Wellhead Protection Plan amendment – Part 1

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

City of Redwood Falls
Redwood Falls, Minnesota
Carlson McCain Project #7270

Prepared for:

City of Redwood Falls
333 South Washington Street
PO Box 526
Redwood Falls, Minnesota 56283

March 4, 2019

Carlson McCain

15650 36th Ave N, Suite 110
Plymouth, MN 55446
Tel 952-346-3900
Fax 952-346-3901
www.carlsonmccain.com

ENVIRONMENTAL • ENGINEERING • LAND SURVEYING

TABLE OF CONTENTS
(Page 1 of 2)

TABLES

FIGURES

TABLE OF CONTENTS
(Page 2 of 2)

APPENDICES

Glossary of Terms

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

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

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

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

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

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

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

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

Acronyms

DNR - Minnesota Department of Natural Resources

EPA - United States Environmental Protection Agency

MDA - Minnesota Department of Agriculture

MDH - Minnesota Department of Health

MGD – Million Gallons per Day

MGS - Minnesota Geological Survey

MLAEM - Multi-Layer Analytic Element Model

MnDOT - Minnesota Department of Transportation

MnGEO - Minnesota Geospatial Information Office

MPCA - Minnesota Pollution Control Agency

MSL - Mean Sea Level

MWI - Minnesota Well Index

NRCS - Natural Resource Conservation Service

QBAA – Quaternary Buried Artesian Aquifer

SWCD - Soil and Water Conservation District

UMN - University of Minnesota

USDA - United States Department of Agriculture

USGS - United States Geological Survey

1.0 INTRODUCTION

Carlson McCain, Inc. (Carlson McCain) has been retained by the City of Redwood Falls (City) to complete a Wellhead Protection (WHP) Plan Part 1 Amendment. The City owns and operates the wells and associated infrastructure as part of its public water supply system (PWSID 1640008). The work was performed in accordance with the Minnesota Wellhead Protection Rule, parts 4720.5100 to 4720.5590.

This report presents delineations of the wellhead protection areas (WHPAs), emergency response areas (ERAs) and drinking water supply management areas (DWSMAs), and the vulnerability assessments for the public water supply wells and DWSMAs. Figure 1 illustrates the boundaries for the WHPAs, ERAs and the DWSMA. The WHPA is defined by a 10-year time of travel and the ERA is defined by a 1-year time of travel. Complete definitions of rule-specific terms used herein are provided in the "Glossary of Terms" on page i and acronyms used in this report are listed on page ii.

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

The City's water supply is currently obtained from five wells located near Highway 71, south of the City, in Redwood Falls and Paxton Townships. Table 1 below lists the basic information for each well currently in the City's public water supply system and Figure 1 shows the location.

Table 1 - Redwood Falls Public Water Supply Wells

Local Well ID	Unique Number	Use[1]/ Status	Casing Diameter (inches)	Casing Depth (feet)	Well Depth (feet)	Date Constructed & Reconstructed	Aquifer[2]	Well Vulnerability
RF-1	209660	P/Active	12	142	182	1954	QBAA	Not Vulnerable
RF-2	455796	P/Active	12	116	168	10/27/1988	QBAA	Not Vulnerable
RF-3	403995	P/Active	12	189	230	05/21/1985	QBAA	Not Vulnerable
RF-5	403955	P/Active	16/10[3]	220	268	05/21/1984 & 2017[3]	QBAA	Not Vulnerable
RF-RAMSEY	241414	P/Active	12	82	94	1950	QBAA	Vulnerable

Notes:
1. Primary (P)
2. Quaternary Buried Artesian Aquifer (QBAA)
3. RF-5 was originally constructed in 1984 and was reconstructed in 2017. The reconstruction involved installation of an 10-inch liner inside the original casing which had deteriorated.

2.0 ASSESSMENT OF DATA ELEMENTS

MDH staff met with representatives of the City on December 1, 2017, for a scoping meeting that identified the data elements required to prepare Part I of the WHP plan. Table 2 presents the assessment of these data elements relative to the present and future implications of planning items specified in Minnesota Rules, part 4720.5210.

Table 2 - Assessment of Data Elements

Data Element	Present and Future Implications				Data Source
	Use of the Well (s)	Delineation Criteria	Quality and Quantity of Well Water	Land and Groundwater Use in DWSMA	
Precipitation	M	M	M	H	MN State Climatology Office
Geology					
Maps and geologic descriptions	M	H	H	H	MGS, DNR, USGS, Consultant Reports
Subsurface data	M	H	H	H	MGS, MDH, DNR, MWI
Borehole geophysics	M	H	H	H	MGS, Consultant Reports
Surface geophysics	L	L	L	L	DNR, Consultant Reports
Maps and soil descriptions	M	M	M	M	NRCS Soil Survey, USGS Recharge Map
Eroding lands					
Water Resources					
Watershed units	M	M	M	M	DNR
List of public waters	L	L	L	L	DNR
Shoreland classifications					
Wetlands map					
Floodplain map					
Land Use					
Parcel boundaries map	L	H	L	L	Redwood County
Political boundaries map	L	H	L	L	MN Geospatial Commons
Public Land Survey map	L	H	L	L	MN Geospatial Commons
Land use map and inventory					
Comprehensive land use map					
Zoning map					
Public Utility Services					
Transportation routes and corridors	L	L	L	L	MN Geospatial Commons
Storm/sanitary sewers and PWS system map	L	L	L	L	City of Redwood Falls
Oil and gas pipelines map					
Public drainage systems map or list	M	M	M	M	DNR, Redwood County
Records of well construction, maintenance, and use	H	H	H	H	City of Redwood Falls, MWI, MDH
Surface Water Quantity					
Stream flow data	L	L	L	L	DNR

Data Element	Present and Future Implications				Data Source
	Use of the Well (s)	Delineation Criteria	Quality and Quantity of Well Water	Land and Groundwater Use in DWSMA	
Ordinary High Water Mark data	L	L	L	L	DNR
Permitted withdrawals	L	L	L	L	DNR
Protected levels/flows	L	L	L	L	DNR
Water use conflicts	L	L	L	L	DNR
Groundwater Quantity					
Permitted withdrawals	H	H	H	H	DNR
Groundwater use conflicts	H	H	H	H	DNR
Water levels	H	H	H	H	DNR, MDH, City of Redwood Falls
Surface Water Quality					
Stream and lake water quality management classification					
Monitoring data summary	L	L	L	L	DNR, Redwood County
Groundwater Quality					
Monitoring data	H	H	H	H	MDH, City of Redwood Falls
Isotopic data	H	H	H	H	MDH
Tracer studies	L	L	L	L	NA
Contamination site data	L	L	L	L	NA
Property audit data from contamination sites					
MPCA and MDA spills/release reports	L	L	L	L	NA

Definitions Used for Assessing Data Elements:

High (H) - the data element has a direct impact
Moderate (M) - the data element has an indirect or marginal impact
Low (L) - the data element has little if any impact
Shaded - the data element was not required by MDH for preparing the WHP plan

3.0 GENERAL DESCRIPTIONS

3.1 Description of the Water Supply System

The City obtains its drinking water supply from five primary wells, summarized in Table 1, which are completed in sand and gravel aquifer formations at varying depths within the glacial till. While the wells are completed in three aquifer horizons all three aquifers are classified as Quaternary Buried Artesian Aquifers (QBAA) by the Department of Natural Resources (DNR). The City operates a 1.5 million gallon per day (mgd) water treatment facility designed to reduce iron and manganese concentrations to acceptable levels. This system is combined with a reverse osmosis (RO) process using a 75% blend ratio to produce finished water that meets both primary and secondary drinking standards.

3.2 Description of the Hydrogeologic Setting

The City of Redwood Falls is located on the south side of the Minnesota River at the base of a broad, poorly drained till plain between the eastern slope of a regional topographic feature known as the Prairie Coteau and the Minnesota River. The Prairie Coteau trends in a northwesterly direction and there is a prominent drop in topographic relief in a northeasterly direction all along its entire eastern slope. From the base of the slope to the northeast towards the Minnesota River, is a lowland plain. Precambrian crystalline bedrock and Cretaceous shale are exposed in the Minnesota River valley where the surface elevation is approximately 850 feet above mean sea level (msl). Most of the City lies in the adjacent upland area at an elevation of 1000 to 1050 feet msl and is underlain by deposits of clayey glacial till. Due to the presence of a variable bedrock surface, the thickness of the glacial deposits range from approximately 50 feet to more than 250 feet. The deepest deposits are thought to be associated with a bedrock valley that generally parallels the Minnesota River, on the south side near the City of Redwood Falls. The City's wellfield is located south of the City with most of the wells located near Highway 71. Figure 4 presents the locations of three cross-sections through the City wells. Cross-section A – A' (Figure 5) is oriented west to east through the Ramsey Well just south of the City. Cross-section B – B' (Figure 6) is oriented west to east through City Wells 1, 2 and 3 approximately 3 miles south of the City and cross-section C – C' (Figure 7) is oriented north to south from the City, through the City wells, to a point approximately five miles south of the City. The stratigraphy shown on the cross-sections is adapted and interpreted from C-36, the Geologic Atlas Redwood County (MGS 2016). The Atlas contains detailed maps and descriptions of the stratigraphic units in the Redwood Falls area.

A - Aquifer
The City's Ramsey Well is constructed in the A - Aquifer just south of the City. The A - Aquifer consists of sand and gravel glacial outwash and is about 8 to 31 feet thick but thins to just a few feet in areas further away from the Ramsey Well. This aquifer occurs between the depths of approximately 50 and 100 feet and is confined by clayey glacial till both above and below the sand and gravel aquifer material.

Table 3 - Description of the Hydrogeologic Setting for the A - Aquifer

Attribute	Descriptor	Data Source
Aquifer Material	Sand and gravel	Geologic Log for Redwood Falls' Ramsey Well (Unique Number 241414)
Porosity Type and Value	Effective porosity, n_e = 0.25	City of Redwood Falls 2008 Wellhead Protection Plan Part 1 (Liesch, 2008)
Aquifer Thickness	Range of Thickness: 8 to 31 feet Modeled Thickness: 20 feet	Redwood Falls WHP Cross-Sections and Well Logs
Stratigraphic Top Elevation	971 feet MSL	Redwood Falls WHP Cross-Sections and Well Logs
Stratigraphic Bottom Elevation	951 feet MSL	Redwood Falls WHP Cross-Sections and Well Logs
Hydraulic Confinement	Confined	Redwood Falls WHP Cross-Sections and Well Logs
Transmissivity (T)	Range of Values: 9,357 – 10,159 ft^2/day Reference Value: 9,758 ft^2/day	The Aquifer Test Plan presents a range of transmissivity values obtained from pumping test and specific capacity data during exploration and development of the Redwood Water Supply including aquifer tests by Liesch and the USGS. The reference value is the average T based on the pumping test data.
Hydraulic Conductivity (K)	Range of Values: 468 – 508 ft/day Reference Value: 488 ft/day	Hydraulic conductivities are based on the T values provided above and the estimated aquifer thickness near the Ramsey Well.
Groundwater Flow Field	Flow to the north-northeast	Modeled groundwater flow field calibrated to pre-pumping water levels provided in the USGS Water Supply Paper 1669-R

B/C - Aquifer

The B/C - Aquifer is comprised of two aquifer horizons that are composed of buried sand and gravel outwash and are separated by a discontinuous clay layer where the aquifers overlap. The B - Aquifer horizon is approximately 50 thick and is where Wells 1 and 2 are completed at depths of 182 and 172 feet, respectively. Wells 3 and 5 are completed at depths of 231 and 268 feet in the underlying C – Aquifer, respectively. The C – Aquifer is approximately 50 feet thick and directly overlies the crystalline bedrock at depths of up to 275 feet. The combined B and C – Aquifer horizons appear to function as a single aquifer near the City wells based on pumping test data and the fact that the aquifers appear to be in direct contact near the wellfield. For the model, the B and C aquifers were combined into a single model layer due to the degree of hydraulic connectivity.

Table 4 – Description of Hydrogeologic Setting for the B/C - Aquifer

Attribute	Descriptor	Data Source
Aquifer Material	Sand and gravel	Redwood Falls production well logs
Porosity Type and Value	Effective porosity, n_e = 0.25	City of Redwood Falls 2008 Wellhead Protection Plan Part 1 (Liesch, 2008)
Aquifer Thickness	Range of Thickness: 20 to 95 feet Modeled Thicknesses: B Aquifer = 49 feet C Aquifer = 56 feet, B/C Aquifer = 95 feet	Redwood Falls WHP Cross-Sections and Well Logs
Stratigraphic Top Elevation	B Aquifer = 869 feet msl C Aquifer = 836 feet msl B/C Aquifer = 875 feet msl	Redwood Falls WHP Cross-Sections and Well Logs
Stratigraphic Bottom Elevation	B Aquifer = 820 feet msl C Aquifer = 780 feet msl B/C Aquifer = 780 feet msl	Redwood Falls WHP Cross-Sections and Well Logs
Hydraulic Confinement	Confined	Redwood Falls WHP Cross-Sections and Well Logs
Transmissivity (T)	Reference Value: B Aquifer = 16,843 ft^2/ft C Aquifer = 25,000 ft^2/ft	The reference T value for the B Aquifer is from the USGS test at Well 1 (Water Supply Paper 1669-R) The reference T value for the C Aquifer was selected based on MDH analysis of a pumping test (MDH Test No. 507) conducted by Liesch at Well 5.
Hydraulic Conductivity (K)	Reference Value: B Aquifer = 306 ft/day C Aquifer = 455 ft/day B/C Aquifer = 373 ft/day	The B and C reference values for hydraulic conductivity were obtained from the reference values for transmissivity and the Aquifer thicknesses. The B/C reference value is the geometric mean of the B and C values.
Groundwater Flow Field	Flow is towards the north-northwest	Modeled groundwater flow field calibrated to pre-pumping water levels provided in the USGS Water Supply Paper 1669-R.

4.0 DELINEATION OF THE WELLHEAD PROTECTION AREAS

4.1 Delineation Criteria

The boundaries of the WHPAs for the City are shown in Figures 1 and 2. Tables 5 and 6 describe how the delineation criteria specified under Minnesota Rules, part 4720.5510, were addressed to the A - Aquifer and B/C - Aquifer, respectively.

Table 5 - Description of WHPAs Delineation Criteria for the A - Aquifer

Criterion	Descriptor	How the Criterion was Addressed
Flow Boundary	Aquifer Boundary	Represented as inhomogeneity: high conductivity aquifer within low conductivity model domain.
Flow Boundary	Redwood River	Represented as a linesink with a resistance of 100 days based on well logs, cross-sections, actual stream elevations and degree of connectivity.
Flow Boundary	Minnesota River	Represented as a head specified linesink based on well logs, cross-sections, actual stream elevations and degree of connectivity.
Flow Boundary	Sleepy Eye River	Represented as a linesink with a resistance of 100 days based on well logs, cross-sections, actual stream elevations and degree of connectivity.
Flow Boundary	Spring Creek	Represented as a linesink with a resistance of 100 days based on well logs, cross-sections, actual stream elevations and degree of connectivity.
Flow Boundary	Ramsey Creek	Represented as a linesink with a resistance of 100 days based on well logs, cross-sections, actual stream elevations and degree of connectivity.
Daily Volume of Water Pumped	See Table 7	Annual pumping information was obtained from the MN DNR Permitting and Reporting System (MPARS) for the City of Redwood Falls (Permit No. 1954-0268) and was converted to a daily volume pumped by the Ramsey well .
Groundwater Flow Field	See Figure 8	The model calibration process addressed the relationship between the calculated versus observed groundwater flow field.
Aquifer Transmissivity (T)	Reference Value: 9,758 ft^2/day	The reference T value was selected on the basis of pumping tests conducted in the A – Aquifer as outlined in the Aquifer Test Plan
Time of Travel	10 years	The City of Redwood Falls selected a 10-year time of travel.

Table 6 - Description of WHPAs Delineation Criteria for the B/C Aquifer

Criterion	Descriptor	How the Criterion was Addressed
Flow Boundary	Aquifer Boundary	Represented as inhomogeneity: high conductivity aquifer within low conductivity model domain.
Flow Boundary	Redwood River	Represented as a linesink with a resistance of 100 days based on well logs, cross-sections, actual stream elevations and degree of connectivity.
Flow Boundary	Minnesota River	Represented as a head specified linesink based on well logs, cross-sections, actual stream elevations and degree of connectivity.
Flow Boundary	Sleepy Eye River	Represented as a linesink with a resistance of 100 days based on well logs, cross-sections, actual stream elevations and degree of connectivity.
Flow Boundary	Spring Creek	Represented as a linesink with a resistance of 100 days based on well logs, cross-sections, actual stream elevations and degree of connectivity.
Flow Boundary	Ramsey Creek	Represented as a linesink with a resistance of 100 days based on well logs, cross-sections, actual stream elevations and degree of connectivity.
Daily Volume of Water Pumped	See Table 7	Annual pumping information was obtained from MPARS for the City of Redwood Falls (Permit No. 1954-0268) and was converted to a daily volume pumped by wells 1, 2, 3 and 5.
Groundwater Flow Field	See Figure 9	The model calibration process addressed the relationship between the calculated versus observed groundwater flow field.
Aquifer Transmissivity (T)	Reference Value: 9,758 ft^2/day	The reference T value was selected on the basis of pumping tests conducted in the A – Aquifer as outlined in the Aquifer Test Plan
Time of Travel	10 years	The City of Redwood Falls selected a 10-year time of travel.

Pumping data was obtained from the DNR's Permit and Reporting System (MPARS) for the City's Water Appropriation Permit No. 1954-0268. These values, confirmed by the City, were used to identify the maximum volume of water pumped annually at each well over the previous five-year period, as shown in Table 7. The maximum daily volume of discharge used as an input parameter in the model was calculated by dividing the greatest annual pumping volume by 365 days.

Table 7 - Annual Volume of Water Discharged from Water Supply Wells

Well Name	Unique No.	Total Annual Volume (million gallons/year)						Daily Volume	
		2013	2014	2015	2016	2017	2022 (est.)	Gallons	M^3
RF-1	209660	**36.148**	34.071	34.867	30.037	35.261	34.076	99,036	375
RF-2	455796	**39.914**	38.176	38.815	35.457	36.700	37.812	109,353	414
RF-3	403995	51.993	54.816	50.928	49.869	**63.057**	54.133	172,759	654
RF-5	403955	74.431	**75.027**	72.037	69.647	49.654	68.159	205,553	778
RF-Ramsey	241414	21.652	21.556	20.336	20.367	**25.399**	21.862	69,586	265

Source: MPARS and the City of Redwood Falls

In addition to the wells used by the public water supplier, Table 8 shows an additional high-capacity well included in the delineation hydrogeologic flow boundaries near the Ramsey Well. Estimated daily pumping volumes were based on reported annual water use.

Table 8 - Other Permitted High-Capacity Wells

Well Name	Unique No.	Permittee	DNR Permit Number	Aquifer	Use	Volume of Water Pumped		
						Annual (mgy)	Daily (gpd)	Daily (cubic meters)
Tersteeg	229604	Tersteeg	1977-4164	QBAA	Irrigation	3.3	9,041	34.22

4.2 Method Used to Delineate the Wellhead Protection Areas

The WHPAs for the City's wells were determined by using the analytic element method of groundwater flow modeling described by Strack (1989). In particular, the computer software program used to conduct the modeling was the Multi-Layer Analytical Element Model (MLAEM), developed by Strack Consulting. MLAEM model calculates the groundwater capture zones deterministically by using representative analytic elements (e.g. pumping wells, lakes, rivers, uniform flow) and aquifer parameters that are input into the code. The resulting particle pathlines are then traced back a set amount of time, in this case one year for the ERA and ten years for the WHPA. The input files for the final model are available at MDH upon request. Text files showing the input codes for each aquifer are included in Appendix A. Coordinate data are listed in the Universal Transverse

Mercator (UTM) coordinate system, Zone 15, and elevations are listed in meters above mean sea level.

For this delineation, each of the two aquifers (A-Aquifer and B/C-Aquifer) were modeled separately. A single-layer model was used for each of the aquifers because they are unconsolidated, Quaternary-age sand and gravel aquifers that have not been observed to have significant interaction with overlying or underlying aquifers. The aquifers were modeled as inhomogeneities within the surrounding Cretaceous-age bedrock and Quaternary-age clay till. Aquifer properties used as model inputs are listed in Tables 3 and 4. The geometry of the inhomogeneities correspond with aquifer boundaries that were determined based on MWI well logs and previous geologic mapping activities which identified the lateral extents of the aquifers. For the purposes of the model, this "global aquifer" was assigned a hydraulic conductivity of 1.7 meters per day, effective porosity of 0.2, and thickness of 130 meters. These are estimated values and based on the fine-grained nature of the Cretaceous bedrock and Quaternary till, it is reasonable to expect a decrease in hydraulic conductivity of one to two orders of magnitude, as well as a decrease in effective porosity.

A - Aquifer

The delineated WHPA for the A-Aquifer wellfield (consisting of the South Ramsey well) corresponding to the ten-year time of travel capture zone is illustrated in Figures 1 and 2. The A - Aquifer model was constructed in MLAEM by representing the low-permeability, Quaternary-age till as the "global aquifer" with the aquifer parameters described above. The A - Aquifer was then delineated as an inhomogeneity within the global aquifer. To help refine the potentiometric surface and flow direction in the area of the A - Aquifer, additional analytic elements were inserted into the model domain. For both the A and B/C - Aquifers, these analytic elements include several head-specified or resistance-specified linesinks representing significant surface water features such as the Redwood River, Minnesota River, Sleepy Eye River, Ramsey Creek and Spring Creek. The numerical parameters for head and resistance assigned to the linesinks are based on actual stream elevations and degree of connectivity with the water table. The A - Aquifer is overlain in most locations by significant thicknesses of fine-grained sediments and have a relatively low degree of connection with the surface water features; therefore, modeled resistance values are high (e.g. 100 days). Combining all of the analytic elements results in a general southwest to northeast flow direction within the aquifer, as shown on Figure 8.

In addition to the aquifer properties listed in Table 3, the A - Aquifer was modeled to receive two inches of surficial recharge per year within the aquifer boundary. This was done to account for the likelihood that there is some surficial recharge of relatively recent atmospheric water, as evidenced by tritium concentrations in groundwater samples from the aquifer noted on Table 9. The value of two inches per year is consistent with the number used in the previous model of the aquifer which is similar to the range of approximately 2.0 to 4.0 inches per year reported for the Redwood Falls area by Smith and Westenbroek (2015) in the USGS publication *Potential Groundwater Recharge for the State of Minnesota Using the Soil-Water-Balance Model, 1996-2010*. As described in Section 4.3.2, below, additional model runs were conducted using different recharge values, however these resulted in more deviation between the observed and modeled heads, i.e. the model calibration got worse. Therefore, the original value of two inches per year was used in the final model. Further discussion on surficial recharge and L-scores is presented in presented in Section 6 of this report.

In general, the high volume of pumping and the geometry of the aquifer are reflected in the orientation of the capture zone. As shown in Figure 8, the ten-year capture zone spans nearly the full width of the aquifer. The pathlines extend radially outward from the pumping center and are elongated, parallel to the long axis of the aquifer, and perpendicular to the equipotential lines.

BC - Aquifer

The delineated WHPA for the B/C - Aquifer wellfield (consisting of wells RF-1, RF-2, RF-3, and RF-5) corresponding to the ten-year time of travel capture zone is illustrated in Figures 1 and 2. The global aquifer and linesinks in the B/C model are essentially the same as the A model with the exception of the recharge. The recharge is modeled as leakage into the B/C - Aquifer using a given-strength area element with a strength of approximately 1.4 inches per year, which is lower than the two inches per year modeled in the A - Aquifer.

The resulting WHPA and capture zones are shown on Figure 9. The greater thickness of the BC-Aquifer results in a more truncated capture zone than is observed in the A - Aquifer, however the capture zones still exhibit the characteristic elongation and asymmetry that would be expected in a relatively uniform flow field, with a stagnation point relatively close to the well on the downgradient side and a longer 'tail' of pathlines extending in the upgradient direction.

4.3 Results of Model Calibration and Sensitivity Analysis

4.3.1 Model Calibration

Model calibration is a procedure that compares the modeled results to measured or observed results to assess the goodness of fit of the model to real-life conditions. In groundwater flow models, calibration is commonly performed using water elevation and/or flux. Both the A - Aquifer and the B/C - Aquifer were calibrated using a combination of these two techniques.

<u>Head Comparison</u> – this involved comparing modeled head values for non-pumping conditions to reported groundwater elevations from pre-pumping conditions obtained from USGS Water Supply Paper 1669-R (USGS 1964). The well locations and groundwater elevations were digitized from paper maps in the USGS report and the resulting coordinate and elevation data could then be compared numerically with modeled results within MLAEM. Calibration results are included in Appendix B, and demonstrate that differences between modeled and observed results ranged from 0.2 meters to 3.6 meters and the root mean square error was calculated to be 2.1 meters. A graph showing a comparison of measured head and modeled head is also included in Appendix B, and illustrates that the calibration points track reasonably well with a target trendline having a slope equal to one (i.e. measured head equals modeled head).

<u>Flux Comparison</u> – this involved comparing the model discharge for the Redwood River element in the non-pumping condition to available base flow data for the river. Discharge data for the years

1994 through 2018 compiled by the USGS for Redwood River gauging station No. 05316500 near Redwood Falls indicates a median low flow value of approximately 10 cubic feet per second. This compares favorably with a two-year return frequency value of 6 cubic feet per second for the period from 1986 to 2005 reported by the University of Minnesota (Dadaser-Celik and Stefan, 2009). The model reports total discharge in cubic meters per day, and the values for the Redwood River element for the A - Aquifer and B/C - Aquifer are 34,859 and 27,650 cubic meters per day, respectively. These values are relatively similar to the median low flow value of 10 cubic feet per second, or 24,500 cubic meters per day. Discharge reports from MLAEM are included in Appendix B.

4.3.2 Model Sensitivity

Model sensitivity is the amount of change in the output, in this case the capture zones, observed when selectively varying model input parameters. The following is a description of several sensitivity parameters and their influence on the model results:

- **Pumping Rate** – higher pumping rates increase the size of the capture zone and result in more elongated capture zones for nearby wells due to locally increasing the hydraulic gradient. In this model pumping rates have been predefined (see Tables 7 and 8) and therefore are not variable.

- **Direction of groundwater flow** – the direction of groundwater flow determines the orientation of the capture zone. In both the A and B/C models, flow directions are based on the linesink geometry and numerical parameters (e.g. head, discharge, resistance). Linkesink geometry is fixed, thereby eliminating one source of variability. The numerical parameters have been assigned based on actual stream elevations and degree of connection with the water table. Both aquifers are overlain in most locations by significant thicknesses of fine-grained sediments and have a relatively low degree of connection with the surface water features, and therefore have high resistance values. This further reduces the potential variability. As described above, the calibration data indicates that the modeled head and groundwater flow direction is appropriate based on historical observations, however potential variability in flow direction is accounted for by rotating the flow field +/- 10 degrees as required in Minnesota Rules, part 4720.5510.

- **Hydraulic gradient** – a flat hydraulic gradient results in a circular capture zone, and increases in hydraulic gradient cause elongation and narrowing of the capture zone. The hydraulic gradient is only a user-defined parameter in models which utilize a uniform flow, or “uniflow” element to define the flow field. Neither the A - Aquifer nor the B/C - Aquifer models utilize the uniflow element, so hydraulic gradients are fixed.

- **Hydraulic conductivity** – hydraulic conductivity primarily affects drawdown; as conductivity increases, drawdown decreases. Hydraulic conductivity is calculated from the transmissivity and aquifer thickness. In the A and B/C models both thickness and transmissivity values have been predefined, so the primary values used for hydraulic conductivity correspond to the reference values shown in Tables 3 and 4. Varying hydraulic conductivity during individual model runs resulted in minor variations in capture zone geometry and orientation, but there were no obvious model improvements using higher or lower values, so for consistency it was determined that the average value should be used.

- Aquifer **thickness** and **porosity** – Decreasing either thickness or porosity results in a larger capture zone, as there is less volume available for fluid flow near the well. In this model, both of these values have been predefined (see Tables 3 and 4) and are therefore not variable.

- Surficial **recharge** – Changing the amount of surficial recharge will affect the amount of drawdown in the aquifer, as more surficial recharge means less water is needed from aquifer storage to supply the volume pumped. Increasing the recharge in the A-Aquifer model resulted in less drawdown at the calibration points and decreasing recharge resulted in more drawdown. In either scenario, greater differences were observed between measured and modeled heads, indicating that the currently-used value represents the best fit.

4.4 Addressing Model Uncertainty

Because any model is a simplification of a complex natural system, and has a limited number of inputs, there will always be some degree of uncertainty about the reliability of the model outputs. In the presence of such uncertainty, it is prudent to use conservative assumptions when preparing WHPA models to provide a delineation that is the most protective of public health.

The following measures were taken to address uncertainty with this delineation:

- The pumping rate for each well is based on the greatest annual volume of water used during the previous five years or projected water use over the next five years, whichever is greater (Minn. Rules 4720.5510, subp. 4).

- The ambient flow field was varied by ten degrees in each direction from the angle of ambient flow to create a composite capture zone which was used to delineate the WHPA . This results in a larger WHPA.

5.0 DELINEATION OF THE DRINKING WATER SUPPLY MANAGEMENT AREA

The boundaries of the Drinking Water Supply Management Areas (DWSMAs) were defined by the City using the following features (Figures 8 and 9):

- Extents of modeled WHPAs;

- A polygon was developed to enclose the WHPA for each DWSMA using the Township, Range and Section system. The smallest division used is ¼ of ¼ of a section, or approximately 40 acres.

6.0 VULNERABILITY ASSESSMENTS

The Part I wellhead protection plan includes the vulnerability assessments for the City's production wells and DWSMAs. These vulnerability assessments will be used to help define potential contamination sources within the DWSMAs and to select appropriate measures for reducing the risk that they present to the public water supply.

6.1 Assessment of Well Vulnerability

A - Aquifer

The Ramsey Well is the only well that utilizes the A – Aquifer and, in accordance with the Scoping Decision Notice and summarized on Table 1, this well is considered vulnerable. While the well appears to be constructed to current Minnesota Rules (part 4725) for well construction, Tritium analyses suggests that water within the aquifer is of relatively recent origin. The Ramsey Well has a Tritium concentration above the threshold of 1 TU indicating that the well is receiving relatively recent (post -1953) recharge and is automatically considered vulnerable.

Available water quality results for the Ramsey Well are presented below in **Table 9**.

Table 9 - Isotope and Water Quality Results (2012 & 2014) – A Aquifer

Well	Tritium (TU)	Nitrate (mg/L)	Chloride/Bromide ratio	Chloride (mg/L)	Bromide (mg/L)
Ramsey	**1.45**	<0.05	39	4.69	0.12

B/C Aquifer

In accordance with the Scoping Decision Notice and summarized on Table 1, all wells that obtain water from the B/C - Aquifer (RF-1, RF-2, RF-3 and RF-5) are considered not vulnerable. The individual wells are constructed to current Minnesota Rules (part 4725) for well construction, and Tritium analyses suggests that water within the aquifer is not of relatively recent origin. Recent analysis of Nitrate, Chloride and Bromide also do not suggest anthropogenic influences on well water quality. In addition, the geologic conditions at the well sites includes a thick cover of clay-rich geologic materials over the aquifer that serves to retard the vertical movement of contaminants. The B/C – Aquifer wells are considered to be non-vulnerable.

Available water quality results for the Dudley Wellfield are presented below in **Table 10**.

Table 10 - Isotope and Water Quality Results (2012 & 2014) – B/C Aquifer

Well	Tritium (TU)	Nitrate (mg/L)	Chloride/Bromide ratio	Chloride (mg/L)	Bromide (mg/L)
1	<0.8	<0.05	41	2.03	0.05
2	Not analyzed	<0.05	27	1.37	0.05
3	<0.8	<0.05	34	1.71	0.05
5	<0.8	<0.05	47	3.32	0.07

6.2 Assessment of Drinking Water Supply Management Area Vulnerability

Two separate DWSMAs have been identified on the basis of the modeled WHPAs, one for the Ramsey Well (A - Aquifer) and one for the remaining wells (B/C – Aquifer). The vulnerability of the DWSMAs has been assessed using well construction data, L-score procedures and water quality analyses performed by MDH. L-scores are calculated by MDH using the MWI reported geologic materials and thicknesses to assess sensitivity to contamination. The lower the L-score, the higher the sensitivity. In addition, geologic logs in the MWI; geologic maps, reports and cross-sections; previous test drilling and aquifer testing conducted by the City were also considered. Methods outlined in the MDH Guidance Document: "Assessing Well and Aquifer Vulnerability for Wellhead Protection" were used to assess DWSMA vulnerability.

The vulnerabilities of the DWSMAs are shown on Figure 3 and are based upon the following information for each Aquifer utilized by the City:

A - Aquifer

The vulnerability of A - Aquifer DWMSA is moderate based upon the L-scoring values, water quality results and geologic sensitivity. The L-scores for the MWI wells located within the DWSMA indicate a low to moderate geologic sensitivity rating and the single production well has been determined to be vulnerable primarily based on the detection of tritium in the well. The water quality data indicates relatively recent recharge based on tritium testing that suggests mixing of recent (since 1953) and with older waters; however, the tritium detected in the Ramsey well was low and the lack of other indicators of human impact is consistent with a moderate vulnerability rating. The results of the L-scoring and the DWSMA vulnerability are illustrated on Figure 3.

B/C - Aquifer

L-scoring procedures were also used at the B/C - Aquifer DWSMA where the aquifer material is confined by thick sequences of glacial deposits. The L-score results for wells within the DWSMA indicate a low geological sensitivity with a single well showing moderate vulnerability. Two wells with low geological sensitivity are located on the same parcel and are considered to be more representative of actual conditions above the B/C – Aquifer. None of the four City wells sampled for tritium has had a tritium result above 1.0 tritium units suggesting no mixing of recent (since 1953) and older waters. Based on this information the vulnerability of the B/C - Aquifer DWSMA is Low, the same as the geological sensitivity rating. The results of the L-scoring and the DWSMA vulnerability are illustrated on Figure 3.

7.0 RECOMMENDATIONS

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

1) Well Inventory: The Wellhead Protection Plan Part 2 should provide for an inventory of wells within the DWSMAs as part of the Potential Contaminant Source Inventory. The inventory should be updated periodically and include both active and sealed wells This can be accomplished using the Minnesota Well Index and through collaboration with high capacity well users and with the DNR High Capacity Appropriation permit program.

   The City should attempt to verify unused wells in the vicinity of the wellfields and provide guidance or assistance to seal the wells as appropriate. Well sealing assistance may be available in certain circumstances through the county or as part of the MDH implementation grant program. Additional information can be found at the MDH Well Management Program website.

2) If the pump in the Ramsey well is pulled for maintenance or replacement during plan implementation, the City should consider a downhole video inspection to look for potential flaws in the well casing that could result in the low-level detections of tritium seen in samples from the well.

3) Water Level Monitoring: The City should consider developing and implementing a water level monitoring program if suitable wells can be identified for use as potential long-term monitoring points. The use of water level data loggers could simplify data collection over time and provide a record of water level changes that could be correlated with groundwater withdrawals and varying recharge based on climatic patterns.

4) Water Quality Monitoring: During year five or six of plan implementation the City should consider development of a sampling plan for the active public water supply wells. MDH may be able assist with development and implementation of the plan which would include sampling for the MDH vulnerability parameters including chloride, bromide, sulfate, nitrate, ammonia, tritium, field measurements, alkalinity, water stable isotopes and total organic carbon. This information would be used to inform the next amendment of the City's Wellhead Protection Plan.

8.0 SELECTED REFERENCES

Alexander, S.C., and Alexander, E.C., Jr. (1989), *Residence times of Minnesota Groundwaters,* University of Minnesota, Minneapolis, Minnesota.

Blum, Justin (2016), *Analysis of Redwood Falls 5 (403955) Pumping Test, May 15, 1984, Quaternary Buried Artesian Aquifer.* Aquifer Test No. 507, Minnesota Department of Health, St. Paul, Minnesota

Dadaser-Celik, Filiz, and Stefan, Heinz (2009), *Stream Flow Response to Climate in Minnesota*, University of Minnesota, Minneapolis, Minnesota.

Liesch (2008). Wellhead Protection Plan Part I, Redwood Falls, Minnesota, Liesch Associates, Inc., Plymouth Minnesota.

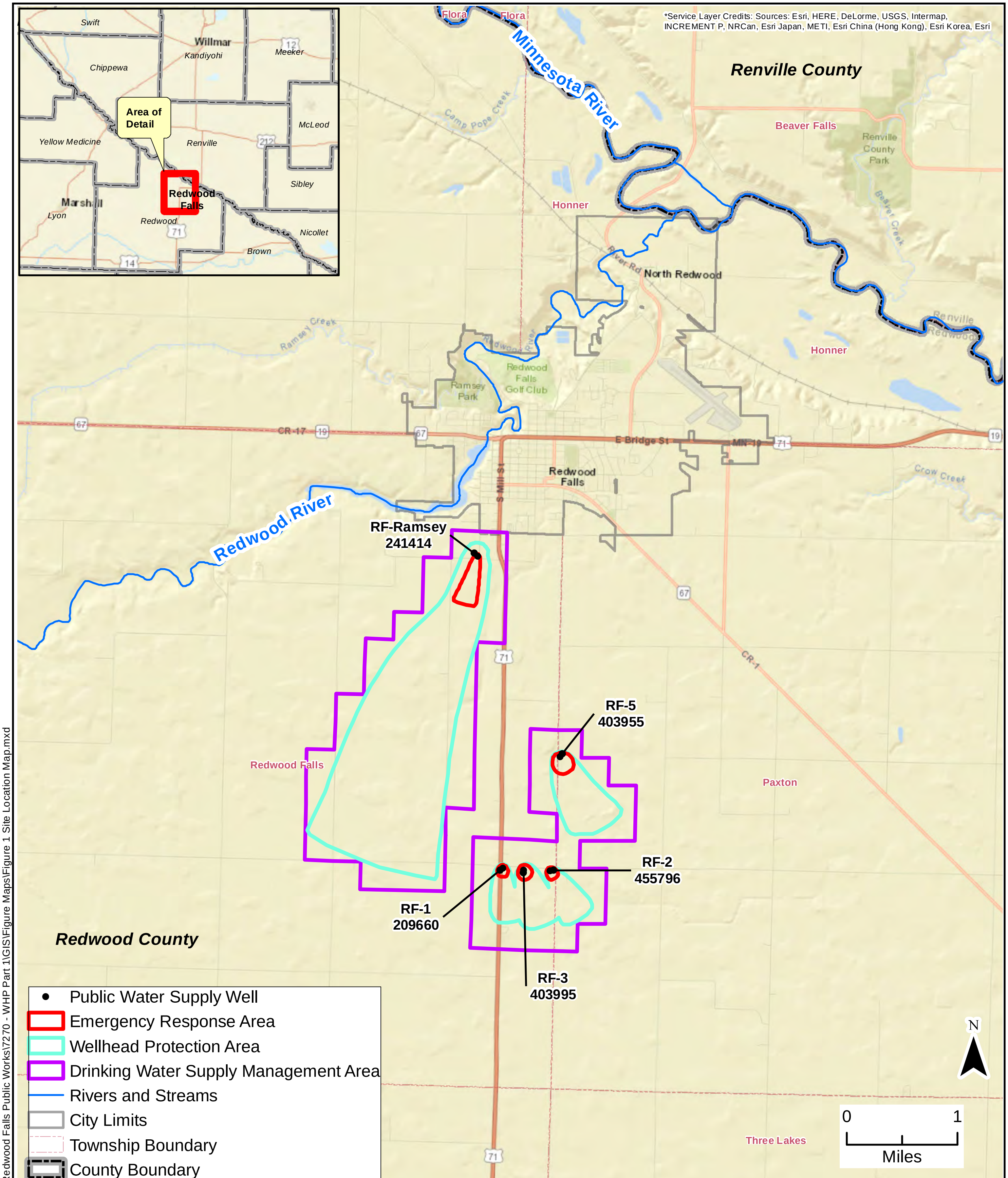
Smith, E.A., and Westenbroek, S.M., 2015, Potential groundwater recharge for the State of Minnesota using the Soil-Water-Balance model, 1996–2010: U.S. Geological Survey Scientific Investigations Report 2015–5038, 85 p., http://dx.doi.org/10.3133/sir20155038.

Strack, O.D.L. (1987). *The Analytical Element Method for Regional Groundwater Modeling*, University of Minnesota, Minneapolis, Minnesota.

Strack, O.D.L. (1989), *Groundwater Mechanics*, Prentice Hall, Englewood Cliffs, New Jersey.

USGS (1964). 1669-R *Geology and Occurrence of Ground Water, Redwood Falls Area, Minnesota*, United States Government Printing Office, Washington, District of Columbia.

Figures

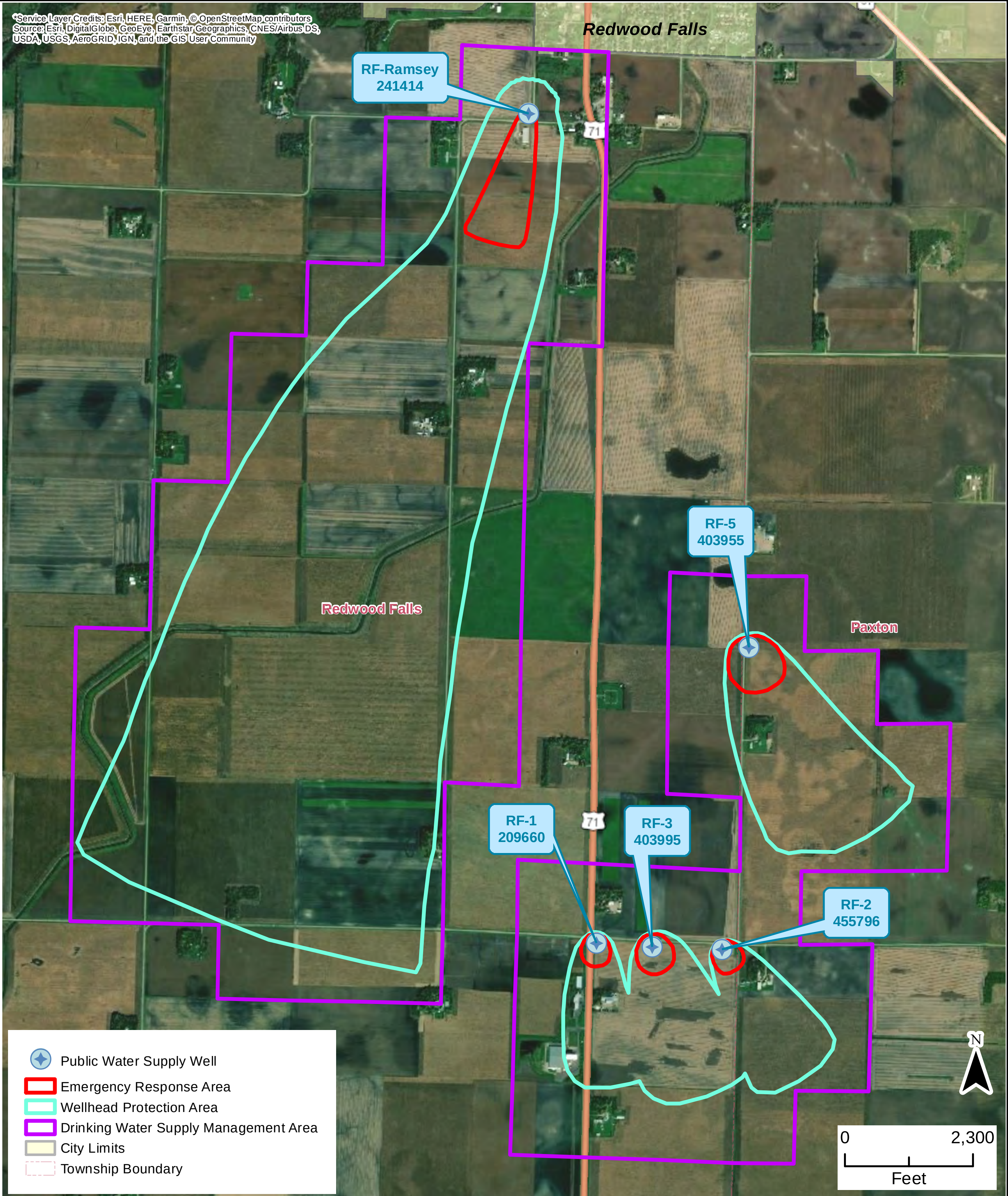


Document Path: P:\Projects\Redwood Falls Public Works\7270 - WHP Part 1\GIS\Figure Maps\Figure 1 Site Location Map.mxd

Carlson McCain
ENVIRONMENTAL · ENGINEERING · SURVEYING

WELLHEAD PROTECTION PLAN - PART 1 AMENDMENT
City of Redwood Falls
333 South Washington Street
Redwood Falls, Minnesota

FIGURE 1
DRINKING WATER SUPPLY MANAGEMENT AREA LOCATION MAP

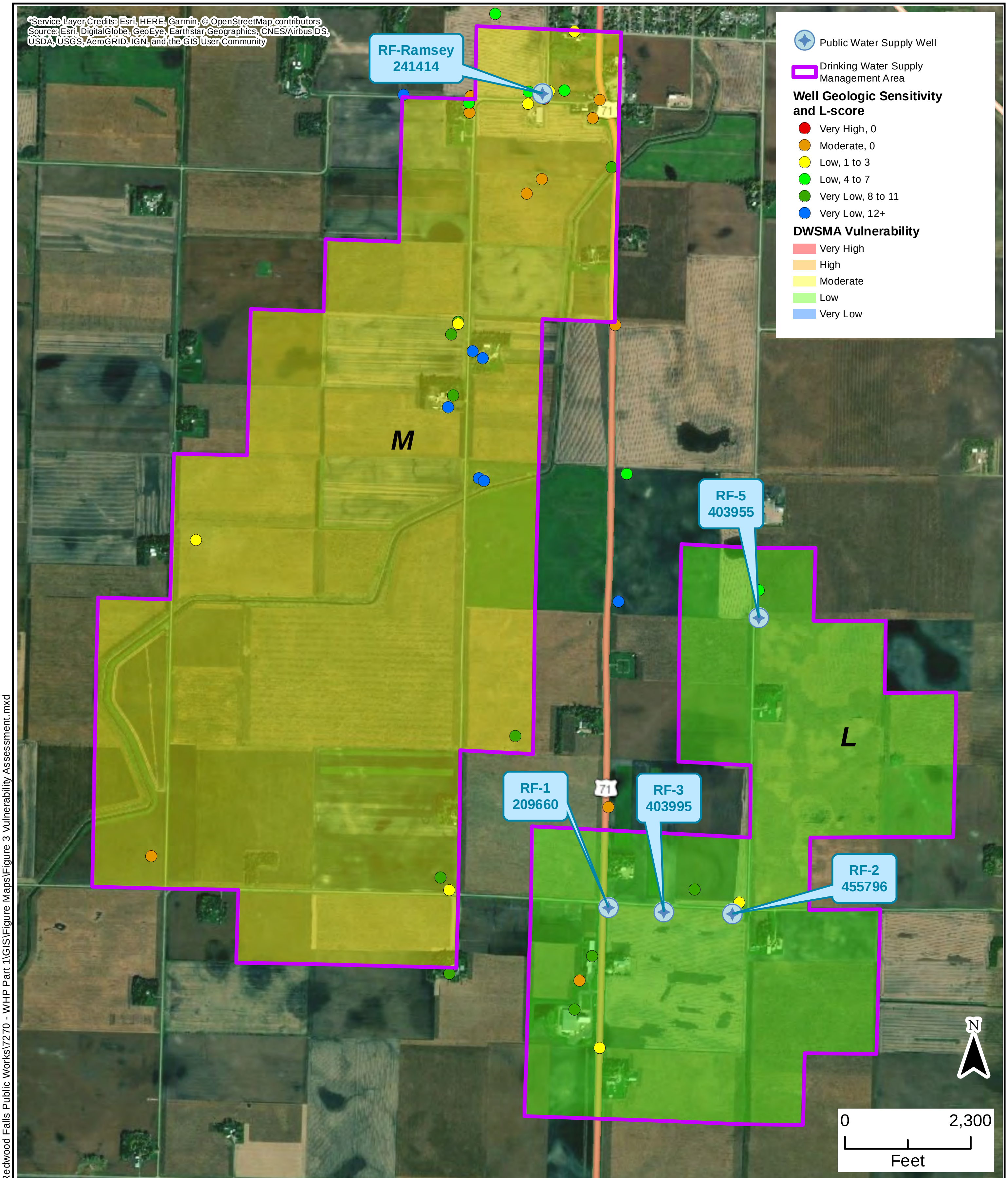


Document Path: P:\Projects\Redwood Falls Public Works\7270 - WHP Part 1\GIS\Figure Maps\Figure 2 DWSMA,WHPA Map.mxd

Carlson McCain
ENVIRONMENTAL · ENGINEERING · SURVEYING

WELLHEAD PROTECTION PLAN - PART 1 AMENDMENT
City of Redwood Falls
333 South Washington Street
Redwood Falls, Minnesota

FIGURE 2
DRINKING WATER SUPPLY MANAGEMENT AREAS

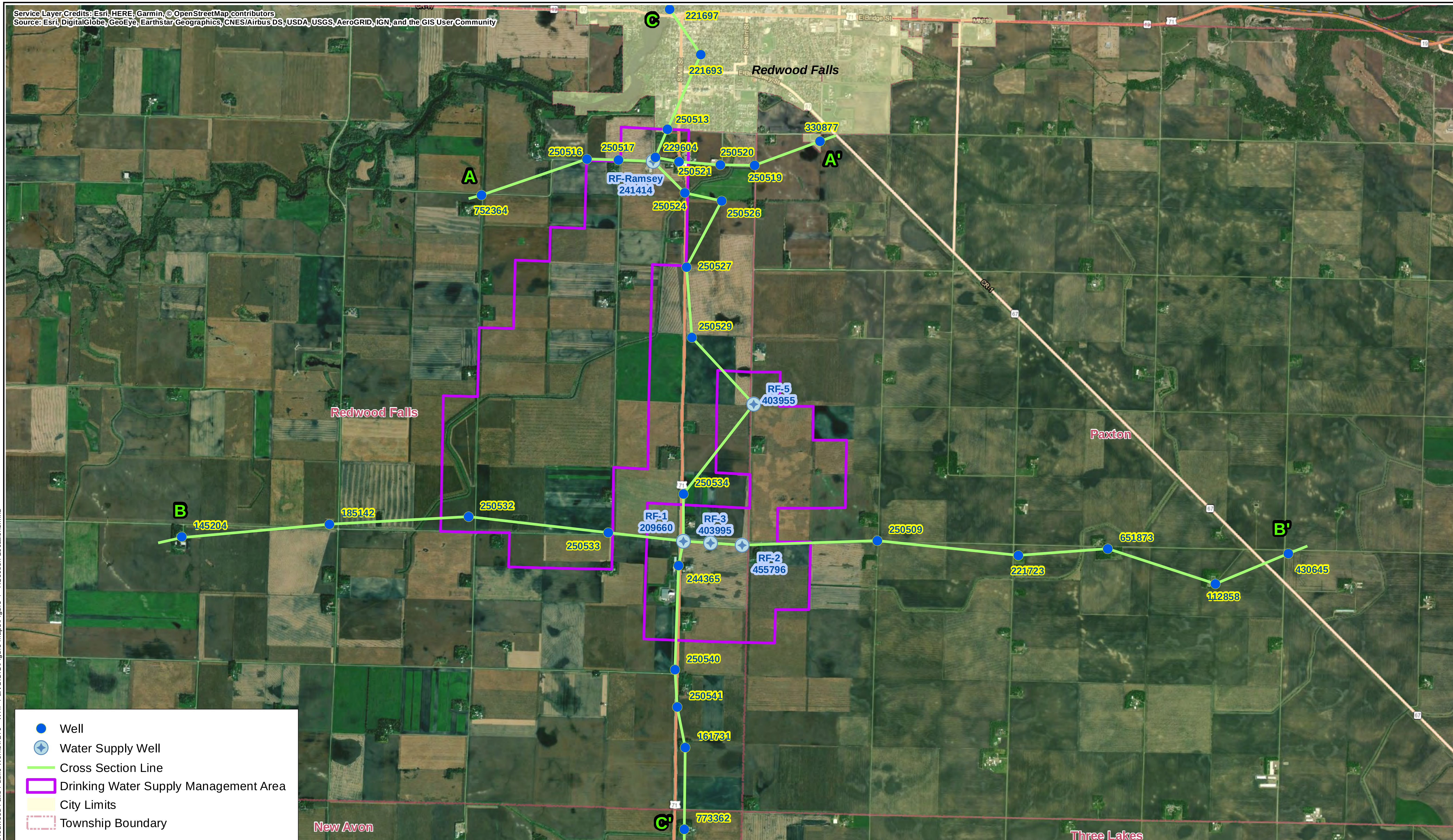


Document Path: P:\Projects\Redwood Falls Public Works\7270 - WHP Part 1\GIS\Figure Maps\Figure 3 Vulnerability Assessment.mxd

Carlson McCain
ENVIRONMENTAL · ENGINEERING · SURVEYING

WELLHEAD PROTECTION PLAN - PART 1 AMENDMENT
City of Redwood Falls
333 South Washington Street
Redwood Falls, Minnesota

FIGURE 3
DWSMA VULNERABILITY ASSESSMENTS



Document Path: P:\Projects\Redwood Falls Public Works\7270 - WHP Part 1\GIS\Figure Maps\Figure 4 - XSection Locations.mxd

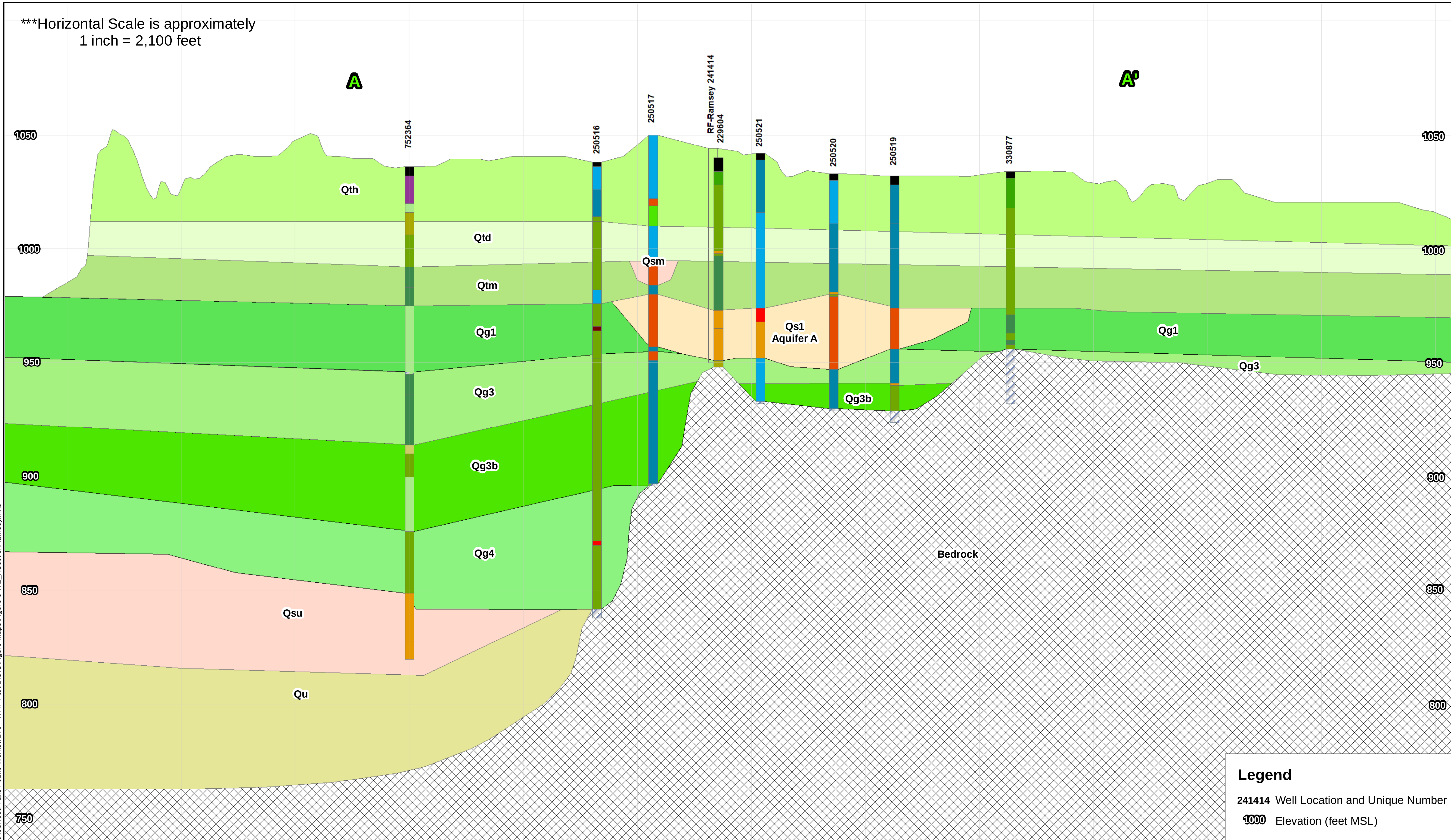
Carlson McCain
ENVIRONMENTAL · ENGINEERING · SURVEYING

0 3,500
Feet

N

WELLHEAD PROTECTION PLAN -
PART 1 AMENDMENT
CITY OF REDWOOD FALLS
REDWOOD FALLS, MINNESOTA

FIGURE 4
GEOLOGIC CROSS-SECTION LOCATIONS

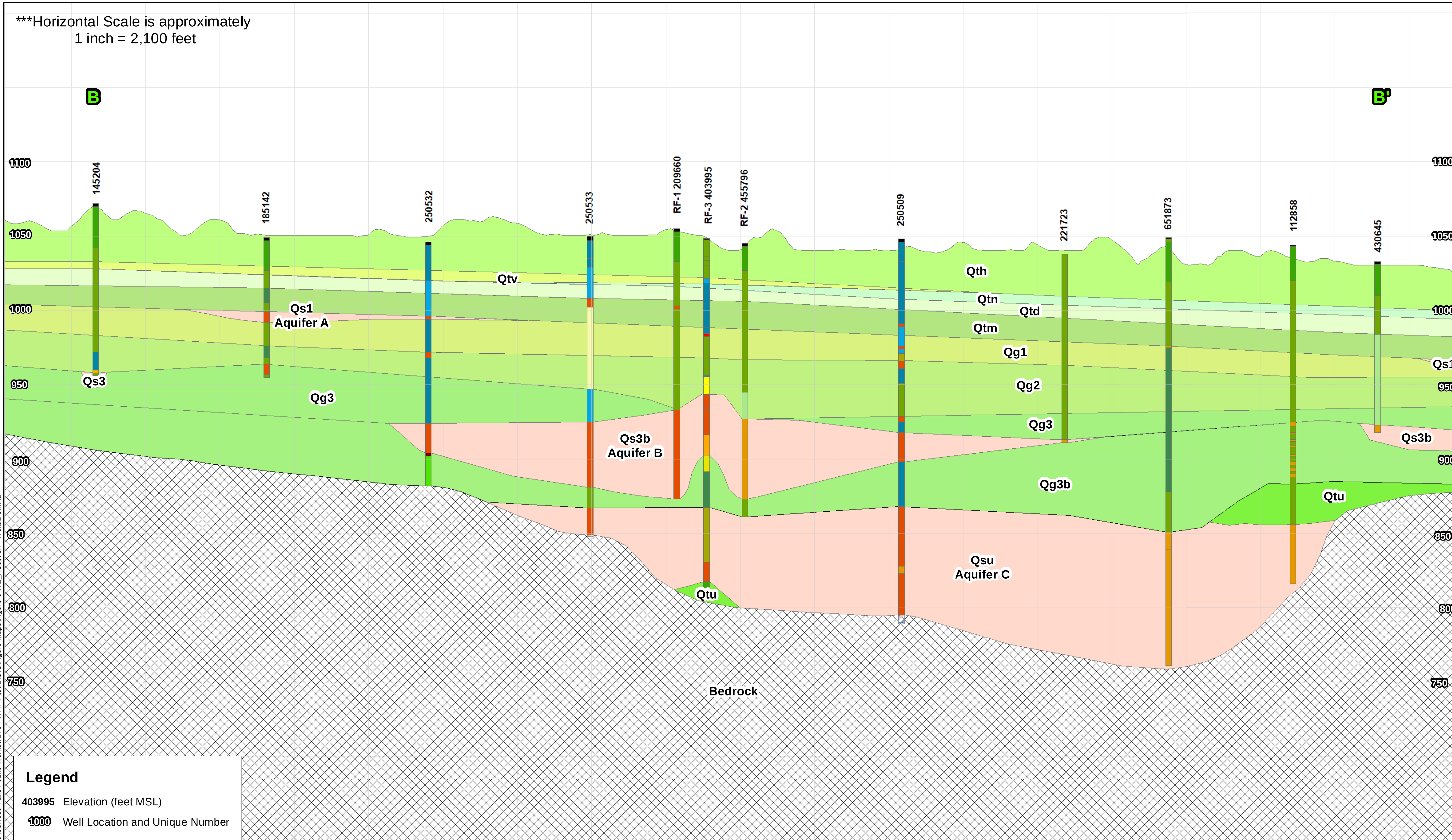


Carlson McCain
ENVIRONMENTAL · ENGINEERING · SURVEYING

Note: Well stratigraphy and stratigraphic layers presented on this map are adapted and interpreted from the Redwood County Geologic Atlas (MGS, 2016). Please refer to MGS, 2016 for a description of the well stratigraphy and stratigraphic layers presented on this map.

WELLHEAD PROTECTION PLAN - PART 1 AMENDMENT
CITY OF REDWOOD FALLS
REDWOOD FALLS, MINNESOTA

FIGURE 5
WEST-EAST RAMSEY WELL GEOLOGIC CROSS-SECTION

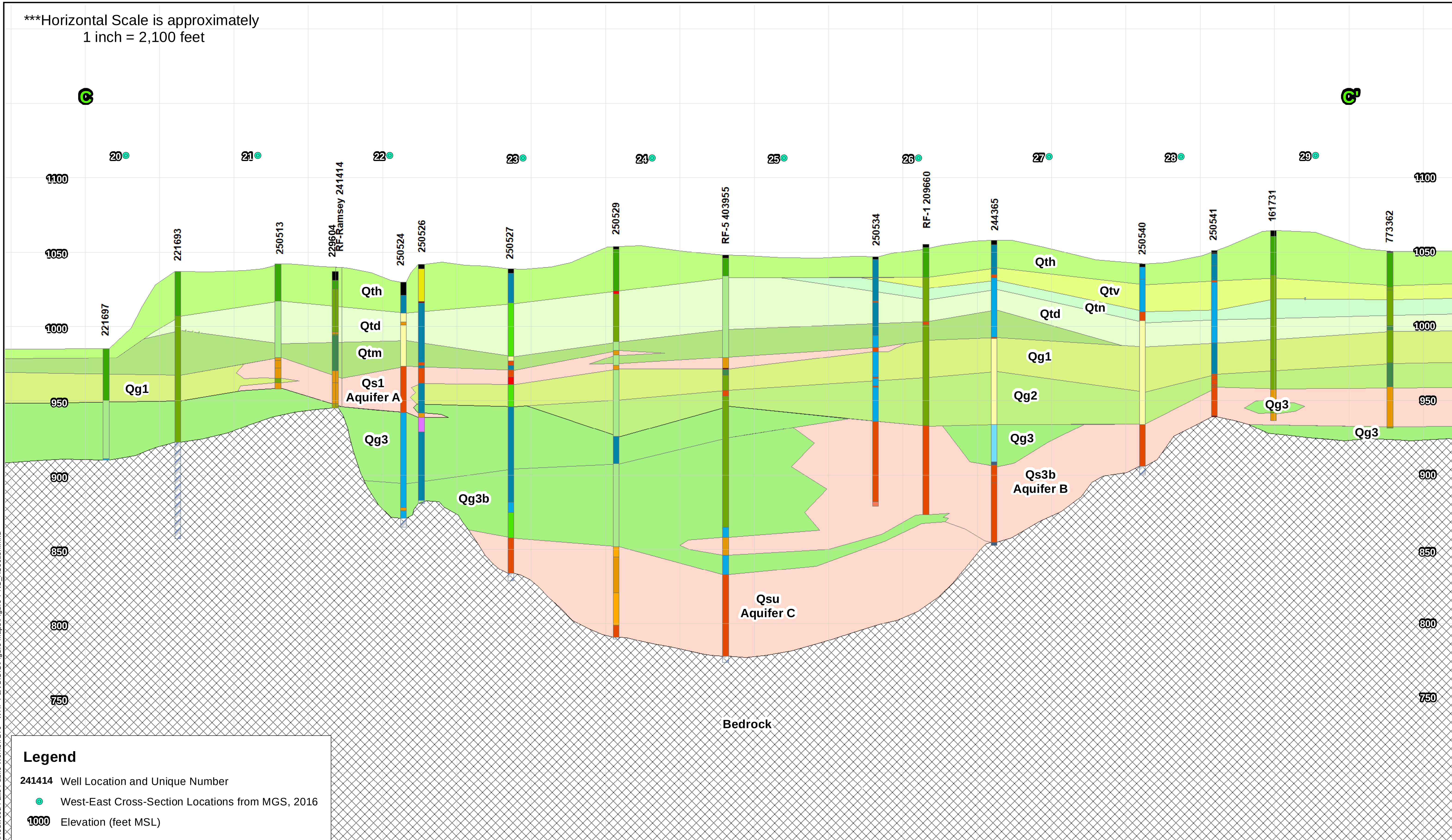


Carlson McCain
ENVIRONMENTAL · ENGINEERING · SURVEYING

Note: Well stratigraphy and stratigraphic layers presented on this map are adapted and interpreted from the Redwood County Geologic Atlas (MGS, 2016). Please refer to MGS, 2016 for a description of the well stratigraphy and stratigraphic layers presented on this map.

WELLHEAD PROTECTION PLAN -
PART 1 AMENDMENT
CITY OF REDWOOD FALLS
REDWOOD FALLS, MINNESOTA

FIGURE 6
WEST-EAST WELLS
1-3 GEOLOGIC
CROSS-SECTION



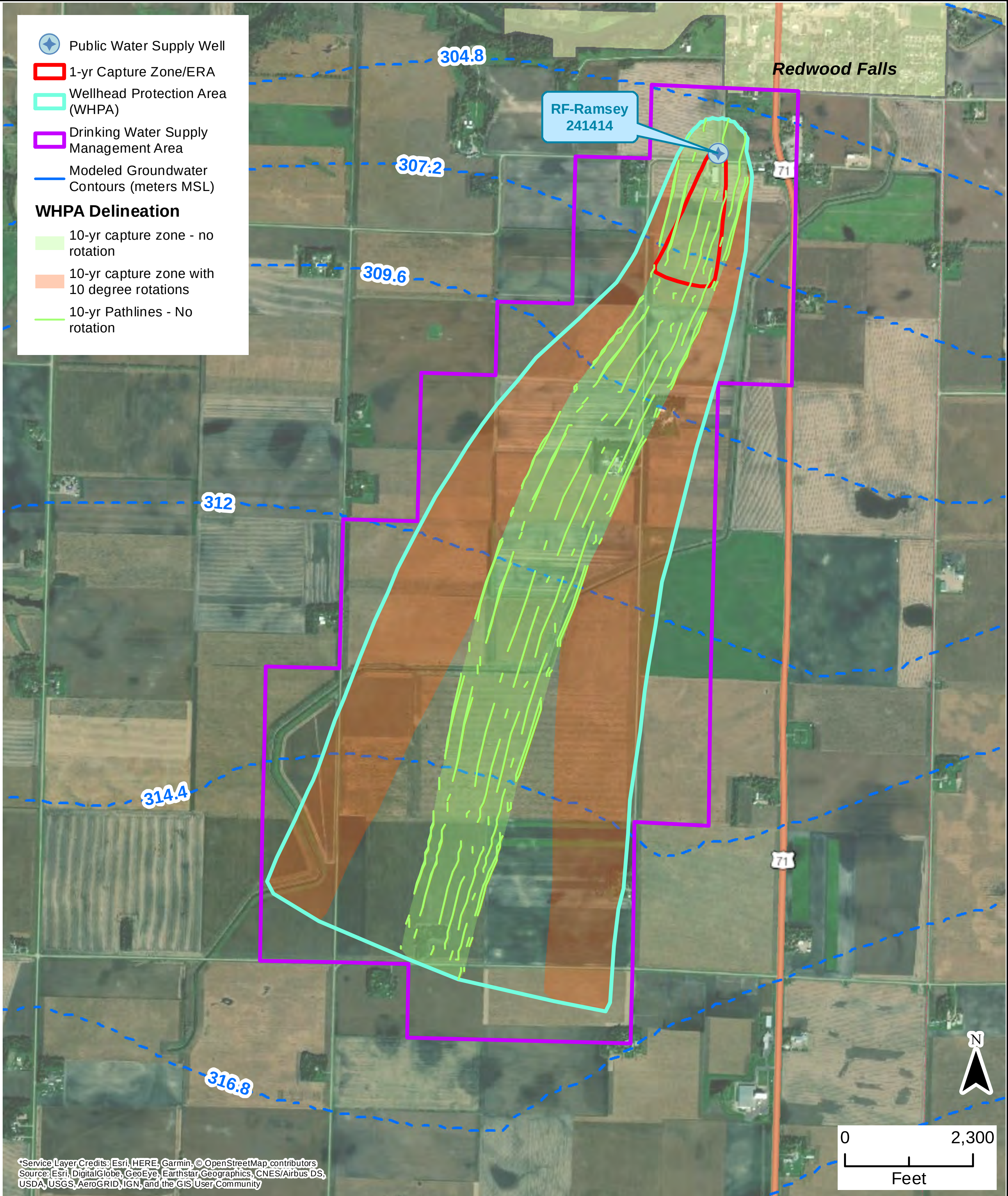
Document Path: P:\Projects\Redwood Falls Public Works\7270 - WHP Part 1\GIS\Figure Maps\Figure 7 NS_XSection.mxd

Carlson McCain
ENVIRONMENTAL · ENGINEERING · SURVEYING

Note: Well stratigraphy and stratigraphic layers presented on this map are adapted and interpreted from the Redwood County Geologic Atlas (MGS, 2016). Please refer to MGS, 2016 for a description of the well stratigraphy and stratigraphic layers presented on this map.

WELLHEAD PROTECTION PLAN -
PART 1 AMENDMENT
CITY OF REDWOOD FALLS
REDWOOD FALLS, MINNESOTA

FIGURE 7
NORTH-SOUTH
GEOLOGIC
CROSS-SECTION

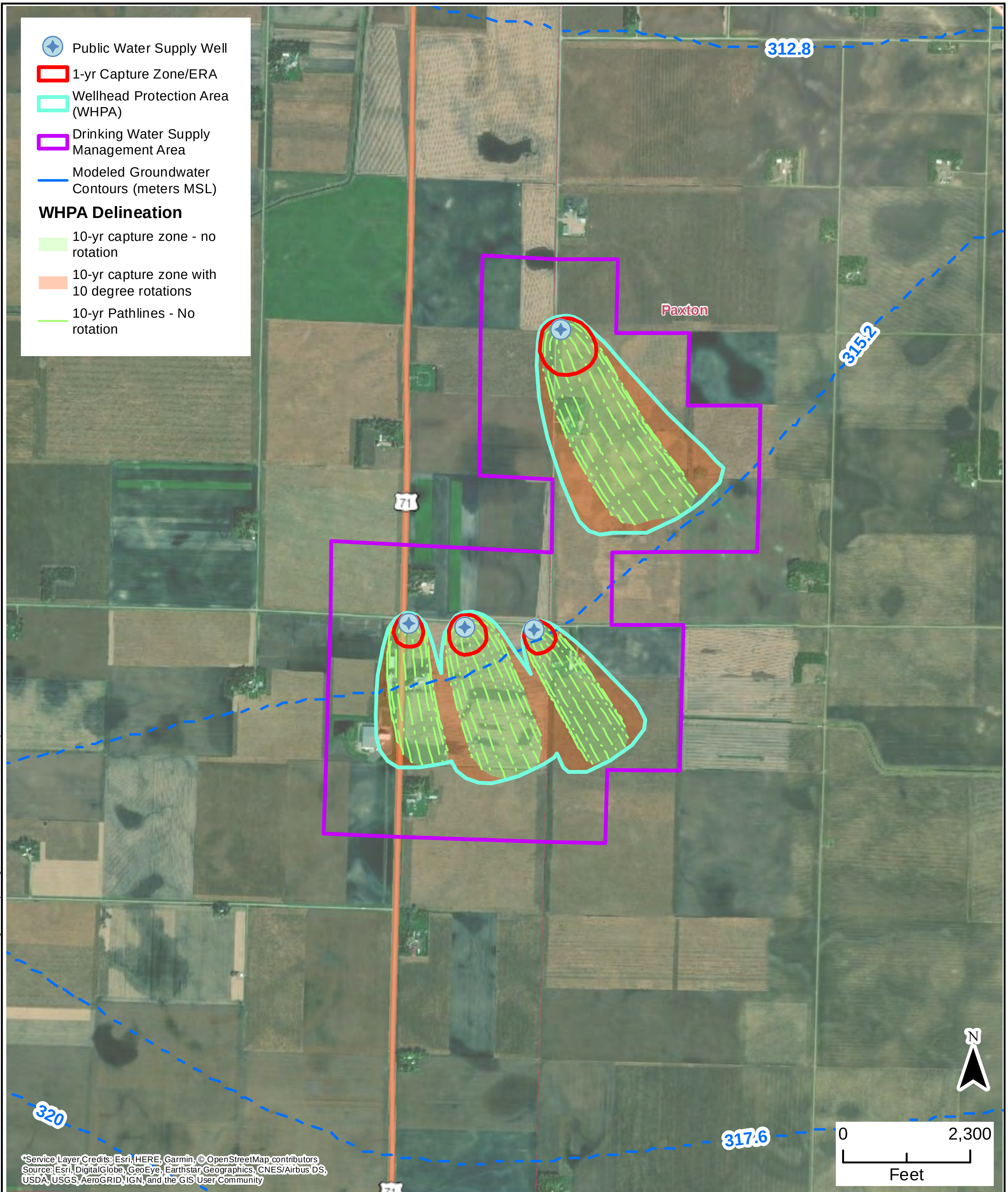


Document Path: P:\Projects\Redwood Falls Public Works\7270 - WHP Part 1\GIS\Figure Maps\Figure 8 Model GW Cont - pathlines.mxd

Carlson McCain
ENVIRONMENTAL · ENGINEERING · SURVEYING

WELLHEAD PROTECTION PLAN - PART 1 AMENDMENT
City of Redwood Falls
333 South Washington Street
Redwood Falls, Minnesota

FIGURE 8
MODELED GROUNDWATER CONTOURS AND PATHLINES - AQUIFER A



Document Path: P:\Projects\Redwood Falls Public Works\7270 - WHP Part 1\GIS\Figure Maps\Figure 9 B-C Model GW Cont - pathlines.mxd

Carlson McCain
ENVIRONMENTAL · ENGINEERING · SURVEYING

WELLHEAD PROTECTION PLAN - PART 1 AMENDMENT
City of Redwood Falls
333 South Washington Street
Redwood Falls, Minnesota

FIGURE 9
MODELED GROUNDWATER CONTOURS AND PATHLINES - AQUIFER B/C

Appendices

Appendix A

MLAEM Codes

```
  return
window 3.20115e+005 4.92463e+006 3.41799e+005 4.93505e+006
aquifer
  layer 1
  global
    base 238.000000
    perm 3.00000e+000
    thick 150.000000
    por 0.300000
  ret
reference
  layer 1
  0.000000 4911140.000000 310.000000
  return
polygon
  input A3
  3.307473125000000e+005 4.931721500000000e+006
  3.328674062500000e+005 4.931306000000000e+006
  3.343010312500000e+005 4.932885500000000e+006
  3.341348750000000e+005 4.935379500000000e+006
  3.305393125000000e+005 4.933675500000000e+006
  input RAIN
  2.650381250000000e+005 4.960902500000000e+006
  2.879606562500000e+005 4.880118000000000e+006
  3.864635000000000e+005 4.884829000000000e+006
  3.847303750000000e+005 4.958796000000000e+006
  input AEXTEND
  3.328674062500000e+005 4.931306000000000e+006
  3.307473125000000e+005 4.931721500000000e+006
  3.288647414325862e+005 4.928773872034951e+006
  3.310877273673915e+005 4.928525457696352e+006
  3.322207500000000e+005 4.929644000000000e+006
  input CA
  3.307473125000000e+005 4.931721500000000e+006
  3.278789062500000e+005 4.931784000000000e+006
  3.270268437500000e+005 4.930308500000000e+006
  3.275884062500000e+005 4.928916500000000e+006
  3.288647414325862e+005 4.928773872034951e+006
  input CB
  3.310877273673915e+005 4.928525457696352e+006
  3.316824375000000e+005 4.928459000000000e+006
  3.339893437500000e+005 4.929560500000000e+006
  3.328674062500000e+005 4.931306000000000e+006
  3.322207500000000e+005 4.929644000000000e+006
  input AEXTEND2
  3.306623898149077e+005 4.928572988337517e+006
  3.288647414325862e+005 4.928773872034951e+006
  3.264468750000000e+005 4.926914000000000e+006
```

```
  3.285212812500000e+005 4.925568000000000e+006
  3.298898125000000e+005 4.925722500000000e+006
  return
aquifer
  layer 1
  polygon A3
    base 332358.187500 4933029.500000 290.000000
    perm 332358.187500 4933029.500000 1.49000e+002
    thick 332358.187500 4933029.500000 6.100000
    por 332358.187500 4933029.500000 0.250000
  polygon AEXTEND
    base 331410.218750 4930339.500000 290.000000
    perm 331410.218750 4930339.500000 1.49000e+002
    thick 331410.218750 4930339.500000 6.100000
    por 331410.218750 4930339.500000 0.250000
  polygon CA
    base 328354.437500 4930315.500000 290.000000
    perm 328354.437500 4930315.500000 1.49000e+002
    thick 328354.437500 4930315.500000 6.100000
    por 328354.437500 4930315.500000 0.250000
  polygon CB
    base 332822.593750 4929691.000000 290.000000
    perm 332822.593750 4929691.000000 1.49000e+002
    thick 332822.593750 4929691.000000 1.000000
    por 332822.593750 4929691.000000 0.250000
  polygon AEXTEND2
    base 329271.562500 4927399.500000 290.000000
    perm 329271.562500 4927399.500000 1.49000e+002
    thick 329271.562500 4927399.500000 15.000000
    por 329271.562500 4927399.500000 0.250000
  return
well
  layer 1
  given
  3.3127200000e+005 4.9324600000e+006 2.65000e+002 0.305000 [SRAMSEY]
  3.3140837500e+005 4.9327295000e+006 3.40000e+001 0.300500 [229604]
  3.3157790625e+005 4.9274135000e+006 0.00000e+000 0.305000 [502652]
  3.3164100000e+005 4.9279190000e+006 0.00000e+000 0.305000 [REDWOOD1]
  3.3233000000e+005 4.9278840000e+006 0.00000e+000 0.305000 [REDWOOD2]
  3.3194700000e+005 4.9278980000e+006 0.00000e+000 0.254000 [REDWOOD3]
  3.3247700000e+005 4.9295380000e+006 0.00000e+000 0.305000 [REDWOOD5]
  return
varel
  layer 1
  top
  polygon RAIN
  given const
   3.3757265625e+005 4.9181590000e+006 -1.39000e-004 [RAIN]
```

```
  return
linesink
  layer  1
  head
   3.09993E+05  4.93082E+06
   3.14865E+05  4.92856E+06
   3.12400E+02 [0]
  head
   2.86601E+05  4.93082E+06
   3.09993E+05  4.93082E+06
   3.18500E+02 [0]
  head
   2.76880E+05  4.93781E+06
   2.86601E+05  4.93082E+06
   3.27700E+02 [0]
  head
   3.05892E+05  4.94540E+06
   3.17740E+05  4.94844E+06
   3.12400E+02 [0]
  head
   3.00728E+05  4.93781E+06
   3.05892E+05  4.94540E+06
   3.19400E+02 [0]
  head
   2.92016E+05  4.95224E+06
   3.07444E+05  4.95677E+06
   2.95700E+02 [0]
  head
   2.88024E+05  4.95461E+06
   2.92016E+05  4.95224E+06
   3.12400E+02 [0]
  head
   2.85154E+05  4.95273E+06
   2.87982E+05  4.95461E+06
   3.13900E+02 [0]
  head
   2.84323E+05  4.94820E+06
   2.85154E+05  4.95273E+06
   3.17900E+02 [0]
  head
   2.71098E+05  4.94359E+06
   2.84323E+05  4.94820E+06
   3.27700E+02 [0]
  head
   2.65152E+05  4.94442E+06
   2.71098E+05  4.94359E+06
   3.33800E+02 [0]
  head
```

```
    2.56668E+05  4.92491E+06
    2.65235E+05  4.94446E+06
    3.61200E+02 [0]
   head
    3.09140E+05  4.90625E+06
    2.93730E+05  4.91444E+06
    3.30000E+02 [0]
   head
    3.09232E+05  4.90622E+06
    3.32903E+05  4.89482E+06
    3.20000E+02 [0]
   head
    3.32903E+05  4.89482E+06
    3.49753E+05  4.90080E+06
    3.05000E+02 [0]
   head
    3.49753E+05  4.90080E+06
    3.55972E+05  4.89833E+06
    3.00000E+02 [0]
   head
    3.55972E+05  4.89833E+06
    3.58536E+05  4.90229E+06
    2.95000E+02 [0]
   head
    3.58536E+05  4.90229E+06
    3.62576E+05  4.89994E+06
    2.85000E+02 [0]
   head
    3.62576E+05  4.89994E+06
    3.68328E+05  4.90648E+06
    2.80000E+02 [0]
   head
    3.68328E+05  4.90650E+06
    3.81717E+05  4.90900E+06
    2.60000E+02 [0]
   head
    3.38637E+05  4.91105E+06
    3.46914E+05  4.90653E+06
    3.00000E+02 [0]
   head
    3.46914E+05  4.90653E+06
    3.58224E+05  4.90220E+06
    2.90000E+02 [0]
   return
 lleak
 return
 string
   open
```

```
input MINN_R
cu
  3.2143355947e+005 4.9464754138e+006
  3.2822896867e+005 4.9421514221e+006
  3.3356821875e+005 4.9387540000e+006
cu
  3.3414637033e+005 4.9383861160e+006
  3.3460063228e+005 4.9380970642e+006
cu
  3.4472791295e+005 4.9348212596e+006
  3.6743905193e+005 4.9188774378e+006
cu
  3.7596919246e+005 4.9128890530e+006
  3.8682573495e+005 4.9052674723e+006
  return
open
input REDWD_R
cu
  3.3452615650e+005 4.9381444539e+006
  3.3282840840e+005 4.9343586416e+006
  3.2342101524e+005 4.9313211782e+006
cu
  3.1966786353e+005 4.9301007598e+006
  3.1489112500e+005 4.9285475000e+006
  return
open
input SLPEYE_R
cu
  3.1489112500e+005 4.9285475000e+006
  3.2031994598e+005 4.9223643770e+006
  3.2465160577e+005 4.9183187964e+006
cu
  3.2820885688e+005 4.9149964796e+006
  3.3863712500e+005 4.9110515000e+006
  return
open
input SPR_CK
cu
  3.6731218750e+005 4.9189665000e+006
  3.6599369303e+005 4.9168537151e+006
  3.5599531250e+005 4.9179940000e+006
cu
  3.5453665625e+005 4.9143840000e+006
  3.5238509375e+005 4.9133425000e+006
cu
  3.5058164132e+005 4.9142045376e+006
  3.4828633822e+005 4.9153016763e+006
  return
```

```
  open
  input RAMSEY
  cu
    3.3097142509e+005 4.9344412622e+006
    3.2950411272e+005 4.9363360041e+006
    3.2014068750e+005 4.9330270000e+006
    return
  return
curel
  layer 1
  string MINN_R
  head
  element 1 6 4.000000
  element 2 6 4.000000
  element 3 8 4.000000
  element 4 6 4.000000
  boundary condition
    3.2143355947e+005 4.9464754138e+006 256.000000 300.000000
    3.3371040257e+005 4.9386635269e+006 252.000000 300.000000
    3.3585810231e+005 4.9376653129e+006 250.000000 300.000000
    3.5188521964e+005 4.9293002617e+006 245.000000 300.000000
    3.6795591773e+005 4.9185145843e+006 240.000000 300.000000
    return
  layer 1
  string REDWD_R
  resistance
  element 1 8 4.000000
  element 2 8 4.000000
  boundary condition
    3.3373672585e+005 4.9368061209e+006 50.000000 259.000000 50.000000
    3.3129105174e+005 4.9346384708e+006 100.000000 298.000000 50.000000
    3.2400334025e+005 4.9315112855e+006 100.000000 302.000000 50.000000
    3.1928515950e+005 4.9299763153e+006 100.000000 306.000000 50.000000
    3.1489112500e+005 4.9285475000e+006 100.000000 310.000000 50.000000
    return
  layer 1
  string SLPEYE_R
  resistance
  element 1 6 4.000000
  element 2 6 4.000000
  boundary condition
    3.1637528238e+005 4.9268738150e+006 100.000000 316.000000 100.000000
    3.1873443905e+005 4.9242886701e+006 100.000000 320.000000 100.000000
    3.2260265725e+005 4.9202902396e+006 100.000000 317.000000 100.000000
    3.2800415247e+005 4.9158663163e+006 100.000000 314.000000 100.000000
    3.3863712500e+005 4.9110515000e+006 100.000000 310.000000 100.000000
    return
  layer 1
```

```
  string SPR_CK
  resistance
  element 1 6 4.000000
  element 2 6 4.000000
  element 3 6 4.000000
  boundary condition
    3.6713251002e+005 4.9187036608e+006 50.000000 240.000000 25.000000
    3.6481406516e+005 4.9174947260e+006 100.000000 250.000000 25.000000
    3.6204036036e+005 4.9174397255e+006 100.000000 275.000000 25.000000
    3.5994175531e+005 4.9175871943e+006 100.000000 300.000000 25.000000
    3.5463022536e+005 4.9153407789e+006 100.000000 305.000000 25.000000
    3.4828633822e+005 4.9153016763e+006 100.000000 310.000000 25.000000
    return
  layer 1
  string RAMSEY
  resistance
  element 1 6 4.000000
  boundary condition
    3.2917736368e+005 4.9355037810e+006 100.000000 305.000000 25.000000
    3.2187428861e+005 4.9336334969e+006 100.000000 310.000000 25.000000
    return
  return
doublet
  layer 1
  order 8
  controlpoints 32
  element
    3.270268437500000e+005 4.930308500000000e+006
    3.278789062500000e+005 4.931784000000000e+006
  order 8
  controlpoints 32
  element
    3.328674062500000e+005 4.931306000000000e+006
    3.339893437500000e+005 4.929560500000000e+006
  order 8
  controlpoints 32
  element
    3.270268437500000e+005 4.930308500000000e+006
    3.275884062500000e+005 4.928916500000000e+006
  order 8
  controlpoints 32
  element
    3.316824375000000e+005 4.928459000000000e+006
    3.339893437500000e+005 4.929560500000000e+006
  order 8
  controlpoints 32
  element
    3.307473125000000e+005 4.931721500000000e+006
```

```
  3.328674062500000e+005 4.931306000000000e+006
order 8
controlpoints 32
element
  3.307473125000000e+005 4.931721500000000e+006
  3.305393125000000e+005 4.933675500000000e+006
order 8
controlpoints 32
element
  3.305393125000000e+005 4.933675500000000e+006
  3.341348750000000e+005 4.935379500000000e+006
order 8
controlpoints 32
element
  3.341348750000000e+005 4.935379500000000e+006
  3.343010312500000e+005 4.932885500000000e+006
order 8
controlpoints 32
element
  3.343010312500000e+005 4.932885500000000e+006
  3.328674062500000e+005 4.931306000000000e+006
order 6
controlpoints 24
element
  3.328674062500000e+005 4.931306000000000e+006
  3.307473125000000e+005 4.931721500000000e+006
order 6
controlpoints 24
element
  3.328674062500000e+005 4.931306000000000e+006
  3.307473125000000e+005 4.931721500000000e+006
order 6
controlpoints 24
element
  3.307473125000000e+005 4.931721500000000e+006
  3.288647414325862e+005 4.928773872034951e+006
order 6
controlpoints 24
element
  3.310877273673915e+005 4.928525457696352e+006
  3.322207500000000e+005 4.929644000000000e+006
order 6
controlpoints 24
element
  3.322207500000000e+005 4.929644000000000e+006
  3.328674062500000e+005 4.931306000000000e+006
order 6
controlpoints 24
```

```
  element
    3.316824375000000e+005 4.928459000000000e+006
    3.310877273673915e+005 4.928525457696352e+006
  order 6
  controlpoints 24
  element
    3.307473125000000e+005 4.931721500000000e+006
    3.278789062500000e+005 4.931784000000000e+006
  order 6
  controlpoints 24
  element
    3.288647414325862e+005 4.928773872034951e+006
    3.275884062500000e+005 4.928916500000000e+006
  order 6
  controlpoints 24
  element
    3.288647414325862e+005 4.928773872034951e+006
    3.264468750000000e+005 4.926914000000000e+006
  order 6
  controlpoints 24
  element
    3.264468750000000e+005 4.926914000000000e+006
    3.285212812500000e+005 4.925568000000000e+006
  order 6
  controlpoints 24
  element
    3.285212812500000e+005 4.925568000000000e+006
    3.298898125000000e+005 4.925722500000000e+006
  order 6
  controlpoints 24
  element
    3.298898125000000e+005 4.925722500000000e+006
    3.306623898149077e+005 4.928572988337517e+006
  order 6
  controlpoints 24
  element
    3.288647414325862e+005 4.928773872034951e+006
    3.306623898149077e+005 4.928572988337517e+006
  order 6
  controlpoints 24
  element
    3.306623898149077e+005 4.928572988337517e+006
    3.310877273673915e+005 4.928525457696352e+006
  return
switch
  end
```

```
  return
window 3.00855e+005 4.91339e+006 3.69967e+005 4.94663e+006
aquifer
  layer 1
  global
    base 238.000000
    perm 1.50000e+000
    thick 150.000000
    por 0.300000
  ret
reference
  layer 1
  0.000000 4911140.000000 310.000000
  return
polygon
  input C3
  3.275884062500000e+005 4.928916500000000e+006
  3.316824375000000e+005 4.928459000000000e+006
  3.339893437500000e+005 4.929560500000000e+006
  3.328674062500000e+005 4.931306000000000e+006
  3.307473125000000e+005 4.931721500000000e+006
  3.278789062500000e+005 4.931784000000000e+006
  3.270268437500000e+005 4.930308500000000e+006
  input C4
  3.275465625000000e+005 4.928209000000000e+006
  3.314734062500000e+005 4.925184500000000e+006
  3.411906875000000e+005 4.925785000000000e+006
  3.365666562500000e+005 4.928937000000000e+006
  3.339480937500000e+005 4.927274000000000e+006
  3.315993750000000e+005 4.926214000000000e+006
  input B3
  3.339893437500000e+005 4.929560500000000e+006
  3.365666562500000e+005 4.928937000000000e+006
  3.389772500000000e+005 4.931015000000000e+006
  3.366703750000000e+005 4.931098000000000e+006
  input A3
  3.307473125000000e+005 4.931721500000000e+006
  3.328674062500000e+005 4.931306000000000e+006
  3.343010312500000e+005 4.932885500000000e+006
  3.341348750000000e+005 4.935379500000000e+006
  3.305393125000000e+005 4.933675500000000e+006
  input RECHARGE
  3.102522187500000e+005 4.948685000000000e+006
  3.095736250000000e+005 4.909711000000000e+006
  3.709314375000000e+005 4.911322500000000e+006
  3.694802500000000e+005 4.947172500000000e+006
  input B&C
  3.275884062500000e+005 4.928916500000000e+006
```

```
  3.275465625000000e+005 4.928209000000000e+006
  3.315993750000000e+005 4.926214000000000e+006
  3.339480937500000e+005 4.927274000000000e+006
  3.365666562500000e+005 4.928937000000000e+006
  3.339893437500000e+005 4.929560500000000e+006
  3.316824375000000e+005 4.928459000000000e+006
  return
aquifer
  layer 1
  polygon C3
    base 330250.093750 4930184.500000 238.000000
    perm 330250.093750 4930184.500000 1.39000e+002
    thick 330250.093750 4930184.500000 17.000000
    por 330250.093750 4930184.500000 0.250000
  polygon C4
    base 335113.906250 4926322.000000 238.000000
    perm 335113.906250 4926322.000000 1.39000e+002
    thick 335113.906250 4926322.000000 17.000000
    por 335113.906250 4926322.000000 0.250000
  polygon B3
    base 336461.937500 4930020.000000 250.000000
    perm 336461.937500 4930020.000000 9.30000e+001
    thick 336461.937500 4930020.000000 15.000000
    por 336461.937500 4930020.000000 0.250000
  polygon A3
    base 332358.187500 4933029.500000 290.000000
    perm 332358.187500 4933029.500000 1.49000e+002
    thick 332358.187500 4933029.500000 6.100000
    por 332358.187500 4933029.500000 0.250000
  polygon B&C
    base 333325.500000 4928201.000000 238.000000
    perm 333325.500000 4928201.000000 1.14000e+002
    thick 333325.500000 4928201.000000 29.000000
    por 333325.500000 4928201.000000 0.250000
  return
well
  layer 1
  given
  3.3127200000e+005 4.9324600000e+006 0.00000e+000 0.305000 [SRAMSEY]
  3.3140837500e+005 4.9327295000e+006 0.00000e+000 0.300500 [229604]
  3.3164100000e+005 4.9279190000e+006 3.75000e+002 0.305000 [REDWOOD1]
  3.3233000000e+005 4.9278840000e+006 4.14000e+002 0.305000 [REDWOOD2]
  3.3194700000e+005 4.9278980000e+006 6.54000e+002 0.254000 [REDWOOD3]
  3.3247700000e+005 4.9295380000e+006 7.78000e+002 0.305000 [REDWOOD5]
  return
varel
  layer 1
  top
```

```
  polygon RECHARGE
  given const
   3.3945309375e+005 4.9173045000e+006 -1.00000e-004 [#2]
  return
linesink
  layer  1
  head
   3.09993E+05  4.93082E+06
   3.14865E+05  4.92856E+06
   3.12400E+02 [0]
  head
   2.86601E+05  4.93082E+06
   3.09993E+05  4.93082E+06
   3.18500E+02 [0]
  head
   2.76880E+05  4.93781E+06
   2.86601E+05  4.93082E+06
   3.27700E+02 [0]
  head
   3.05892E+05  4.94540E+06
   3.17740E+05  4.94844E+06
   3.12400E+02 [0]
  head
   3.00728E+05  4.93781E+06
   3.05892E+05  4.94540E+06
   3.19400E+02 [0]
  head
   2.92016E+05  4.95224E+06
   3.07444E+05  4.95677E+06
   2.95700E+02 [0]
  head
   2.88024E+05  4.95461E+06
   2.92016E+05  4.95224E+06
   3.12400E+02 [0]
  head
   2.85154E+05  4.95273E+06
   2.87982E+05  4.95461E+06
   3.13900E+02 [0]
  head
   2.84323E+05  4.94820E+06
   2.85154E+05  4.95273E+06
   3.17900E+02 [0]
  head
   2.71098E+05  4.94359E+06
   2.84323E+05  4.94820E+06
   3.27700E+02 [0]
  head
   2.65152E+05  4.94442E+06
```

```
   2.71098E+05  4.94359E+06
   3.33800E+02 [0]
  head
   2.56668E+05  4.92491E+06
   2.65235E+05  4.94446E+06
   3.61200E+02 [0]
  head
   3.09140E+05  4.90625E+06
   2.93730E+05  4.91444E+06
   3.30000E+02 [0]
  head
   3.09232E+05  4.90622E+06
   3.32903E+05  4.89482E+06
   3.20000E+02 [0]
  head
   3.32903E+05  4.89482E+06
   3.49753E+05  4.90080E+06
   3.05000E+02 [0]
  head
   3.49753E+05  4.90080E+06
   3.55972E+05  4.89833E+06
   3.00000E+02 [0]
  head
   3.55972E+05  4.89833E+06
   3.58536E+05  4.90229E+06
   2.95000E+02 [0]
  head
   3.58536E+05  4.90229E+06
   3.62576E+05  4.89994E+06
   2.85000E+02 [0]
  head
   3.62576E+05  4.89994E+06
   3.68328E+05  4.90648E+06
   2.80000E+02 [0]
  head
   3.68328E+05  4.90650E+06
   3.81717E+05  4.90900E+06
   2.60000E+02 [0]
  head
   3.38637E+05  4.91105E+06
   3.46914E+05  4.90653E+06
   3.00000E+02 [0]
  head
   3.46914E+05  4.90653E+06
   3.58224E+05  4.90220E+06
   2.90000E+02 [0]
  return
lleak
```

```
return
string
  open
  input MINN_R
  cu
    3.2143355947e+005 4.9464754138e+006
    3.2822896867e+005 4.9421514221e+006
    3.3356821875e+005 4.9387540000e+006
  cu
    3.3414637033e+005 4.9383861160e+006
    3.3460063228e+005 4.9380970642e+006
  cu
    3.4472791295e+005 4.9348212596e+006
    3.6743905193e+005 4.9188774378e+006
  cu
    3.7596919246e+005 4.9128890530e+006
    3.8682573495e+005 4.9052674723e+006
    return
  open
  input REDWD_R
  cu
    3.3452615650e+005 4.9381444539e+006
    3.3282840840e+005 4.9343586416e+006
    3.2342101524e+005 4.9313211782e+006
  cu
    3.1966786353e+005 4.9301007598e+006
    3.1489112500e+005 4.9285475000e+006
    return
  open
  input SLPEYE_R
  cu
    3.1489112500e+005 4.9285475000e+006
    3.2031994598e+005 4.9223643770e+006
    3.2465160577e+005 4.9183187964e+006
  cu
    3.2820885688e+005 4.9149964796e+006
    3.3863712500e+005 4.9110515000e+006
    return
  open
  input SPR_CK
  cu
    3.6731218750e+005 4.9189665000e+006
    3.6599369303e+005 4.9168537151e+006
    3.5599531250e+005 4.9179940000e+006
  cu
    3.5453665625e+005 4.9143840000e+006
    3.5238509375e+005 4.9133425000e+006
  cu
```

```
    3.5058164132e+005 4.9142045376e+006
    3.4828633822e+005 4.9153016763e+006
    return
  open
  input RAMSEY
  cu
    3.3097142509e+005 4.9344412622e+006
    3.2950411272e+005 4.9363360041e+006
    3.2014068750e+005 4.9330270000e+006
    return
  return
curel
  layer 1
  string MINN_R
  head
  element 1 6 4.000000
  element 2 6 4.000000
  element 3 8 4.000000
  element 4 6 4.000000
  boundary condition
    3.2143355947e+005 4.9464754138e+006 256.000000 300.000000
    3.3371040257e+005 4.9386635269e+006 252.000000 300.000000
    3.3585810231e+005 4.9376653129e+006 250.000000 300.000000
    3.5188521964e+005 4.9293002617e+006 245.000000 300.000000
    3.6795591773e+005 4.9185145843e+006 240.000000 300.000000
    return
  layer 1
  string REDWD_R
  resistance
  element 1 8 4.000000
  element 2 8 4.000000
  boundary condition
    3.3373672585e+005 4.9368061209e+006 50.000000 259.000000 50.000000
    3.3129105174e+005 4.9346384708e+006 100.000000 298.000000 50.000000
    3.2400334025e+005 4.9315112855e+006 100.000000 302.000000 50.000000
    3.1928515950e+005 4.9299763153e+006 100.000000 306.000000 50.000000
    3.1489112500e+005 4.9285475000e+006 100.000000 310.000000 50.000000
    return
  layer 1
  string SLPEYE_R
  resistance
  element 1 6 4.000000
  element 2 6 4.000000
  boundary condition
    3.1637528238e+005 4.9268738150e+006 100.000000 316.000000 100.000000
    3.1873443905e+005 4.9242886701e+006 100.000000 320.000000 100.000000
    3.2260265725e+005 4.9202902396e+006 100.000000 317.000000 100.000000
    3.2800415247e+005 4.9158663163e+006 100.000000 314.000000 100.000000
```

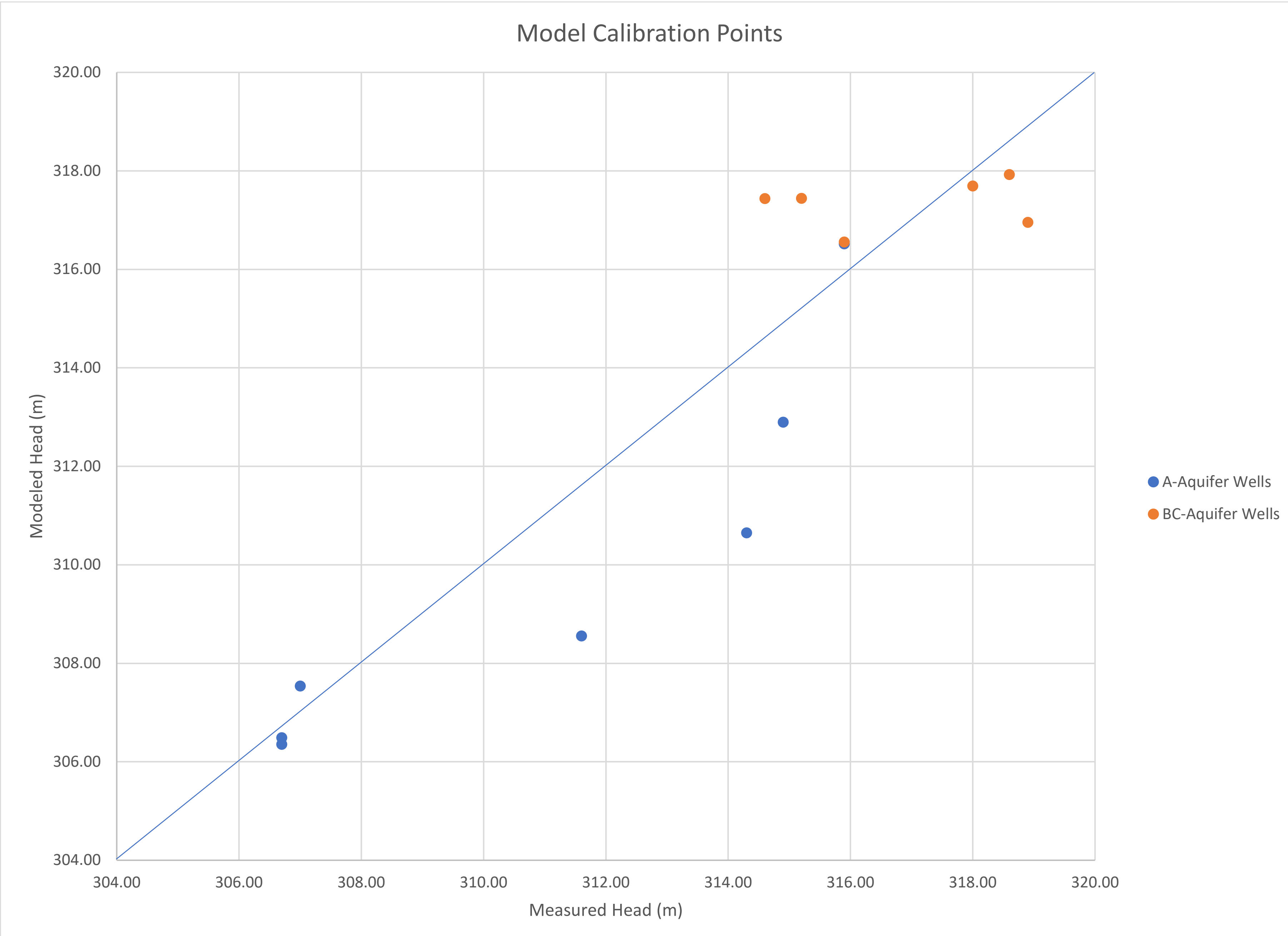
```
    3.3863712500e+005 4.9110515000e+006 100.000000 310.000000 100.000000
    return
  layer 1
  string SPR_CK
  resistance
  element 1 6 4.000000
  element 2 6 4.000000
  element 3 6 4.000000
  boundary condition
    3.6713251002e+005 4.9187036608e+006 50.000000 240.000000 25.000000
    3.6481406516e+005 4.9174947260e+006 100.000000 250.000000 25.000000
    3.6204036036e+005 4.9174397255e+006 100.000000 275.000000 25.000000
    3.5994175531e+005 4.9175871943e+006 100.000000 300.000000 25.000000
    3.5463022536e+005 4.9153407789e+006 100.000000 305.000000 25.000000
    3.4828633822e+005 4.9153016763e+006 100.000000 310.000000 25.000000
    return
  layer 1
  string RAMSEY
  resistance
  element 1 6 4.000000
  boundary condition
    3.2917736368e+005 4.9355037810e+006 100.000000 305.000000 25.000000
    3.2187428861e+005 4.9336334969e+006 100.000000 310.000000 25.000000
    return
  return
doublet
  layer 1
  order 8
  controlpoints 32
  element
    3.270268437500000e+005 4.930308500000000e+006
    3.278789062500000e+005 4.931784000000000e+006
  order 8
  controlpoints 32
  element
    3.278789062500000e+005 4.931784000000000e+006
    3.307473125000000e+005 4.931721500000000e+006
  order 8
  controlpoints 32
  element
    3.328674062500000e+005 4.931306000000000e+006
    3.339893437500000e+005 4.929560500000000e+006
  order 8
  controlpoints 32
  element
    3.339893437500000e+005 4.929560500000000e+006
    3.366703750000000e+005 4.931098000000000e+006
  order 8
```

```
controlpoints 32
element
  3.366703750000000e+005 4.931098000000000e+006
  3.389772500000000e+005 4.931015000000000e+006
order 8
controlpoints 32
element
  3.389772500000000e+005 4.931015000000000e+006
  3.365666562500000e+005 4.928937000000000e+006
order 8
controlpoints 32
element
  3.365666562500000e+005 4.928937000000000e+006
  3.411906875000000e+005 4.925785000000000e+006
order 8
controlpoints 32
element
  3.411906875000000e+005 4.925785000000000e+006
  3.314734062500000e+005 4.925184500000000e+006
order 8
controlpoints 32
element
  3.314734062500000e+005 4.925184500000000e+006
  3.275465625000000e+005 4.928209000000000e+006
order 8
controlpoints 32
element
  3.270268437500000e+005 4.930308500000000e+006
  3.275884062500000e+005 4.928916500000000e+006
order 8
controlpoints 32
element
  3.275884062500000e+005 4.928916500000000e+006
  3.316824375000000e+005 4.928459000000000e+006
order 8
controlpoints 32
element
  3.316824375000000e+005 4.928459000000000e+006
  3.339893437500000e+005 4.929560500000000e+006
order 8
controlpoints 32
element
  3.339893437500000e+005 4.929560500000000e+006
  3.365666562500000e+005 4.928937000000000e+006
order 8
controlpoints 32
element
  3.365666562500000e+005 4.928937000000000e+006
```

```
    3.339480937500000e+005 4.927274000000000e+006
  order 8
  controlpoints 32
  element
    3.339480937500000e+005 4.927274000000000e+006
    3.315993750000000e+005 4.926214000000000e+006
  order 8
  controlpoints 32
  element
    3.315993750000000e+005 4.926214000000000e+006
    3.275465625000000e+005 4.928209000000000e+006
  order 8
  controlpoints 32
  element
    3.275465625000000e+005 4.928209000000000e+006
    3.275884062500000e+005 4.928916500000000e+006
  order 8
  controlpoints 32
  element
    3.307473125000000e+005 4.931721500000000e+006
    3.328674062500000e+005 4.931306000000000e+006
  order 8
  controlpoints 32
  element
    3.307473125000000e+005 4.931721500000000e+006
    3.305393125000000e+005 4.933675500000000e+006
  order 8
  controlpoints 32
  element
    3.305393125000000e+005 4.933675500000000e+006
    3.341348750000000e+005 4.935379500000000e+006
  order 8
  controlpoints 32
  element
    3.341348750000000e+005 4.935379500000000e+006
    3.343010312500000e+005 4.932885500000000e+006
  order 8
  controlpoints 32
  element
    3.343010312500000e+005 4.932885500000000e+006
    3.328674062500000e+005 4.931306000000000e+006
  return
switch
  end
```

Appendix B

Hydraulic Head Calibration Results from Final Models


Model Calibration Points
320.00
318.00
316.00
314.00
312.00
310.00
308.00
306.00
304.00
Modeled Head (m)
304.00
306.00
308.00
310.00
312.00
314.00
316.00
318.00
320.00
Measured Head (m)
A-Aquifer Wells
BC-Aquifer Wells