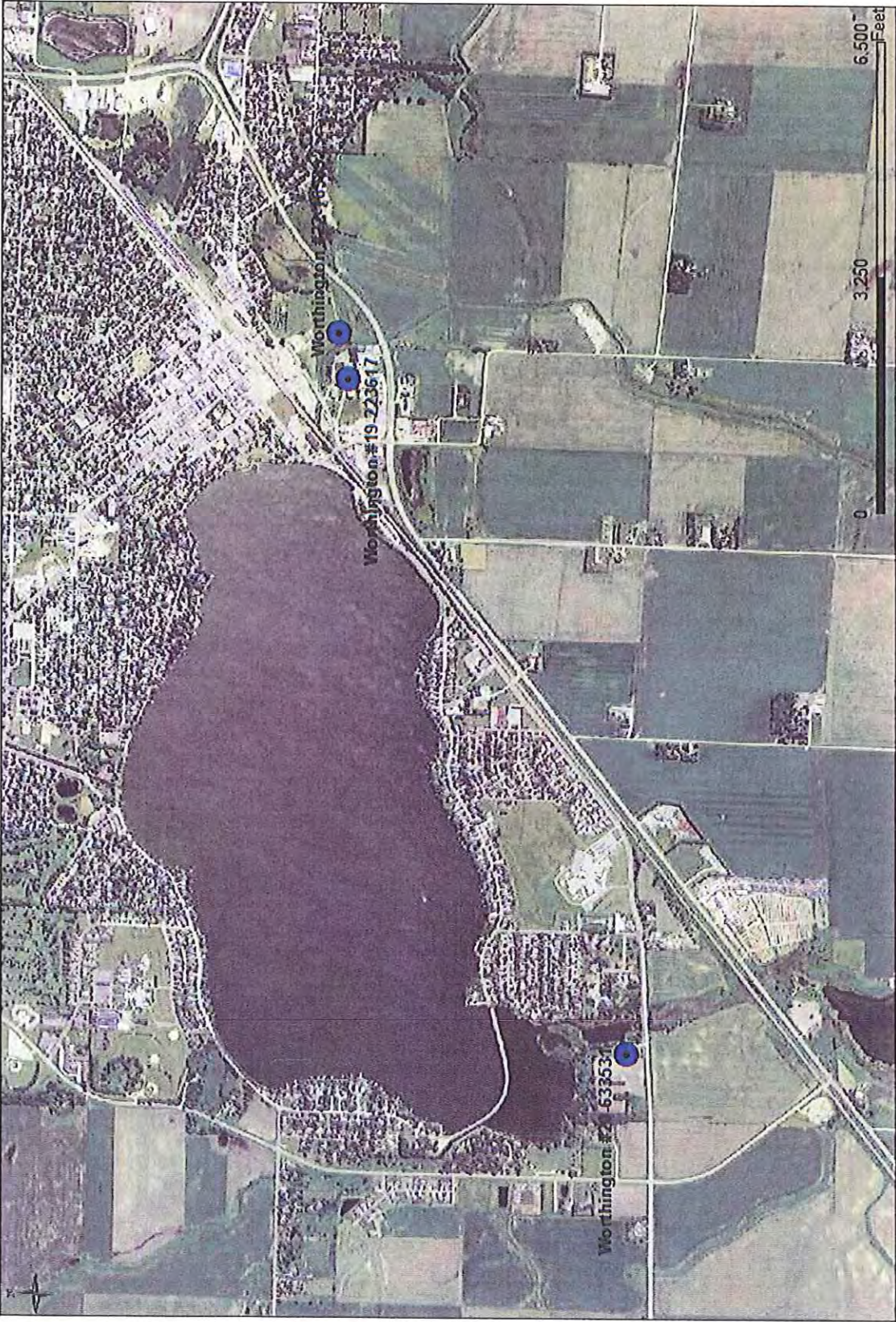
Well Name/ Number	2009	2010	2011	2012	2013	Projected* 2018
Well 19	45,100,000	62,100,000	41,400,000	*	*	
Well 20	50,600,000	54,000,000	5,200,000	*	*	
Well 22	15,300,000	No data	No data	*	*	
Well 24	26,700,000	33,300,000	32,800,000	*	*	
Well 25	204,000,000	220,400,000	194,300,000	*	*	
Well 26	165,600,000	152,500,000	175,400,000	*	*	
Well 27	177,100,000	214,800,000	186,300,000	*	*	
Well 28	188,000,000	213,100,000	208,500,000			
Well 29	64,500,000	32,900,000	86,300,000			
Well 31	59,300,000	81,300,000	150,900,000			

Source: DNR State Water Use Database System.

* Data to be provided by the city.



Map Showing City of Worthington Public Water Supply Wells in the Lake Bella Wellfield



Map Showing City of Worthington Public Water Supply Wells in the Malcolm Wellfield

Appendix B

Well Logs

Unique No. 00223617

MINNESOTA DEPARTMENT OF HEALTH
WELL AND BORING RECORD

Update Date 2001/12/26

County Name Nobles

Minnesota Statutes Chapter 1031

Entry Date 1988/04/13

Township Name Township Range Dir Section Subsection
102 40 W 26 AACDA

Well Depth Depth Completed Date Well Completed
68 ft. 63 ft. 1957/10/03

Well Name WORTHINGTON NO.19

Drilling Method

Contact's Name WORTHINGTON NO.19
WORTHINGTON MN 56187

Drilling Fluid Well Hydrofractured? Yes No
From ft. to ft.

Use Community Supply (municipal)

Casing Drive Shoe? Yes N Hole Diameter

GEOLOGICAL MATERIAL COLOR HARDNESS FROM TO

Casing Diameter Weight(lbs/ft)

TILL	TAN		0	9
TILL	GRAY		9	46
SAND & GRAVEL			46	49
TILL OR SANDY CLAY	DK. GR		49	54
SAND & GRAVEL			54	63
TILL	GRAY		63	68

24 in. to	22 ft
12 in. to	58 ft

Screen Y Open Hole From ft. to ft.

Make JOHNSON Type L

Diameter Slot Length Set Fitting
12 80 5 ft. to ft

Static Water Level 40 ft. from Land surface Date 1957/10/03

PUMPING LEVEL (below land surface)
ft. after hrs. pumping 200 g.p.m.

Well Head Completion
Pitless adapter mfr Model
Casing Protection 12 in. above grade
 At-grade(Environmental Wells and Borings ONLY)

Grouting Information Well grouted? Yes No

Nearest Known Source of Contamination
ft. direction type
Well disinfected upon completion? Yes No

Pump Not Installed Date Installed Y
Mfr name Model HP Volts
Drop Pipe Length ft. Capacity 200 g.p.m.
Type S

Any not in use and not sealed well(s) on property? Yes No

Was a variance granted from the MDH for this Well? Yes No

Well CONTRACTOR CERTIFICATION Lic. Or Reg. No. 27118

License Business Name
Name of Driller TRI STATE DRL

REMARKS, ELEVATION, SOURCE OF DATA, etc.

CITY WATER DEPT.

USGS Quad Worthington South Elevation 1573
Aquifer: QWTA Alt Id: 63-1128

Report Copy

Unique No. 633531

County Name Nobles

MINNESOTA DEPARTMENT OF HEALTH
WELL AND BORING RECORD

Minnesota Statutes Chapter 1031

Update Date

Entry Date 2001/04/25

Township Name Township Range Dir Section Subsection
102 40 W 27 CCD

Well Depth Depth Completed Date Well Completed
49 ft. 49 ft. 2000/07/03

Well Name CITY OF WORTHINGTON - WA

Drilling Method Non-specified Rotary

Contact's Name CITY OF WORTHINGTON - WATER & LIG
RR 2
WORTHINGTON MN 56187-

Drilling Fluid Well Hydrofractured? Yes No
Other From ft. to ft.

Contact's Name CITY OF WORTHINGTON - WATER & LIG
318 NINTH ST P.O. BOX 458
WORTHINGTON MN 56187-

Use Other (specify in remarks)

Casing Drive Shoe? Yes N Hole Diameter

Casing Diameter Weight(lbs/ft)
20 in. to 28.5 ft

GEOLOGICAL MATERIAL	COLOR	HARDNESS	FROM	TO
TOP SOIL	BLACK	SFT-MED	0	2
SANDY SILTY CLAY	BLACK	SFT-MED	2	7
SANDY CLAY	BLACK	SFT-MED	7	11
SAND & GRAVELS WITH FI	GRAY	SOFT	11	36
SANDY CLAY	GRAY	M.HARD	36	44

Screen Y Open Hole From ft. to ft.

Make JOHNSON Type L

Diameter Slot Length Set Fitting
8 60 20 28.5 ft. to 36.5 ft

Static Water Level 16 ft. from Land surface Date 2000/07/03

PUMPING LEVEL (below land surface)
26.7 ft. after 24 hrs. pumping 150 g.p.m.

Well Head Completion
Pitless adapter mfr Model
Casing Protection 12 in. above grade
 At-grade(Environmental Wells and Borings ONLY)

Grouting Information Well grouted? Yes No
Material From To (ft.) Amount(yds/bags)
B 0 18.5 20 S

Nearest Known Source of Contamination
ft. direction type
Well disinfected upon completion? Yes No

Pump Not installed Date Installed N
Mfr name
Model HP Volts
Drop Pipe Length ft. Capacity g.p.m
Type

Any not in use and not sealed well(s) on property? Yes No

Was a variance granted from the MDH for this Well? Yes No

USGS Quad

Elevation

Aquifer:

Alt Id: 1530011S15

Well CONTRACTOR CERTIFICATION Lic. Or Reg. No. 65252

License Business Name

Name of Driller ERVIN, B. & D.

Report Copy

Unique No. 00169892	MINNESOTA DEPARTMENT OF HEALTH			Update Date 2001/12/26				
County Name Nobles	WELL AND BORING RECORD			Entry Date 1992/08/13				
	<i>Minnesota Statutes Chapter 1031</i>							
Township Name	Township	Range	Dir	Section	Subsection	Well Depth	Depth Completed	Date Well Completed
	102	40	W	25	BBCBDB	150 ft.	64 ft.	
Well Name WORHTINGTON 22A						Drilling Method Non-specified Rotary		
Contact's Name WORHTINGTON 22A						Drilling Fluid		
WORHTINGTON MN 56187						Well Hydrofractured? <input type="checkbox"/> Yes <input type="checkbox"/> No		
						From ft. to ft.		
						Use Community Supply (municipal)		
						Casing Drive Shoe? <input type="checkbox"/> Yes <input type="checkbox"/> N		Hole Diameter
GEOLOGICAL MATERIAL						Casing Diameter		Weight(lbs/ft)
COLOR						8 in. to 45 ft		
HARDNESS								
FROM								
TO								
FILL AND BLACK DIRT						0 10		
CLAY						10 34		
SAND						34 37		
CLAY						37 46		
SAND						46 67		
CLAY						67 135		
SAND						135 140		
CLAY						140 150		
						Screen Y		Open Hole From ft. to ft.
						Make JOHNSON Type L		
						Diameter Slot Length Set		Fitting
						8 75 45 ft. to 64 ft		
						Static Water Level 0 ft. from Land surface		Date
						PUMPING LEVEL (below land surface)		
						10 ft. after 12 hrs. pumping 240 g.p.m.		
						Well Head Completion		
						Pitless adapter mfr		Model
						Casing Protection		<input checked="" type="checkbox"/> 12 in. above grade
						<input type="checkbox"/> At-grade(Environmental Wells and Borings ONLY)		
						Grouting Information		Well grouted? <input type="checkbox"/> Yes <input type="checkbox"/> No
						Nearest Known Source of Contamination		
						ft. direction		type
						Well disinfected upon completion? <input type="checkbox"/> Yes <input type="checkbox"/> No		
						Pump <input type="checkbox"/> Not Installed		Date Installed Y
						Mfr name VALLEY		
						Model		HP 15 Volts 230
						Drop Pipe Length 42 ft.		Capacity 250 g.p.m
						Type S		
						Any not in use and not sealed well(s) on property? <input type="checkbox"/> Yes <input type="checkbox"/> No		
						Was a variance granted from the MDH for this Well? <input type="checkbox"/> Yes <input type="checkbox"/> No		
USGS Quad Worthington South						Elevation 1572		
Aquifer: QBAA						Alt Id: 63-1128		
Report Copy						Well CONTRACTOR CERTIFICATION Lic. Or Reg. No. 12013		
						License Business Name		
						Name of Driller THEIN, R.		

Township Name Township Range Dir Section Subsection 101 40 W 26 CCCBCC	Well Depth 76 ft.	Depth Completed 76 ft.	Date Well Completed 1984/06/21
---	----------------------	---------------------------	-----------------------------------

Well Name WORTHINGTON NO.24	Drilling Method Non-specified Rotary
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Contact's Name WORTHINGTON NO.24 WORTHINGTON MN 56187	Drilling Fluid	Well Hydrofractured? <input type="checkbox"/> Yes <input type="checkbox"/> No From ft. to ft.
--	----------------	--

	Use Community Supply (municipal)	
	Casing Drive Shoe? <input type="checkbox"/> Yes <input type="checkbox"/> N	Hole Diameter 0 in. to 75.5 ft

GEOLOGICAL MATERIAL	COLOR	HARDNESS	FROM	TO
FILL SAND GRAVEL CLAY A	BROW		0	10
CLAY AND GRAVEL LENSE	BLACK		10	18
GRAVEL AND ROCK SMALL	VARIE		18	35
CLAY WITH LENSES OF CO			35	54
SAND NICE TOOK WATER	GRAY		54	63
SAND COARSE TOOK LOTS	GRAY		63	76

Screen Y	Open Hole From	ft. to ft.
Make JOHNSON	Type L	
Diameter Slot Length Set	Fitting	
12 60 20 55	ft. to 75 ft	

Static Water Level 7.3 ft. from Land surface	Date 1984/06/21
--	-----------------

PUMPING LEVEL (below land surface)	20.3 ft. after 20 hrs. pumping 770 g.p.m.
------------------------------------	---

Well Head Completion	
Pitless adapter mfr	Model
Casing Protection	<input checked="" type="checkbox"/> 12 in. above grade
	<input type="checkbox"/> At-grade(Environmental Wells and Borings ONLY)

Grouting Information	Well grouted?	<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No
Material	From To (ft.)	Amount(yds/bags)
G	0 40	2.5 Y

Nearest Known Source of Contamination	
40 ft.	direction N type O
Well disinfected upon completion? <input checked="" type="checkbox"/> Yes <input type="checkbox"/> No	

Pump <input checked="" type="checkbox"/> Not Installed	Date Installed N
Mfr name	
Model	HP Volts
Drop Pipe Length	ft. Capacity g.p.m
Type	

Any not in use and not sealed well(s) on property?	<input type="checkbox"/> Yes <input type="checkbox"/> No
--	--

Was a variance granted from the MDH for this Well?	<input type="checkbox"/> Yes <input type="checkbox"/> No
--	--

USGS Quad Worthington South	Elevation 1553	
Aquifer: QBAA	Alt Id: 63-1128	
Well CONTRACTOR CERTIFICATION		Lic. Or Reg. No. 91353
License Business Name		
Name of Driller		VERDECK, D.

Report Copy

Unique No. 00195163

MINNESOTA DEPARTMENT OF HEALTH
WELL AND BORING RECORD

Update Date 2003/05/21

County Name Nobles

Minnesota Statutes Chapter 1031

Entry Date 1991/12/12

Township Name Township Range Dir Section Subsection
101 40 W 27 CACCBA

Well Depth Depth Completed Date Well Completed
80 ft. 80 ft.

Well Name WORTHINGTON NO.25-B

Drilling Method Non-specified Rotary

Contact's Name WORTHINGTON NO.25-B
WORTHINGTON MN 56187

Drilling Fluid Well Hydrofractured? Yes No
From ft. to ft.

Use Community Supply (municipal)

Casing Drive Shoe? Yes N Hole Diameter

GEOLOGICAL MATERIAL	COLOR	HARDNESS	FROM	TO
FILL			0	4
DIRT	BLACK		4	6
SAND GRAVEL AND CLAY L			6	21
SAND			21	29
ROCK			29	30
ROCK AND SAND			30	33
CLAY	BLUE		33	39
SAND MED. TO COARSE			39	71
CLAY	BLUE		71	80

Screen Y Open Hole From ft. to ft.

Make JOHNSON Type Q

Diameter Slot Length Set Fitting

12 120 15 ft. to ft

Static Water Level 11 ft. from Land surface Date 1983/12/01

PUMPING LEVEL (below land surface)

22.5 ft. after 4 hrs. pumping 780 g.p.m.

Well Head Completion

Pitless adapter mfr Model
Casing Protection 12 in. above grade
 At-grade(Environmental Wells and Borings ONLY)

Grouting Information Well grouted? Yes No

Material From To (ft.) Amount(yds/bags)
G

Nearest Known Source of Contamination

ft. direction type
Well disinfected upon completion? Yes No

Pump Not installed Date Installed N

Mfr name Model HP Volts
Drop Pipe Length ft. Capacity g.p.m.
Type

Any not in use and not sealed well(s) on property? Yes No

Was a variance granted from the MDH for this Well? Yes No

Well CONTRACTOR CERTIFICATION Lic. Or Reg. No. 12050

License Business Name
Name of Driller PLUCKER, D.

USGS Quad Worthington South Elevation 1582
Aquifer: QBAA Alt Id: 63-1128

Report Copy

Unique No. 654756

County Name Nobles

MINNESOTA DEPARTMENT OF HEALTH
WELL AND BORING RECORD

Minnesota Statutes Chapter 1031

Update Date 2002/06/13

Entry Date 2001/11/15

Township Name Township Range Dir Section Subsection
101 40 W 26 CCC

Well Depth Depth Completed Date Well Completed
91 ft. 85 ft. 2001/09/17

Well Name CITY OF WORTHINGTON

Drilling Method Non-specified Rotary

Drilling Fluid Bentonite Well Hydrofractured? Yes No
From ft. to ft.

Use Community Supply (municipal)

Casing Drive Shoe? Yes N Hole Diameter
in. to 91 ft

GEOLOGICAL MATERIAL	COLOR	HARDNESS	FROM	TO
TOP SOIL	BLACK		0	1
SAND	BROW		1	13
SAND W/GRAVEL	BROW		13	26
ROCK	BROW		26	27
SAND & GRAVEL	BROW		27	32
SAND (FINE)	BROW		32	36
SAND, SOME GRAVEL	BROW		36	61
SAND	VARIE		61	71
GRAVEL	VARIE		71	76
CLAY	GRAY		76	91

Casing Diameter Weight(lbs/ft)
20 in. to 85 ft 78.6

Screen Y Open Hole From ft. to ft.

Make JOHNSON Type L

Diameter Slot Length Set Fitting
20 65 15 62 ft. to 77 ft

Static Water Level 13 ft. from Land surface Date 2001/09/17

PUMPING LEVEL (below land surface)
ft. after hrs. pumping g.p.m.

Well Head Completion
Pitless adapter mfr Model
Casing Protection Y 12 in. above grade
 At-grade(Environmental Wells and Borings ONLY)

Grouting Information Well grouted? Yes No
Material From To (ft.) Amount(yds/bags)
G 0 52 1.25 Y

Nearest Known Source of Contamination
ft. direction type
Well disinfected upon completion? Yes No

Pump Not Installed Date Installed N
Mfr name Model HP Volts
Drop Pipe Length ft. Capacity g.p.m
Type

Any not in use and not sealed well(s) on property? Yes No

Was a variance granted from the MDH for this Well? Yes No

USGS Quad Elevation
Aquifer: Alt Id:

Well CONTRACTOR CERTIFICATION Lic. Or Reg. No. 91686

License Business Name
Name of Driller RANUM, C.

Report Copy

Unique No. 654757

County Name Nobles

MINNESOTA DEPARTMENT OF HEALTH
WELL AND BORING RECORD

Minnesota Statutes Chapter 1031

Update Date 2003/06/15

Entry Date 2001/11/15

Township Name Township Range Dir Section Subsection
101 40 W 26 CCB

Well Depth Depth Completed Date Well Completed
76 ft. 73 ft. 2001/09/17

Well Name CITY OF WORTHINGTON

Drilling Method Non-specified Rotary

Contact's Name WORTHINGTON
P.O. BOX 279
WORTHINGTON MN 56187-

Drilling Fluid Bentonite Well Hydrofractured? Yes No
From ft. to ft.

Use Community Supply (municipal)

Casing Drive Shoe? Yes N Hole Diameter
in. to 76 ft

Casing Diameter Weight(lbs/ft)
20 in. to 73 ft 78.6

GEOLOGICAL MATERIAL	COLOR	HARDNESS	FROM	TO
FILL	BROW		0	7
TOP SOIL	BLACK		7	8
SILTY SAND	BROW		8	10
CLAY	BROW		10	14
COBBLES	BROW		14	15
SAND	BROW		15	26
SANDY CLAY	BROW		26	27
SAND	BROW		27	47
SAND	VARIE		47	59
ROCK & GRAVEL	VARIE		59	65
CLAY	GRAY		65	76

Screen Y Open Hole From ft. to ft.

Make JOHNSON Type L
Diameter Slot Length Set Fitting

20 65 8 57 ft. to 65 ft

Static Water Level 14 ft. from Land surface Date 2001/09/17

PUMPING LEVEL (below land surface)
ft. after hrs. pumping g.p.m.

Well Head Completion
Pitless adapter mfr Model
Casing Protection Y 12 in. above grade
 At-grade(Environmental Wells and Borings ONLY)

Grouting Information Well grouted? Yes No
Material From To (ft.) Amount(yds/bags)
G 0 47 1.25 Y

Nearest Known Source of Contamination
ft. direction type
Well disinfected upon completion? Yes No

Pump Not Installed Date Installed N
Mfr name
Model HP Volts
Drop Pipe Length ft. Capacity g.p.m
Type

Any not in use and not sealed well(s) on property? Yes No

Was a variance granted from the MDH for this Well? Yes No

USGS Quad

Elevation

Aquifer:

Alt Id: 1530011S16

Well CONTRACTOR CERTIFICATION Lic. Or Reg. No. 91686

License Business Name

Name of Driller RANUM, C.

Report Copy

Unique No. 00455791

MINNESOTA DEPARTMENT OF HEALTH
WELL AND BORING RECORD

Update Date 2001/12/26

County Name Nobles

Minnesota Statutes Chapter 1031

Entry Date 1991/12/12

Township Name Township Range Dir Section Subsection Well Depth Depth Completed Date Well Completed
101 40 W 27 DDAAAC 80 ft. 75 ft. 1989/01/24

Well Name WORTHINGTON NO.28 Drilling Method Non-specified Rotary

Contact's Name WORTHINGTON NO.28 Drilling Fluid Bentonite Well Hydrofractured? [] Yes [] No
WORTHINGTON MN 56187 From ft. to ft.

Use Community Supply (municipal)

Casing Drive Shoe? [] Yes [x] N Hole Diameter 0 in. to 50 ft

GEOLOGICAL MATERIAL	COLOR	HARDNESS	FROM	TO
TOP SOIL	BLACK		0	1
SAND GRAVEL AND CLAY	VARIE		1	9
BLACK DIRT FILL	BLACK		9	17
SAND AND GRAVEL WITH B	VARIE		17	20
SAND AND GRAVEL W/COA	VARIE		20	45
SAND AND GRAVEL NOT A	VARIE		45	77
CLAY	BLUE		77	80

Casing Diameter Weight(lbs/ft)
12 in. to 50 ft 49.56

Screen Y Open Hole From ft. to ft.

Make JOHNSON Type O

Diameter Slot Length Set Fitting
10 80 28 22 ft. to 50 ft

Static Water Level 32 ft. from Land surface Date 1989/01/24

PUMPING LEVEL (below land surface)
38.3 ft. after 24 hrs. pumping 748 g.p.m.

Well Head Completion Pitless adapter mfr Model Casing Protection [x] 12 in. above grade [] At-grade(Environmental Wells and Borings ONLY)

Grouting Information Well grouted? [x] Yes [] No
Material From To (ft.) Amount(yds/bags)
G 0 50 2 Y

Nearest Known Source of Contamination ft. direction type Well disinfected upon completion? [x] Yes [] No

Pump [x] Not Installed Date Installed N Mfr name Model HP Volts Drop Pipe Length ft. Capacity g.p.m. Type

Any not in use and not sealed well(s) on property? [] Yes [] No

Was a variance granted from the MDH for this Well? [] Yes [] No

REMARKS, ELEVATION, SOURCE OF DATA, etc.

IS THIS REALLY WELL NO.28
NO, 28 WAS DRILLED IN 1964 @ 82' DEEP
NEW NO.28 WAS DRILLED 10' AWAY FROM OLD WELL
OLD WELL WILL BE SEALED IN NEAR FUTURE

USGS Quad Worthington South Elevation 1550
Aquifer: QWTA Alt Id: 63-1128

Well CONTRACTOR CERTIFICATION Lic. Or Reg. No. 91353
License Business Name

Unique No. 00455790

County Name Nobles

MINNESOTA DEPARTMENT OF HEALTH
WELL AND BORING RECORD

Minnesota Statutes Chapter 1031

Update Date 2001/12/26

Entry Date 1991/12/12

Township Name Township Range Dir Section Subsection
101 40 W 35 BBAABD

Well Depth Depth Completed Date Well Completed
120 ft. 102 ft. 1988/12/16

Well Name WORTHINGTON 29

Drilling Method Non-specified Rotary

Contact's Name WORTHINGTON 29

WORTHINGTON MN 56187

Drilling Fluid Bentonite Well Hydrofractured? Yes No
From ft. to ft.

Use Community Supply (municipal)

Casing Drive Shoe? Yes N Hole Diameter
0 in. to 77 ft

GEOLOGICAL MATERIAL	COLOR	HARDNESS	FROM	TO
CLAY	YELLO		0	6
SOFT SANDY CLAY WITH S	YELLO		6	24
CLAY SANDY	BLUE		24	38
SANDY CLAY W/SOME SAN	BLUE		38	41
SAND AND GRAVEL SOME	VARIE		41	75
SAND AND GRAVEL FINE DI	VARIE		75	87
SAND AND GRAVEL	VARIE		87	104
CLAY AND PEBBLES	BLUE		104	120

Casing Diameter Weight(lbs/ft)
12 in. to 77 ft 49.56
in. to ft

Screen Y Open Hole From ft. to ft.

Make JOHNSON Type O
Diameter Slot Length Set Fitting
10 80 28 74 ft. to 102 ft

Static Water Level 53 ft. from Land surface Date 1988/12/16

PUMPING LEVEL (below land surface)
62.4 ft. after 24 hrs. pumping 608 g.p.m.

Well Head Completion
Pitless adapter mfr Model
Casing Protection 12 in. above grade
 At-grade(Environmental Wells and Borings ONLY)

Grouting Information Well grouted? Yes No
Material From To (ft.) Amount(yds/bags)
G 0 77 2.75 Y

Nearest Known Source of Contamination
ft. direction type
Well disinfected upon completion? Yes No

Pump Not Installed Date Installed N
Mfr name
Model HP Volts
Drop Pipe Length ft. Capacity g.p.m.
Type

Any not in use and not sealed well(s) on property? Yes No

Was a variance granted from the MDH for this Well? Yes No

USGS Quad Worthington South Elevation 1575
Aquifer: QBAA Alt Id: 63-1128

Well CONTRACTOR CERTIFICATION Lic. Or Reg. No. 91353

License Business Name
Name of Driller SOWL, D.

Report Copy

760572

MINNESOTA DEPARTMENT OF HEALTH
WELL AND BORING RECORD
Minnesota Statutes, Chapter 103T

WELL OR BORING LOCATION

County Name

Nobles

Township Name **Bigelow** Township No. **101** Range No. **40** Section No. **35** Fraction **ownown**

WELL/BORING DEPTH (completed) **90** ft. DATE WORK COMPLETED **8-7-09**

GPS LOCATION: Latitude _____ degrees _____ minutes _____ seconds
Longitude _____ degrees _____ minutes _____ seconds

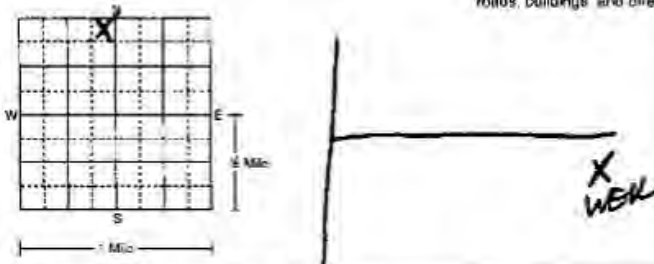
DRILLING METHOD
 Cable Tool Driven Dug
 Auger Rotary Jetted

House Number, Street Name, City, and Zip Code of Well Location or F.R. Number

not assigned 330th St Worthington

DRILLING FLUID **bentonite water** WELL HYDROFRACTURED? Yes No

Show exact location of well/boring in section grid with "X." Sketch map of well/boring location showing property lines, roads, buildings, and direction.



USE Domestic Monitoring Heating/Cooling
 Noncommunity PWS Environ. Bore Hole Industry/Commercial
 Community PWS Irrigation Remedial
 Elevator Dewatering

CASING MATERIAL Drive Shoe? Yes No
 Steel Threaded Welded
 Plastic

CASING Diameter Weight Specifications HOLE DIAM.
16 in. to **66** ft. **62** lbs./ft. **58** **20** in. to **90** ft.

PROPERTY OWNER'S NAME/COMPANY NAME

City of Worthington #30 well replacement

Property owner's mailing address if different than well location address indicated above.

**318 ninth St
Worthington, mn 56187**

SCREEN **johnson** OPEN HOLE
Make **stainless steel** From _____ ft. To _____ ft.

Type **weld on** Diam. **16"**
Slot/Gauze Length **24'**

Set between **66** ft. and **90** ft. FITTINGS

STATIC WATER LEVEL Measured from _____
8 ft. Below Above land surface Date measured _____

WELL OWNER'S NAME/COMPANY NAME

same

Well/boring owner's mailing address if different than property owner's address indicated above.

PUMPING LEVEL (below land surface)
18 ft. after **1** hrs. pumping **800** g.p.m.

WELLHEAD COMPLETION
 Pileless/adapted manufacturer Model _____
 Casing Protection _____ **12** in. above grade
 At-grade (Environmental Well and Boring ONLY)

GROUTING INFORMATION
Well grouted Yes No
Grout material Neat cement Bentonite Concrete Other _____

bentonite From **66** To **61** ft. **5** Yds. **4** Bags
neat cement From **61** To **top** ft. **5** Yds. **4** Bags

GEOLOGICAL MATERIALS	COLOR	HARDNESS OF MATERIAL	FROM	TO
top soil	black	soft	0	2
clay	yellow	soft	2	23
sandy clay	brown	soft	23	35
sand w/clay	mixed	soft	35	55
sand & gravel	fine	soft	55	69
sand & gravel	coarse	med	69	89
caly	blue	med	89	94

NEAREST KNOWN SOURCE OF CONTAMINATION
50 feet **West** direction **well** type

Well disinfected upon completion? Yes No

PUMP
 Not installed Date installed _____
Manufacturer's name **Grundfos**
Model Number **4755** HP **4** volts **460V**
Length of drop pipe **100** ft. Capacity **750** g.p.m.
Type Submersible L.S. Turbine Reciprocating Jet

ABANDONED WELLS
Does property have any not in use and not sealed well(s)? Yes No

VARIANCE
Was a variance granted from the MDH for this well? Yes No TN# _____

WELL CONTRACTOR CERTIFICATION
This well was drilled under my supervision and in accordance with Minnesota Rules, Chapter 4725. The information contained in this report is true to the best of my knowledge.

REMARKS, ELEVATION, SOURCE OF DATA, etc.



MINN. DEPT. OF HEALTH COPY

760572

Peterson Well Drilling, inc. 2293

Licensee Business Name Lic. or Reg. No.
Shawn Peterson 444
Certified Representative Signature Certified Reg. No. Date **8/19/09**
Name of Driller

Appendix C

Aquifer Test Plans



Environmental Health Division
 Drinking Water Protection Section
 Source Water Protection Unit
 P.O. Box 64975
 St. Paul, Minnesota 55164-0975

Determination of Aquifer Properties and Aquifer Test Plan (DAP-ATP) Form

Public Water Supply ID:	1530011	PWS Name:	Worthington
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Contact Information for Person Completing this Form

Name:	Jacob Macholl
Address:	SEH, Inc.
	156 High Street, Suite 300
City, State, Zip:	New Richmond, WI 54017
Phone, Fax, e-mail:	715.861.1944, 888.908.8166, jmacholl@sehinc.com

Aquifer Properties Determination Methods

1) An existing pumping test that meets the requirements of wellhead protection rule part 4720.5520 and that was previously conducted on a well connected to the public water supply system.

2) An existing pumping test that meets the requirements of wellhead protection rule part 4720.5520 and that was previously conducted on another well in a hydrogeologic setting determined by the department to be equivalent.

3) A proposed new test to be conducted on a new or existing well connected to the public water supply system and that meets the requirements for larger-sized water systems (wellhead protection rule part 4720.5520). A test plan must be approved before conducting the test.

4) A proposed new test to be conducted on a new or existing public well connected to the public water supply system and that meets the requirements for smaller-sized water systems (wellhead protection rule part 4720.5530). A test plan must be approved before conducting the test.

5) An existing pumping test that does not meet the requirements of wellhead protection rule part 4720.5520 and that was previously conducted on: 1) a public water supply well or 2) another well in a hydrogeologic setting determined by the department to be equivalent.

6) Existing specific capacity test(s) conducted on the public water supply well(s) or specific capacity tests conducted on other wells in a hydrogeologic setting determined by the department to be equivalent.

7) An existing published transmissivity value.

- Include all test data and analysis documentation with the estimated transmissivity, ft²/day, when the aquifer properties determination method is; 1, 2, 5, 6, or 7, listed above.
- Attach detailed aquifer test plan for methods 3 or 4.

Submitted by: Melanie Niday	Prof. License: PG#30346	Date: 03/24/2015
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Rationale for: 1) Aquifer Properties Determination or 2) Proposed New Test

Briefly describe the rationale for: 1) selected method to determine aquifer properties from existing data, or 2) a new aquifer test to be conducted on the pumped well referenced below. Include unique well numbers of all wells that were (or will be) monitored during data collection. How does the existing or proposed test deviate from the ideal. (e.g. rate, duration, no. of obwells, interfering wells, etc.) Attach documentation as necessary.

Aquifer Name: Quaternary/Quaternary Buried Artesian Confined Unconfined Fractured Rock

Pump test data are available for existing wells as described in Table 4 (pg 12) of the 2004 Part I WPP Report. Table 2 (pg 9) of the 2004 Part I Report describes the aquifer—water table (Quaternary) or buried sand and gravel (Quaternary Buried Artesian)—each well is completed to.

A new well, #31 (00760572), was constructed in November 2008 to replace well #30. Pump tests were completed in well #31 in February 2009 to characterized the buried artesian aquifer in which the well is completed (see attached report). This test deviates from the ideal due to the short duration of the pump test; however, drawdown appeared to stabilize after approximately 2 hours and the K and T values determined from well #31 were within the range of values from tests completed in nearby wells in the Lake Bella Wellfield (26, 28, 29, 30) completed to the same aquifer and to similar depths.

Note—The Quaternary aquifer is Unconfined; the Quaternary Buried Artesian aquifer is characterized as Semi-Confined or Confined; it has been assumed that the aquifer conditions for Well 30 meet the assumptions to apply the Cooper-Jacob (1946) solution.

Proposed New Test Information Summary

Pumped Well Name (Unique Number):		Test Duration (Hours):	
Location: X, Y (meters) UTM-Z15N or Lat-Lon (decimal degrees) datum: NAD83		Pump Type:	
		Discharge Rate:	
Number of Observation Wells:		Flow Rate Measuring Device Type:	

▪ A map showing the location of the pumping well and observation well(s) must be included.

List the unique number of each public water supply well to which this DAP-ATP Form applies

00223617 (19)	00240094 (27)				
00633531 (20)	00455791 (28)				
00169892 (22)	00455790 (29)				
00197476 (24)	00760572 (31)				
00195163 (25)					
00654756 (26)					

Reviewed by:

Approved: Yes No

Approval Date:

Well Analysis
Well #30 – Replacement 2009
Worthington Public Utilities
Worthington, Minnesota
March 10, 2009

Peterson Well Drilling drilled a 21" nominal diameter hole approximately 35 feet east of existing well #30. On November 20, 2008 twenty-four feet of #60 slot stainless steel screen was placed in the hole along with four 19.5' lengths of 16" diameter steel casing pipe. Each piece was welded to the adjacent piece with full depth welding technique. Following the final setting of the screen and casing 9' 3" of the casing pipe was removed to reduce the amount of steel casing pipe extending out of the ground.

The first pump test began on December 4, 2008 following several hours of development. The well had a drawdown of nearly 16 feet indicating an efficiency of approximately 15%. Well drawdown was 15' in the first one minute of pumping. The flow rate per foot of drawdown was established at 43 gpm per foot which does not match any of the existing well information. The test pumping was stopped with recommendation that additional well development be performed.

Additional well development occurred between February 12 and February 20, 2009. The second pump test was performed on February 23, 2009. The pump was started at 11:26 a.m. with an average flow of 695 gpm. The pump test ran for approximately 2 hours and the drawdown appeared to stabilize at 3'-10". This indicates that the flow for the well is 181 gpm per foot of drawdown with an efficiency of approximately 95%, similar to the existing wells in the area.

The well analysis based on the data from pump test number two is as follows:

Cooper-Jacob Analysis w/ efficiency computation main well:

K = 880 feet per day

T = 47,000 feet² per day

Efficiency = 95% based on the first log cycle before data leveled out.

Cooper-Jacob Analysis based on Recovery Data

K = 880 feet per day

T = 47,000 feet² per day

Cooper-Jacob Analysis based on Distance/Drawdown Data

K = 490 feet per day

T = 26,000 feet² per day

Where K is the permeability and T is the Transmissivity of the aquifer. The data above indicates the pump test resulted in data that is closely related. The distance-drawdown data may have varied due to only two points for

the curve. An additional monitoring well within 5' of the new production well may have improved the data results.

These results indicate that water moves through the aquifer very quickly and will respond immediately to periods of recharge or drought conditions. Thus the static water level will be a direct indicator of water availability within the aquifer. The Well, as constructed, meets the hydraulic requirements of the specifications.

The alignment test was performed on February 24, 2009 in accordance with AWWA 100 Appendix D. Readings were taken at the top of the casing and then at 10' increments to 70 feet. Two readings were taken at each interval at 90 degrees to determine plumbness in two vertical planes. The alignment test indicated that the misalignment was 1/8" in the east-west alignment and 11/16" in the north-south alignment in 70 feet. This yields a misalignment diameter of only 1.5-inches which would allow a pump with a diameter of 13.75-inches to be placed in the well with out bending. The outside diameter of the proposed Grundfoss 475S400 is only 7-inches. Therefore the well misalignment test shows that the well, as constructed, meets specifications.

The well was designed for a capacity to produce 500 gpm with ½ of the screen plugged. The well, as constructed with 24' of #60 slot stainless steel Johnson screen, can produce 635 gpm with ½ the screen plugged. The drawdown at 635 gpm is anticipated to be approximately 3' 6". The drawdown while pumping 695 gpm was 3' 10". The anticipated drawdown with a clean screen at 500 gpm is 2' 10". As the well ages it is anticipated that the drawdown will continue to increase to approximately 5' 6" indicating that the screen is plugging and needs to be rejuvenated.

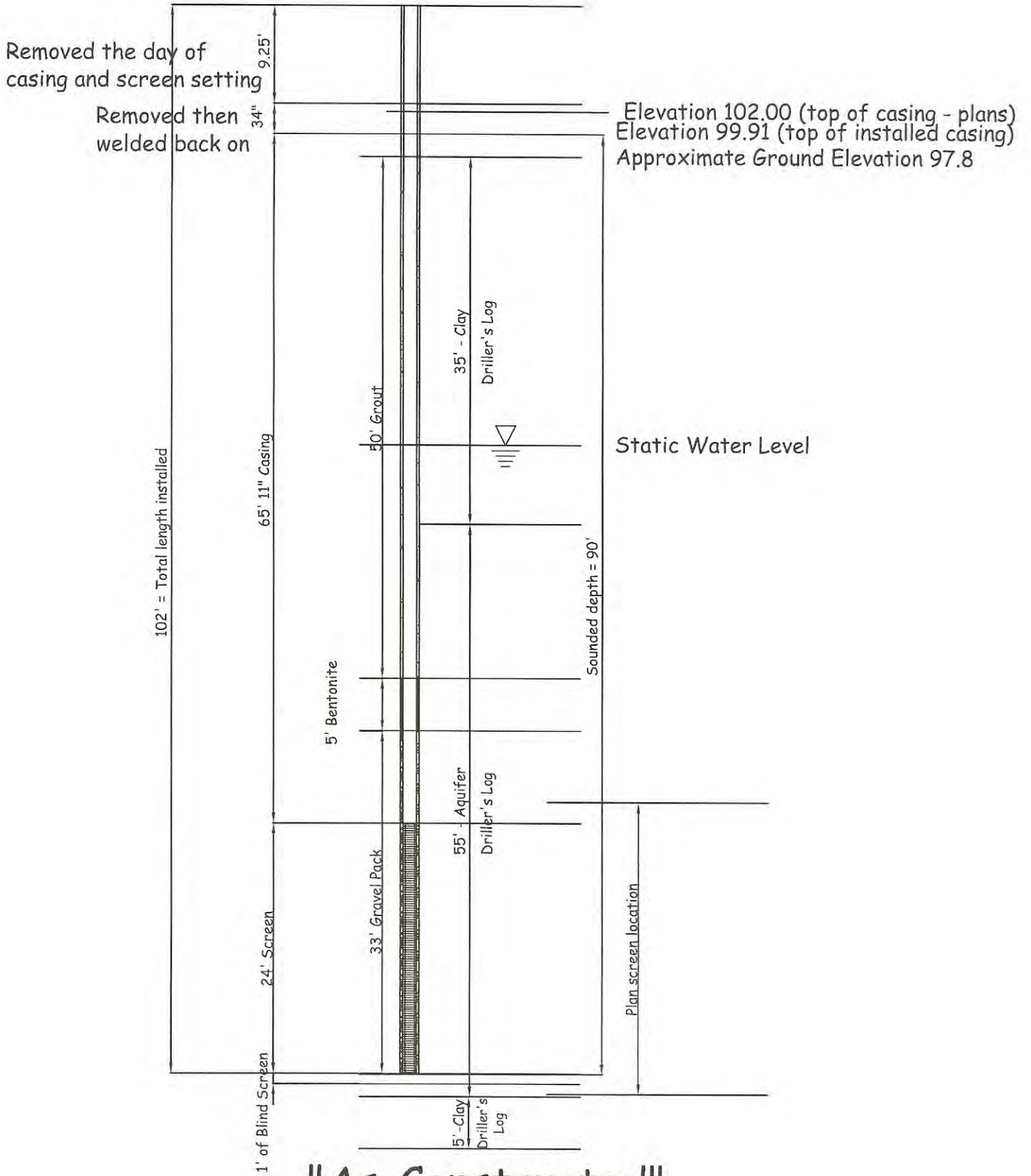
Summary

Well Depth – 90 feet
Well Casing Diameter – 16-inches - Steel
Screen – Johnson #60 Slot Stainless Steel
Capacity – 635 gpm with ½ screen plugged
Permeability – K = 880 ft/day
Transmissivity – T = 47000 ft²/day
Well Efficiency – 95%
Pump – Grundfoss 475S400

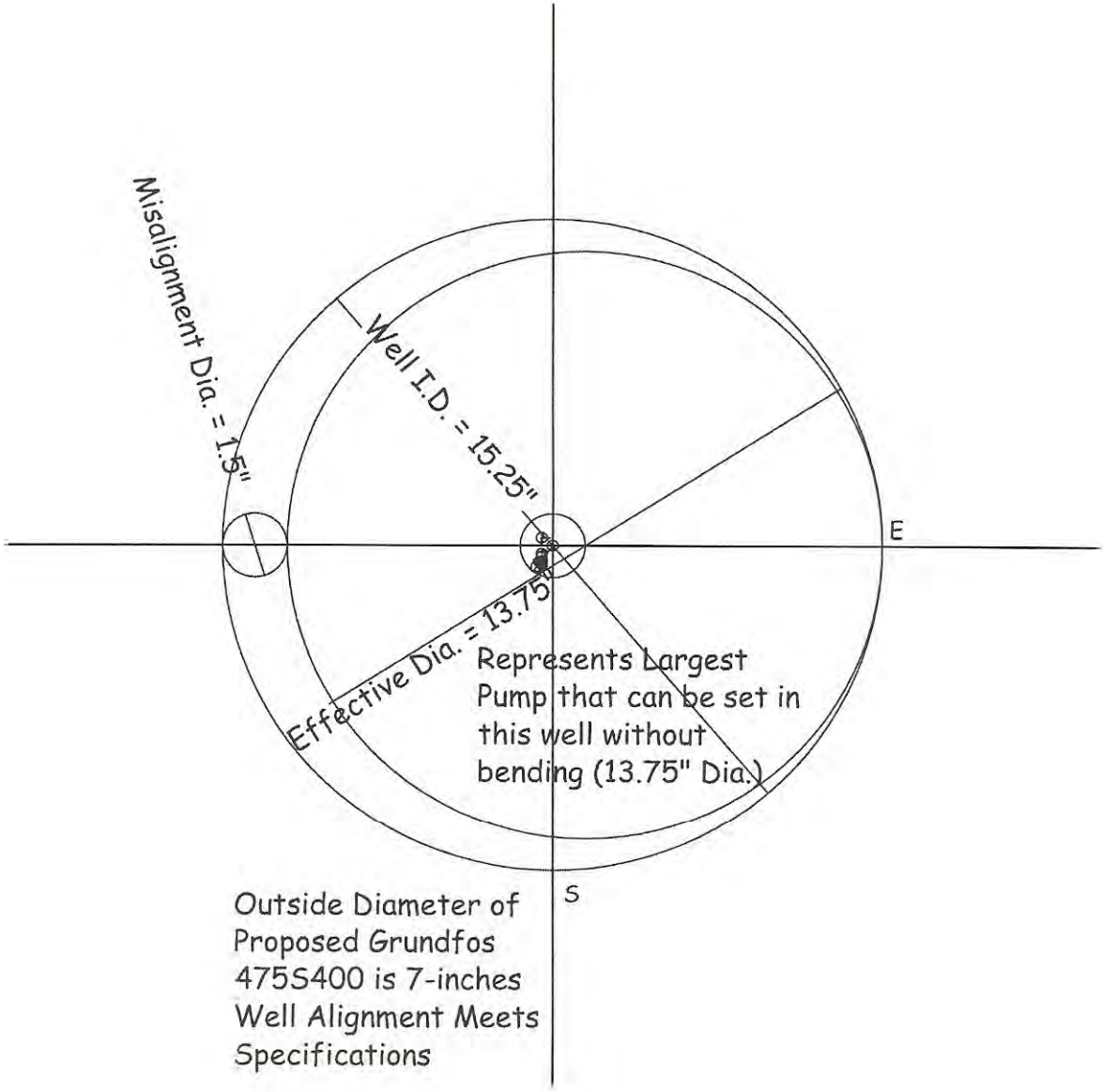
The well, as constructed, meets the specifications for drawdown efficiency of 75%, pumping capacity of 500 gpm and plumbness. Banner Associates, Inc recommends approval of the replacement well for Worthington Utilities Well #30.

Attachments:

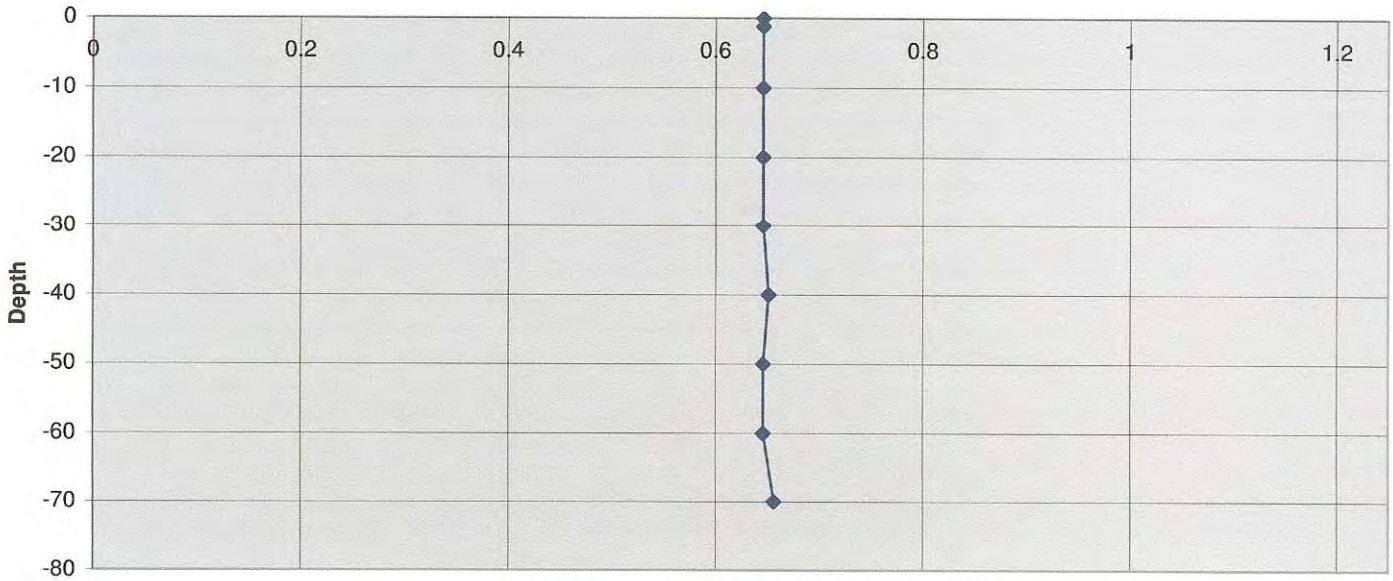
As-Constructed Well Section
Well alignment computations
Well analysis computations



"As-Constructed" Well Section



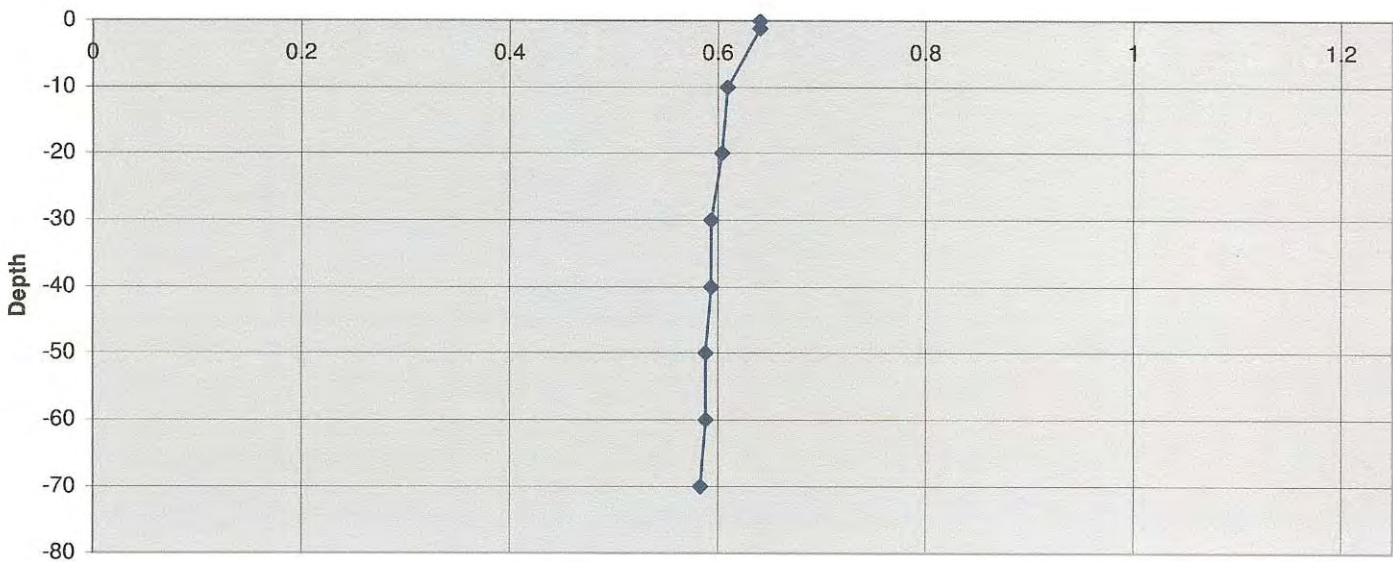
East-West Alignment (ft)



Misalignment - Maximum misalignment is 1/8"
Meets Specifications

—◆— Depth

North-South Alignment (ft)



Misalignment - Maximum misalignment is 11/16"
Meets Specifications

—◆— Depth

WELL ID: Hypo-Recovery

Local ID: Well #30

Date: 2/23/2009

Time: 11:26

INPUT

Construction:	
Casing dia. (d_c)	16 Inch
Annulus dia. (d_w)	21 Inch
Screen Length (L)	24 Feet
Depths to:	
water level (DTW)	29.58333 Feet
Top of Aquifer	37 Feet
Base of Aquifer	90 Feet
Annular Fill:	
across screen --	Coarse Sand
above screen --	Bentonite
Aquifer Material --	Gravel
FLOW RATE	695 GPM

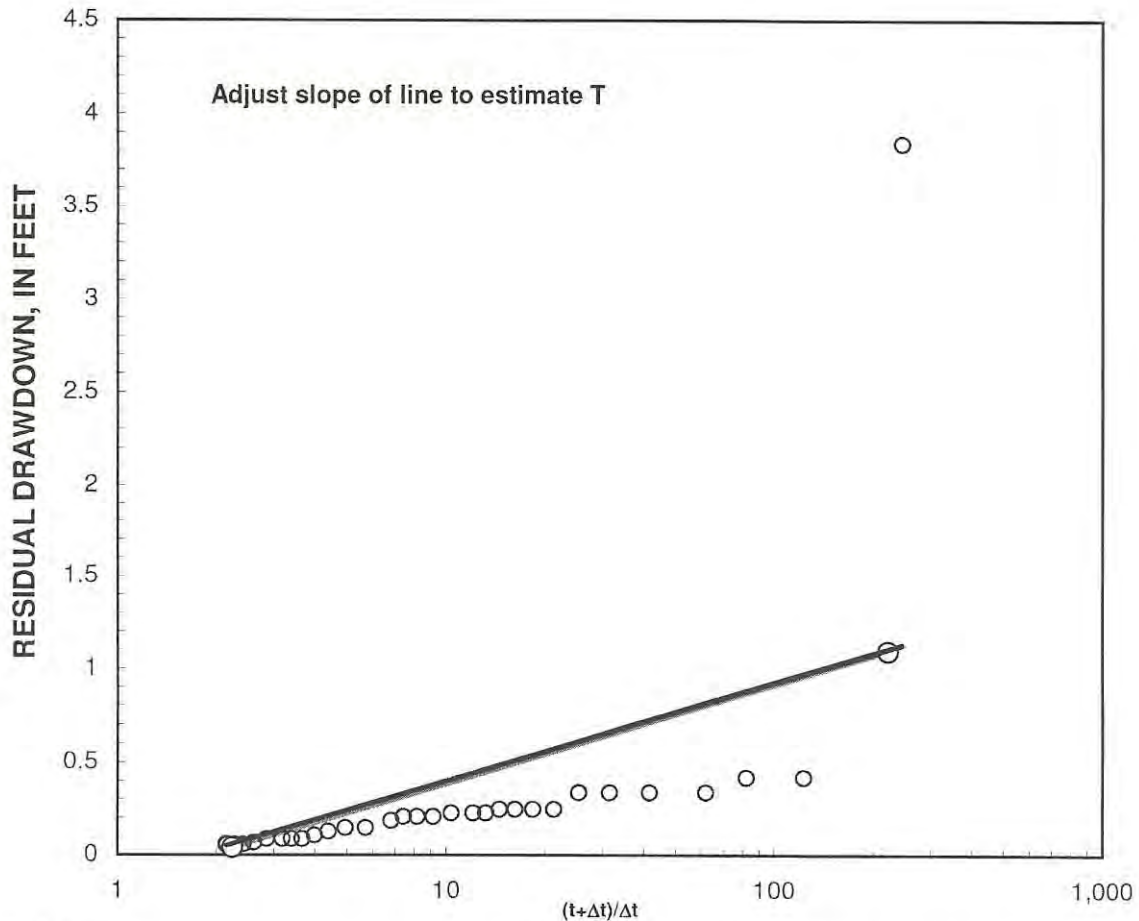
COMPUTED

Aquifer thickness = 53 Feet

Slope = 0.5262894 Feet/log10

Input is consistent.

K =	880 Feet/Day
T =	47000 Feet ² /Day



REMARKS:

Cooper-Jacob recovery analysis of single-well aquifer test

Well #30 recovery test

Reduced Data		
Entry	Time, Date Hr:Min:Sec	Water Level Feet
1	2/23/09 11:26:00	29.58
2	2/23/09 13:28:00	33.42
3	2/23/09 13:28:30	33.42
4	2/23/09 13:29:00	30.00
5	2/23/09 13:29:30	30.00
6	2/23/09 13:30:00	29.92
7	2/23/09 13:31:00	29.92
8	2/23/09 13:32:00	29.92
9	2/23/09 13:33:00	29.92
10	2/23/09 13:34:00	29.83
11	2/23/09 13:35:00	29.83
12	2/23/09 13:36:00	29.83
13	2/23/09 13:37:00	29.83
14	2/23/09 13:38:00	29.81
15	2/23/09 13:39:00	29.81
16	2/23/09 13:41:00	29.81
17	2/23/09 13:43:00	29.79
18	2/23/09 13:45:00	29.79
19	2/23/09 13:47:00	29.79
20	2/23/09 13:49:00	29.77
21	2/23/09 13:54:00	29.73
22	2/23/09 13:59:00	29.73
23	2/23/09 14:04:00	29.71
24	2/23/09 14:09:00	29.69
25	2/23/09 14:14:00	29.67
26	2/23/09 14:19:00	29.67
27	2/23/09 14:24:00	29.67
28	2/23/09 14:34:00	29.67
29	2/23/09 14:44:00	29.65
30	2/23/09 14:54:00	29.64
31	2/23/09 15:04:00	29.64
32	2/23/09 15:14:00	29.64

WELL ID: Worthington - Well #30

Local ID: Well #30

Date: 2/23/2009

Time: 11:26

INPUT

Construction:	
Casing dia. (d_c)	16 Inch
Annulus dia. (d_w)	21 Inch
Screen Length (L)	24 Feet
Depths to:	
water level (DTW)	29.58333 Feet
Top of Aquifer	37 Feet
Base of Aquifer	90 Feet
Annular Fill:	
across screen --	Coarse Sand
above screen --	Bentonite
Aquifer Material --	Gravel
FLOW RATE	695 GPM
Assumed Storage =	0.001 d'less

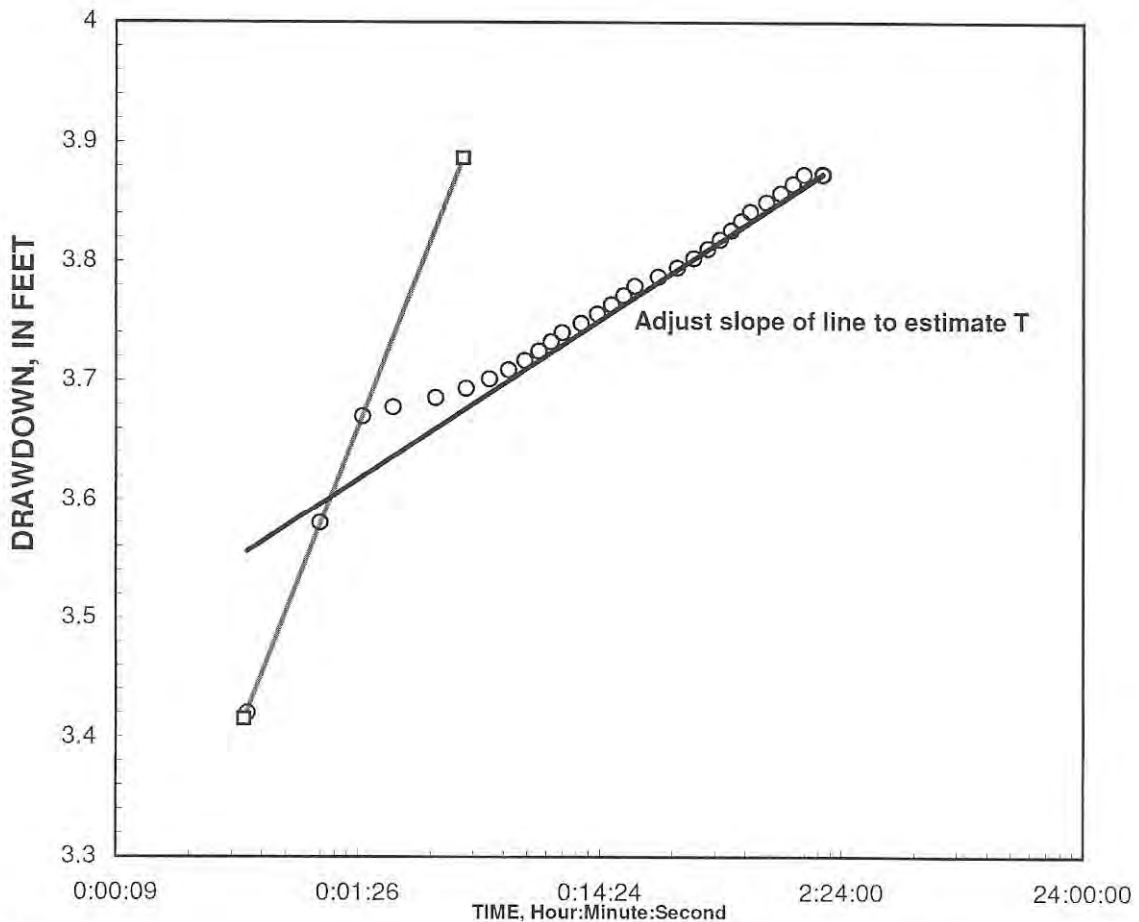
COMPUTED

Aquifer thickness = 53 Feet

Slope = 0.5221239 Feet/log10

Input is consistent.

K =	880 Feet/Day
T =	47000 Feet ² /Day
Efficiency:	95%



REMARKS: Cooper-Jacob analysis of single-well aquifer test
Well #30 Replacement - Worthington, Minnesota

Entry	Reduced Data		Water Level Feet
	Date	Time, Hr:Min:Sec	
1	2/23/09	11:26:00	29.58
2	2/23/09	11:26:30	33.00
3	2/23/09	11:27:00	33.16
4	2/23/09	11:27:30	33.25
5	2/23/09	11:28:00	33.26
6	2/23/09	11:29:00	33.27
7	2/23/09	11:30:00	33.27
8	2/23/09	11:31:00	33.28
9	2/23/09	11:32:00	33.29
10	2/23/09	11:33:00	33.30
11	2/23/09	11:34:00	33.30
12	2/23/09	11:35:00	33.31
13	2/23/09	11:36:00	33.32
14	2/23/09	11:38:00	33.33
15	2/23/09	11:40:00	33.34
16	2/23/09	11:42:00	33.34
17	2/23/09	11:44:00	33.35
18	2/23/09	11:46:00	33.36
19	2/23/09	11:51:00	33.37
20	2/23/09	11:56:00	33.38
21	2/23/09	12:01:00	33.38
22	2/23/09	12:06:00	33.39
23	2/23/09	12:11:00	33.40
24	2/23/09	12:16:00	33.41
25	2/23/09	12:21:00	33.41
26	2/23/09	12:26:00	33.42
27	2/23/09	12:36:00	33.43
28	2/23/09	12:46:00	33.44
29	2/23/09	12:56:00	33.45
30	2/23/09	13:06:00	33.45
31	2/23/09	13:26:00	33.45

PUMPING WELL ID: Well #30

Local ID: Well #30

Date: 2/23/2009

Time: 11:26

INPUT

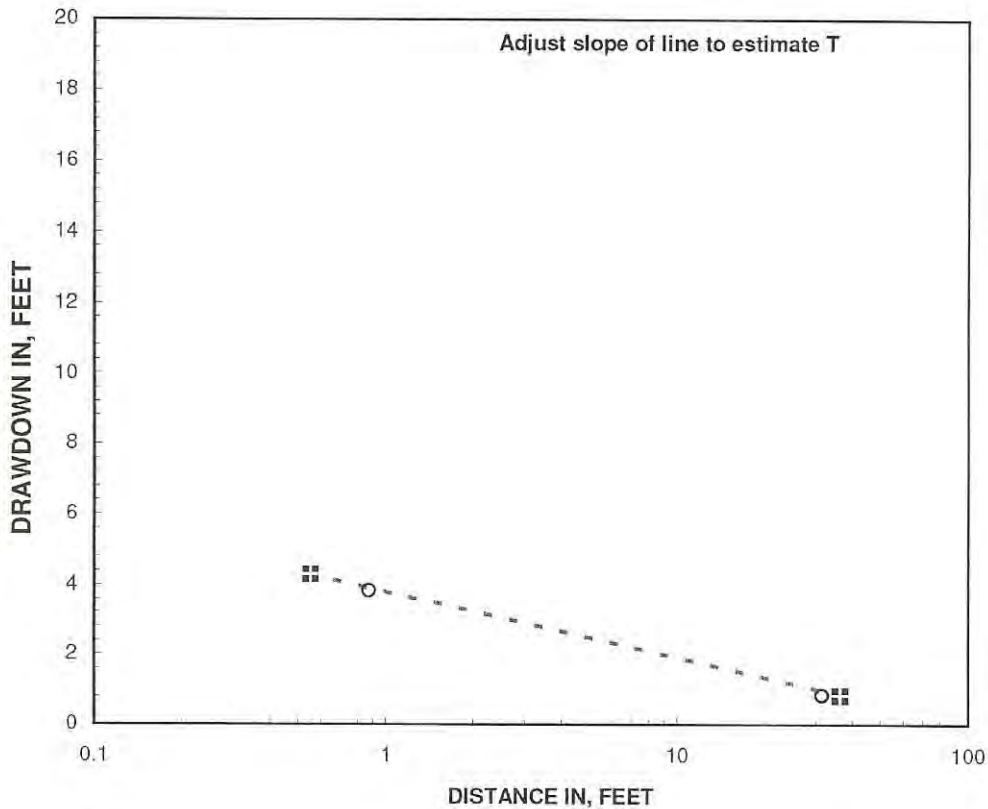
Construction:	
Casing dia. (d_c)	16 Inch
Annulus dia. (d_w)	21 Inch
Screen Length (L)	24 Feet
Depths to:	
Initial Depth to Water	29.41666 Feet
Top of Aquifer	37 Feet
Base of Aquifer	90 Feet
Annular Fill:	
across screen --	Coarse Sand
above screen --	Bentonite
Aquifer Material --	Gravel
FLOW RATE	695 GPM

COMPUTED

Aquifer thickness = 53 Feet
 Aquifer is: **CONFINED**
 Slope = -1.90478 Feet/log10

Input is consistent.

K = 490 Feet/Day
 T = 26000 Feet²/Day



REMARKS:

Drawdown-Distance analysis of multi-well aquifer test

Aquifer Test AT5A, NIROP, Fridley, MN
 Data from end of 40 hours of pumping

Appendix D

Model Files (CD)

Appendix E

GIS Shapefiles (CD)

Appendix F

Vulnerability Assessments



**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: 1530011
SYSTEM NAME: Worthington
WELL NAME: Well #19

TIER: 2
WHP RANK:
UNIQUE WELL #: 00223617

COUNTY: Nobles TOWNSHIP NUMBER: 102 RANGE: 40 W SECTION: 26 QUARTERS: AAAC

<u>CRITERIA</u>	<u>DESCRIPTION</u>	<u>POINTS</u>
Aquifer Name(s)	: Quaternary Buried Artesian	
DNR Geologic Sensitivity Rating	: Low	20
L Score	: 2	
Geologic Data From	: Well Record	
Year Constructed	: 1957	
Construction Method	: Cable Tool/Bored	0
Casing Depth	: 58	10
Well Depth	: 63	
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	: 100	5
Pathogen Detected?		NOT VULNERABLE
Surface Water Characteristics?		NOT VULNERABLE
Maximum nitrate detected	: Unknown	0
Maximum tritium detected	: <.8 09/16/2013	NOT VULNERABLE
Non-THMS VOCs detected?		0
Pesticides detected?		0
Carbon 14 age	: Unknown	0
Wellhead Protection Score	: 40	
Wellhead Protection Vulnerability Rating	: NOT VULNERABLE	
Vulnerability Overridden	:	

COMMENTS



**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: 1530011
SYSTEM NAME: Worthington
WELL NAME: Well #20

TIER: 2
WHP RANK:
UNIQUE WELL #: 00633531

COUNTY: Nobles TOWNSHIP NUMBER: 102 RANGE: 40 W SECTION: 27 QUARTERS: CCD

<u>CRITERIA</u>	<u>DESCRIPTION</u>	<u>POINTS</u>
Aquifer Name(s)	: Quaternary Water Table	
DNR Geologic Sensitivity Rating	: High	0
L Score	: 0	
Geologic Data From	: Well Record	
Year Constructed	: 2000	
Construction Method	: Rotary/Drilled	0
Casing Depth	: 28	20
Well Depth	: 44	
Casing grouted into borehole?	Yes	0
Cement grout between casings?	Not applicable	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?	No	0
Isolation distance violations?		0
Pumping Rate	: 150	5
Pathogen Detected?		0
Surface Water Characteristics?		0
Maximum nitrate detected	: Unknown	0
Maximum tritium detected	: 6.3 09/16/2013	VULNERABLE
Non-THMS VOCs detected?		0
Pesticides detected?		0
Carbon 14 age	: Unknown	0
Wellhead Protection Score	: 25	
Wellhead Protection Vulnerability Rating	: VULNERABLE	
Vulnerability Overridden	:	

COMMENTS



**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: 1530011
SYSTEM NAME: Worthington
WELL NAME: Well #22

TIER: 2
WHP RANK:
UNIQUE WELL #: 00169892

COUNTY: Nobles TOWNSHIP NUMBER: 102 RANGE: 40 W SECTION: 25 QUARTERS: BCB

<u>CRITERIA</u>	<u>DESCRIPTION</u>	<u>POINTS</u>
Aquifer Name(s)	: Quaternary Buried Artesian	
DNR Geologic Sensitivity Rating	: Low	20
L Score	: 2	
Geologic Data From	: Well Record	
Year Constructed	: 1980	
Construction Method	: Rotary/Drilled	0
Casing Depth	: 45	20
Well Depth	: 64	
Casing grouted into borehole?	Unknown	5
Cement grout between casings?	Not applicable	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	: 100	5
Pathogen Detected?		0
Surface Water Characteristics?		0
Maximum nitrate detected	: <.4 06/01/1981	0
Maximum tritium detected	: 3.1 09/16/2013	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



**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: 1530011
SYSTEM NAME: Worthington
WELL NAME: Well #24

TIER: 2
WHP RANK:
UNIQUE WELL #: 00197476

COUNTY: Nobles TOWNSHIP NUMBER: 101 RANGE: 40 W SECTION: 26 QUARTERS: Ccca

<u>CRITERIA</u>	<u>DESCRIPTION</u>	<u>POINTS</u>
Aquifer Name(s) :	Quaternary Buried Artesian	
DNR Geologic Sensitivity Rating :	Low	20
L Score :	1	
Geologic Data From :	Well Record	
Year Constructed :	1984	
Construction Method :	Rotary/Drilled	0
Casing Depth :	56	10
Well Depth :	76	
Casing grouted into borehole?	Yes	0
Cement grout between casings?	Not applicable	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 :	500	5
Pathogen Detected?		0
Surface Water Characteristics?		0
Maximum nitrate detected :	Unknown	0
Maximum tritium detected :	Unknown	0
Non-THMS VOCs detected?		0
Pesticides detected?		0
Carbon 14 age :	Unknown	0
Wellhead Protection Score :		35
Wellhead Protection Vulnerability Rating :		VULNERABLE

Vulnerability Overridden : Yarta Clemens-Billaigb
9/5/2014 09:05:12

COMMENTS



**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: 1530011
SYSTEM NAME: Worthington
WELL NAME: Well #25

TIER: 2
WHP RANK:
UNIQUE WELL #: 00195163

COUNTY: Nobles TOWNSHIP NUMBER: 101 RANGE: 40 W SECTION: 27 QUARTERS: ABCC

<u>CRITERIA</u>	<u>DESCRIPTION</u>	<u>POINTS</u>
Aquifer Name(s)	: Quaternary Water Table	
DNR Geologic Sensitivity Rating	: Very high	0
L Score	: 0	
Geologic Data From	: Well Record	
Year Constructed	: 1984	
Construction Method	: Rotary/Drilled	0
Casing Depth	: 56	10
Well Depth	: 71	
Casing grouted into borehole?	Yes	0
Cement grout between casings?	Not applicable	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	: 500	5
Pathogen Detected?		0
Surface Water Characteristics?		0
Maximum nitrate detected	: .1	0
Maximum tritium detected	: 4.6 09/16/2013	VULNERABLE
Non-THMS VOCs detected?		0
Pesticides detected?		0
Carbon 14 age	: M	0
Wellhead Protection Score	: 15	
Wellhead Protection Vulnerability Rating	: VULNERABLE	
Vulnerability Overridden	:	

COMMENTS



**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: 1530011
SYSTEM NAME: Worthington
WELL NAME: Well #26

TIER: 2
WHP RANK:
UNIQUE WELL #: 00455788

COUNTY: Nobles TOWNSHIP NUMBER: 101 RANGE: 40 W SECTION: 26 QUARTERS: CCCC

<u>CRITERIA</u>	<u>DESCRIPTION</u>	<u>POINTS</u>
Aquifer Name(s)	: Quaternary Water Table	
DNR Geologic Sensitivity Rating	: High	0
L Score	: 0	
Geologic Data From	: Well Record	
Year Constructed	: 1989	
Construction Method	: Rotary/Drilled	0
Casing Depth	: 44	20
Well Depth	: 69	
Casing grouted into borehole?	Yes	0
Cement grout between casings?	Not applicable	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	: 500	5
Pathogen Detected?		0
Surface Water Characteristics?		0
Maximum nitrate detected	: .4	0
Maximum tritium detected	: 13.6 11/19/1991	VULNERABLE
Non-THMS VOCs detected?		0
Pesticides detected?		0
Carbon 14 age	: M	0
Wellhead Protection Score	: 25	
Wellhead Protection Vulnerability Rating	: VULNERABLE	

Vulnerability Overridden :

COMMENTS



**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: 1530011
SYSTEM NAME: Worthington
WELL NAME: Well #27

TIER: 2
WHP RANK:
UNIQUE WELL #: 00240094

COUNTY: Nobles TOWNSHIP NUMBER: RANGE: SECTION: QUARTERS:

<u>CRITERIA</u>	<u>DESCRIPTION</u>	<u>POINTS</u>
Aquifer Name(s) :	Quaternary Water Table	
DNR Geologic Sensitivity Rating :	High	0
L Score :	0	
Geologic Data From :	Data Inferred From Nearby Wells	
Year Constructed :	1963	
Construction Method :	Cable Tool/Bored	0
Casing Depth :	52	10
Well Depth :	62	
Casing grouted into borehole?	Unknown	0
Cement grout between casings?	Not applicable	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?	No	0
Isolation distance violations?		0
Pumping Rate :	500	5
Pathogen Detected?		0
Surface Water Characteristics?		0
Maximum nitrate detected :	<.4 06/01/1981	0
Maximum tritium detected :	8.5 09/16/2013	VULNERABLE
Non-THMS VOCs detected?		0
Pesticides detected?		0
Carbon 14 age :	Unknown	0
<hr/>		
Wellhead Protection Score :		15
Wellhead Protection Vulnerability Rating :		VULNERABLE
<hr/>		
Vulnerability Overridden :		

COMMENTS



**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: 1530011
SYSTEM NAME: Worthington
WELL NAME: Well #28

TIER: 2
WHP RANK:
UNIQUE WELL #: 00455791

COUNTY: Nobles TOWNSHIP NUMBER: 101 RANGE: 40 W SECTION: 27 QUARTERS: CACD

<u>CRITERIA</u>	<u>DESCRIPTION</u>	<u>POINTS</u>
Aquifer Name(s) :	Quaternary Water Table	
DNR Geologic Sensitivity Rating :	High	0
L Score :	0	
Geologic Data From :	Well Record	
Year Constructed :	1989	
Construction Method :	Rotary/Drilled	0
Casing Depth :	50	20
Well Depth :	75	
Casing grouted into borehole?	Yes	0
Cement grout between casings?	Not applicable	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 :	500	5
Pathogen Detected?		0
Surface Water Characteristics?		0
Maximum nitrate detected :	.1	0
Maximum tritium detected :	14.8	VULNERABLE
Non-THMS VOCs detected?		0
Pesticides detected?		0
Carbon 14 age :	M	0
Wellhead Protection Score :		25
Wellhead Protection Vulnerability Rating :		VULNERABLE

Vulnerability Overridden :

COMMENTS



**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: 1530011
SYSTEM NAME: Worthington
WELL NAME: Well #29

TIER: 2
WHP RANK:
UNIQUE WELL #: 00455790

COUNTY: Nobles TOWNSHIP NUMBER: 101 RANGE: 40 W SECTION: 35 QUARTERS: B

<u>CRITERIA</u>	<u>DESCRIPTION</u>	<u>POINTS</u>
Aquifer Name(s)	: Quaternary Buried Artesian	
DNR Geologic Sensitivity Rating	: Low	20
L Score	: 3	
Geologic Data From	: Well Record	
Year Constructed	: 1988	
Construction Method	: Rotary/Drilled	0
Casing Depth	: 77	10
Well Depth	: 102	
Casing grouted into borehole?	Yes	0
Cement grout between casings?	Not applicable	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	: 500	5
Pathogen Detected?		0
Surface Water Characteristics?		0
Maximum nitrate detected	: Unknown	0
Maximum tritium detected	: 6.3 09/16/2013	VULNERABLE
Non-THMS VOCs detected?		0
Pesticides detected?		0
Carbon 14 age	: Unknown	0
Wellhead Protection Score	: 35	
Wellhead Protection Vulnerability Rating	: VULNERABLE	
Vulnerability Overridden	: Jim Walsh	

COMMENTS

VULNERABLE RATING BASED ON TRITIUM AND STABLE ISOTOPE DATA FROM OTHER WELLS IN THE AREA.



**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: 1530011
SYSTEM NAME: Worthington
WELL NAME: Well #31

TIER: 2
WHP RANK:
UNIQUE WELL #: 00760572

COUNTY: Nobles TOWNSHIP NUMBER: RANGE: SECTION: QUARTERS:

<u>CRITERIA</u>	<u>DESCRIPTION</u>	<u>POINTS</u>
Aquifer Name(s) :	Quaternary Buried Artesian	
DNR Geologic Sensitivity Rating :	Low	20
L Score :	2	
Geologic Data From :	Well Record	
Year Constructed :	2009	
Construction Method :	Rotary/Drilled	0
Casing Depth :	66	10
Well Depth :	90	
Casing grouted into borehole?	Yes	0
Cement grout between casings?	Unknown	5
All casings extend to land surface?	Yes	0
Gravel - packed casings?	Unknown	5
Wood or masonry casing?	No	0
Holes or cracks in casing?	Unknown	0
Isolation distance violations?		0
Pumping Rate :		0
Pathogen Detected?		0
Surface Water Characteristics?		0
Maximum nitrate detected :	Unknown	0
Maximum tritium detected :	7 09/16/2013	VULNERABLE
Non-THMS VOCs detected?		0
Pesticides detected?		0
Carbon 14 age :	Unknown	0
<hr/>		
Wellhead Protection Score :		40
Wellhead Protection Vulnerability Rating :		VULNERABLE
<hr/>		
Vulnerability Overridden :		

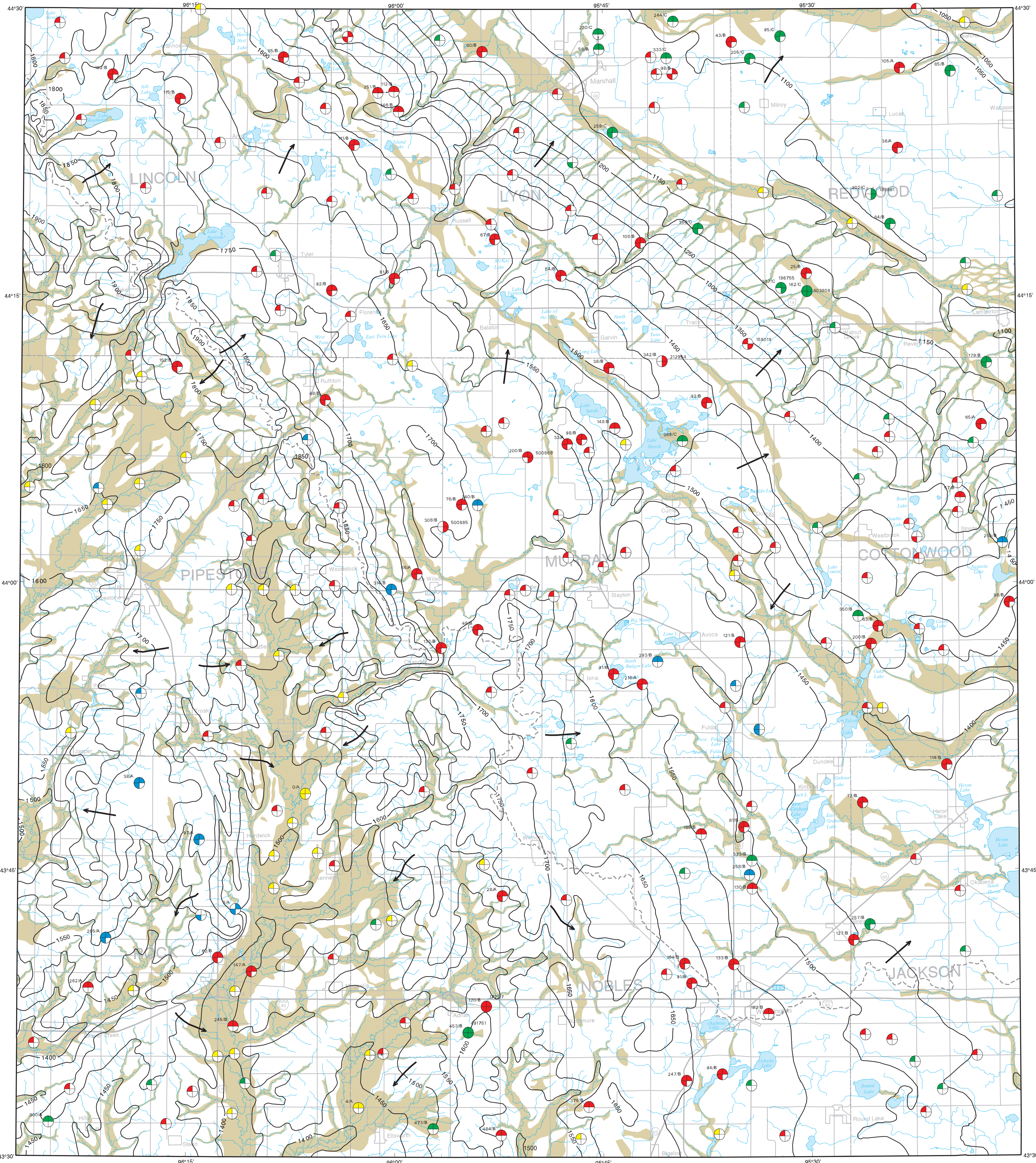
COMMENTS

Geologic Sensitivity of Wells within DWSMA				
Unique Well No.	Well Name	Aquifer	L Score	Geologic Sensitivity
251240	DNR 53-2		8	L
616893	DNR 53-5		24	L
223591	WORTHINGTON TW-2		4	L
223590	WORTHINGTON TW-3		7	L
223620	WORTHINGTON 12	QBAA	4	L
453606	ERICKSON WMA		0	M
223403	DEAN CHENOWITH & FAY WHI		21	L
223618	WORTHINGTON 56-10		0	M
223588	WORTHINGTON TW-4		10	L
223514	GOOD, JOHN		21	L
223592	WORTHINGTON		0	M
223513	LING, HAROLD	QBAA	7	L
223619	WORTHINGTON 13	QUUU	3	L
604803	NELSON, ELMER	KRET	34	L
268081	WORTHINGTON OBS-1A-89		0	M
247785	N-14		0	VH
268051	PERMANENT OBSERVATION PIEZOMETER		0	VH
247780	N-9		0	VH
223594	WORTHINGTON		1	L
268080	WORTHINGTON TW-1A-89		-99	VH
223593	WORTHINGTON TW-2		13	L
247777	N-6		0	VH
223595	WORTHINGTON 10	QBAA	7	L
223589	WORTHINGTON TW-4	QBAA	0	M
187836	WORTHINGTON TW-25		0	VH
247778	N-7		0	M
247779	N-8		0	VH
247776	N-5		0	VH
223511	LARSON, BURTON	QBAA	34	L
223615	WORTHINGTON 56-9		0	M
223512	LING, HAROLD	QBAA	4	L
111893	STRANDBERG, DOUGLAS	QBUA	6	L
189511	BUYSMAN, LESTER	QWTA	2	L

L Scores computed by MDH

Appendix G

Regional Hydrogeologic Assessment of Southwestern Minnesota: Plate 3



EXPLANATION

- 1000 Water table elevation (feet above sea level)
- General direction of ground-water movement
- Regional surface-water divide
- Aquifer**
 - Quaternary, unconfined
 - Quaternary, confined
 - Cretaceous
 - Sioux Quartzite
- Data collection symbols**
 - Well measured for water level
 - Well sampled for general chemistry
 - Well sampled for tritium
 - Well Sampled for ¹⁴C, ³H, and ¹⁸O; data are shown in Table 2.
- Approximate depth to top of aquifer (feet) - not shown for wells measured only for water levels.
- Unique number - shown only for wells sampled for isotopes listed in Table 2.
- Water type
- Water types**
 - A - Calcium-magnesium-bicarbonate
 - B - Calcium-magnesium-sulfate
 - C - Sodium-sulfate
- Surficial sand and gravel deposits** - Map units *sh, sd, sld, so, and sv* as shown on Plate 1, Part A. Indicates approximate extent of surficial aquifers. Uncolored where water table occurs in materials that do not yield significant quantities of water.

SURFICIAL HYDROGEOLOGY

By
Randy Bradt
1997

INTRODUCTION

The Southwestern Minnesota Regional Hydrogeologic Assessment study area extends north one degree of latitude and east one degree of longitude from the southwestern corner of the state. The study area covers 4,136 square miles and includes all or part of nine counties. This plate describes on a regional scale, ground-water occurrence, movement, and chemistry, with primary focus on ground water in surficial deposits. Data collected for this study include two synoptic water-level measurements of 230 domestic and 40 observation wells, and general water chemistry analyses for 107 wells. Samples were also collected for isotope analysis including tritium for 76 wells and ¹⁴C and stable isotopes of hydrogen and oxygen for nine wells.

Quaternary unconfined aquifers are usually used to a greater extent than confined sand and gravel aquifers for drinking water supplies, not only for their lower degree of mineralization, but also for their greater yields and lower well construction costs. However, surficial aquifers are geographically limited, and are commonly associated with floodplains, making them inaccessible to most domestic well owners. In addition, they are more susceptible to contamination and drought conditions than confined aquifers. Confined aquifers are scattered throughout most of the study area, are better protected from contamination, and are less susceptible to drought. However, they are difficult to locate, tend to have smaller yields and higher well construction costs, and the water is likely to have a higher degree of mineralization.

The Piper trilinear diagram in Figure 1 shows the results of water chemical analyses for the three main aquifers. Plotted on the lower left and right triangles (ternary diagrams) are points representing the positively charged ions (cations) and negatively charged ions (anions) in each sample. Each vertex represents 100 percent of a particular ion or group of ions. The position of sample points on each ternary diagram reflects the relative percentages in milliequivalents per liter of the major cations and anions in each sample. The cation and anion percentages for each sample are projected onto the center diagram. The plotted water chemistry data can be classified into three types based on major ion concentrations. The three water types are indicated on Figure 1. The first type is calcium-magnesium-sulfate water, which is defined by greater than 50 percent calcium plus magnesium and greater than 50 percent bicarbonate plus carbonate ions. Many wells completed in Quaternary deposits or the Sioux Quartzite have water of this type. Also, this type tends to be relatively low TDS. The remaining two water types are sodium-sulfate and calcium-magnesium-sulfate, which have much higher TDS values. The sodium-sulfate water type is defined by greater than 50 percent sodium plus potassium and greater than 50 percent sulfate plus chloride and nitrate. Sodium-sulfate waters are calcium-magnesium-sulfate-type water. Waters of this type are defined by greater than 50 percent calcium plus magnesium and greater than 50 percent sulfate plus chloride and nitrate ions. Many samples from wells completed in either Cretaceous or Quaternary deposits plot in the region defined as calcium-magnesium-sulfate water. The similarity in water chemistry may be due to either incorporation of Cretaceous sediments into till during ice advances or seepage of water from Cretaceous deposits into the overlying till.

Many of the wells were sampled for one or more stable isotopes as part of the same element that have different masses. Tritium is an isotope of hydrogen that is used for age dating ground water. Most tritium in ground water is attributable to elevated levels of tritium in precipitation caused by atmospheric testing of nuclear weapons during the 1950s and 1960s. The presence of detectable tritium in ground water indicates a component of post-1953 recharge. Tritium samples were collected from 76 wells. Tritium was detected in all samples from wells completed within 50 feet of the land surface. However, detectable tritium was found in only half of the wells completed between 50 and 100 feet below the surface. Only three wells completed at depths greater than 100 feet had detectable tritium. The depth at which tritium is found is an indicator of the ability of the less permeable material surrounding the aquifer to inhibit ground-water flow.

Elevated levels of nitrate, from sources such as septic systems and fertilizers, may also indicate recently recharged precipitation. Data from Adolphson (1983) and this study indicate elevated nitrate levels were found mostly in wells completed in Quaternary unconfined or confined aquifers within 150 feet of the land surface. These findings are consistent with the tritium results.

Tritium results show that ground water in wells completed more than 150 feet below the surface entered the ground before about 1953. Nine samples of ground water from wells completed 180 to 405 feet below the surface were collected for age date determination using the ¹⁴C isotope technique. As shown in Table 2, eight of the samples had ages in the range from 5,000 to greater than 35,000 years old. Water from Cretaceous aquifers, on average, was older than water from Quaternary aquifers. The relatively young waters found in aquifers within 150 feet of the surface suggest the presence of local and intermediate flow systems that recharge and discharge over distances of a few miles or less. The much older waters found in aquifers deeper than 150 feet are interpreted to reflect regional flow systems that recharge and discharge over much longer distances.

The nine samples listed in Table 2 were also analyzed for levels of stable isotopes of hydrogen (³H) and oxygen (¹⁸O). The results indicate the ground water samples were mostly recharged from precipitation. Additionally, the data suggest that most of the precipitation infiltrated during a climatic period having a mean annual air temperature similar or slightly cooler than today.

WATER TABLE

Construction of a water-table map usually relies on water levels obtained from wells located in a water-table aquifer. However, the water table in most of the study area exists in loam to clay loam till, materials generally not considered suitable as an aquifer. Therefore, water-table wells are rarely found in these areas. However, the water table is commonly expressed at the surface in lakes, rivers, and wetlands. The water-table elevations for these features were obtained from U.S. Geological Survey (USGS) 1:24,000 topographic maps. Additional information included depth to water-table data from geophysical work by Department of Natural Resources staff in Rock and Pipestone counties. The available information suggests that the water table is everywhere within 50 feet of the land surface and approximates a subdued surface topography. Therefore, topographic contours from USGS 1:100,000 map sheets were used to guide contour placement in areas lacking water-table information. The water-table contours shown on the map provide a regional description of the water-table surface. The general direction of ground-water flow is at right angles to these lines toward lower elevations, as shown by the arrows on the map. However, the lack of control points and the scale at which the map was created preclude its use for determining depth to the water table.

Recharge to the water table occurs throughout the study area by infiltration of precipitation, surface runoff, and ground-water movement from adjacent areas. The ability of geologic materials to transmit water hydraulically varies. The Bemis Moraine, which is at or near the surface in Pipestone and Rock counties, is a subsurface ridge of Sioux Quartzite extends eastward from Pipestone County to northwestern Cottonwood County. The supply potential for Sioux Quartzite aquifers is generally as little as a few to several tens of gallons per minute (gpm). The supply potential is quite variable depending on the hydraulic characteristics of fractures (Kaniavetsky, 1978) and weathered zones in the quartzite, and the degree of hydraulic connection to the overlying or to an overlying aquifer. These factors are difficult to identify or predict with existing information.

Cretaceous sediments overlie the Precambrian crystalline rocks (Setterholm, 1990) and are found in geologically low areas on the bedrock surface. These sedimentary deposits are composed primarily of interbedded shale, siltstone, and sandstone. In drill cuttings these deposits may be difficult to distinguish from glacial sediments. In the northeastern part of the study area, chiefly Lyon and Redwood counties, wells completed in Cretaceous deposits are common because the overlying Quaternary deposits are typically less than 100 feet thick and in many places lack a reliable aquifer. Woodward and Anderson (1986) described yields from wells in Cretaceous sandstones as variable, ranging from a few to several tens of gpm.

Quaternary sediments in the study area represent several glacial advances and retreats which occurred over the last 2 million years (see Plate 2, Part A). The bulk of these deposits are made up of till, which is an unsorted mixture of clay, silt, sand, and gravel. Till in the study area has a low hydraulic conductivity and is considered a confining unit. During each glacial retreat, water from the melting ice left behind sand and gravel deposits generally referred to as outwash. These deposits tend to form networks of long, narrow, meltwater channels generally oriented parallel or perpendicular to northeast-southwest-trending end moraines. Subsequent glacial events buried these potential aquifers beneath confining materials, including till, lacustrine sediments, loess (wind-blown deposits) or alluvial sediments. The last glacial retreat deposited surficial sand and gravel, mapped as stream sediment on Plate 1, Part A. These deposits are in many areas unconfined and form the beds of present-day streams. The extent of the mapped stream sediment approximates the extent of the surficial aquifer. Yields for Quaternary sediments are extremely variable. Higher yields are generally associated with surficial sand and gravel deposits that can yield as much as 1,000 gpm. However, yields are generally less than 100 gpm (Adolphson, 1983; Kaniavetsky, 1979).

AQUIFERS

Most wells in the study area are completed in Quaternary sand and gravel deposits. Locally important aquifers include Cretaceous sandstones and fractured Precambrian Sioux Quartzite. Precambrian rocks are composed of Sioux Quartzite, which is at or near the surface in Pipestone and Rock counties. A subsurface ridge of Sioux Quartzite extends eastward from Pipestone County to northwestern Cottonwood County. The supply potential for Sioux Quartzite aquifers is generally as little as a few to several tens of gallons per minute (gpm). The supply potential is quite variable depending on the hydraulic characteristics of fractures (Kaniavetsky, 1978) and weathered zones in the quartzite, and the degree of hydraulic connection to the overlying or to an overlying aquifer. These factors are difficult to identify or predict with existing information.

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WATER CHEMISTRY

Water samples for chemical analysis were collected from April 1994 to June 1995 from 122 wells completed in Quaternary deposits (only two samples represent unconfined sand and gravel deposits), 26 wells completed in Cretaceous sediments, and 9 wells completed in the Sioux Quartzite. The locations of the sampled wells, with the exception of 16 wells located just outside the study area, are indicated on the map. The results were used to characterize water from these aquifers, and to evaluate ground-water recharge processes. Table 1 summarizes the water chemistry by aquifer.

Ground water contains dissolved minerals derived from the geologic materials (soil, till, etc.) through which it moves. Factors affecting ground-water chemistry include residence time, length of flow path, initial water chemistry, chemical reactions, and land use.

Generally, ground water in the study area is very hard with total dissolved solids (TDS) ranging from 270 milligrams per liter (mg/L) to 2,249 mg/L, with most samples exceeding 500 mg/L, the U.S. Environmental Protection Agency's (EPA) secondary (non-enforceable) standard for public drinking water supplies. Chemical constituents commonly exceeding EPA's secondary drinking water standard include sulfate, iron, and manganese. Excessive quantities of these chemicals may give water an objectionable taste or odor, stain laundry and porcelain, or even plug well screens.

EPA's primary (enforceable) public water supply standard for nitrate, 10 mg/L, was exceeded in less than 10 percent of samples analyzed. Seven samples from wells completed in Quaternary deposits and two samples from wells completed in Sioux Quartzite exceeded the standard. No samples from wells completed in Cretaceous sediments exceeded the EPA primary standard for nitrate.

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Setterholm, D.R., 1990. Geologic maps of the late Cretaceous rocks, southwestern Minnesota. Minnesota Geological Survey Miscellaneous Map Series M-69, 2 pls., scale 1:750,000 and smaller.

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ACKNOWLEDGMENTS

I would like to express my sincere appreciation for the assistance provided by Division of Waters staff at the Minnesota Department of Natural Resources. Thanks are due to the report review committee members for their constructive comments. Special thanks are owed to all of the well owners who provided access to their wells.

TABLE 2. Oxygen, hydrogen, and carbon isotope data for nine wells in the Southwestern Minnesota RHA study area.

(Samples collected during 1994 and 1995 by Minnesota Department of Natural Resources staff; permil, parts per thousand; B.P., before present; TU, tritium units; n.s., not sampled)

Unique Number	Well depth (feet)	$\delta^{18}O$ (permil)	δ^2H (permil)	$\delta^{13}C$ (permil)	¹⁴ C (percent modern)	Age* (years B.P.)	Tritium (TU)
Quaternary wells†							
158019	193	-10.42	-73.8	-15.3	0.141	13,000	n.s.
172117	180	-9.4	-63.2	-20.5	0.004	>35,000	<0.8
212554	390	-11.34	-79	-17.2	0.005	18,000	n.s.
502889	215	-9.61	-77.1	-12.8	0.300	5,000	n.s.
500885	320	-11.09	-70.6	-15.9	0.036	24,000	n.s.
Cretaceous wells							
193961	222	-11.33	-80.2	-17.9	0.012	34,000	n.s.
196755	350	-11.25	-80.8	-16.7	0.021	29,000	n.s.
403908	194	-11.61	-83.8	-17.3	0.003	>35,000	<0.8
491751	496	-10.70	-79.9	-20.1	0.843	100	<0.8

* Age interpretation by Dr. E. Calvin Alexander, Jr., University of Minnesota.
† Buried aquifer wells only.

TABLE 1. Characteristics of natural waters by aquifer in the Southwestern Minnesota RHA study area.

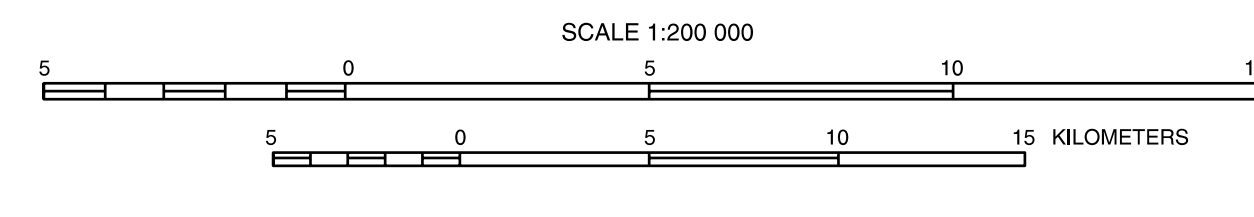
(Samples collected during 1994 and 1995 by Minnesota Department of Natural Resources staff; μ S/cm, microsiemens per centimeter; TDS, total dissolved solids; bicarbonate volatilization correction method. (Hem, 1992); °C, degrees centigrade; mV, millivolts; mg/L, milligrams per liter; TU, tritium units)

Aquifer	Conduc-tivity μ S/cm	TDS mg/L	Temp °C	pH	Eh mV	Dis-solved oxygen mg/L	Alka-linity as CaCO ₃ mg/L	Nitrate- ³ N mg/L	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	Fe mg/L	SO ₄ mg/L	Cl mg/L	Nitrite- ³ N mg/L	Mn mg/L	Sr mg/L	B mg/L	SiO ₂ mg/L	Tritium TU
Quaternary																					
Mean	1515	1495	9.8	7.08	44	0.25	341	286	82.4	60.9	9.70	4.34	816	11.1	3.4	1.063	1.457	0.243	14.39	5.4	
Median	1524	1543	9.7	7.11	49	<0.01	293	284	85.1	8.17	3.71	3.88	52.4	8.17	3.71	0.216	1.480	0.637	4.74	<0.8	
Minimum	426	338	8.4	6.95	-185	<0.01	227	69.7	19.3	4.78	1.78	0.01	2.21	0.51	<0.01	0.012	0.239	0.052	8.14	<0.8	
Maximum	2768	2731	14.4	7.69	432	9.11	502	926	168.0	185.2	128	16.77	1700	198	56.5	3.620	3.279	0.623	26.25	35.5	
Standard deviation	549	618	0.9	0.25	116	1.17	63	121	31.5	43.9	14.5	3.82	456	19.9	10.5	0.893	0.691	0.146	2.96	9.0	
Number of samples	75	72	75	75	75	75	75	75	72	72	72	72	72	72	72	72	72	72	72	18	57
Cretaceous																					
Mean	1854	1591	11.0	7.66	-13	0.06	295	158	54.8	277.8	9.35	1.95	861	40.8	0.3	0.464	1.821	1.116	8.36	<0.8	
Median	1225	1522	10.5	7.65	2	<0.01	290	128	37.3	256.9	8.59	0.76	402	12.28	0.2	0.016	1.786	0.637	4.74	<0.8	
Minimum	653	571	9.4	6.98	-250	<0.01	174	79.4	3.24	30.32	3.71	0.03	171	0.72	<0.01	0.012	0.225	0.162	2.99	<0.8	
Maximum	3337	2749	14.1	8.54	309	0.88	425	456	167.8	741.0	16.1	10.91	1720	143	2.4	2.870	4.280	2.755	20.25	>12	
Standard deviation	581	584	1.3	0.51	116	0.17	69	134	47.8	206	3.91	2.88	406	11.1	1.16	0.815	1.127	1.106	5.76	>12	
Number of samples	27	27	27	27	27	27	27	27	26	26	26	26	26	26	26	26	26	26	26	26	11
Sioux Quartzite																					
Mean	1164	1135	9.6	7.09	31	2.59	283	215	65.5	51.4	5.73	2.6	591	8.79	5.9	0.546	1.053	0.220	10.79	3.2	
Median	1059	1094	9.6	7.10	79	0.18	290	216	62.1	36.0	5.69	2.7	534	9.4	5.3	0.504	1.127	0.164	10.54	<1	
Minimum	505	270	8.7	6.87	-148	<0.01	163	65.3	22.1	11.20	<0.07	<0.01	20.49	0.39	<0.01	<0.003	0.229	<0.023	8.53	<0.8	
Maximum	2410	2518	10.7	7.33	195	9.52	364	399	155.0	122.7	10.0	7.0	1653	35.2	2.92	1.477	2.294	0.844	13.24	13.6	
Standard deviation	598	612	0.7	0.13	121	3.50	61	130	45.5	41.6	3.08	2.0	591	11.0	0.539	0.728	0.210	1.55	4.6	4.6	
Number of samples	11	9	11	11	11	11	11	11	11	9	9	9	9	9	9	9	9	9	9	6	9

Digital roads data modified from 1990 Census TIGER/Line Files of the U.S. Bureau of the Census (source scale 1:100,000). Digital hydrology data modified from 1989 Digital Line Graph (DLG) files from the U.S. Geological Survey (source scale 1:100,000). Digital base annotation by the Minnesota Geological Survey and the Minnesota Department of Natural Resources.

Universal Transverse Mercator projection, grid zone 15, 1983 North American Datum. Vertical datum is mean sea level. Compiled 1996.

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This information is available in an alternative format upon request.

This map was compiled and generated using geographic information system technology. Digital data products are available from the Land Management Information Center, Minnesota Planning Office, St. Paul.

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