City of Circle Pines Wellhead Protection Plan Amendment

Part I:

Delineation of the Wellhead Protection Area (WHPA), Drinking Water Supply Management Area (DWSMA), and Assessments of Well and DWSMA Vulnerability

Prepared for
City of Circle Pines

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4300 MarketPointe Drive, Suite 200
Minneapolis, MN 55435
Phone: 952.832.2600
Fax: 952.832.2601

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Certifications

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

John C. Greer	Date
PG #: _____	

Public Water Supply Profile

The following persons are the contacts for the Circle Pines Wellhead Protection Plan:

Public Water Supply Contact

Chandra Peterson
Assistant City Administrator for Public Services
200 Civic Heights Circle
Circle Pines, Minnesota 55014
Telephone: 763-231-2611
Email: cpeterson@ci.circle-pines.mn.us

Wellhead Protection Manager

Patrick Antonen
City Administrator
200 Civic Heights Circle
Circle Pines, Minnesota 55014
Telephone: 763-231-2605
Email: jkeinath@ci.circle-pines.mn.us

Wellhead Protection Consultant

John Greer, PG
Barr Engineering Company
4300 MarketPointe Drive, Suite 200
Minneapolis, Minnesota 55435
Telephone: 952-832-2600
Fax: 952-832-2601
E-mail: jgreer@barr.com

General Information

UNIQUE WELL NUMBER(S) 208995, 208636

SIZE OF POPULATION SERVED 4,918 (2010 Census)

COUNTY Anoka

1.0 Introduction

In compliance with the Minnesota Wellhead Protection Rules (MN Rules 4720.5100 through 4720.5590), wellhead protection areas (WHPAs) and a Drinking Water Supply Management Area (DWSMA) were delineated for the City of Circle Pines in 2001 (MDH, 2001). Minnesota Rule 4720.5570 states that wellhead protection plans must be reviewed and amended at least every ten years. In addition, the Minnesota Department of Health (MDH) has instituted requirements for inclusion of fracture-flow analysis in the delineation of WHPAs since the last delineation of the City's WHPA and DWSMA.

As required by Minnesota Rule 4720.5570, a new WHPA and a new DWSMA have been delineated for the City of Circle Pines. This report summarizes work completed to update the delineation of the Circle Pines WHPA and DWSMA in compliance with the Minnesota Wellhead Protection Rules and to meet the current MDH requirements. Data elements used in preparation of the report are presented in Table 1.

The City of Circle Pines currently has 2 primary municipal water supply wells. Well 2 (unique number 208995) is completed in the confined Quaternary glacial drift aquifer. Well 3 (unique number 208636) is completed in the Jordan Sandstone aquifer. Well locations are shown on Figure 1. Table 2 summarizes construction, use, and vulnerability information for the Circle Pines water supply wells. Well logs for the City's wells are presented in Appendix A.

2.0 Criteria for Wellhead Protection Area Delineation

The following criteria were used to ensure accurate delineation of the WHPAs.

2.1 Time of Travel

A minimum 10-year groundwater time of travel criterion must be used to delineate a WHPA (MN Rule 4720.5510) so there is sufficient reaction time to remediate potential health impacts in the event of contamination of the aquifer. A groundwater time of travel of ten years was considered in this study. As required by the Wellhead Protection Rules, the one-year groundwater time of travel was also determined for each well addressed in this study.

2.2 Aquifer Transmissivity

For this study, transmissivities of the confined Quaternary glacial drift aquifer and the Jordan Sandstone aquifer were estimated using a pumping test conducted at Lexington Well 1 (Quaternary) and a pumping test conducted at Hugo Well 6 (Jordan). Summaries of the aquifer tests are included in Appendix B. See Section 2.5 below for details regarding how these transmissivity values were incorporated into the groundwater model.

Analysis of data from a pumping test conducted at Lexington Well 1 (unique number 208996) estimated a representative transmissivity of 22,100 ft^2/day (2,050 m^2/day) for the confined Quaternary glacial drift aquifer. This aquifer is thicker at Circle Pines Well 2 (136 feet) than at Lexington Well 1 (104 feet), so the pumping test transmissivity was scaled by the ratio of these thicknesses to obtain a confined Quaternary transmissivity of 28,900 ft^2/day (2,690 m^2/day) for model input at Circle Pines Well 2.

Analysis of data from a pumping test conducted at Hugo Well 6 (unique number 773400) estimated a transmissivity of 1,830 ft^2/day (170 m^2/day) for the Jordan Sandstone aquifer. The Jordan thicknesses at Hugo Well 6 and Circle Pines Well 3 are similar, so no scaling was applied to the pumping test analysis result.

2.3 Daily Volume of Water Pumped

Pumping data for the City of Circle Pines for the period 2011 through 2015 are summarized in Table 3. The largest annual withdrawal for 2011-2015 was 182,279,000 gallons in 2012. The City's Water Emergency and Conservation Plan (WSB, 2007) projected constant demand of 149.65 million gallons per year (MGY) through 2016 and City staff indicated that this projection is still valid for 2021 (Peterson, 2016). Projected 2021 pumping rates for each well were calculated by multiplying the total 2021 projected demand by the 2011-2015 average percentage of total withdrawal for each well. The pumping rate used in the model for each Circle Pines well for the WHPA delineation was either this 2021 projection or the historical maximum for the period 2011-2015, whichever was greater. The maximum 2011-2015 rates were greater than the projected 2021 rates for both wells. Table 3 summarizes the pumping rates used in the model for delineation of the WHPAs. Water system records indicate that unaccounted water (the difference between the total volume pumped annually by the City's wells and the total amount billed to users) averages approximately 9%.

2.4 Conceptual Hydrogeologic Model

The regional hydrogeologic conceptual model is presented in Metropolitan Council (2014). Additional geological information is included below, along with discussion of groundwater flow boundaries and flow directions specific to the Circle Pines area.

2.4.1 Regional Bedrock Geology

A bedrock map derived from the Twin Cities ten-county metropolitan area geologic map (Mossler, 2013) is shown on Figure 1. Locations of two geologic cross sections through the study area are also shown on Figure 1. Geologic cross section A-A' (Figure 2) is a west to east cross section that intersects north to south cross section B-B' (Figure 3) at Circle Pines Well 3.

The hydrostratigraphic units of importance for this study are described in more detail below.

Jordan Sandstone

The Cambrian-aged Jordan Sandstone consists of two interlayered facies: a medium- to coarse-grained, friable, quartz sandstone and a very fine-grained, feldspathic sandstone with lenses of siltstone and shale (Mossler, 2012). Where it is not eroded the Jordan Sandstone is typically 85 to 100 feet thick. As shown on Figure 1, Well 3 is completed in an isolated "island" of Jordan Sandstone surrounded by unconsolidated Quaternary deposits.

Quaternary Glacial Drift

The Quaternary-aged sediments that overlie the bedrock in Circle Pines were deposited by multiple glacial advances during the Pleistocene Epoch (Meyer et al., 2013) and vary in thickness from approximately 110 feet thick where the Prairie du Chien Group is the uppermost bedrock at Well 3 to 300+ feet thick where the Tunnel City Group is the uppermost bedrock. As shown on Figures 2 and 3, the upper 30-50 feet of the Quaternary sediments are typically comprised of sand and gravel. The deeper sediments are comprised of discontinuous sequences of fine-grained sediments (i.e., clays and silts) and sands and gravels. Figures 2 and 3 indicate an apparently continuous confining unit between the shallow Quaternary aquifer and the deeper confined Quaternary aquifers.

2.4.2 Flow Boundaries

The Mississippi River to the southwest of Circle Pines is a regional groundwater flow boundary. Local flow directions in Circle Pines are influenced by multiple high-capacity pumping wells in the area; see Section 2.6 below for more discussion.

2.5 Model Description

To accurately delineate the WHPAs, it is necessary to assess how nearby wells, rivers, lakes, and variations in geologic conditions affect groundwater flow directions and velocities in the aquifer. A groundwater model constructed using the finite difference code MODFLOW-NWT (Niswonger, et al., 2011) was used for this study to simulate groundwater flow in the hydrostratigraphic units from the Quaternary aquifer down to the Mt. Simon Sandstone. MODFLOW-NWT is public domain software that is available at no cost from the United States Geological Survey. The pre- and post-processor Groundwater Vistas (version 6) (Environmental Simulations, Inc., 2011) was used to create the model data files and evaluate the model results.

2.5.1 Base Model

Since the previous Circle Pines Wellhead Protection Plan was prepared, the Twin Cities Metropolitan Area Regional Groundwater Flow Model, Version 3.0 (Metropolitan Council, 2014) was developed by Barr Engineering (Barr) for the Metropolitan Council. A more refined model of the Blaine area based on Metro Model 3 was developed by Barr for the Blaine WHPP Amendment (Barr, 2016), and, per discussions at the Pre-Delineation Meeting (MDH, 2016a), this refined model was used as the base model for the new Circle Pines WHPA delineations.

The refined Circle Pines model is divided into 12 layers to represent the major hydrostatigraphic units in the Twin Cities Metropolitan Area. (The original Metro Model 3 has 9 layers; three additional layers were added to the refined Circle Pines model to better represent Quaternary features.) In Circle Pines, the model layers represent the following (ordered from youngest to oldest; i.e., shallowest to deepest):

- Layer 1: Quaternary glacial drift
- Layer 2: St. Peter Sandstone or Quaternary glacial drift (where present)
- Layer 3: St. Peter Sandstone or Quaternary glacial drift (where present)
- Layer 4: Prairie du Chien Group or Quaternary glacial drift (where present)
- Layer 5: Prairie du Chien Group or Quaternary glacial drift (where present)
- Layer 6: Jordan Sandstone or Quaternary glacial drift (where present)
- Layer 7: Jordan Sandstone or Quaternary glacial drift (where present)
- Layer 8: St. Lawrence Formation or Quaternary glacial drift (where present)
- Layer 9: Tunnel City Group or Quaternary glacial drift (where present)
- Layer 10: Wonewoc Sandstone
- Layer 11: Eau Claire Formation
- Layer 12: Mt. Simon Sandstone

Major rivers near Circle Pines (i.e., the Mississippi River) as well as lakes in the area are simulated using the River Package within MODFLOW-NWT. Baseflow measurements for rivers and streams in the area were used during calibration of Metro Model 3.

Recharge for the groundwater flow model was determined using the SWB recharge model (Westenbroek et al., 2010) for the Twin Cities metropolitan area as described in Metropolitan Council (2012).

Modifications made to the base model for the Circle Pines WHPA delineations are discussed in the following section.

2.5.2 Model Modifications and Updates

The following modifications and updates were made to the base model:

- The pumping rates for the City's wells were changed to the model input rates shown in Table 3.
- Pumping rates for 12 high-capacity wells within 2 miles of Circle Pines were updated to use 2010-2015 averages. A list of these wells is included as Table C1 in Appendix C.
- The model grid was refined from the 250-m square cells in the far field of the base model down to 7.81-m square cells in the immediate vicinity of the Circle Pines wells.
- The base model layer contact elevations did not line up well with the geologic unit contacts reported on the logs for Wells 2 and 3 (Appendix A). The bottom elevation surfaces of Layers 1-8 were adjusted within a bounding box of the cross section extents in order to better match the logs for Wells 2 and 3.
- Horizontal hydraulic conductivity values (Kx) were updated so that model layer transmissivities in the vicinity of the Circle Pines wells match aquifer test transmissivities (Section 2.2; Appendix B) as described below. Table C2 in Appendix C summarizes the effective hydraulic conductivity values used in the model in order to match the aquifer test transmissivities. Appendix C also includes maps of model hydraulic conductivity fields for the model layers that contain Circle Pines municipal wells (Figures C1-C3).
    - Quaternary. Detailed mapping of sand and glacial till units from the Anoka County Geologic Atlas (Meyer et al., 2013) was utilized in the model edits.
        - Layers 7 and 8: Dividing the adjusted Quaternary pumping test transmissivity of 28,900 ft^2/day (2,690 m^2/day) by the combined Layers 7 and 8 thickness of 138 feet (42.0 m) at Well 2 gave an effective Kx of 210 ft/day (64.0 m/day). Sand unit Sx appears to represent the confined Quaternary aquifer tapped by Well 2. The effective Quaternary Kx value was applied to all cells representing the Quaternary in Layers 7 and 8 within a region derived from the mapped extents of sand unit Sx in the vicinity of Circle Pines. A Kx/Kz ratio of 10 was assumed for the modified areas.
        - Layer 6: According to the log for Well 2, Layer 6 should represent a glacial till unit at this well. Kx and Kz were set to 1.57 ft/day (0.48 m/day) and 0.0049 ft/day (0.0015 m/day), respectively, within a region of Layer 6 derived from the mapped extents of till unit Ce. These Kx and Kz values are derived from the Metro Model 3 calibration.
        - Layers 3 and 4: Minor adjustments were made to Kx and Kz values in Layers 3 and 4 to better match the stratigraphy observed at Wells 2 and 3.
        - Layer 2: The apparently continuous confining unit described above in Section 2.4.1 is mapped as till unit Nu in the Anoka County Geologic Atlas and is shown as present throughout Circle Pines. This feature was added to the base model within Blaine; the extents were expanded to include Circle Pines. Kx and Kz in this area were set to 1.57 ft/day (0.48 m/day) and 0.0049 ft/day (0.0015 m/day), respectively.
    - Jordan. The pumping test transmissivity of 1,830 ft^2/day (170 m^2/day) was divided by the combined Layers 6 and 7 thickness of 100 feet (30.5 m) to obtain an effective Kx value of

18 ft/day (5.6 m/day). This Kx value was applied to model cells in Layers 6 and 7 within the "island" of Jordan containing Well 3. A Kx/Kz ratio of 10 was assumed for these cells.

As discussed at the Pre-Delineation Meeting, no additional recalibration of the model was deemed necessary. Calibration summary plots for the updated model are included in Appendix C (Figure C4). Full discussion of the Metro Model 3 calibration is presented in Metropolitan Council (2014) and discussion of the calibration of the refined base model is discussed in Barr (2014) and Barr (2016). MODFLOW files for the updated model are included in Appendix F.

2.6 Groundwater Flow Field

The groundwater flow field used for delineation of the WHPAs was determined by the groundwater flow model; modeled contours for the Jordan Sandstone (Layers 6 and 7) and confined Quaternary glacial drift (Layers 7 and 8) are shown on Figures 4 and 5, respectively.

In general, Figures 4 and 5 show westerly flow directions in the Jordan and confined Quaternary aquifers. No published groundwater contours are known for these aquifers in Anoka County, but the modeled contours appear to be reasonable since they indicate groundwater flow towards the Mississippi River. Based on this modeled flow toward the regional groundwater discharge zone and the acceptable calibration of the groundwater model, the groundwater flow field was determined to be of acceptable accuracy.

The cone of depression from concentrated high-capacity pumping at Blaine Wells 6 and 11 (located approximately 2,800 and 3,600 feet, respectively, north and slightly east of Circle Pines Well 2) is readily apparent in the 870-foot head contour on Figures 4 and 5. Blaine Wells 6 and 11 are both completed in the Tunnel City Group-Wonewoc Sandstone aquifer, which is hydraulically connected to the confined Quaternary aquifer. As a result of the Blaine pumping, the modeled flow direction at Well 2 is to the north-northwest.

3.0 Delineation of the Wellhead Protection Area

Delineation of the WHPA for the Circle Pines wells involved the evaluation of porous media flow only. Per discussions at the Pre-Delineation Meeting (MDH, 2016a), a fracture flow evaluation was deemed unnecessary.

3.1 Porous Media Flow Evaluation

The groundwater flow model discussed above in Section 2 was used to simulate the groundwater flow field in the vicinity of Circle Pines. The porous media capture zone for the Circle Pines well field was delineated using the software program MODPATH (Version 5) with the modeled groundwater flow field. A minimum of 180 particles were tracked from each well. The particles were released from 6 vertical points in each layer along the open interval of each well. These particles were tracked backwards in time for both one and ten years. In plan view, the areas encompassed by the particle traces were then outlined as the 1-year and 10-year porous media time of travel zones for the well field.

Porosity values used for the porous media flow evaluation were as follows (Norvitch et al., 1974, Schwartz and Zhang, 2003):

- Quaternary Glacial Drift = 0.25
- Prairie du Chien Group = 0.056
- Jordan Sandstone = 0.2

3.1.1 Sensitivity Analysis

A sensitivity analysis was performed to test the sensitivity of the model results to varying hydraulic conductivity in the confined Quaternary glacial drift and Jordan Sandstone aquifers. The ranges of transmissivities estimated for the various aquifers by the pumping test analyses (Appendix B) were used to calculate upper and lower bounds on hydraulic conductivity for the model sensitivity analysis. The ratio of horizontal to vertical hydraulic conductivity used in the base model run was preserved for each sensitivity run. The model was most sensitive to lowering the hydraulic conductivity of the confined Quaternary aquifer. A plot of the sensitivity analysis results is included in Appendix C.

Multiple particle tracking simulations were conducted to account for uncertainty in the groundwater flow model. In addition to the base model run, particle tracking simulations were conducted for the upper and lower conductivity bounds of each sensitivity run. Particle traces from all simulations were used to delineate the 1-year and 10-year porous media capture zones for each well.

3.2 WHPA Delineations

The composite 10-year porous media capture zones define the WHPA. The overlapping individual capture zones from Wells 2 and 3 combine to form a single WHPA. The Emergency Response Area (ERA) is delineated for each well by the composite 1-year porous media capture zones. The WHPA and ERAs are shown on Figure 6.

3.3 Conjunctive Delineation

As discussed below in section 6.0, there are no regions of High aquifer vulnerability within the Circle Pines DWSMA. Therefore, delineation of a surface water capture area (i.e., a conjunctive delineation) was not performed.

4.0 Delineation of the Drinking Water Supply Management Area

The Circle Pines DWSMA encompasses the WHPA with boundaries that correspond to geographically identifiable features (e.g., roads, parcel boundaries, quarter-quarter section lines). Anoka County 2016 parcel data were used to delineate the DWSMA, which extends north of the Circle Pines city limits into Blaine and Lino Lakes. The Circle Pines DWSMA is shown on Figure 6.

5.0 Well Vulnerability Assessment

MDH evaluated the vulnerability of the Circle Pines municipal wells to contamination from contaminants released at the surface. The evaluation parameters include geology, well construction, pumping rate, and water quality. Circle Pines Wells 2 and 3 are both classified as “vulnerable.” Copies of the MDH well vulnerability scoring sheets for the Circle Pines wells are included in Appendix D.

6.0 Drinking Water Supply Management Area Vulnerability Assessment

The vulnerabilities of the Quaternary glacial drift and Jordan Sandstone within the DWSMA associated with the Circle Pines wells were evaluated in a manner consistent with MDH guidance for assessing aquifer vulnerability (MDH, 1997) using geologic sensitivities based on L scores computed from boring log data and water quality data for the Circle Pines wells.

The first step in the assessment is to determine the geologic sensitivity rating of the aquifer. The Minnesota Department of Natural Resources (MnDNR) defines geologic sensitivity based on the travel time of water moving vertically from the surface to the aquifer of interest as follows (see MnDNR, 1991):

- Sensitivity = Very High: vertical travel time is hours to months
- Sensitivity = High: vertical travel time is weeks to years
- Sensitivity = Moderate: vertical travel time is years to decades
- Sensitivity = Low: vertical travel time is several decades to a century
- Sensitivity = Very Low: vertical travel time is more than a century

Geologic logs listed in the CWI for wells in the vicinity of the 10-year groundwater capture zone were reviewed and "L scores" based on the thickness of low permeability units at each well location were assigned to each well. [See MnDNR (1991) for a discussion of how to determine L scores]. The MDH L score tool was used to compute the L scores and assign geologic sensitivity ratings. Well logs lacking detail in the Quaternary stratigraphy were excluded from the L score calculations. Figure E1 in Appendix E shows geologic sensitivity calculated from Quaternary wells of similar depth to Circle Pines 2 and from Jordan and Prairie du Chien wells in the same "island" as Circle Pines 3. Geologic sensitivity is low throughout the area for both the confined Quaternary and Jordan Sandstone aquifers.

The second step in the assessment is to refine the geologic sensitivity using water quality data from the water supply wells. In their source water assessment program, MDH uses a classification scheme that rates the vulnerability of groundwater to surface contamination based on sampling data for a list of parameters that indicate man-made impacts or similarity to rainwater (MDH, 2011) and gives some indication of relative groundwater residence time in the subsurface. There are five main categories lettered A to E in descending order of vulnerability, ranging from Category A which indicates that groundwater has been recharged rapidly from precipitation to Category E which indicates old, saline groundwater with a very long residence time in the subsurface. Table 4 summarizes water quality data from Wells 2 and 3. Water from both wells was classified as Category B4, which is described as "Post-1953 Impacted Non-Pathogen".

Tritium samples were collected at Wells 2 and 3 in 1996 and 1991, respectively. Tritium (^3H), a radioactive isotope of hydrogen, has been used extensively to date groundwater. Tritium activities peaked during atmospheric hydrogen bomb testing of the 1950s and 1960s, and values of ^3H in precipitation reached a maximum of approximately 10,000 T.U. (tritium units) in 1963 (Mazor, 2004). Natural production of ^3H in the upper atmosphere introduces approximately 5 T.U. to precipitation each year (Mazor, 2004). Because ^3H has a relatively short half-life of 12.43 years, radioactive decay since the bomb peak has reduced tritium activities to near background levels and ^{3}H is used mostly for relative age dating today. Groundwater that has little or no detectible ^{3}H is stated to be "vintage" or pre-bomb. Groundwater with detectable concentrations of ^{3}H is stated to be "young" or post-bomb. The presence of tritium at concentrations above 1 tritium unit indicates the presence of a significant fraction of post-1954 (i.e., recently infiltrated) water in the groundwater sample. As shown on Table 4, tritium was detected in the samples collected from Wells 2 and 3 at concentrations of 17.7 and 7.3 T.U., respectively.

Finally, sampling for stable isotopes of hydrogen and oxygen was conducted at Wells 2 and 3 in January 2016 (MDH, 2016b). Stable isotope analysis is used to determine whether recharge to the aquifer is from local precipitation or from surface water features (e.g., lakes, wetlands). The samples are analyzed for the ratios of hydrogen isotopes deuterium to protium ($^{2}H/^{1}H$) and oxygen isotopes oxygen-18 to oxygen-16 ($^{18}O/^{16}O$), measured in parts per thousand (per mille). $\delta^{2}H$ and $\delta^{18}O$, the differences between the sample ratios and an international standard composition, are then plotted on the same figure as a meteoric water line, which is a linear relationship between $\delta^{2}H$ and $\delta^{18}O$ derived from analysis of multiple stable isotope samples from local precipitation. If the aquifer recharge is from local precipitation, the sample results should plot close to the meteoric water line. Evaporation from surface water features results in enrichment of the heavier oxygen-18 isotope, so sample results that plot well below the meteoric water line indicate recharge from surface water features. Figure E2 in Appendix E shows that the isotope samples collected from both Circle Pines wells plot close to the meteoric water line. Therefore, the water pumped from the Circle Pines wells is not groundwater under the influence of surface water. In other words, lakes and wetlands in the vicinity of Circle Pines are not contributing water to the City's wells.

When water quality data does not indicate the presence of tritium or other constituents that are consistent with contamination from the surface the aquifer vulnerability classification and the geologic sensitivity rating can be the same. The presence of tritium in groundwater samples from a well suggests that the water traveled vertically from the ground surface to the aquifer in less than about 50 years. When tritium has been detected in a well, geologic sensitivity ratings of low or very low would not be consistent with water quality data, unless groundwater flow information would indicate a nearby connection to an area of rapid vertical movement of water (e.g., a buried bedrock valley filled with sand and gravel) where water could travel from the surface to the aquifer quickly enough that tritium could be detected in a well with a geologic sensitivity rating of low or very low. If there is no hydraulic connection to an area of rapid vertical movement of water, the aquifer vulnerability would need to be classified as no lower than moderate to explain the presence of tritium in the well.

While the geologic sensitivity classification in the Circle Pines DWSMA is low, the water quality data indicate some connection between the aquifers and the ground surface. The water quality data do not conclusively indicate a rapid connection between the aquifers and the ground surface; therefore, moderate vulnerability was assigned to the entire Circle Pines DWSMA. While the tritium concentration of 17.7 T.U. at Well 2 is high, this concentration is not inconsistent with the definition of moderate vulnerability (i.e., surface to aquifer travel times ranging from a few years to decades). The tritium concentration measured at Well 2 in 1996 could be indicative of water that was precipitating at the time of the bomb peak reaching the confined Quaternary aquifer.

Figure 7 shows the final aquifer vulnerability map for the uppermost aquifer supplying water to municipal wells in the Circle Pines DWSMA.

7.0 Recommendations

Moderate rather than high aquifer vulnerability was assigned to the DWSMA due to the absence of water quality data that definitively indicate rapid recharge to the aquifer from the ground surface. It is recommended that the City work with the MDH to conduct tritium sampling of the municipal wells in order to have current data available when updating the aquifer vulnerability assessment as part of the next wellhead protection plan amendment. If desired, another dating method such as sulfur hexafluoride could be used to provide an additional data point for groundwater age.

8.0 Supporting Data Files

The groundwater model files and GIS files are included in Appendix F. (Appendix F can be found in the "Part1" folder on the CD.)

The groundwater model can be reviewed using MODFLOW-NWT (Niswonger et al., 2011). MODPATH files can be reviewed using MODPATH Version 5.

All coordinates in the modeling files are based on UTM NAD 83 Zone 15 N datum. Elevations are in meters above mean sea level (m MSL). Time units are days. Length units are meters.

The GIS files have been named according to the MDH conventions. Shapefiles are in UTM NAD83 Zone 15 N datum.

9.0 References

Barr Engineering Company (Barr), 2016. Northeast Well Field Evaluation – Phase 3. Technical Memorandum from John Greer, PG, Adam Janzen, and Brian LeMon, PE to Stefan Higgins, prepared for the City of Circle Pines, January 2016.

Barr Engineering Company (Barr), 2014. Northeast Well Field Evaluation – Phase 2 Aquifer Test. Technical Memorandum from John Greer, PG, Adam Janzen, and Brian LeMon, PE to Stefan Higgins, prepared for the City of Circle Pines, September 2014.

Environmental Simulations, Inc., 2011. Guide to using Groundwater Vistas, Version 6, Environmental Simulations Inc.

Landon, M.K., Delin, G.N., Komor, S.C., and C.P. Regan, 2000. Relation of Pathways and Transit Times of Recharge Water to Nitrate Concentrations Using Stable Isotopes. *Ground Water* v. 38, no. 3, pp. 381-395

Mazor, E, 2004. Chemical and Isotopic Groundwater Hydrology, 3rd ed., New York: Marcel Dekker Inc.

Metropolitan Council, 2014. Twin Cities Metropolitan Area Regional Groundwater Flow Model, Version 3.0. Prepared by Barr Engineering. Metropolitan Council: Saint Paul, MN.

Metropolitan Council, 2012. Using the soil water balance model (SWB) to estimate recharge for the Twin Cities Metropolitan Area Groundwater Model Version 3. Prepared by Barr Engineering. Metropolitan Council: Saint Paul, MN.

Meyer, G.N., Tipping, R.G., and R.S. Lively, 2013. Sand Distribution Model. Plate 5 of 6, *in* Geologic Atlas of Anoka County, Minnesota: D.R. Setterholm (ed.). Minnesota Geological Survey County Atlas Series, Atlas C-27. University of Minnesota, St. Paul.

Minnesota Department of Health (MDH), 2016a. Personal communication: Pre-Delineation Meeting with MDH and Barr Engineering staffs held on August 19, 2016 at Barr Engineering Company, Bloomington, MN.

Minnesota Department of Health (MDH), 2016b. *1020013 - Circle Pines - Deuterium vs O18 Plot.xlsx*. [email] Message from Amal Djerrari of the MDH to Adam Janzen and John Greer of Barr Engineering, Sent 8/23/2016.

Minnesota Department of Health (MDH), 2011. Draft Assessment Monitoring Pilot Study, Minnesota Department of Health, May 2011, Workgroup Review Draft Version 2.0.

Minnesota Department of Health (MDH), 2001. Circle Pines Part I Wellhead Protection Plan, Part I, Wellhead Protection Area Delineation, Drinking Water Supply Management Area Delineation, Vulnerability Assessment. Prepared by Steve Robertson of the MDH for the City of Circle Pines, June 2001.

Minnesota Department of Natural Resources (MnDNR), Division of Waters. 1991. *Criteria and Guidelines for Assessing Geologic Sensitivity of Ground Water Resources in Minnesota*. Prepared for the Legislative Commission on Minnesota Resources, 122 p., June 1991.

Mossler, J.H., 2012. Bedrock Geology. Plate 2 of 6, *in* Geologic Atlas of Anoka County, Minnesota: D.R. Setterholm (ed.). Minnesota Geological Survey County Atlas Series, Atlas C-27. University of Minnesota, St. Paul.

Mossler, J.H., 2013. Bedrock geology of the Twin Cities ten-county metropolitan area, Minnesota. Miscellaneous Map Series M-194, Minnesota Geological Survey.

Niswonger, R.G., Panday, S., and Ibaraki, M., 2011. MODFLOW-NWT, A Newton formulation for MODFLOW-2005. U.S. Geological Survey Techniques and Methods 6-A37, 44 p.

Norvitch, R.F., Ross, T.G., and A. Brietkrietz, 1974. Water resources outlook for the Minneapolis-St. Paul metropolitan area. Metropolitan Council of the Twin Cities area, 219pp.

Peterson, C., 2016. *RE: Data Needed for Part 1 WHPP Amendment.* [email] Message from Chandra Peterson of the City of Circle Pines to John Greer of Barr Engineering and Jim Keinath of the City of Circle Pines. Sent 5/10/2016.

Schwartz, F.W. and H. Zhang, 2003. *Fundamentals of Ground Water.* John Wiley and Sons, Inc. New York, New York.

WSB & Associates, Inc., 2007. Water Emergency and Conservation Plan for the City of Circle Pines, Minnesota. Prepared for the City of Circle Pines, October 2007.

Westenbroek, S.M., V.A. Kelson, W.R. Dripps, R.J. Hunt, and K.R. Bradbury, 2010. SWB – A Modified Thornthwaite-Mather Soil-Water-Balance Code for Estimating Groundwater Recharge, Techniques and Methods 6-A31, U.S. Geological Survey, Groundwater Resources Program, Reston, VA, 72 pp.