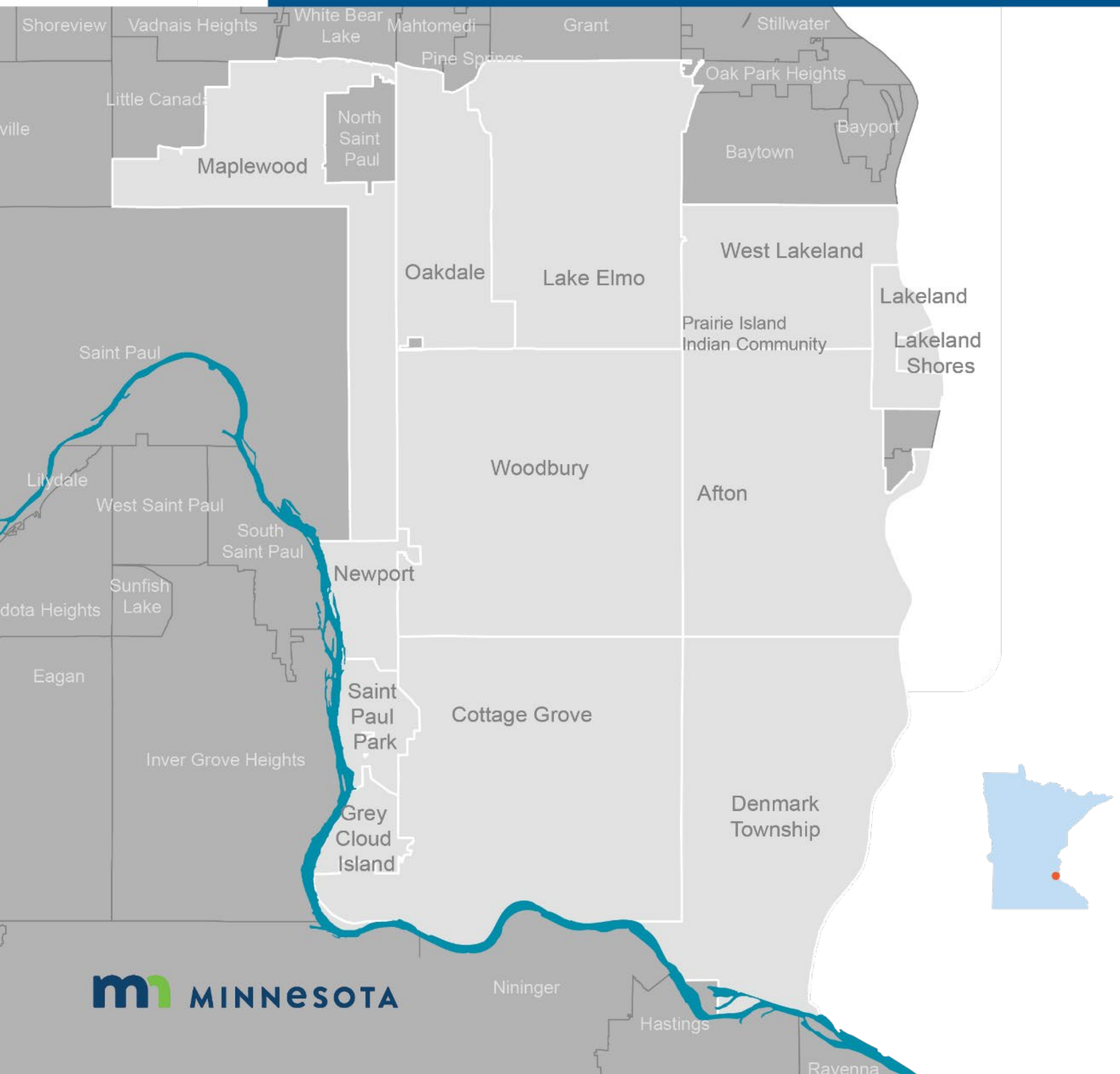
Conceptual Drinking Water Supply Plan

Long-term options for the East Metropolitan area.



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Contents

Glossary

3M Grant for Water Quality and Sustainability Fund (Grant) – Under terms of the Settlement, an $850 million Grant was provided by 3M to the State to be used to enhance the quality, quantity, and sustainability of the drinking water in the East Metropolitan Area; to restore and enhance natural resources and outdoor recreational opportunities; and to reimburse the State for certain other expenses.

2007 Consent Order – An agreement between 3M and the MPCA requiring 3M to investigate and take remedial actions to address releases and threatened releases of PFAS from the 3M Cottage Grove Site, the 3M Oakdale Disposal Site, and the 3M Woodbury Disposal Site; and to reimburse the Minnesota Pollution Control Agency (MPCA) for its costs to oversee the remediation actions taken under the Consent Order to help provide safe drinking water to affected homes and communities (e.g., installation of temporary or permanent treatment).

2018 Agreement and Order (Settlement) – An agreement to settle the State's Natural Resources Damage lawsuit against 3M for $850 million. Minnesota's Attorney General sued 3M in 2010, alleging that the company's disposal of PFAS had damaged and continues to damage drinking water and natural resources in the East Metropolitan Area. After legal and other expenses were paid, about $720 million is available to finance drinking water and natural resource projects in this region. The MPCA and the Minnesota Department of Natural Resources (DNR) are Co-Trustees of these funds.

Alignment – Location of water lines relative to other infrastructure, typically roadways.

Aquifer – An underground layer of water-bearing permeable rock; rock fractures; or loose, unpacked materials (gravel, sand, or silt). In a water-table (unconfined) aquifer, the water table (upper water surface) rises and falls with the amount of water in the aquifer. In a confined aquifer, layers of impermeable material both above and below cause the water to be under pressure, so that when the aquifer is penetrated by a well, the water will rise above the top of the aquifer (artesian condition).

Aquitard – An underground layer that has low permeability and limits, but does not completely prevent the flow of water to or from an adjacent aquifer.

Booster pump station – A pump station located within the water supply system that is designed to boost the pressure of water within a long pipeline.

Capital costs – One-time costs to build or rebuild infrastructure, including water treatment plants, wells, distribution systems, and other facilities.

Centralized system – A centralized water treatment approach for a given service that treats water at a single treatment facility in a central location and then distributes the water via a dedicated water distribution network across the service area.

Citizen-Business Group – One of three work groups to help the MPCA and the DNR identify and recommend priorities and projects for Settlement funding. This group is composed of the MPCA; the DNR; and about 15 citizen, business, and nongovernmental representatives who live or work in the East Metropolitan Area. One representative from the Government and 3M Working Group serves as a liaison to this group.

Conceptual Drinking Water Supply Plan (Conceptual Plan) – This plan, developed from a strategic planning effort as a step toward addressing the goal of Priority 1 of the Settlement, which is to ensure safe drinking water in sufficient supply to residents and businesses in the East Metropolitan Area to meet current and future needs. The Conceptual Plan presents a recommendation consisting of sets of conceptual projects (called scenarios) that, when combined, address drinking water quality and quantity issues for the 14 communities currently known to be affected by per- and polyfluoroalkyl substances (PFAS) contamination in the East Metropolitan Area. This Conceptual Plan will be used to guide the development and implementation of projects to be funded under the Grant.

Conceptual projects – Project ideas developed by the work groups, members of the public, and the Co-Trustees to address PFAS-related drinking water quality and quantity issues in the East Metropolitan Area. These conceptual projects are consistent with the water supply improvement options, but provide more detail, such as information on project location(s), project component(s), and PFAS treatment technologies.

Conceptual site model (CSM) – A simplified set of assumptions, data, and information that was used to develop a picture of how the groundwater system functions as the basis for developing the more detailed groundwater model.

Co-Trustees – The MPCA and DNR. Under the Minnesota Environmental Response and Liability Act (MERLA), the State on Minnesota (State) is the Trustee for all natural resources in the State, including air, water, and wildlife. The Governor's Executive Order 19-29 (inclusive of 11-09) designated the Commissioners of the MPCA and DNR as Co-Trustees for natural resources under MERLA and other laws.

Decentralized system – A decentralized water treatment approach that may rely on multiple treatment facilities at various locations to serve communities/neighborhoods in a given service area. Typically, these treatment facilities are far enough apart that it mitigates the cost and/or water quality concerns of a centralized treatment facility. On a much smaller scale, a decentralized system may also rely on point-of-entry treatment systems (POETSs) or point-of-use treatments (POUTs) that are installed at individual homes or businesses to achieve potable water.

Distribution line – A smaller diameter line, typically between 6 and 16 inches, that supplies water to consumers.

Distribution system – The portion of a water supply network that conveys potable water from transmission lines to water consumers and provides for residential, commercial, industrial, and fire-fighting water demand requirements. A distribution system can contain distribution lines, booster pump stations, pressure-reducing valves, and storage facilities such as water storage tanks or towers.

Drinking water distribution model – A comprehensive representation of the current and planned drinking water supply infrastructure in the East Metropolitan Area, used to support the evaluation of scenarios in this Conceptual Plan. The model includes information on drinking water supply infrastructure (e.g., connections, demand, water use, available water supply, system pressures, layouts and locations of infrastructure) as well as private and non-community public supply well data.

Drinking Water Supply Technical Subgroup (Subgroup 1) – One of the three work groups; composed of technical experts and formed to analyze options, deliver assessments, and provide advice for long-term options for drinking water supply and treatment to the Government and 3M Working Group, and the Citizen-Business Group.

East Metropolitan Area – Communities to the east of the Minneapolis/St. Paul Metropolitan Area that have been affected by PFAS releases from the 3M Company (3M) source areas. Currently includes the cities of Afton, Cottage Grove, Lake Elmo, Lakeland, Lakeland Shores, Maplewood, Newport, Oakdale, St. Paul Park, and Woodbury; the townships of Denmark, Grey Cloud Island, and West Lakeland; and the Prairie Island Indian Community.

EPA Health Advisory Levels (HALs) – Non-enforceable and non-regulatory technical guidance for state agencies and other public health officials on health effects, analytical methodologies, and treatment technologies associated with drinking water contamination. HALs are based on non-cancer health effects for different lengths of exposure (1 day, 10 days, or a lifetime). In 2016, the U.S. Environmental Protection Agency (EPA) released HALs for perfluorooctanoic acid (PFOA) and perfluorooctane sulfonate (PFOS).

Government and 3M Working Group – One of three work groups to help the Co-Trustees identify and recommend priorities and projects for Settlement funding. The formation of a working group consisting of representatives from the MPCA, the DNR, Washington County, the East Metropolitan Area communities, and 3M to identify and recommend projects was a requirement of the 2018 Agreement and Order (Settlement). One representative from the Citizen-Business Group serves as a liaison to this group.

Granular activated carbon (GAC) – GAC is made from raw organic materials (such as coconut shells or coal) that are high in carbon. Heat, in the absence of oxygen, is used to increase (activate) the surface area of the carbon, which is why these filters are sometimes referred to as “charcoal” filters. The activated carbon removes certain chemicals that are dissolved in water passing through a filter containing GAC, by trapping (adsorbing) the chemical onto the GAC.

Groundwater Management Area – A designation created by the Minnesota legislature as a tool for the DNR to address difficult groundwater-related resource challenges. Within these areas, the DNR may limit total annual water appropriations and uses to ensure sustainable use of groundwater that protects ecosystems, water quality, and the ability of future generations to meet their own needs. Washington County, along with Ramsey County and portions of Anoka and Hennepin Counties, falls within the North and East Metropolitan Groundwater Management Area.

Groundwater model – A numerical, three-dimensional representation of the groundwater aquifers in the East Metropolitan Area used to support the evaluation of scenarios in this Conceptual Plan. The purpose of the groundwater model is to provide insight into the current groundwater flow system, and predict impacts to flow paths and groundwater resources through the year 2040 from the proposed scenarios. These flow paths and quantity estimates are based on projected groundwater recharge/precipitation rates, surface water elevations, and pumping volumes of the proposed scenarios.

Health advisory – Notice from MDH that a drinking water supply has exceeded health-based guidance values developed by MDH.

Health-based value (HBV) – A health-based water guidance value developed by the Minnesota Department of Health (MDH) using the same scientific methods as health risk limits (HRLs), including peer review. Like an HRL, it is the concentration of a water contaminant, or a mixture of contaminants, that, based on current knowledge, can be consumed with little or no risk to health by the most exposed and sensitive individuals in a population. HBVs are developed to provide water guidance between rule-making cycles for chemicals that may have been recently detected in the water or for which new health information has become available.

Health risk index (HRI; health index, HI) – An indicator of the combined risk of exposure to PFAS compounds that cause the same health effects. It is determined by calculating the concentration of each PFAS compound divided by its HRL or HBV, and adding the resulting ratios. An HI equal to or greater than one indicates possible combined effects. The HRI is referred to interchangeably throughout the document as the health risk index, the health index, the HI, or the HRI. While HRI and HI are terms used for every chemical, the Conceptual Plan always uses them in reference to PFAS contamination. See the definition for PFAS for more information.

Health risk limit (HRL) – A health-based water guidance value developed by MDH that has been promulgated through the Minnesota rule-making process, which includes peer review and public input. It is the concentration of a groundwater contaminant, or a mixture of contaminants, that, based on current knowledge, can be consumed with little or no risk to health by the most exposed and sensitive individuals in a population.

High-service pumps – Pumps located at the water treatment facility that deliver large volumes of treated, potable water to the water supply system.

Horizontal directional drilling – A minimal impact trenchless method of installing underground utilities such as pipe, conduit, or cables in a relatively shallow arc or radius along a prescribed underground path using a surface-launched drilling rig.

Ion exchange (IX) – IX processes are reversible chemical reactions for removing dissolved ions from a solution and replacing them with other similarly charged ions. In water treatment, it is primarily used for softening, where calcium and magnesium ions are removed from water; however, it is being used more frequently for the removal of other dissolved ionic species.

Jack and bore – A method of horizontal boring construction for installing casing or steel pipes under roads or railways. Construction crews drill a hole underground horizontally between two points (the sending and receiving pits) without disturbing the surface in between. This is accomplished by using an auger boring machine that inserts casing pipe as it moves through the earth while simultaneously removing the soil from within the casing pipe.

Maximum contaminant level (MCL) – The maximum level of a contaminant allowed in water delivered from a public water supply. MCLs are set by EPA through a scientific process that evaluates the health impacts of the contaminant and the technology and cost required for prevention, monitoring, and/or treatment. States are allowed to enforce lower (i.e., stricter) standards than MCLs, but are not allowed to enforce higher (i.e., less strict) standards.

Metropolitan Council – The regional policy-making body, planning agency, and provider of essential services for the Twin Cities metropolitan region, including transportation, wastewater, water supply planning, growth planning, parks and trails, and affordable housing. The Minnesota Legislature established the Metropolitan Council in 1967; it has 17 members who are appointed by the Governor.

Municipal supply well – A drinking water well that serves as a source of water for a municipal water system.

Municipal water system – Refers to an existing municipality's drinking or potable water treatment and distribution system.

Non-community public supply well – A well that provides water to the public in places other than their homes – where people work, gather, and play (e.g., schools, offices, factories, childcare centers, or parks) – and is part of a non-community public water system (see definition below).

Non-community public water system – A drinking water system that supplies water from private water supply well(s) on a year-round basis to:

- A residential development with six or more private residences (e.g., apartment buildings, private subdivisions, condominiums, townhouse complexes, mobile home parks), or
- A mobile home park or campground with six or more sites with a water service hookup.

Non-municipal well – A well that is considered non-municipal in this Conceptual Plan, and includes domestic, irrigation, commercial, and non-community public water supply wells.

Operations and maintenance (O&M) – All work activities necessary to operate and maintain all water treatment and supply facilities from the source of water through the distribution systems.

Per- and polyfluoroalkyl substances (PFAS) – A family of synthetic chemicals, initially developed by 3M, used to make products that resist heat, oil, stains, grease, and water. They are extremely resistant to breakdown in the environment, accumulate in humans and animals, and are “emerging contaminants” that are the focus of active research and study. Specific chemicals within the PFAS family include perfluorooctanoic acid (PFOA), perfluorooctane sulfonate (PFOS), perfluorohexane sulfonate (PFHxS), perfluorobutane sulfonate (PFBS), and perfluorobutanoic acid (PFBA).

Point-of-entry treatment system (POETS) – Water treatment system installed on the water line as it enters an individual home, business, school, or other building. These systems treat all the water entering the building.

Point-of-use treatment (POUT) – Water treatment system installed on the water line at the point of use, such as a faucet.

Pressure-reducing stations – Locations within the water supply system where a pressure-reducing valve has been installed.

Pressure-reducing valves – A valve fitted in a pipe system, which, in spite of varying pressures on the inlet side (inlet pressure), ensures that a certain pressure on the outlet side (outlet pressure) is not exceeded, thus protecting the components and equipment on the outlet side.

Priority 1 – The first priority of the Grant is to enhance the quality, quantity, and sustainability of drinking water in the East Metropolitan Area. The goal of this highest-priority work is to ensure safe drinking water in sufficient supply to residents and businesses in the East Metropolitan Area to meet their current and future water needs. Examples of projects in this first priority may include, but are not limited to, the development of alternative drinking water sources for municipalities and individual households (including, but not limited to, creation or relocation of municipal wells), the treatment of existing water supplies, water conservation and efficiency, open-space acquisition, and groundwater recharge (including projects that encourage, enhance, and assist groundwater recharge). For individual households, projects may include, but are not limited to, connecting those residences to municipal water supplies, providing individual treatment systems, or constructing new wells.

Priority 2 – The second priority of the Settlement is to restore and enhance aquatic resources, wildlife, habitat, fishing, resource improvement, and outdoor recreational opportunities in the East Metropolitan Area and in downstream areas of the Mississippi and St. Croix Rivers. The Co-Trustees have immediate access to $20 million in Settlement funds for projects in this priority category. After the safe drinking water goals of the first priority have been reasonably achieved, all remaining Settlement funds will then be available for natural resource restoration and enhancement projects.

Priority 3 – If funds remain after the first two priority goals have been met, the Grant can be used for statewide environmental improvement projects. Only projects in categories such as statewide water resources, habitat restoration, open space preservation, recreation improvements, or other sustainability projects would be eligible.

Private well – A domestic drinking water well that is not part of a public water system. The quality and safety of water from private wells are not regulated by the federal Safe Drinking Water Act, nor in most cases by state laws.

Public supply well – A drinking water well that serves as a source of water for a public water system.

Public water system – A regulatory term under the federal Safe Drinking Water Act for a drinking water supply system that serves at least 15 homes or 25 people for at least 60 days a year.

Recharge – Water added to the aquifer from the surface through the unsaturated (dry or vadose) zone in the uppermost soils through processes called infiltration and percolation following any precipitation (rain or snow) event.

Regional water supply system – A water system that supplies potable water to more than one community or water system.

Scenarios – Sets of conceptual projects that consider water supply, distribution, and demand, and are evaluated in this Conceptual Plan using drinking water distribution and groundwater models.

Small community water system – A private and voluntary water system that serves neighborhood-sized clusters of residences.

Special Well Boring and Construction Area (SWBCA) – A mechanism that provides for controls on the drilling or alteration of wells in an area where groundwater contamination has resulted or may result in risks to public health. The purposes of an SWBCA are to inform the public of potential health risks in areas of groundwater contamination, provide for the construction of safe water supplies, and prevent the spread of contamination due to the improper drilling of wells or borings.

Sustainability – Responsible interaction with the environment to provide, improve, and protect the drinking water for future generations by lessening environmental impacts, thoughtfully managing demands, and empowering conservation through education and targeted projects. Minnesota Statute § 103G.287, subd. 5, describes groundwater sustainability as the development and use of groundwater resources to meet current and future beneficial uses without causing unacceptable environmental or socioeconomic consequences.

Transmission line – A large-diameter pipeline designed to convey large volumes of water at higher pressures from a source (typically a water treatment facility) to a distribution system for use. Water transmission lines are typically larger in diameter (greater than 16 inches), and consumers are not typically placed on transmission lines because of their high velocities and pressures.

Watershed districts – Special government entities that monitor and regulate the use of water within certain watersheds in Minnesota, rather than within political boundaries, which were first authorized by the legislature in 1955.

Water storage tank – A water storage facility consisting of a cylindrical tank that has a base elevation at the existing ground surface. Storage facilities provide sufficient water volume to meet peak hour water demands.

Water storage tower – An elevated water storage facility (also referred to as a water tower) that supports a water storage tank with a base elevation above the existing ground surface to provide sufficient pressure to the water distribution system, and to provide emergency storage for fire protection.

Water supply improvement options – A reasonable range of options that could improve drinking water quality and quantity, including both centralized and decentralized systems, which are evaluated against a set of screening criteria in this Conceptual Plan to determine their relevance to the individual communities in the East Metropolitan Area.

Water supply system – A system for the treatment, transmission, storage, and distribution of water from source to consumers (e.g., homes, commercial establishments, industry, irrigation facilities, and public agencies for water).

Work groups – Three groups formed by the Co-Trustees to help identify and recommend priorities and projects for Settlement funding: the Government and 3M Working Group, the Citizen-Business Group, and the Drinking Water Supply Technical Subgroup.

Acronyms and abbreviations

AACE	Association for the Advancement of Cost Engineering
Abt	Abt Associates
ADD	average daily demand
CAD	computer-aided design
Conceptual Plan	Conceptual Drinking Water Supply Plan
CSM	conceptual site model
DNR	Minnesota Department of Natural Resources
EPA	United States Environmental Protection Agency
GAC	granular activated carbon
GIS	geographic information system
Grant	3M Grant for Water Quality and Sustainability Fund
GWTP	groundwater treatment plant
HAL	EPA Health Advisory Level
HBV	health-based value
HI	health index (used interchangeably with HRI)
HRI	health risk index (used interchangeably with HI)
HRL	health risk limit
IX	ion exchange
MCES	Metropolitan Council Environmental Services
MCL	maximum contaminant level
MDH	Minnesota Department of Health
MERLA	Minnesota Environmental Response and Liability Act
mgd	million gallons per day
MGS	Minnesota Geological Survey
MPCA	Minnesota Pollution Control Agency
N/A	not applicable
NPS	National Park Service
O&M	operations and maintenance
PFAS	per- and polyfluoroalkyl substances
PFBA	perfluorobutanoic acid
PFBS	perfluorobutane sulfonate
PFHxS	perfluorohexane sulfonate
PFOA	perfluorooctanoic acid
PFOS	perfluorooctane sulfonate
POETS	point-of-entry treatment system
POUT	point-of-use treatment
QA/QC	quality assurance/quality control
Settlement	2018 Agreement and Order
SPRWS	St. Paul Regional Water Services
State	State of Minnesota
Subgroup 1	Drinking Water Supply Technical Subgroup
SWBCA	Special Well Boring and Construction Area

SWTP	surface water treatment plant
3M	3M Company
2007 Consent Order	2007 Settlement Agreement and Consent Order
TCE	trichloroethylene
VOC	volatile organic compound
Wood	Wood Environment & Infrastructure Solutions, Inc.

Appendix A. Introduction

In February 2018, the State of Minnesota and the 3M Company (3M) announced an agreement to settle the State's Natural Resources Damage lawsuit for per- and polyfluoroalkyl substances (PFAS) contamination in the East Metropolitan Area of the Twin Cities. As part of the settlement, the State of Minnesota and 3M entered into a 2018 Agreement and Order (2018 Settlement or Settlement) that established the 3M Grant for Water Quality and Sustainability Fund (Grant). Under the first and highest priority (Priority 1) of this Agreement, the Minnesota Pollution Control Agency (MPCA) and the Minnesota Department of Natural Resources (DNR) will use the Grant for long-term projects to enhance the quality, quantity, and sustainability of drinking water for residents and businesses affected by PFAS in the East Metropolitan Area. As a step toward addressing Priority 1, the MPCA and DNR have developed this Conceptual Drinking Water Supply Plan (Conceptual Plan) to evaluate and recommend a set of projects that provide clean, sustainable drinking water to the 14 communities currently known to be affected by PFAS contamination in the East Metropolitan Area, now and into the future. The options presented here are based on the totality of evaluating all appropriate and feasible alternatives, and incorporate feedback from the work groups and public outreach. Any of the recommended options would be reasonable and necessary in response to PFAS releases in the East Metro settlement area, and not inconsistent with provisions found in Minn. Stat. 115B, the Minnesota Environmental Response and Liability Act.

This chapter provides background information on the Agreement, the overall goals of the planning and implementation effort, an overview of the Conceptual Plan, and information on communication and public involvement.

A.1 Afton

A.1.1 Community background

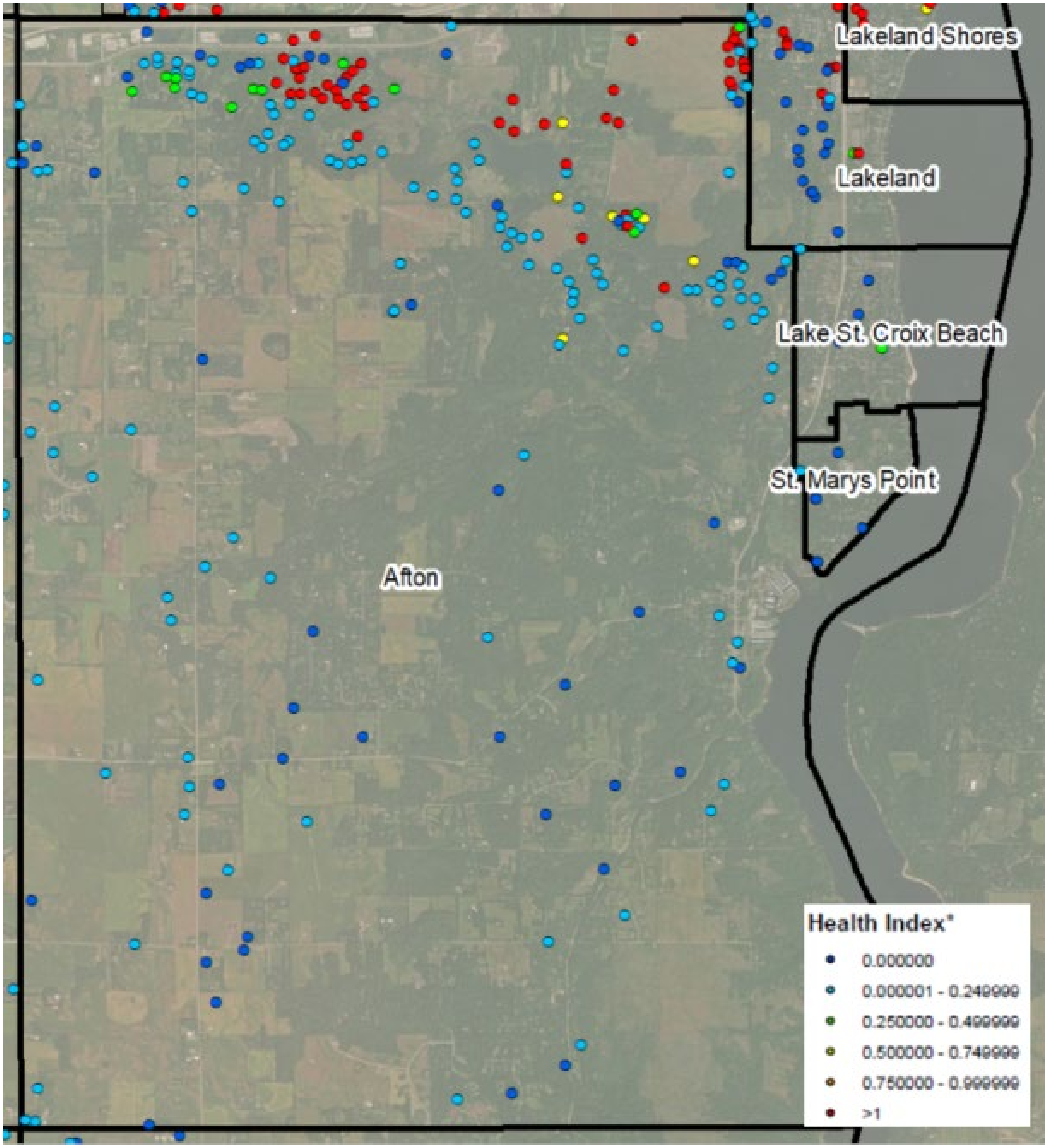
Afton, located on the eastern side of the East Metropolitan Area, is a rural city designated as a Diversified Rural community by the Metropolitan Council (2014). According to the city's Comprehensive Plan (City of Afton, 2015), residents value their rural lifestyle and try to maintain it by regulating low residential housing densities and not implementing a municipal system that will encourage urbanization. In Afton, most lots are a minimum of five acres, with many being substantially larger, and many being located among large agricultural properties and wooded ravines. On many of these large lots, the homes are set back 400 feet or more from the public road. Afton currently has no municipal water system, with residents and businesses in the community on private wells. While a small percentage of Afton is designated for industrial uses, the primary land uses are agricultural and rural residential. The community is anticipated to have a population of 3,070 in the year 2020, and a population of 3,140 in the year 2040 (Metropolitan Council, 2015a).

According to the Minnesota Well Index (MWI), Afton has an estimated 808 non-municipal wells. However, discussions with Afton and manual counts of parcels have indicated that there are approximately 1,195 wells of which approximately 242 have been sampled as of October 2020. Based on the currently available PFAS sampling data, the northern border of Afton, adjacent to West Lakeland, is the only area of the community with PFAS levels that exceed the Minnesota Department of Health (MDH) Health Index (HI) of 1 (Figure A.1). The remaining areas of the community that have been sampled to date have detectable levels of PFAS but do not exceed the HI of 1.

A.1.2 Current and proposed projects

As shown in Figure A.1, Afton has several non-municipal wells along its northern border with West Lakeland that exceed the HI of 1. To date, granular activated carbon (GAC) point-of-entry treatment (POET) systems have been provided for these individual residences that have received well advisories. The City has expressed their intention to continue providing such systems as residents receive well advisories and depending on the HI treatment threshold as discussed in Appendix E.

Figure A.1. HI levels at sampled non-municipal wells in Afton.



A.2 Cottage Grove

A.2.1 Community background

Cottage Grove, located on the southwestern side of the East Metropolitan Area, is designated as a Suburban Edge community by the Metropolitan Council (2014). The community is bordered by the Mississippi River to the south; Denmark Township to the east; Woodbury to the north; and Grey Cloud Island, St. Paul Park, and Newport to the west. Local PFAS sources contributing to groundwater contamination include the 3M Cottage Grove Disposal Site along the southern border of the community and the Woodbury Disposal Site on its northern border. Table A.1 summarizes Cottage Grove's 2020 and 2040 population, average daily demand, and maximum daily demand.

Table A.1. Cottage Grove population and demand projections. Source: City of Cottage Grove, 2018.

	2020	2040
Total projected population	38,400	47,000
Projected population served	38,400	47,000
Average daily demand in gpm (mgd)	2,667 (3.84)	3,264 (4.7)
Maximum daily demand in gpm (mgd)	8,000 (11.52)	9,792 (14.1)

gpm = gallons per minute, mgd = million gallons per day.

Cottage Grove has a municipal water system as well as residences on private wells. Cottage Grove's municipal water system has 12 municipal supply wells (Table A.2) to meet the city's water demands. All wells receive chemical treatment with fluoride and chlorine. To date, 8 out of the city's 12 municipal supply wells have PFAS levels that exceed the HI of 1 (Table A.2). Of the PFAS-impacted wells, Wells 2 and 4 have been taken offline, Well 7 is offline but used for blending if needed, and Wells 3, 7, and 10 receive GAC treatment and are in use. However, the GAC water treatment plants (WTPs) at Wells 3 and 10 are interim treatment solutions and are not long-term options.

Cottage Grove currently faces operational challenges as the PFAS contamination levels in their untreated wells continue to fluctuate. With each quarterly sampling, the city updates their standard water supply operations to account for changes in the HI. High fluctuations in PFAS concentrations for the city's municipal supply wells require revisions to operations and can directly impact available supply to meet peak water demands. Operational information provided by the city in February 2019 indicates that Cottage Grove can meet its current demand by operating the WTPs at Wells 3 and 10; and a combination of Wells 1, 5, 6, 8, 9, 11, and 12. If Well 7 is included for blending purposes, these wells can provide a total flow 12,400 gpm (17.86 mgd).

The groundwater source firm capacity for a municipal water system, as defined by the 2012 Recommended Standards for Water Works, is "the total developed groundwater source capacity, unless otherwise specified by the reviewing authority, that shall equal or exceed the design maximum day demand with the largest producing well out of service" (Health Research, 2012, p. 18). However, the city considers their firm capacity as two wells being out of service due to a seven-year well maintenance schedule. Additionally, the city must review their firm supply capacity in relation to the three pressure zones and raw water blending in the Intermediate Pressure Zone. Under this assumption and assuming the two largest operating wells are out-of-service, the firm capacity of the system would be 8,900 gpm (12.8 mgd). However, according to Cottage Grove, Wells 1 and 2 are not anticipated to be long-term water supply options due to their age, condition, lower capacity, and distance from the other wells; and the high HI for Well 2. Therefore, the city anticipates replacement of these municipal supply well(s) in the Low-Pressure Zone for future supply.

Table A.2. Cottage Grove supply well summary.

Well no.	Unique well no.	Design capacity (gpm)	Aquifer	HI value	Status[e]
1	208808	600	Prairie du Chien-Jordan	0.660	In use
2	208809	600	Prairie du Chien-Jordan	2.370	Offline
3	208807	800	Prairie du Chien-Jordan	2.48	In use[a]
4	208805	1,000	Prairie du Chien-Jordan	2.880	Offline
5	208806	1,000	Prairie du Chien-Jordan	1.230	In use
6	201238	1,000	Prairie du Chien-Jordan	1.630	In use
7	201227	1,000	Prairie du Chien-Jordan	1.290	Offline[b]
8	110464	1,500	Prairie du Chien-Jordan	1.150	In use
9	165602	1,500	Prairie du Chien-Jordan	0.830	In use
10	191904	2,000	Prairie du Chien-Jordan	2.430	In use[a]
11	655944	1,500	Prairie du Chien-Jordan	0.330	In use
12	830682	1,500	Prairie du Chien-Jordan	0.010	In use
Total capacity		14,000 gpm (20.2 mgd)			
Total available capacity[c]		12,400 gpm (17.86 mgd)			
Firm capacity[d]		8,900 gpm (12.82 mgd)			

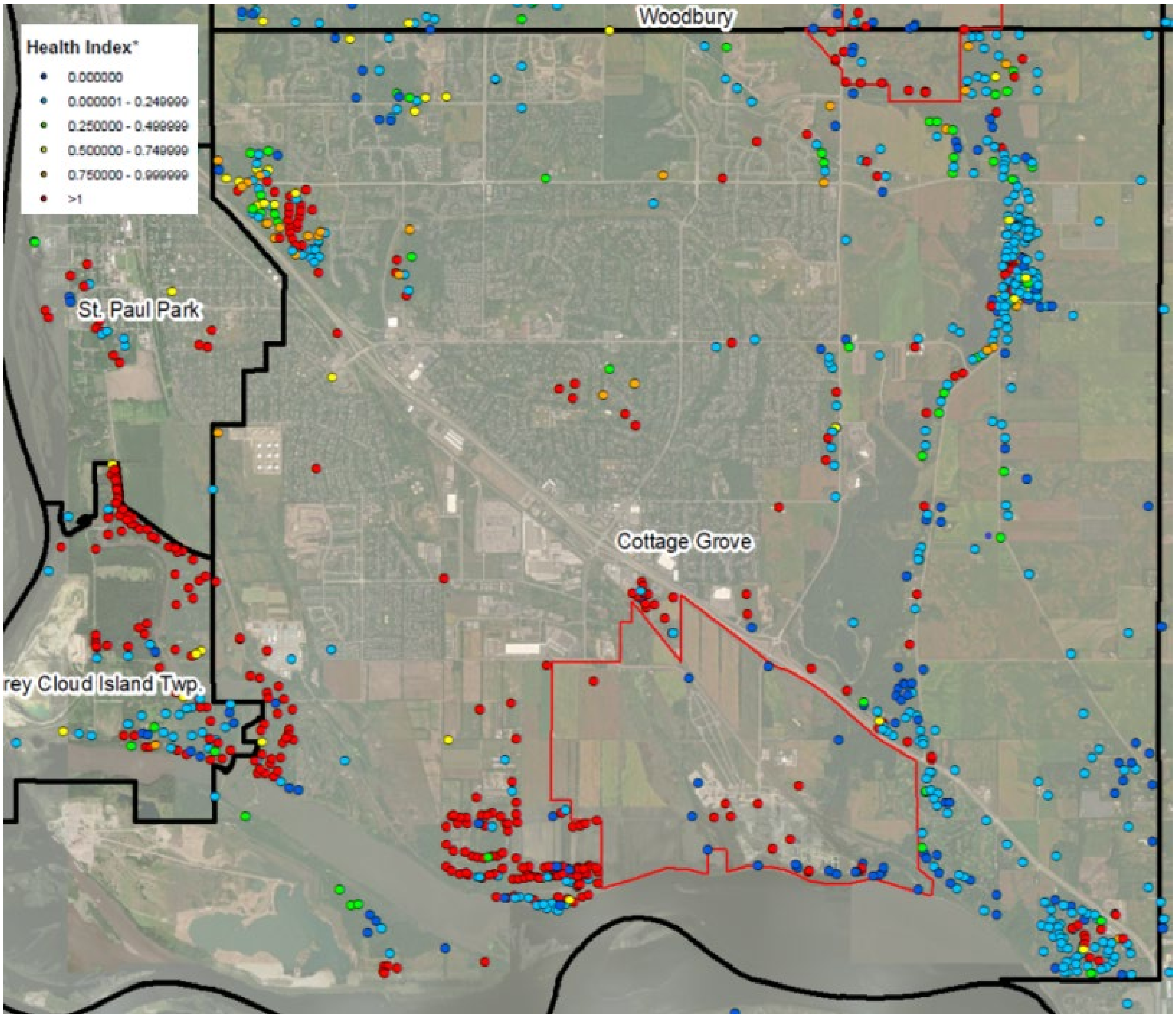
Notes:
Green indicates wells that have a HI greater than 1.
a. Well is receiving GAC treatment and is in operation.
b. Used for blending if needed.
c. Excludes wells that are offline and/or have a HI greater than 1 and are not used for blending.
d. As defined by the community's Standard Operating Procedures (SOPs) and this appendix.
e. Well operation status is not fixed and may change over time depending on operations.

Under these assumptions, Cottage Grove currently has sufficient water supply to meet the anticipated 2020 maximum daily demands of 11.5 mgd, if the active municipal supply wells maintain an HI value less than 1. However, the city would need an additional well to replace Wells 1 and 2 and treat more wells to meet their 2040 maximum daily demands of 14.1 mgd depending on the HI treatment threshold as discussed in Appendix E.

The City of Cottage Grove owns and operates their municipal water system, which consists of six water storage tanks and two booster pump stations and operates across three pressure zones. Wells are operated to maintain set water levels in the water storage towers/tanks. The city has one interconnect with St. Paul Park, which is not active under normal operating conditions. As such, a condition assessment should be performed to determine its capacity and operational condition. It is estimated that the existing interconnect has a capacity of 400–500 gpm, but this needs to be verified.

The majority of Cottage Grove is served by the city's municipal water system; however, the city is still experiencing growth and is expanding their municipal water system to both new and existing developments. According to the MWI, Cottage Grove has an estimated 868 non-municipal wells, mostly in the southern, eastern, and western extents of the city. Of these wells, approximately 723 have been sampled as of October 2020 and many of the non-municipal wells in Cottage Grove exceed the HI of 1 (Figure A.2). Treatment has been provided for the individual residences that have received well advisories and will continue to receive treatment depending on the HI treatment threshold as discussed in Appedix E.

Figure A.2. HI levels at sampled non-municipal wells in Cottage Grove. The 3M source areas are outlined in red.



A.2.2 Current and proposed projects

Cottage Grove implemented GAC WTPs at Wells 3 and 10 in 2017. However, the WTP at Well 10 was intended to be an interim solution for five years as it is partially located on adjacent lands, which required easements for construction. There is no room for expansion and the GAC vessels are being rented from Carbonair, which is a not a viable long-term solution.

Cottage Grove is currently working with their consulting engineers and the Minnesota Pollution Control Agency (MPCA) on a pilot study to establish ion exchange (IX) as an approved alternative for PFAS treatment. Cottage Grove also submitted two expedited projects that proposed to connect two subdivisions currently on private wells to the city's municipal water system. The City has expressed their intention to continue expanding upon the existing centralized treatment system. The city is also currently in the process of implementing a temporary treatment system at an existing well which was accepted by the Co-Trustees as an interim measure to address additional well exceedances as well as the demand challenges the city is facing due to PFAS contamination.

A.3 Denmark

A.3.1 Community background

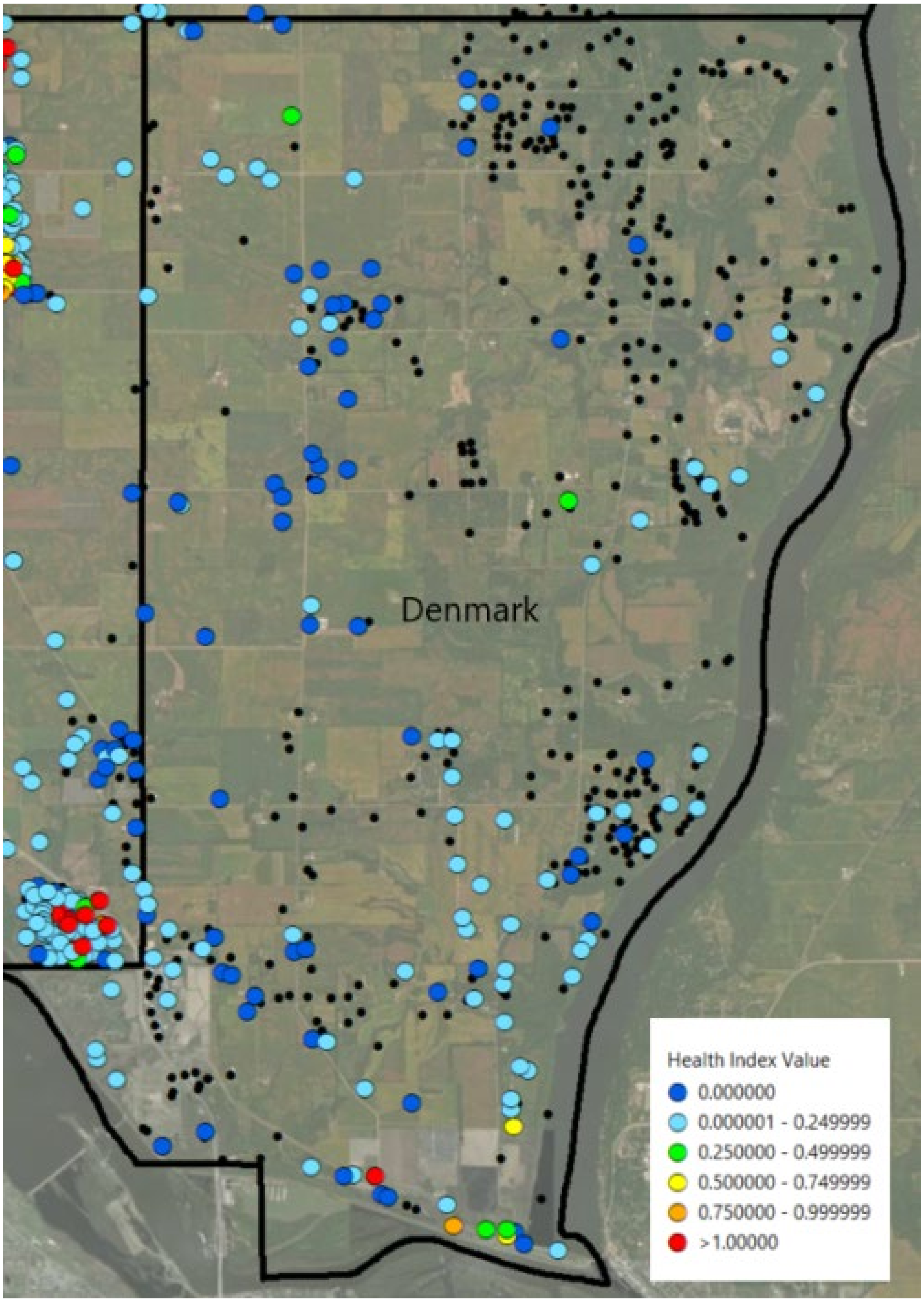
Denmark, located on the southeastern side of the East Metropolitan Area, is a rural township designated as a Diversified Rural community by the Metropolitan Council (2014). According to the community's Comprehensive Plan (Denmark Township, 2019) and similar to Afton, residents value their rural lifestyle and try to maintain it by regulating low residential housing densities and not implementing public facilities that will encourage urbanization, though the community is growing. Denmark has no municipal water system, with residents and businesses in the community on private wells. The largest land use in Demark is agricultural, accounting for 54% of the total existing land use in 2016, with only 6% for residential, single-family use (Denmark Township, 2019). The community is anticipated to have a population of 1,920 in the year 2020, and a population of 2,410 in the year 2040 (Metropolitan Council, 2015c).

According the MWI, Denmark has an estimated 487 non-municipal wells; however, conversations with Denmark and manual counts have indicated there is approximately 761 wells. Of these wells, approximately 133 have been sampled as of October 2020. According to the available PFAS sampling data, one well in the community has a PFAS level that exceeded the HI of 1 (Figure A.3). The remaining areas of the community that have been sampled to date have detectable levels of PFAS and seven (7) exceed an HI ≥ 0.3.

A.3.2 Current and proposed projects

As shown in Figure A.3, Denmark has little PFAS contamination based on data available to date. As a result, the community has not implemented any projects to address the PFAS contamination. Denmark has expressed that it is their intention to provide granular activated carbon (GAC) point of entry treatment systems (POETSs) to residents that receive well advisories.

Figure A.3. HI levels at sampled non-municipal wells in Denmark.



A.4 Grey Cloud Island

A.4.1 Community background

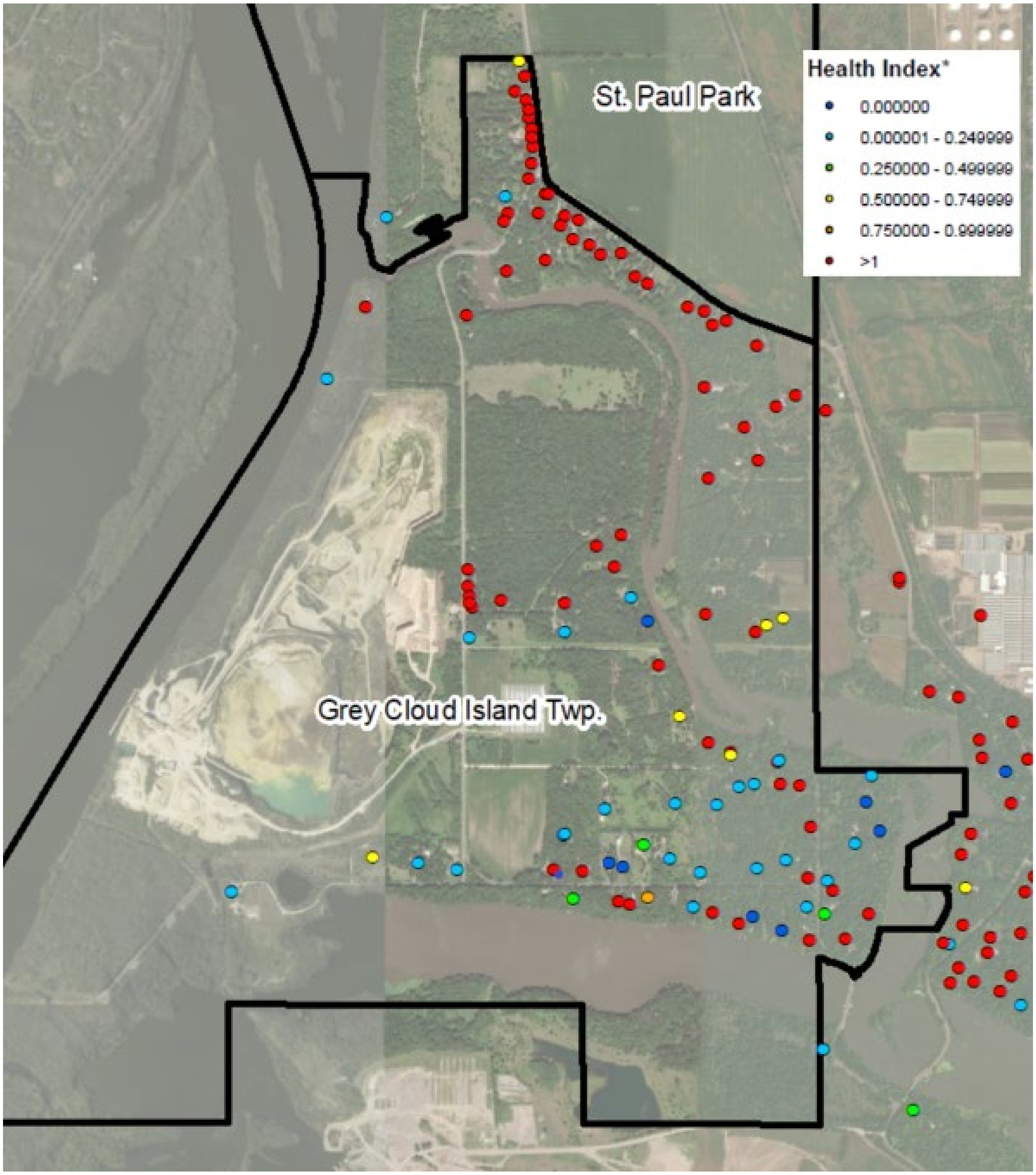
Grey Cloud Island, located on the southwestern side of the East Metropolitan Area, is a small, rural township designated as a Diversified Rural community by the Metropolitan Council (2014). The community is bordered by the Mississippi River, with St. Paul Park to the north and Cottage Grove to the east. According to the community's Comprehensive Plan (Grey Cloud Island Township, 2018), residents value their rural lifestyle, which they try to maintain by regulating low residential housing densities and not implementing public facilities that will encourage urbanization. Grey Cloud Island has no municipal water system, with residents and businesses in the community on private wells. Most homes in the community were built in the 1940s and 1950s. The community is anticipated to have a population of 300 in the year 2020, and a population of 270 in the year 2040 (Metropolitan Council, 2015d).

According to available data from October 2020 PFAS sampling, Grey Cloud Island has detectable levels of PFAS in the majority of their estimated 123 non-municipal wells, and PFAS exceeding the HI of 1 in many of them (Figure A.4). Depending on the date of installations, private wells in Grey Cloud Island range from shallow to deep wells, and the data suggest that PFAS-contaminated wells are in the shallower aquifers resulting in varying HI values in close proximity.

A.4.2 Current and proposed projects

As shown in Figure A.4, Grey Cloud Island has several non-municipal wells that exceed the HI of 1. Bottled water and/or POETSs have been provided for these individual residences that have received well advisories. The community has expressed an interest in exploring various options to address PFAS contamination including POETSs and implementing a distribution system to receive water from neighboring municipal water systems.

Figure A.4. HI levels at sampled non-municipal wells in Grey Cloud Island. The 3M source area is outlined in red.



A.5 Lake Elmo

A.5.1 Community background

Lake Elmo, located on the northern side of the East Metropolitan Area, is designated as both an Emerging Suburban Edge and Rural Residential community by the Metropolitan Council (2014). Lake Elmo is bordered by Woodbury to the south, Oakdale to the west, and West Lakeland to the east. The community, traditionally rural with large residential lots, originally did not intend to have a municipal water system, with the exception of the Old Village area and the Eagle Point Business Park. This changed, however, after 2006 when sampling indicated that PFAS contamination was impacting the southern two-thirds of the city, areas generally south of the Washington County Landfill. The Washington County Landfill and the Oakdale Disposal Site were previous disposal sites for 3M and a source of PFAS contamination to Lake Elmo. Sampling efforts have been ongoing and have focused on the southern two-thirds of the city where perfluorooctanoic acid (PFOA) and perfluorooctane sulfonate (PFOS) levels have exceeded health standards. The northern part of Lake Elmo is believed to be upgradient of the contamination, where only slight levels of perfluorobutanoic acid (PFBA) have been found, similar to levels found throughout much of the Twin City's Metropolitan Area. Table A.3 summarizes Lake Elmo's 2020 and 2040 population, average daily demand, and maximum daily demand.

Table A.3. Lake Elmo population and demand projections. Source: City of Lake Elmo, 2019.

	2020	2040
Total projected population	11,020	22,304
Projected population served	7,302	21,165
Average daily demand gpm (mgd)	532 (0.77)	1,597 (2.3)
Maximum daily demand gpm (mgd)	1,597 (2.3)	4,325 (6.1)

Lake Elmo has a municipal water system as well as residences on private wells. Currently, the Lake Elmo municipal water system has two municipal supply wells in use and a third being installed (Well 5; Table A.4) to meet the city's water demands. At this time, Well 1 has exceeded the HI of 1 and has been removed from operation. In addition, Well 1 is a multi-aquifer well that the Department of Natural Resources (DNR) and MDH have requested to be sealed. Lake Elmo's Well 4 falls within a 5-mile radius of White Bear Lake, which has legally impacted the city's appropriation permits. Well 3 was drilled but never equipped or used due to contamination issues.

Based on the capacities in Table A.4, Lake Elmo does not have sufficient firm capacity to supply the maximum daily demands for 2020 or 2040. However, once Well 5 is in operation, there will be sufficient firm capacity to meet current 2020 maximum daily demands, but the city will need to drill additional wells to provide firm capacity that will meet 2040 maximum daily demands. The third additional well is anticipated to be installed before 2040; however, the location of any new wells will be a challenge due to PFAS contamination in the southern two-thirds of the community, as well as the designation of, and requirements for, a Special Well and Boring Construction Area. In addition, new wells located in the northern one-third of the city could have potential impacts on White Bear Lake, which would need to be considered.

Table A.4. Lake Elmo supply well summary.

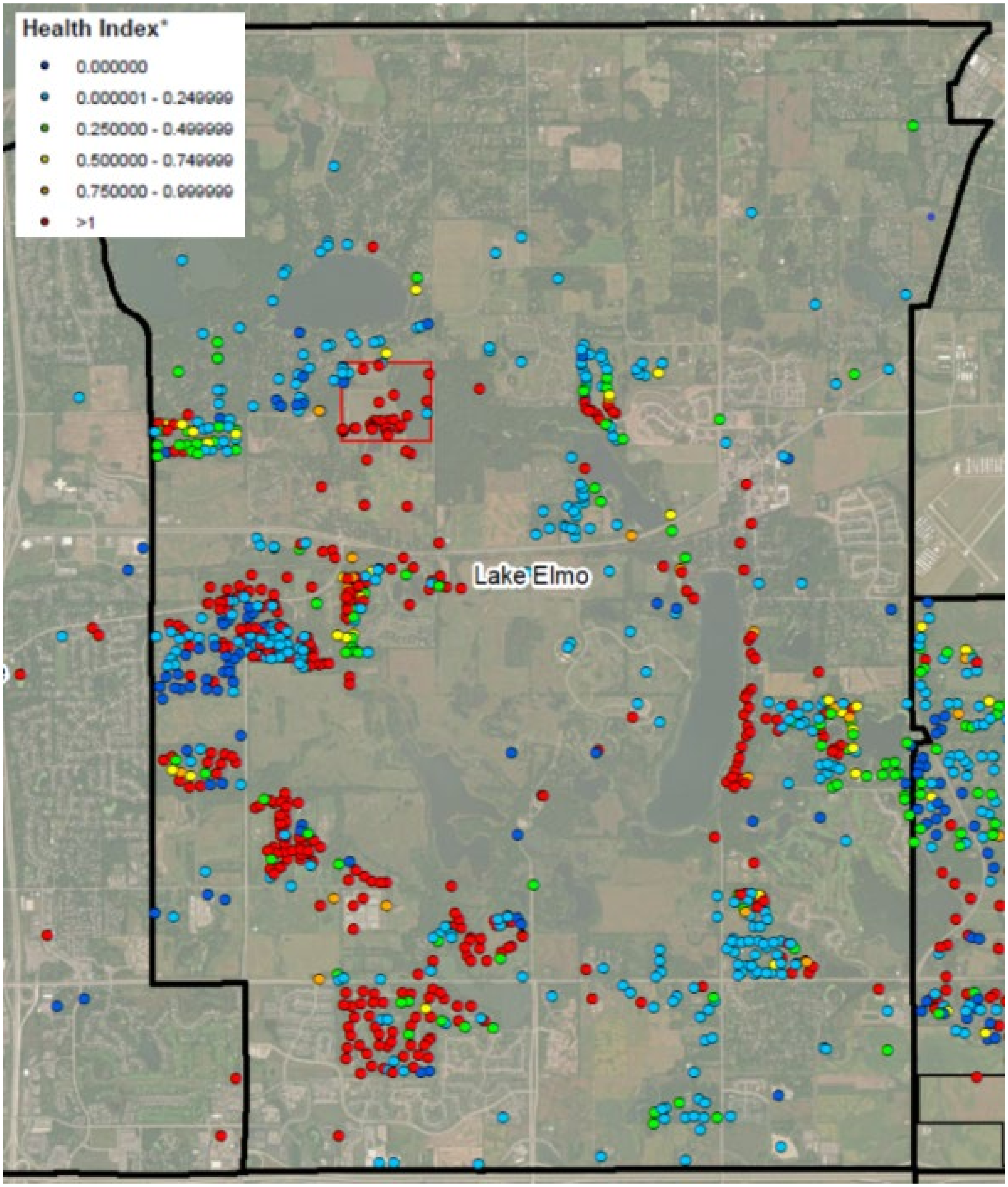
Well no.	Unique well no.	Capacity (gpm)	Aquifer	HI value	Status
1	208448	500	Jordan and Mt. Simons	1.3736	Offline – sealed
2	603085	1,000	Prairie du Chien-Jordan	0.27	In use
4	767874	1,250	Jordan	0.01	In use
5		1,250	Jordan		Being installed
Total capacity[a]		2,250 gpm (3.24 mgd)			
Firm capacity[a, b]		1,000 gpm (1.44 mgd)			
Total capacity[c]		3,500 gpm (5.0 mgd)			
Firm capacity[b, c]		2,250 gpm (3.24 mgd)			

Notes:
Green indicates wells that have a HI greater than 1.
a. Excluding Well 5.
b. With the largest pump out of service.
c. Including Well 5.

For Lake Elmo's municipal water system, it was not until recently that the northern and southern portions of the community were interconnected by a series of water mains. Now, Lake Elmo has two operating water storage tanks (Water Tower 1 will be replaced in the future when Well 5 is placed into operation), and operates across four pressure zones with an installed booster pump on Inwood Avenue to serve the southern region. The city previously had two interconnects of 600 gpm (Hudson Boulevard) and 1,400 gpm (Ideal Avenue and Lake Jane Trail North) with Oakdale, but they are no longer active under normal operating conditions. The Hudson Boulevard interconnect is near the southwest corner of the city and the Ideal Avenue interconnect is near the central part of the city on the western border.

As of 2016, about 49% of Lake Elmo was being served by the city's municipal water system. Currently, the city is experiencing growth and is expanding their municipal water system to both new and existing developments. According to the MWI, Lake Elmo has an estimated 1,386 non-municipal wells, of which 645 have been sampled. PFAS data collected on October 2020 indicate a considerable number of non-municipal wells exceed the HI of 1 (Figure A.5). POETSs have been provided for the individual residences that have received well advisories.

Figure A.5. HI levels at sampled non-municipal wells in Lake Elmo. The 3M source area is outlined in red.



A.5.2 Current and proposed projects

In January 2019, Lake Elmo hired Bolton & Menk to perform the "Lake Elmo Well No. 1 Advisory Study Related to PFC Contaminated Jordan Aquifer," in which six alternatives were evaluated to address the contamination from Well 1. The study found that drilling a new well (Well 5) and abandoning/sealing Well 1 was the cost effective solution. In addition, the city has expressed their plan to continue connecting residents on private wells to the city's municipal water system.

Initially, Lake Elmo submitted four expedited projects to connect residences currently on private wells to the city's municipal water system. Three of the projects were approved by the Co-Trustees, and include extending water mains to:

- Stonegate
- Hamlet on Sunfish Lake
- 31st Street and Stillwater Boulevard Extension.

The City also recently submitted an additional four expedited projects to have four additional neighborhoods connected to the existing municipal system and include:

- Parkview Estates
- Torre Pines
- Whistling Valley
- 38th and 39th Street

The city also plans on installing a 1 million gallon water storage tank (Tank 3) in the south eastern area to help them meet increasing water demands and meet storage requirements. The city has expressed their intention to continue operating and expanding upon their existing system by installing wells in the northeast where treatment would not be required. However, various options will need to be considered to protect water levels in White Bear Lake as discussed in Appendix E.

A.6 Lakeland and Lakeland Shores

A.6.1 Community background

Lakeland and Lakeland Shores, located on the eastern side of the East Metropolitan Area, are designated as Rural Residential communities by the Metropolitan Council (2014). The community is bordered by the St. Croix River, with West Lakeland and Afton to the west. Table A.5 summarizes Lakeland's 2020 and 2040 population, average daily demand, and maximum daily demand. The population and demand numbers include Lakeland Shores and Lake St. Croix Beach that are served by Lakeland's municipal water system.

Table A.5. Lakeland, Lakeland Shores, and Lake St. Croix Beach population and demand projections. Source: City of Lakeland, 2017.

	2020	2040
Total projected population	3,110	3,710
Projected population served	2,587	3,710
Average daily demand gpm (mgd)	174 (0.25)	250 (0.36)
Maximum daily demand gpm (mgd)	521 (0.75)	750 (1.08)

Lakeland has a municipal water system that serves a large fraction of the community, and also serves Lakeland Shores and Lake St. Croix Beach. Lakeland's municipal water system has two municipal supply wells in the Mt. Simon aquifer to meet the city's water demands (Table A.6). With existing firm capacity, Lakeland is able to meet current and future 2040 demands with one well out of service. At this time, neither well has exceeded the HI of 1. However, each well has a pressure filtration system consisting of GAC that is coated with permanganate to remove the high levels of iron and manganese found in these communities' groundwater.

Table A.6. Lakeland supply well summary.

Well no.	Unique well no.	Design capacity (gpm)	Aquifer	HI value	Status
1	420985	750	Mt. Simon	0.0009	In use
2	533517	750	Mt. Simon	0.0008	In use
Total capacity		1,500 gpm (2.16 mgd)			
Firm capacity		750 gpm (1.08 mgd)			

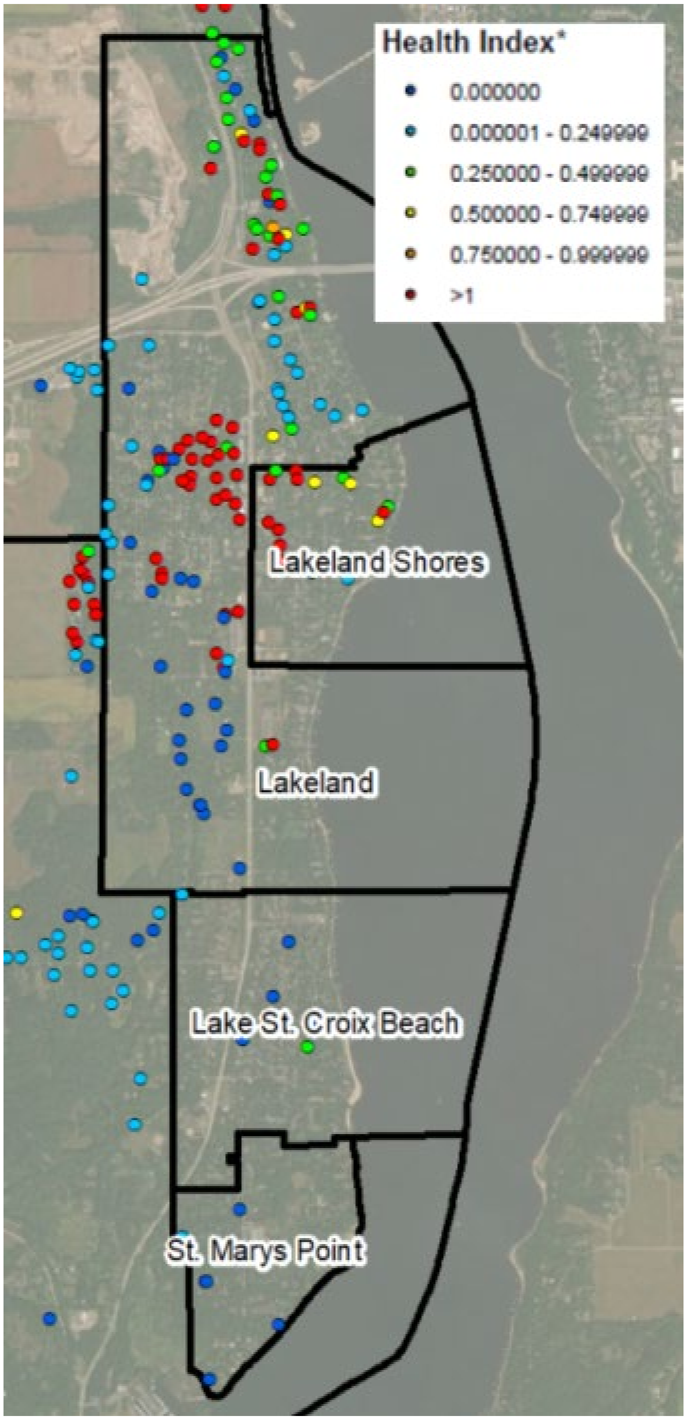
For Lakeland's municipal water system, two water storage tanks operate across one pressure zone, and an installed fire booster pump serves the northern region. The city does not currently have any interconnects. Lakeland is also bordered by a bluff on the western edge of the city that is approximately 120-feet tall, which should be considered when analyzing supplying water options to neighboring communities.

Lakeland's service area is essentially built-out, with the majority (80%) of the population being served by the city's municipal water system. Based on MDH's estimate from 2015, an estimated 296 homes in Lakeland proper are on non-municipal wells. However, after data was provided by the City, it was estimated that approximately 280 homes with wells were also connected to the existing municipal system. According to the city, residences with non-municipal wells are expected to connect to Lakeland's system each year. The city previously received a grant for TCE contamination impacting residential wells, and residents were allowed to keep their wells if they connected to city water. According to the city, residents are using their wells only for irrigation, but an inventory of the wells currently used for irrigation purposes has not been completed.

A.6.2 Current and proposed projects

Since Lakeland's municipal supply wells do not exceed the HI of 1, they do not have any current projects in place to address PFAS contamination. However, according to available data from October 2020 PFAS sampling, some residences on non-municipal wells have exceeded the HI of 1 (Figure A.6). Treatment has been provided for individual residences that have received well advisories, however, the City has expressed their intent to continue to connect residents on private wells to the municipal system.

Figure A.6. HI levels at sampled non-municipal wells in Lakeland and Lakeland Shores.



A.7 Maplewood

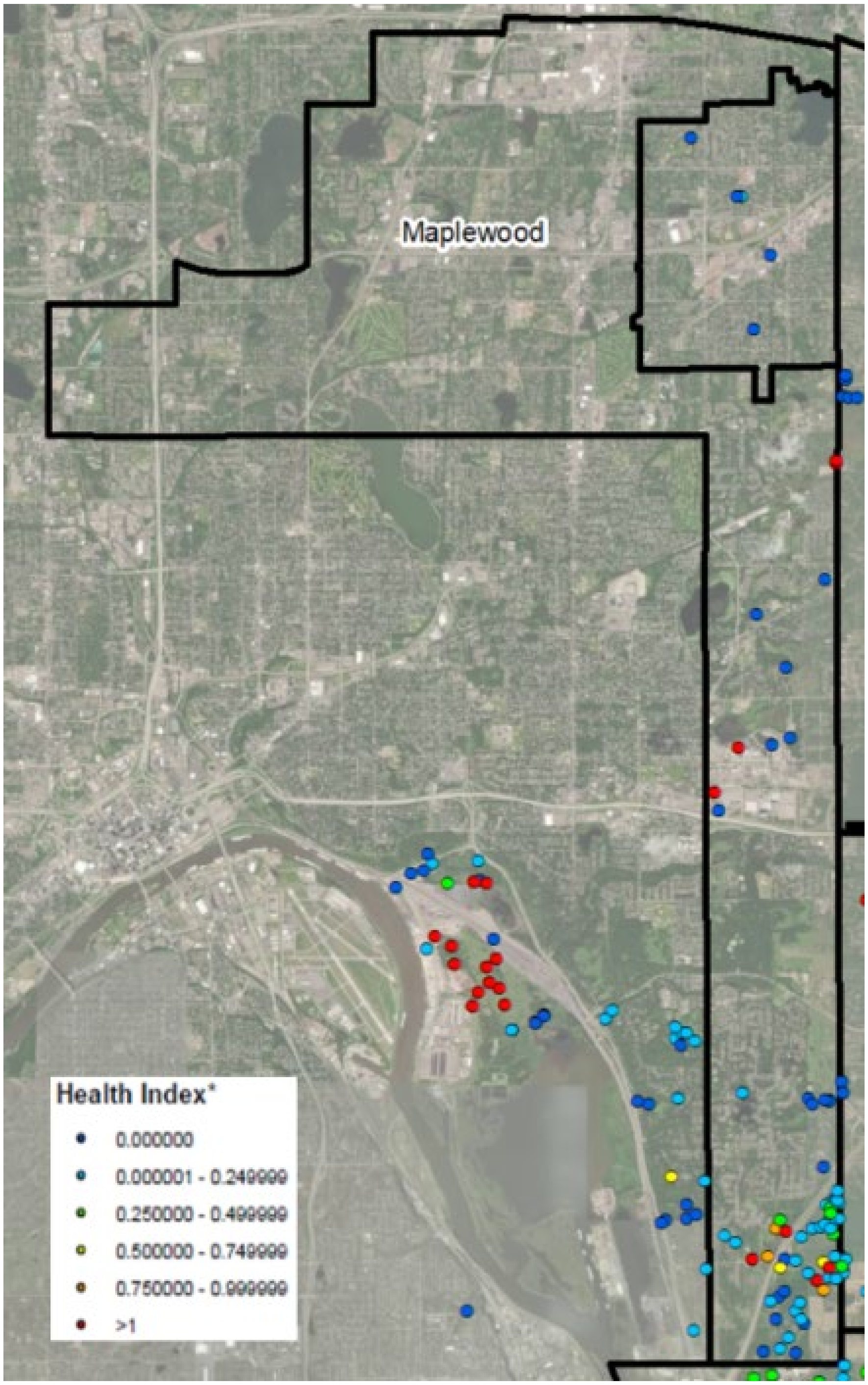
A.7.1 Community background

Maplewood, located on the northwestern side of the East Metropolitan Area, is designated as an Urban community by the Metropolitan Council (2014). The community, primarily supplied by the private utility provider St. Paul Regional Water Services (SPRWS), utilizes a series of surface water bodies (primarily the Mississippi River and a series of lakes) as their source water. Maplewood has an anticipated 2020 population of 42,200 people and a 2040 population of 48,600 people (Metropolitan Council, 2015b). According to the city, approximately 98% of residents are served by SPRWS. However, some residences are on private wells throughout the community, particularly in the southern portion. According to available data from October 2020 PFAS sampling, some of these private wells have exceeded the HI of 1 (Figure A.7).

A.7.2 Current and proposed projects

As shown in Figure A.7, Maplewood has some non-municipal wells that exceed the HI of 1. POETSs have been provided for these individual residences that have received well advisories. Additional options include extending SPRWS lines or extending other nearby municipal service lines to the impacted residences.

Figure A.7. HI levels at sampled non-municipal wells in Maplewood.



A.8 Newport

A.8.1 Community background

Newport, located on the southwestern side of the East Metropolitan Area, is designated as an Urban community by the Metropolitan Council (2014). The community is bordered by the Mississippi River with Cottage Grove and Woodbury to the east, Maplewood and St. Paul to the north, and St. Paul Park to the south. Table A.7 summarizes Newport's 2020 and 2040 population, average daily demand, and maximum daily demand.

Table A.7. Newport population and demand projections. Source: City of Newport, 2016.

	2020	2040
Total projected population	4,400	4,939
Projected population served	4,087	4,587
Average daily demand gpm (mgd)	233 (0.34)	261 (0.38)
Maximum daily demand gpm (mgd)	362 (0.52)	406 (0.58)

The majority of the community is currently served by the city's municipal water system, with the exception of a few private residences and neighborhoods. Newport's municipal water system has two municipals wells in the Jordan aquifer to meet the city's water demands (Table A.8). Wells 1 and 2 have a capacity of 1,000 gpm and 800 gpm, respectively, for a combined capacity of approximately 2.6 mgd and a firm capacity of 1.15 mgd, with the largest pump out of service. The anticipated maximum daily demand is 0.52 mgd for 2020 and 0.585 mgd for 2040, indicating the current wells have sufficient capacity to meet current and future demands. At this time, neither municipal supply well has exceeded the HI of 1.

Table A.8. Newport supply well summary.

Well no.	Unique well no.	Design capacity (gpm)	Aquifer	HI value	Status
1	208353	1,000	Jordan	0.033	In use
2	225904	800	Jordan	0.056	In use
Total capacity		1,800 gpm (2.6 mgd)			
Firm capacity		800 gpm (1.15 mgd)			

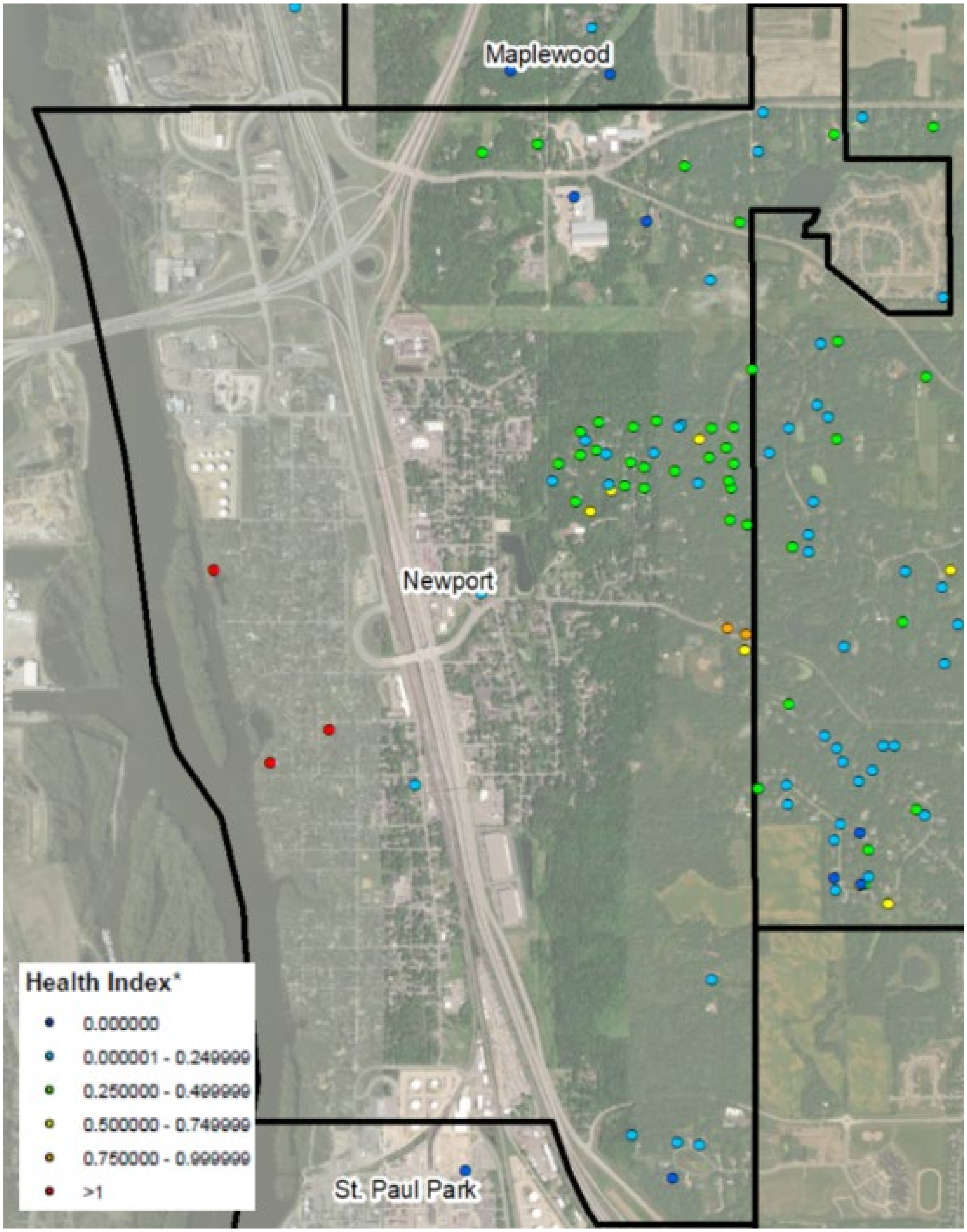
Newport's municipal water system has two water storage reservoirs and one recently installed standpipe, and operates across three pressure zones. The city has a large topography range of approximately 300 feet, which generally slopes down toward the Mississippi River. In addition, Newport recently installed two duplex booster pump stations. While the city does not have any interconnects to neighboring communities' municipal water systems, Newport has agreements with Woodbury and Cottage Grove to provide municipal utilities, and with SPRWS for water system emergency repair. Currently, Newport is providing water to a few private residences in Woodbury and has a packaging plant in the southeast corner that is receiving water from Cottage Grove. In addition, the Xcel Energy and the Recycling and Energy facilities are currently being supplied water by SPRWS through southeastern St. Paul's distribution system located just north of Newport.

The majority of the population (90%) is currently served by the city's municipal water system with the exception of a few remote private residences and neighborhoods. According to the MWI, Newport has approximately 134 non-municipal wells, of these 57 had been sampled as of October 2020. Based on PFAS sampling, three non-municipal wells have exceeded the HI of 1 (Figure A.8).

A.8.2 Current and proposed projects

Since Newport's municipal supply wells and non-municipal wells do not exceed the HI of 1, the city does not have any current projects in place to address PFAS contamination. However, the city has concerns about future contamination if the PFAS migrates from upgradient and/or higher stratigraphy aquifers, as there are non-municipal wells with HI values above 1 to the south, southeast, and north of Newport (Figure A.8). There is also the concern that new, high-capacity, municipal supply wells installed in neighboring communities will impact the flow path of PFAS, possibly resulting in PFAS contamination of Newport's municipal supply wells. The City has expressed interest in various options to address PFAS contamination including provided POETSs, connecting homes to the municipal system, and establishing and interconnect with a neighboring community.

Figure A.8. HI levels at sampled non-municipal wells in Newport.



A.9 Oakdale

A.9.1 Community background

Oakdale, located on the northern side of the East Metropolitan Area, is designated as a Suburban community by the Metropolitan Council (2014). The Oakdale Disposal Site is located near the intersection of 34th Street and Hadley Avenue, a known source of PFAS contamination to the community. Table A.9 summarizes Oakdale's 2020 and 2040 population, average daily demand, and maximum daily demand.

Table A.9. Oakdale population and demand projections. Source: City of Oakdale, 2019.

	2020	2040
Total projected population	28,500	36,000
Projected population served	30,360[a]	36,740[a]
Average daily demand gpm (mgd)	1,743 (2.51)	2,125 (3.06)
Maximum daily demand gpm (mgd)	3,986 (5.74)	4,861 (7)

Note:
a. Includes landfall population served.

The majority of the community is currently served by the city's municipal water system, with the exception of some private residences and neighborhoods. Oakdale's municipal water system has nine municipal supply wells to meet the city's water demands. Currently Wells 5 and 9 are receiving GAC treatment for PFAS; and Wells 1, 2, 7, and 8 were found to exceed the HI of 1. Currently, the city relies primarily on Wells 5 and 9, with water also being supplied from Wells 3 and 10. Water from the four affected wells were previously blended with water from the other four wells in operation in the distribution system. Well 6, Oakdale's largest-producing well, has been taken out of service due to high iron and manganese levels. In addition to the municipal supply wells, an estimated 109 homes are on non-municipal wells. According to available data from October 2020 PFAS sampling, four of the non-municipal wells also exceed the HI of 1 (Figure A.10) that are not within the source area. Treatment or a municipal supply connection has been provided for the individual residences that have received well advisories (Figure A.9).

Based on the capacities in Table A.10, Oakdale has sufficient water supply to meet the anticipated 2020 maximum daily demands of 5.74 mgd as long as the non-impacted, active municipal supply wells maintain an HI value less than the treatment threshold. However, in order to meet their 2040 maximum daily demands of 7 mgd, the city would need an additional well that doesn't require treatment, provide treatment to their existing wells that are currently out of use, or develop a centralized well field and expand their existing WTP.

For Oakdale's municipal water system, the city has four water storage towers and operates across three pressure zones with elevations ranging up to 175 feet. Oakdale supplies water to the city of Landfall. While Oakdale has two interconnects with Lake Elmo and one with Woodbury, the interconnects are not active under normal operations. According to the city, almost all residences are connected to the municipal water system with the exception of neighborhoods in the northeastern and central regions.

Figure A.9. HI levels at sampled non-municipal wells in Oakdale. The 3M source areas are outlined in red.

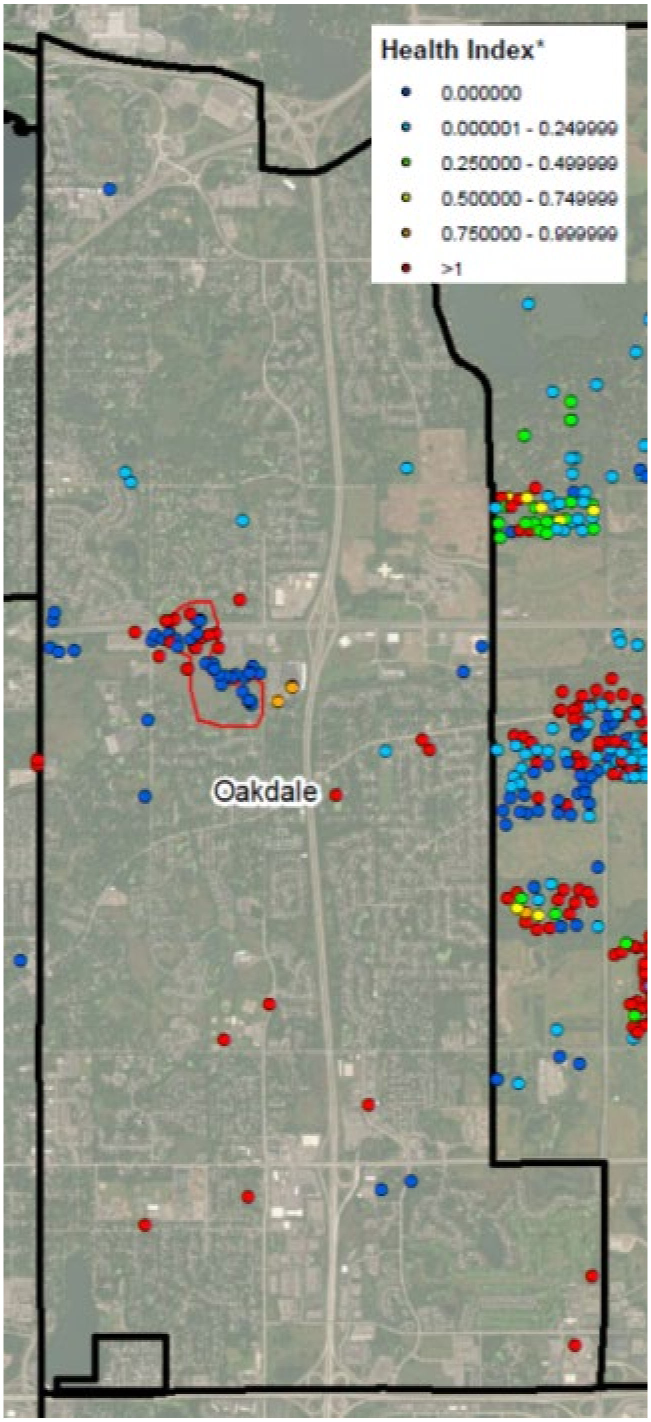


Table A.10. Oakdale supply well summary.

Well no.	Unique well no.	Capacity (gpm)	Aquifer	HI value	Status	Treatment
1	208462	925	Jordan	7.945	Offline	
2	208463	950	Jordan	7.860	Offline	
3	208454	1,000	Jordan	0.013	In use	
5	127287	925	Jordan	61.175	In use	GAC
6	151575	1,650	Jordan	0.010	Offline	
7	463534	1,000	Jordan	30.568	Offline	
8	572608	1,000	Jordan	30.553	Offline	
9	611059	1,500	Jordan	48.613	In use	GAC
10	773389	1,000	Jordan	0.007	In use	
Total capacity[a]		4,425 gpm (6.37 mgd)				
Firm capacity[b]		2,925 gpm (4.21 mgd)				

Notes:

Green indicates wells that have a HI value greater than 1.

a. Total capacity of wells with HI < 1.

b. With largest pump out of service.

A.9.2 Current and proposed projects

Oakdale submitted one expedited project (Application 100010) to evaluate two options that address the impacted municipal supply wells. The first option is to add treatment at each of the municipal supply well sites, and the second option is to develop a centralized well field and expand the existing WTP at the Public Works Facility. The City's intention is to further develop and expand their current municipal treatment and distribution system to address PFAS contamination.

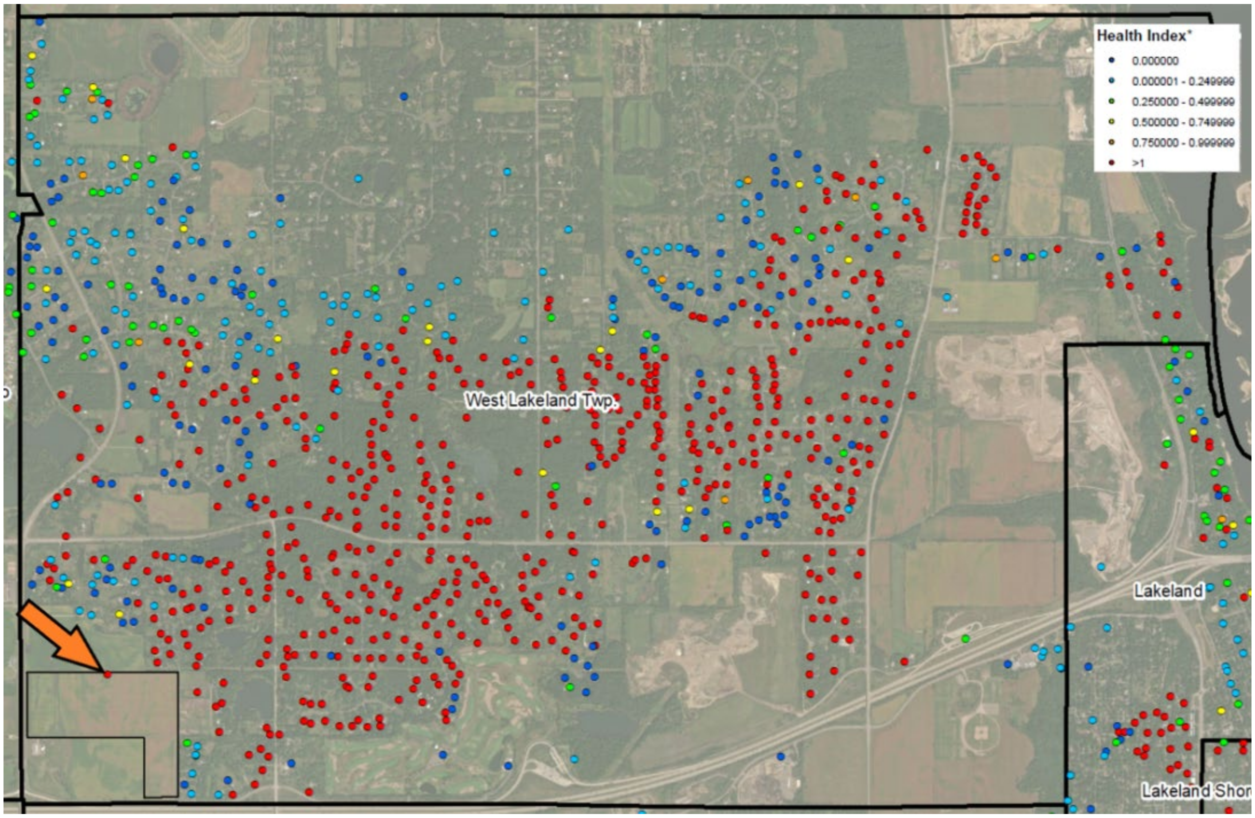
A.10 Prairie Island Indian Community

A.10.1 Community background

The Prairie Island Indian Community (PIIC), which is located in Goodhue County, Minnesota, owns 111 acres of undeveloped land in West Lakeland Township on the northeast corner of Manning Avenue and I-94. The property in West Lakeland Township is intended to be a housing development. PIIC has submitted an initial site plan indicating a proposed 80 residential lots and 11.67 acres for commercial development. One existing irrigation well on the property has a 12-inch casing pipe and an estimated capacity between 600-800 gpm (0.86 – 1.15 mgd).

According to available data from PFAS sampling to date, the irrigation well on PIIC exceeds the HI of 1 (Figure A.10); this well is not currently in use.

Figure A.10. HI levels at sampled non-municipal wells in PIIC. The border of the PIIC is outlined in black in the lower left-hand corner.



A.10.2 Current and proposed projects

As the irrigation well is not currently in use and the property has not been developed, PIIC does not have any current projects in place to address the PFAS contamination.

PIIC submitted an expedited project (Application 100019) to investigate the feasibility of converting the private irrigation well in PIIC to a municipal supply well.

PIIC has also expressed interest in provided water to West Lakeland, should a distribution system for West Lakeland by further evaluated.

A.11 St. Paul Park

A.11.1 Community background

St. Paul Park, located on the southwestern side of the East Metropolitan Area, is designated as an Emerging Suburban Edge community by the Metropolitan Council (2014). The community is bordered by the Mississippi River with Cottage Grove to the east, Newport to the north, and Grey Cloud Island to the south. The city is home to the Marathon Petroleum Corporation refinery in the north-western region and is split by the Burlington Northern Santa Fe Railroad that owns approximately 100 acres in the southern region. Table A.11 summarizes St. Paul Park's 2020 and 2040 population, average daily demand, and maximum daily.

Table A.11. St. Paul Park population and demand projections. Source: City of St. Paul Park, 2018.

	2020	2040
Total projected population	6,000	7,900
Projected population served	6,000	7,900
Average daily demand gpm (mgd)	438 (0.63)	576 (0.83)
Maximum daily demand gpm (mgd)	897 (1.29)	1,181 (1.70)

The majority of the community is currently served by the city's municipal water system, with the exception of some private residences in the central and western portions of St. Paul Park. The city's municipal water system consists of three municipal supply wells (Table A.12) to meet the city's water demands. To date, Wells 3 and 4 have had PFAS concentrations exceeding the HI of 1 (Table A.12). As a result, the city relies primarily on Well 2, with minimal water being supplied from Wells 3 and 4. Currently all three wells are needed to meet maximum daily demands in 2020 as water from the two impacted wells were previously blended with water from Well 2 in the distribution system. However, the city recently constructed a temporary WTP to treat groundwater supplied by Wells 3 and 4. In addition to the municipal supply wells, an estimated 66 homes are on non-municipal wells of which 25 have been sampled. According to available data from October 2020 PFAS sampling, 25 of the non-municipal wells also exceed the HI of 1 (Figure A.11). Treatment has been provided for the individual residences that have received well advisories.

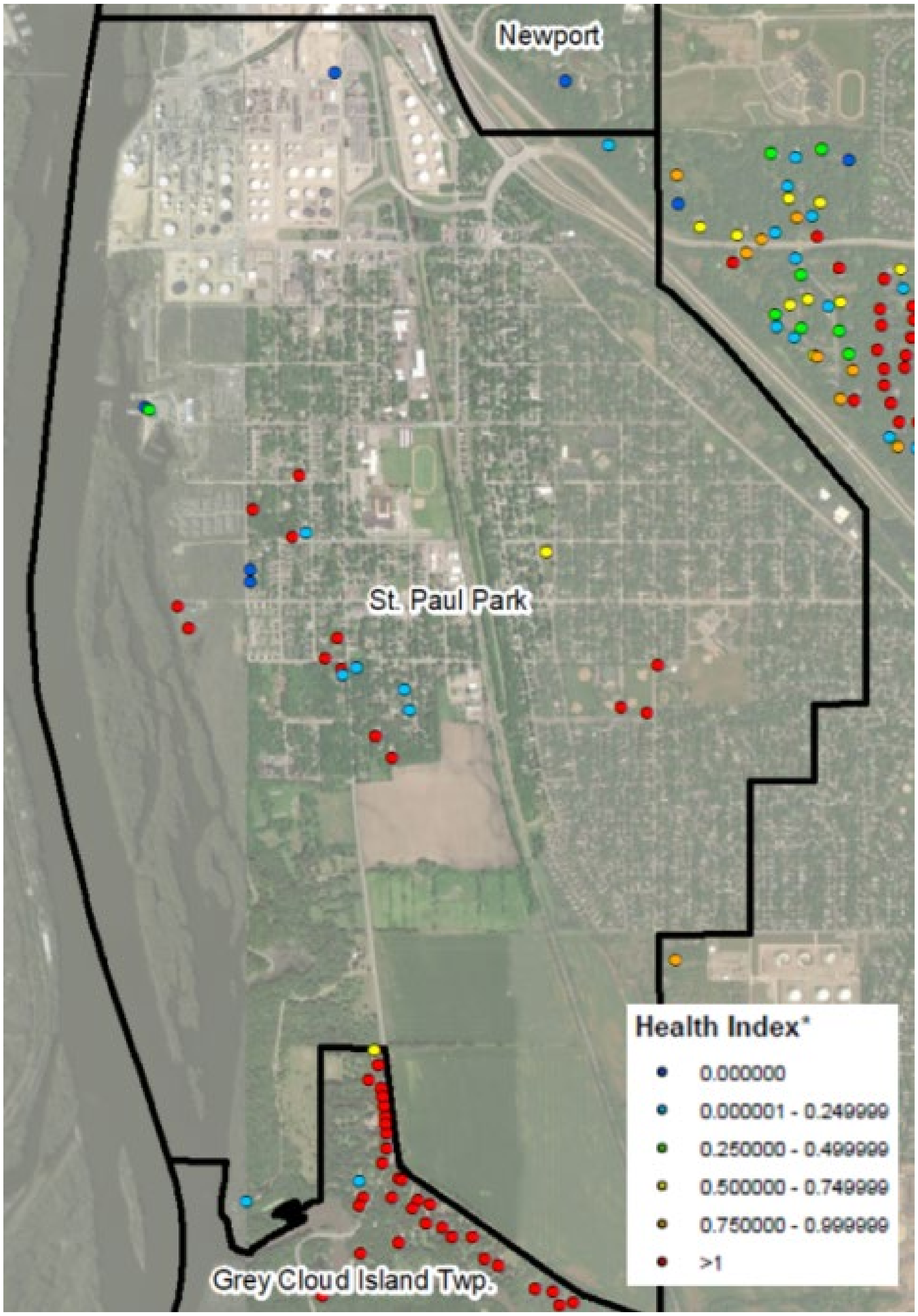
Table A.12. St. Paul Park supply well summary.

Well no.	Unique well no.	Design capacity (gpm)	Aquifer	HI value	Status
2	208418	600	Prairie du Chien-Jordan	0.710	In use
3	208804	600	Jordan	1.430	In use[a]
4	431603	900	Jordan	1.220	In use[a]
Total capacity		2,100 gpm (3.0 mgd)			
Total available capacity[b]		2,100 gpm (3.0 mgd)			
Firm capacity[c]		1,200 gpm (1.73 mgd)			

Notes:
Green indicates wells that have a HI greater than 1.
a. Used for blending if needed.
b. Excludes wells that are offline and/or have a HI greater than 1 and not used for blending.
c. As defined by the community's SOPs and this appendix.

For St. Paul Park's municipal water system, the city has two water storage towers that operate across one pressure zone. The city has an interconnect with Cottage Grove, but it is not active under normal operating conditions. As such, this interconnect needs to undergo a condition assessment to determine its capacity and operational condition. It is estimated that the existing interconnect has a capacity of 350 gpm, but this should be verified.

Figure A.11. HI levels at sampled non-municipal wells in St. Paul Park.



A.11.2 Current and proposed projects

Recently St. Paul Park conducted a "Water Supply and Treatment Options for PFAS Feasibility Study" to determine a short-term solution to the PFAS contamination. The feasibility study looked at several options, including purchasing water from SPRWS; drilling new, deeper wells; and installing a new groundwater WTP. The study results indicated that the groundwater WTP was the best option. Since then, the city has requested funding for and installed a temporary GAC WTP near Well 3 that is covered by the 2007 Consent Order. The GAC WTP will be similar to the Oakdale facility and have eight, 10-foot-diameter vessels to treat water from Wells 3 and 4, with the intent to serve Well 2 at a future date.

A.12 West Lakeland

A.12.1 Community background

West Lakeland, located on the northeastern side of the East Metropolitan Area, is a township designated as a Rural Residential community by the Metropolitan Council (2014). The community is bordered by Lake Elmo to the west and Lakeland to the east. According to the community's Comprehensive Plan (West Lakeland Township, 2019), residents value their rural lifestyle and try to maintain it by regulating low residential housing densities and not implementing public facilities that will encourage urbanization, though the community is growing. West Lakeland has no municipal water system and residents and businesses in the community rely on private wells. A few large-volume water users within the community have DNR-regulated wells; however, the community is primarily residential. Approximately 1,340 non-municipal wells are in the township and according to the MWI there are 1,393 wells. In 2020, the community is anticipated to be "built-out" at a population of 4,500 (West Lakeland Township, 2019).

West Lakeland has been faced with contamination issues from PFAS as well as trichloroethylene (TCE). The northern portion of the community has TCE groundwater contamination from the Baytown Township National Priorities List Site. As a result of the TCE contamination, the city passed an ordinance that requires new homes built after April 9, 2002 to have a POETS provided by the homeowner if the measured groundwater concentration for TCE is above the MDH Health Based Value. Lots platted before that time with measured concentrations of TCE above the Health Based Value were given a POETS. MDH has designated the northern part of West Lakeland a Special Well and Boring Construction Area, which places restrictions on new well construction.

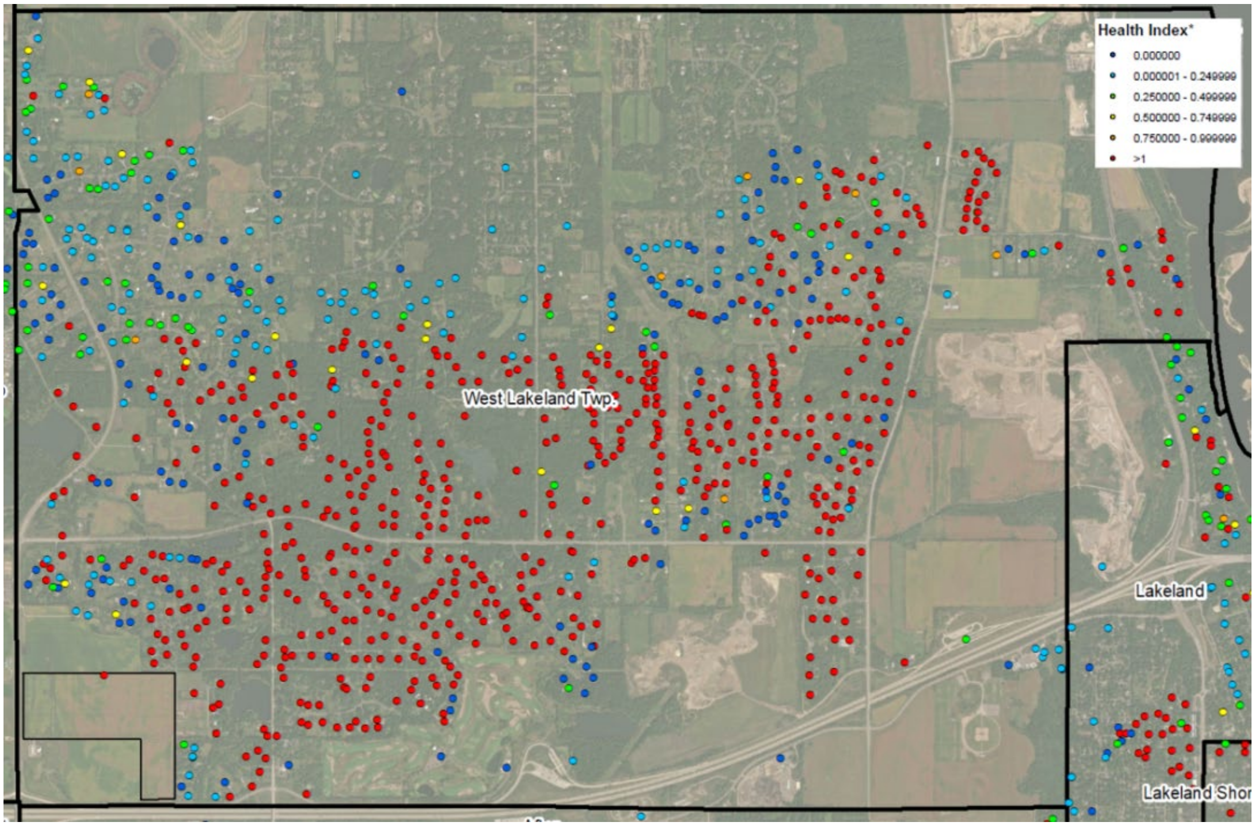
Of the MWI wells, 995 have been sampled as of October 2020. Recent sampling efforts have indicated that groundwater in the southern portion of the community is contaminated with PFAS (Figure A.12). This area of West Lakeland was most likely impacted from the transport of PFAS from western portions of the East Metropolitan Area via a surface water/stormwater management system known as Project 1007. The MPCA is currently conducting a source assessment and feasibility study of Project 1007, as prescribed in the 2018 Settlement Agreement between 3M and the State.

A.12.2 Current and proposed projects

Within West Lakeland, many homes already have POETS installed because of actions taken following the earlier TCE contamination issue. Currently, residences in the southern portion are being provided bottled water until individual POETS are installed.

Proposed projects include constructing a new distribution system with treatment or continuing to remain on POETS. The distribution system project has been proposed as an autonomous option as well as with water treated and supplied by nearby Prairie Island Indian Community.

Figure A.12. HI levels at sampled non-municipal wells in West Lakeland.



A.13 Woodbury

A.13.1 Community background

Woodbury, located on the western side of the East Metropolitan Area, is designated as a Suburban Edge community by the Metropolitan Council (2014). The city is bordered by Cottage Grove to the south, Lake Elmo to the north, Afton to the east, and Maplewood and Newport to the west. Local PFAS sources include the Woodbury Disposal Site on the southeastern border of Woodbury, and the Oakdale Disposal Site and the Washington County Landfill located north of Woodbury. Table A.13 summarizes Woodbury's 2020 and 2040 population, average daily demand, and maximum daily demand

Table A.13. Woodbury population and demand projections. Source: City of Woodbury, 2019.

	2020	2040
Total projected population	72,500	89,630
Projected population served	67,839	88,139
Average daily demand gpm (mgd)	6,111 (8.8)	7,528 (10.84)
Maximum daily demand gpm (mgd)	15,903 (22.9)	19,576 (28.19)

The majority of the community is currently served by Woodbury's municipal water system, with the exception of some residences on private wells, which are primarily in the southern third of the city. Woodbury's municipal water system has 19 municipals wells (Table A.14) to meet the city's water demands, which are distributed in 3 well fields. The Tamarack Well Field is the largest well field with 15 wells, the East Well Field has 3 wells, and the South Well Field has 1 well. All future wells will be located in the South Well Field. Woodbury's consultants have done extensive hydraulic modeling of the city's municipal water system, and provided design and current pumping rates for each well. To date, five wells have been identified as consistently exceeding the HI of 1, all of which are located in the Tamarack Well Field. As of June 2019, a sixth well (Well 4) that is directly adjacent to PFAS-impacted Wells 6 and 7, exceeded the HI of 1. Because of the close proximity of Wells 12 and 14 to the other contaminated wells in the Tamarack Well Field, there is concern that the increased pumping of wells not currently exceeding the HI will influence the migration of contaminants to these wells.

Table A.14. Woodbury supply well summary.

Well no.	Unique well no.	Design capacity (gpm)	Actual capacity[a] (gpm)	Well field	Aquifer	HI value	Status[e]
1	208420	800	725	Tamarack	Jordan	2.761	Off
2	208422	750	760	Tamarack	Jordan	0.464	In use
3	208423	1,000	860	Tamarack	Jordan	0.349	In use[b]
4	208005	1,000	990	Tamarack	Prairie du Chien-Jordan	2.110	In use[b]
5	150353	1,000	940	Tamarack	Jordan	0.720	In use[b]
6	151569	1,200	1,150	Tamarack	Jordan	3.400	Blend
7	433281	1,200	1,350	Tamarack	Jordan	3.320	Blend
8	509051	1,200	900	Tamarack	Jordan	0.380	In use
9	463539	1,200	1,050	Tamarack	Jordan	2.790	Blend
10	541763	1,500	1,305	Tamarack	Jordan	0.220	In use
11	563000	1,500	1,150	Tamarack	Jordan	0.430	In use
12	596646	1,400	1,220	Tamarack	Jordan	0.350	In use
13	593657	1,400	1,530	Tamarack	Jordan	3.890	Off
14	611094	1,500	1,400	Tamarack	Jordan	0.240	In use
15	676415	2,000	1,850	East	Jordan	0.800	In use
16	706811	2,000	1,980	East	Jordan	0.030	In use
17	759572	1,500	1,500	Tamarack	Jordan	0.190	In use[b]
18	786210	2,000	2,000	East	Jordan	0.033	In use
19	805361	2,000	2,000	South	Jordan	0.400	In use
Total capacity[c]		17,865 gpm (25.7 mgd)					
Firm capacity[d]		15,865 gpm (22.8 mgd)					

Notes:
Green indicates wells that have a HI value greater than 1.
a. From Bolton & Menk's Water Supply, Storage, and Distribution Plan for the City of Woodbury (2019).
b. Well runs to blend water with wells that have a HI greater than 1.
c. The total capacity only considers the capacity of wells with a HI less than 1.
d. With the largest well (2,000 gpm) out of service
e. Well operation status is not fixed and will change over time depending on operations.

Woodbury faces operational challenges due to PFAS impacts and the proximity of wells within the Tamarack Well Field. Currently, wells exceeding the HI of 1 are Wells 1, 4, 6, 7, 9, and 13. The city has made operational adjustments that limit the use of wells exceeding the HI of 1. These adjustments include removing Wells 1 and 13 from normal operation, and reducing the pumping rates of the remaining PFAS-impacted wells in order of use, which limits their overall time of operation and places a higher burden on the remaining wells.

The municipal supply wells in Woodbury are not currently treated for PFAS but receive chlorine and fluoride treatment at the well head. Currently, the city relies on blending water from various wells within the distribution system to keep PFAS levels in the system below an HI of 1. The total capacity available based on actual pumping rates for those wells with an HI less than 1 is 17,865 gpm (25.7 mgd). The firm capacity with the largest well out of service is 15,865 gpm (22.8 mgd). Based on the firm capacity, Woodbury does not have sufficient capacity to meet their revised maximum daily demands of 22.9 mgd for year 2020 and 28.19 mgd for year 2040. Additionally, the Tamarack Wells are located very close to each other and, when running simultaneously, can reduce the pumping rates of one another by increasing the effective draw down. Unfortunately, data are not available to provide the pumping rates of these wells when they are all running simultaneously. Therefore, it is a reasonable assumption that Woodbury will need an additional, high-capacity wells in the South Well Field to reliably meet maximum daily demands.

For Woodbury's municipal water system, the city has six water storage tanks with booster pumps, which operate across one pressure zone. Wells are operated to maintain the set levels in the storage tanks. The city has two interconnects – one 10-inch interconnect with Oakdale and one 6-inch interconnect with Maplewood. Both interconnects are not active under normal operating conditions and Maplewood's water is noted to be incompatible with Woodbury's municipal water system.

As of 2016, about 97% of Woodbury's population is being served by the city's municipal water system. The city continues to experience growth along with a corresponding need to expand the municipal water system infrastructure to meet 2040 population projections. According to the MWI, there are 657 non-municipal wells are currently in Woodbury, with the majority located in the southern third of the city. Of these wells 258 have been sampled as of October 2020, a few non-municipal wells exceed the HI of 1 (Figure A.13).

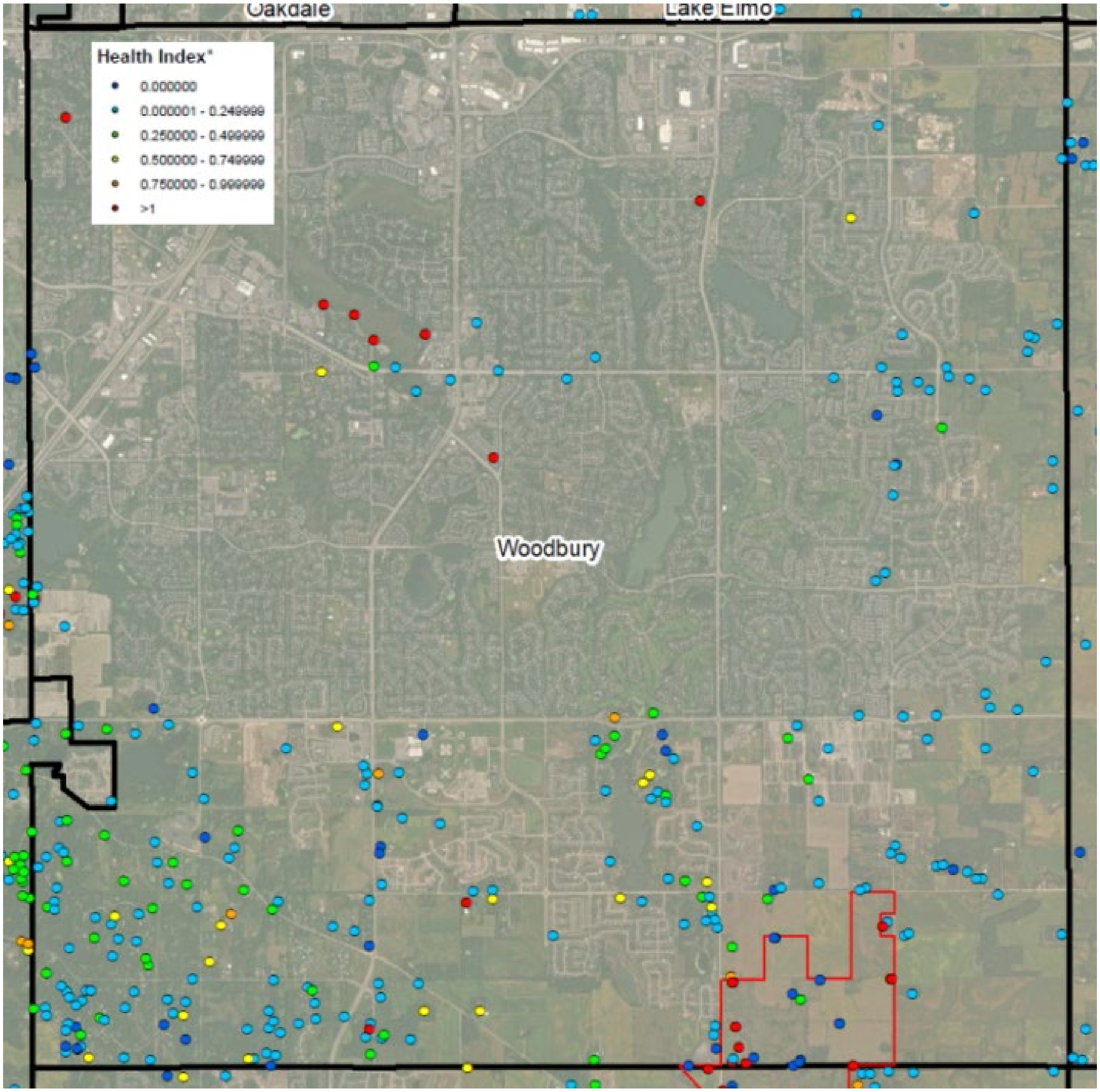
A.13.2 Current and proposed projects

Woodbury, with the State of Minnesota's concurrence, is implementing short-term operational changes and a blending strategy for the municipal water system, and storage tanks as a stop-gap measure to meet drinking water standards. A temporary WTP is also being installed during summer 2020.

The city submitted three expedited projects (Application Nos. 100015, 100016, and 100017) for consideration of funding under the settlement. The expedited project, "Distribution System PFAS Mitigation Feasibility Study" (Application 100016), will help examine the effectiveness of mixing and dilution of PFAS in the city's existing municipal water system. The expedited project, "Salem Meadows Development & Erin Court Water Service Connections" (Application 100015), proposed to connect the Salem Meadows and Erin Court neighborhoods to Woodbury's municipal water system. The expedited project, "In-Home GAC Treatment Grant Program" (Application 1000017), proposed to make in-home POETS available to residences with private wells in Woodbury that are not likely to be serviceable by the municipal water system.

The city is currently in the process of implementing a temporary treatment system in the Tamarack well field, which was accepted by the Co-Trustees as an interim measure to address additional well exceedances as well as the demand challenges the city is facing due to PFAS contamination.

Figure A.13. HI levels at sampled non-municipal wells in Woodbury. The 3M source area is outlined in red.



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Appendix B. Conceptual site model for the East Metropolitan Area

Groundwater modeling was conducted to support the evaluation of scenarios in this Conceptual Drinking Water Supply Plan (Conceptual Plan). The first step in building a groundwater model is to develop a conceptual site model (CSM), which integrates existing technical data and information from various sources. A CSM provides a way to better understand a very complex natural system by reducing it to a simplified set of relevant assumptions, data, and information to develop a picture of how the system functions. The CSM identifies and describes the relevant and important processes that influence groundwater flow in the East Metropolitan Area of the Twin Cities. These are the processes that will be simulated and represented by the numerical, three-dimensional groundwater flow model, which was constructed following the development of this CSM. The numerical model was developed to support the evaluation of scenarios that address drinking water quantity and quality for the 14 communities currently known to be affected by per- and polyfluoroalkyl substances (PFAS) contamination in the East Metropolitan Area, now and through 2040. The numerical model will be used as a basis to create visual representations of the groundwater regime, flow path, and well/pumping scenarios.

This appendix provides an overview of the CSM that was developed for the East Metropolitan Area. Appendix C provides an overview of the numerical model.

B.1 Introduction

B.1.1 Purpose and scope

The CSM presented here is the basis for construction of a numerical, three-dimensional groundwater flow model. The purpose of the groundwater model is to provide insight into the current groundwater flow system, and predict impacts to flow paths and groundwater resources through the year 2040 from the proposed scenarios. These flow paths and quantity estimates are based on projected groundwater recharge/precipitation rates, surface water elevations, and pumping volumes of the proposed scenarios. The year 2040 was selected because it was the time period for which there are population projections in the comprehensive plans and/or water supply plans of each community, which determine drinking water demand.

The objectives of the groundwater model are to:

1. Assess aquifer sustainability and viability of production rates for the proposed scenarios that may involve changes in pumping rates or new water supply wells
2. Analyze contaminant flow paths under the different proposed scenarios and climate conditions to determine the potential risk of PFAS contamination at existing and future wellfields
3. Evaluate potential impacts to groundwater resources in response to projected future groundwater use under the different proposed scenarios and climate conditions
4. Communicate model results and technical issues (e.g., flow direction, impacts to current remediation) internally and to stakeholders through visual representations of simulated flow systems.

This groundwater model may also be used in the future to further evaluate projects as they are refined following the development of this Conceptual Plan.

B.1.2 Data and sources

The data and content within this CSM were selected in collaboration with several agencies, local government units, and consultants. The entities listed below made major contributions to the construction of this CSM:

- Wood Environment & Infrastructure Solutions, Inc. (Wood)
- Minnesota Pollution Control Agency (MPCA)
- Minnesota Geological Survey (MGS)
- Minnesota Department of Natural Resources (DNR)
- Minnesota Department of Health (MDH).

Additional contributors included the local watershed districts and Washington County.

The data compiled and evaluated for the CSM are summarized in Table B.1. The focus of the CSM is the East Metropolitan Area (henceforth regarded as the “Study Area”) and presentation of the compiled data is restricted to the following Minnesota counties: Washington, Ramsey, Dakota, Hennepin, Chisago, Anoka, Scott, and Isanti. An approximate boundary for the groundwater flow model domain in Minnesota was generated for the data collection and the data presented in this appendix are restricted to this boundary, which does not include the Wisconsin side of the St. Croix River (Figure B.1).

Table B.1. Data compiled for the CSM.

Data	Source
3-meter digital elevation model (DEM)	DNR (2019h)
Land use map	MNIT (2019)
Surface water boundaries	USGS (2019a)
Geologic maps	Balaban and Hobbs (1990), Meyer and Swanson (1992), Setterholm (2010, 2013), Bauer et al. (2016), Chandler et al. (2017), Steenberg et al. (2018)
Precipitation data	DNR (2019a)
Lake bathymetry data	DNR (2019d)
Hydraulic conductivity	Runkel et al. (2003), Tipping et al. (2010)
Surface water elevations	DNR (2019f)
Historical and current pumping volumes	DNR (2019b)
Groundwater elevations	DNR (2019e), MDH (2019)
Well construction details	MDH (2019)
Baseflow measurements	DNR (2019c)
Recharge and runoff estimates from 1990s through 2018	DNR (2019i)
Metro Model 3	Metropolitan Council (2019)
U.S. Geological Survey (USGS) Northeast Metro Lakes Groundwater-Flow model files	USGS (2019b)
DNR Northeast Metro Lakes Groundwater-Flow model files	DNR (2019g)
Groundwater sample data	MDH (2019), MPCA (2019a)
PFAS source areas	MDH (2019), MPCA (2019b)

B.2 Physical setting and climate

The Study Area is in east-central Minnesota in the northern continental United States (Figure B.1). The land surface in the Study Area was shaped by multiple glacial advances and retreats, resulting in a gently rolling to flat topography, with occasional outcroppings and erosional surface exposures near major surface water features. The developed metropolitan area is surrounded by suburbs, rural towns, pastures, and cultivated crops. The landscape is also defined by abundant surface water features, including the St. Croix, Minnesota, and Mississippi rivers; in addition to many smaller streams, lakes, and wetlands (Figure B.2).

The climate is sub-humid. Average summer (June through August) monthly temperature and precipitation for the Study Area is approximately 70°F and 4 to 5 inches, respectively, based on a 50-year period of record (1968–2018; Table B.2). In the winter months (December through February), average temperatures are below freezing and average monthly precipitation (typically in the form of snowfall) is approximately 1 to 2 inches.

Table B.2. Average monthly temperature and precipitation based on 50-year period of record (1968–2018).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperature (°F)	14	20	32	47	59	69	74	71	62	49	34	20
Precipitation (inches)	0.94	0.83	1.78	2.92	3.75	4.76	4.26	4.18	3.17	2.64	1.76	1.19

Data source: DNR (2019a).

A plot of average annual precipitation by decade for the entire period of record (1890s to present decade) is shown in Figure B.3. Overall, the plot shows a decreasing trend followed by an increasing trend in precipitation. During the early 1900s, precipitation was on a decreasing trend until it reaches a minimum in the 1930s. Since then, precipitation has been on an increasing trend, with the exception of a slight dip during the 2000–2010 decade. Average annual precipitation for the current decade (34.94 inches) is above the 75th percentile for annual precipitation during the period of record (32.66 inches).

Much of the precipitation received in the Study Area is removed via evapotranspiration, which is a combination of moisture being removed from the soil to the atmosphere (evaporation) and from plants through transpiration. Mean evapotranspiration was estimated by Baker et al. (1979) using two methods: (1) calculating the difference between precipitation and run-off, assuming zero recharge to groundwater; and (2) calculating evapotranspiration using the Thornthwaite method, which takes into account a number of assumptions. The first method provided a mean evapotranspiration in the Twin Cities Metropolitan Area of approximately 20 inches per year. The second method provided a mean potential evapotranspiration of approximately 25 inches per year.

B.3 Geology and hydrostratigraphy

B.3.1 Structural setting

The structural setting for the Twin Cities Metropolitan Area is the Midcontinent Rift System (Figure B.4a). Formation of the rift occurred during the Mesoproterozoic Era (1,600–1,000 million years ago) and resulted in a complex suite of volcanic rock bounded by major northeast-southwest trending faults. The faults were initially extensional during graben development; however, later compressional forces caused the faults to reverse and, consequently, the central graben was uplifted, resulting in a central horst (St. Croix Horst). In the Study Area, the western side of the St. Croix Horst is bounded by the Douglas and Pine faults in Hennepin County (Steenberg et al., 2018). Rocks associated with the Midcontinent Rift System are part of the Keweenawan Supergroup, which is comprised primarily of volcanic rock but also includes sedimentary rock that was deposited within the rift zone after volcanic activity ceased. A long period of erosion occurred after the uplift of the horst and prior to the deposition of the oldest Paleozoic rock mapped in the Study Area (Mt. Simon Sandstone).

The deposition of Paleozoic rock was influenced by another structural feature present in southeast Minnesota: the Hollandale Embayment (Figure B.4b). The Hollandale Embayment was a shallow depositional basin bordered by the Transcontinental Arch to the west-northwest, the Wisconsin Dome to the northeast, and the Wisconsin Arch to the east. Shallow epeiric seas inundating southeast Minnesota and adjacent states during the Paleozoic era occupied the Hollandale Embayment, and resulted in a sequence of Paleozoic sedimentary strata. Reactivation of pre-Cambrian basement faults during the Ordovician Period off-set Paleozoic strata, resulting in the formation of the Twin Cities Basin. The Twin Cities Basin is bounded on the west by the Douglas and Pine faults in Hennepin County, and by the Hudson-Afton Horst (an inverted graben) in southeast Washington County.

B.3.2 Bedrock geology and hydrostratigraphy

Bedrock in the Study Area consists of Paleozoic sedimentary rocks that span in age correlating to the Cambrian through Devonian Periods (Figure B.5). Deposition occurred during transgression and regression of shallow epeiric seas that inundated southeast Minnesota and adjacent states. The Paleozoic bedrock units (sedimentary sequences of sandstone, siltstone, shale, limestone, and dolomite) are discussed below. A stratigraphic column showing lithology and a representative natural gamma log are provided in Figure B.6. A summary of hydraulic conductivity values from Runkel et al. (2003) is provided in Table B.3 and discussed in more detail for individual hydrostratigraphic units in the sections below.

Table B.3. Horizontal hydraulic conductivity (K) ranges for bedrock aquifer and confining units (based on Runkel et al., 2003).

Formation	K-min (feet/day) shallow[a] bedrock	K-max (feet/day) shallow bedrock	K-min (feet/day) deep bedrock	K-max (feet/day) deep bedrock
Decorah Shale	6.01E+01		NA	1.00E-06
Platteville Formation	1.00E-01	1.00E+03 (estimate)	1.00E-03	1.00E-01
Glenwood Formation	NA		1.00E-06 (vertical only)	
St. Peter Sandstone – upper	2.00E+01	3.87E+01	1.30E+00	1.59E+01
St. Peter Sandstone – lower	NA		NA	
Prairie du Chien Group – Shakopee Formation	1.00E-01	1.02E+03	9.00E+00	3.35E+01
Prairie du Chien Group – Oneota Dolomite	7.50E-03		NA	
Jordan Sandstone – upper	3.00E+01	5.00E+02	1.00E-01	1.00E+02
Jordan Sandstone – lower			1.00E-02	
St. Lawrence Formation[b]	4.60E+01		1.00E-02	2.00E+01
Tunnel City Group – upper	1.00E-02	2.20E+02	1.40E+00	2.78E+01
Tunnel City Group – lower			< 1.00E-02	

<table>
<tr><th>Formation</th><th>K-min (feet/day) shallow[a] bedrock</th><th>K-max (feet/day) shallow bedrock</th><th>K-min (feet/day) deep bedrock</th><th>K-max (feet/day) deep bedrock</th></tr>
<tr><td>Wonewoc Sandstone – upper</td><td rowspan="2">1.00E+01</td><td rowspan="2">1.00E+02</td><td colspan="2">5.00E+00</td></tr>
<tr><td>Wonewoc Sandstone – lower</td><td>1.60E+00</td><td>3.10E+01</td></tr>
<tr><td>Eau Claire Formation</td><td colspan="2">3.67E+01</td><td>1.00E-03</td><td>1.00E-02</td></tr>
<tr><td>Mt. Simon Sandstone – upper</td><td colspan="2" rowspan="2">2.93E+01</td><td>1.00E-02</td><td>1.30E+00</td></tr>
<tr><td>Mt. Simon Sandstone – lower</td><td>1.50E+00</td><td>3.95E+01</td></tr>
<tr><td>Blue indicates aquifer properties</td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>Orange indicates aquitard properties</td><td colspan="2"></td><td colspan="2"></td></tr>
</table>

a. Shallow bedrock is generally the upper portion of for each individual formation and deep bedrock is the lower portion.

b. The St. Lawrence Formation can function as a semi-confining unit in portions of the study area. Based on Runkel et al., 2003.

NA = not available.

B.3.2.1 Mt. Simon Sandstone (oldest Paleozoic bedrock formation)

The Mt. Simon Sandstone is a medium- to coarse-grained, well-sorted quartz-rich sandstone with interbedded fine-grained sediment (siltstone and very fine-grained feldspathic sandstone). The thin beds of finer-grained sediment are more abundant in the upper portion of the Mt. Simon Sandstone than in the lower portion.

The Mt. Simon Sandstone unconformably overlies Mesoproterozoic rock (i.e., an erosional surface is at the base of the formation). A quartz conglomerate is present at several stratigraphic positions within the formation and is particularly more prominent at the base. The thickness of the Mt. Simon Sandstone is variable, and in part due to the topography of the erosional surface the formation was deposited onto. Based on borehole data, the thickness of this unit varies between approximately 100 and 400 feet within the Study Area. In Washington County, it has a reported maximum thickness of approximately 280 feet (Bauer et al., 2016).

Horizontal hydraulic conductivity values estimated from specific capacity, discrete interval packer, and standard aquifer tests range between 0.38 and 39.5 feet/day. In shallow bedrock (areas of enhanced fracture porosity in Paleozoic strata within 60 feet of the bedrock surface), where the hydraulic conductivity is enhanced due to secondary porosity (i.e., fractures), the average horizontal hydraulic conductivity is 29.3 feet/day. Based on discrete interval packer tests of similar strata in other parts of the Paleozoic section, the fine clastic vertical hydraulic conductivity could be on the order of 10^{-4} feet/day (Runkel et al., 2003).

The Mt. Simon Sandstone is typically depicted as a single aquifer; however, due to the greater relative abundance of fine-grained beds in the upper Mt. Simon Sandstone compared to the lower portion, it is likely the formation internally consists of at least two hydrogeologic units (Runkel et al., 2003).

B.3.2.2 Eau Claire Formation

The Eau Claire Formation is composed of shale, siltstone, and very fine- to fine-grained feldspar-rich sandstone. The contact between the Eau Claire and underlying Mt. Simon Sandstone is conformable (Bauer et al., 2016). Based on borehole data, where available, the thickness of the Eau Claire Formation ranges from approximately 60 to 100 feet.

The Eau Claire Formation is present in the subsurface throughout the Study Area with the exception of a few localized areas, particularly in northern Isanti and Chisago counties. In parts of Chisago, Isanti, and Anoka counties, the Eau Claire is the uppermost bedrock along the rim of the Twin Cities Basin and along deep buried valleys. In Ramsey and Dakota counties, the Eau Claire Formation is completely covered by younger Paleozoic rock (Balaban and Hobbs, 1990; Meyer and Swanson, 1992).

Horizontal hydraulic conductivity values estimated from discrete interval packer and slug tests range between 10^{-3} and 10^{-2} feet/day. A discrete interval packer test of similar strata in Ramsey County yielded a vertical hydraulic conductivity estimate of 10^{-4} feet/day. The average hydraulic conductivity from specific capacity tests in fractured shallow bedrock is 36.7 feet/day (Runkel et al., 2003).

Due to the fine-grained nature of the formation, the Eau Claire is generally considered a confining unit. However, where well-connected fractures exist, such as in shallow bedrock conditions, the permeability is enhanced and the formation is used as a source of groundwater supply.

B.3.2.3 Wonewoc Sandstone

The Wonewoc Sandstone is a fine- to coarse-grained sandstone with two members. Due to the coarser nature of the lower member compared to the upper member, the Wonewoc Sandstone is divided into an upper and lower aquifer (oldest to youngest): (1) the Galesville Sandstone (lower member) and (2) the Ironton Sandstone (upper member). Previously, the members were identified as separate formations. However, due to the difficulty in distinguishing the two sandstones, they are currently combined and classified as the Wonewoc Sandstone (Mossler, 2008).

The lower Wonewoc is a fine- to coarse-grained sandstone that becomes finer-grained and more well-sorted toward the base. The upper Wonewoc is a very coarse-grained sandstone with thin interbeds of siltstone and shale. The clay and silt components are also observed in the matrix (Mossler, 2008).

The Wonewoc Sandstone conformably overlies the Eau Claire Formation in Minnesota and the contact between the two is transitional. A subtle unconformity is present at the contact between the upper and lower Wonewoc (Runkel et al., 1998). Based on borehole data, the thickness of Wonewoc is approximately 60 feet. In Washington County, the thickness ranges between 45 and 75 feet (Bauer et al., 2016). The Wonewoc is present in the subsurface throughout the Study Area (Meyer and Swanson, 1992), with the exception of areas where Mt. Simon or Eau Claire are directly underlying Quaternary sediment.

Horizontal hydraulic conductivity values estimated from specific capacity, pumping, and packer tests range between 1.6 and 31 feet/day in deep bedrock (Runkel et al., 2003). The horizontal hydraulic conductivity of the lower member, based on a discrete interval packer test in Ramsey County, ranges between 1.6 and 7.9 feet/day. The vertical hydraulic conductivity ranges between 0.16 and 0.79 feet/day. This same test yielded a horizontal hydraulic conductivity estimate of 5 feet/day and a vertical hydraulic conductivity estimate of 0.5 feet/day for the upper member of the Wonewoc. The range of horizontal hydraulic conductivity values is higher for fractured shallow bedrock. Slug and specific capacity tests provide a horizontal hydraulic conductivity range of 10 to 100 feet/day (Runkel et al., 2003).

B.3.2.4 Tunnel City Group

The Tunnel City Group (formerly classified as the Franconia Formation) is composed of three formations: (1) the Davis Formation (not present in the Study Area), (2) the Lone Rock Formation, and (3) the Mazomanie Formation. The Lone Rock and Mazomanie formations intertongue with each other in east-central Minnesota (Mossler, 2008). The Mazomanie Formation is present in the northern part of the Study Area. In Washington County, the Mazomanie overlies and intertongues with the Lone Rock member. It thins toward the south, where it is progressively replaced by the Lone Rock Formation (Bauer et al., 2016). The Lone Rock Formation contains three members (from oldest to youngest): (1) the Birkmose Member, (2) the Tomah Member, and (3) the Reno Member. The Birkmose Member is a massive, very fine- to fine-grained, glauconitic sandstone cemented with dolomite (Mossler, 2013). Burrows are present throughout and are commonly lined or filled with silt. Intraclastic dolostone is present at the top of the member. The Tomah Member is a siltstone to very fine-grained, feldspar-rich sandstone with very thin interbeds of shale (Mossler, 2013). The Reno Member is a very fine-grained, well-sorted, glauconitic, feldspar-rich sandstone with minor siltstone and shale beds (Mossler, 2008). It also has thin beds with dolomitic intraclasts. A siltstone conglomerate in a matrix of sandy dolostone is typically present at the top of the Reno Member and may indicate a period of non-deposition between the Reno and overlying St. Lawrence Formation (Mossler, 2008). The contact between the Lone Rock Formation and underlying Wonewoc Sandstone is conformable.

The Mazomanie Formation is a very fine- to medium-grained dolomitic sandstone (Mossler, 2008). Burrows are common along discrete horizons. The Mazomanie Formation is present in Washington, Ramsey, Anoka, Chisago, and Hennepin counties.

The Tunnel City Group is present in the subsurface throughout the Study Area and its thickness is fairly consistent. Based on available data, the formation ranges between 135 and 180 feet. Where present, the Mazomanie Formation is up to 100-feet thick and individual tongues can be up to 50-feet thick in Washington County (Bauer et al., 2016). Outcrops occur along the St. Croix River from central Washington County to southern Chisago County (Mossler, 2008).

The average horizontal hydraulic conductivity of the Tunnel City Group based on specific capacity tests is 5.9 feet/day where the Mazomanie Formation is thin to absent and 27.8 feet/day where it is thick (Runkel et al., 2003). Discrete interval packer tests in Ramsey County yielded horizontal and vertical hydraulic conductivity estimates of 1.4 to 7.5 and 0.14 to 0.75 feet/day, respectively, for the Mazomanie Formation. The same tests provided a horizontal and vertical hydraulic conductivity estimate of 10^{-2} (or less) and 10^{-4} (or less) feet/day, respectively, for the middle to lower Lone Rock Formation. Where the permeability is enhanced due to well-connected fractures, the average horizontal hydraulic conductivity for the Tunnel City Group is 32 feet/day (Runkel et al., 2003).

Due to the low permeability of the middle-to-lower Lone Rock Formation, this portion of the Tunnel City Group is considered a confining unit. The upper half of the Tunnel City Group contains discrete bedding plane fractures (even in deep bedrock) and a coarser clastic component, and, therefore, is considered an aquifer.

B.3.2.5 St. Lawrence Formation

The St. Lawrence Formation is composed of two distinct lithofacies: sandy/silty dolostone in the lower portion and siltstone in the upper portion. The lower St. Lawrence is the first Paleozoic rock consisting primarily of chemically precipitated carbonate. The lower dolomitic portion of the St. Lawrence includes thin glauconitic sandstone beds and is argillaceous (Mossler, 2008). Thin beds of siltstone and shale are common. The contact between the St. Lawrence and the underlying Tunnel City Group is conformable and distinct. In the northern part of the Study Area, the base of the St. Lawrence is composed of a siltstone and sandy/silty dolostone that overlies the fine- to medium-grained sandstone of the Mazomanie Formation (Runkel et al., 2006). However, in the southern part of the Study Area (Scott, Ramsey, and Dakota counties), the base of the St. Lawrence overlies the very fine-grained, feldspathic sandstone of the Lone Rock Formation and the contact between the two can be harder to distinguish.

The siltstone of the upper St. Lawrence Formation is a dolomitic siltstone and can be slightly glauconitic or sandy within the Study Area (Mossler, 2008). In Washington County, the St. Lawrence is primarily a dolomitic, feldspathic siltstone with interbedded shale and very fine-grained sandstone. The St. Lawrence generally ranges in thickness between 30 and 50 feet in the northern part of the Study Area. In Scott County, the formation is up to 90-feet thick.

The St. Lawrence Formation underlies younger Paleozoic rock in most of Washington, Hennepin, Ramsey, Dakota, eastern Scott, and southern Anoka counties. The formation directly underlies Quaternary deposits in deeply incised buried bedrock valleys. In Ramsey County, the St. Lawrence is the oldest Paleozoic rock to directly underlie Quaternary sediment. The St. Lawrence is not present in most of Chisago and Isanti counties. It is the youngest Paleozoic rock mapped in Isanti County. The St. Lawrence is exposed in thin outcrops along the Minnesota River valley and the St. Croix River in eastern Washington and Chisago counties (Runkel et al., 2006).

Horizontal hydraulic conductivity estimates for the St. Lawrence Formation (deep bedrock) vary considerably and range between 10^{-2} and 20 feet/day based on specific capacity and packer tests. The low end of the range represents intergranular or matrix porosity. The higher end represents secondary porosity, mainly in the form of dissolution cavities formed in carbonate rock. A discrete interval packer test performed in Ramsey County provided a vertical hydraulic conductivity estimate of 10^{-4} feet/day. The average horizontal hydraulic conductivity estimated from specific capacity tests in shallow fractured bedrock is 46 feet/day (Runkel et al., 2003).

Dissolution cavities within the St. Lawrence enhances the permeability of the formation and, as a result, can provide moderate-to-large quantities of water where the dissolution cavities occur. However, the vertical hydraulic conductivity of the formation is sufficiently low for the St. Lawrence to be considered a confining unit. Under shallow bedrock conditions where fractures and large dissolution cavities exist, the formation is considered an aquifer.

B.3.2.6 Jordan Sandstone

The Jordan Sandstone consists of a very fine- to coarse-grained, well-rounded, well-sorted sand. The formation conformably overlies the St. Lawrence Formation and the contact is gradational (Steenberg and Retzler, 2016). The sandstone coarsens upward from a very fine-grained, massive, feldspar-rich sand with thin beds of siltstone and shale to a medium- to coarse-grained, quartz-rich sand (Mossler, 2008). Very fine-grained feldspathic intervals are intercalated within the quartz-rich lithofacies (Mossler, 2008).

The Jordan Sandstone underlies younger Paleozoic rock in much of Washington, Hennepin, Scott, Ramsey, and Dakota counties. The formation is exposed along the Mississippi River and the St. Croix River bluffs in Washington County (Steenberg and Retzler, 2016). In areas where the Jordan Sandstone is present, it ranges in thickness between approximately 80 and 100 feet. In northern Washington County, the formation thins to approximately 65 to 70 feet (Bauer et al., 2016).

Horizontal hydraulic conductivity estimates from specific capacity, pumping, and packer tests in deep bedrock range between 0.1 and 100 feet/day. These estimates may include the overlying Coon Valley Member of the Ordovician Prairie du Chien Formation, since many open borehole intervals of water wells for the Jordan Sandstone also include the Coon Valley Member. Horizontal hydraulic conductivity estimates from discrete interval packer tests of similar strata as the lower lithofacies yield an estimated value on the order of 10^{-2} feet/day. Based on these same tests, the vertical hydraulic conductivity for the fine-grained interval is inferred to be on the order of 10^{-4} feet/day. Specific capacity and pumping tests in shallow fractured bedrock provide a horizontal hydraulic conductivity range of 30 to over 500 feet/day (Runkel et al., 2003).

Given the higher-permeability estimates of the upper quartz-rich portion of the Jordan Sandstone, the upper Jordan Sandstone is considered to be an aquifer. Due to the fine-grained nature of the lower Jordan Sandstone and inferred low permeability, the lower Jordan Sandstone is considered to be a confining unit, together with the underling St. Lawrence Formation.

B.3.2.7 Prairie du Chien Group

The Prairie du Chien Group is the oldest Ordovician rock in the Study Area and is made up of two formations (from oldest to youngest): (1) the Oneota Dolomite and (2) the Shakopee Formation. The group as a whole is largely composed of carbonate rock. As the name implies, the Oneota Dolomite is primarily a massive dolostone. The lower Oneota Dolomite includes the Coon Valley Member, which formerly was identified as part of the Jordan Sandstone. The Coon Valley Member is composed of dolostone, feldspathic sandstone, quartzose sandstone, and shale. It is absent in parts of Washington County. Where present, the Coon Valley is up to 30-feet thick (Bauer et al., 2016). The contact between the Coon Valley Member and the underlying Jordan Sandstone is unconformable, marked by a poorly sorted, pebbly sandstone (Mossler, 2008). The upper member of the Oneota Dolomite is the Hager City Member, a crystalline dolomite. The upper portion has coarse-grained, calcite-filled vugs and is brecciated within the top few feet (Mossler, 2008). In Washington County, the Hager City Member is up to 70-feet thick (Steenberg and Retzler, 2016).

The Shakopee Formation includes two members (from oldest to youngest): (1) the New Richmond Member and (2) the Willow River Member. The New Richmond Member is primarily a fine-grained sandstone but also includes sandy dolostone. The Willow River Member is a dolostone with thin, medium-grained sandstone beds and dolostone beds (Mossler, 2008). The thickness of the Shakopee is variable due to faulting and a period of erosion prior to deposition of the overlying St. Peter Sandstone. In Washington County, the Shakopee is thickest in the southeast (up to 200-feet thick east of the Hudson-Afton Horst). West of the Hudson-Afton Horst, the Shakopee is up to 115-feet thick and thins to the northwest (Bauer et al., 2016). Based on a limited amount of data, the Shakopee is thinner (and may be absent) in areas overlying the Hudson-Afton Horst. Based on thickness changes of the Prairie du Chien across the Hudson-Afton Horst, Paleozoic faulting is interpreted to have occurred during the early-to-middle Ordovician Period (Bauer et al., 2016).

The Prairie du Chien Group is present in Washington, Ramsey, Dakota, Hennepin, and Anoka counties. In Anoka County, the Prairie du Chien is only present in the very southeastern corner. It is the uppermost bedrock across a wide expanse of the Study Area, particularly in Washington, Dakota, Ramsey, Hennepin, and Scott counties. The Prairie du Chien outcrops along the tops of bluffs of the Mississippi and St. Croix River valleys in Washington County, and in places where Quaternary sediment is thin (Bauer et al., 2016).

The Shakopee and upper Oneota have a well-developed network of dissolution cavities and vertical fractures, as well as oomoldic porosity, a form of secondary porosity that can form through the preferential dissolution of oolitic limestone (limestone composed of spherical grains of concentric layers). Specific capacity discrete interval, and pumping tests; dye studies; and flow meter logging provide a horizontal hydraulic conductivity range of 1.6 to greater than 1,023 feet/day. Secondary porosity in the lower-to-middle Oneota is primarily restricted to discrete horizons along bedding planes.

Pumping tests in the middle-to-lower Oneota yielded horizontal and vertical hydraulic conductivity estimates on the order of 10^{-3} and 10^{-4} feet/day, respectively (Runkel et al., 2003).

Given the enhanced permeability from secondary porosity, the combined Shakopee and upper Oneota are considered to be an aquifer. The middle and lower Oneota is considered a confining unit. Under shallow bedrock conditions, the Prairie du Chien exhibits the typical attributes characteristic of a karst system (Runkel et al., 2003). Preferential flow paths occur through fractures and solution features in both shallow and deep conditions.

B.3.2.8 St. Peter Sandstone

The St. Peter Sandstone is divided into a lower Pigs Eye Member and an Upper Tonti Member. The Lower Pigs Eye Member is composed of interbedded sandstone, siltstone, and shale. The sandstone is fine- to medium-grained and quartz-rich. The Tonti Member is a well-sorted, well-rounded, poorly cemented, fine- to medium-grained, quartz-rich sandstone. Bedding and structures are generally absent (Steenberg et al., 2018). In Washington County, the lower Pigs Eye Member is 10- to 40-feet thick and the Tonti Member is 100- to 140-feet thick (Bauer et al., 2016).

A long period of erosion occurred prior to the deposition of the St. Peter Sandstone, and a major unconformity exists at the contact between the Middle to Upper Ordovician St. Peter Sandstone and the underlying Lower Ordovician Prairie du Chien Group. In areas of western Hennepin County, along the edge of the Twin Cities Basin, the Prairie du Chien is absent and the St. Peter Sandstone directly overlies the Jordan Sandstone.

The St. Peter Sandstone is present in Washington, Anoka, Dakota, Hennepin, and Ramsey counties; and is either buried beneath younger Paleozoic rocks or directly underlies Quaternary sediment. Outcrops of St. Peter Sandstone are located along bluffs of the Mississippi River (Steenberg et al., 2018) or where Quaternary deposits are thin. The Lower Pigs Eye member is not exposed in Washington County (Bauer et al., 2016).

Horizontal hydraulic conductivity estimates from specific capacity, packer, and pumping tests range between 1.3 and 15.9 feet/day for deep bedrock. The vertical hydraulic conductivity of the lower Pigs Eye Member was estimated from pumping tests and groundwater modeling, and is on the order of 10^{-3} feet/day (Schoenberg, 1990). In shallow bedrock, horizontal hydraulic conductivity estimates vary but are as high as 38.7 feet/day (Runkel et al., 2003).

The St. Peter Sandstone serves as an aquifer as a result of its high permeability and intergranular porosity. Due to the low vertical hydraulic conductivity of the lower Pigs Eye Member, the lower St. Peter Sandstone is considered a confining unit, where present.

B.3.2.9 Glenwood Formation

The Glenwood Formation is primarily a calcareous and phosphatic, sandy shale (Mossler, 2008). The contact between the Glenwood and the underlying St. Peter Sandstone is marked by a clayey sandstone. The occurrence of pebbles and sandstone fragments along the contact suggest a break in deposition; however, the contact is not designated as a regional unconformity due to the lack of large-scale erosion (Mossler, 2008).

The Glenwood Formation and the overlying Platteville Formation are mapped together in the Study Area. The mapped unit is present in Washington, Hennepin, and Ramsey counties. Where present, the Glenwood thickness is typically 3 to 7 feet (Steenberg et al., 2018).

Based on a laboratory analysis of slug and pumping tests of similar strata, the vertical hydraulic conductivity is estimated to be on the order of 10^{-6} feet/day. Due to the low estimated vertical hydraulic conductivity, the Glenwood Formation is considered a confining unit. In shallow bedrock conditions, open vertical fractures may penetrate through the relatively thin formation and provide a conduit for groundwater recharge to the underlying St. Peter Sandstone (Runkel et al., 2003).

B.3.2.10 Platteville Formation

The Platteville Formation is composed of limestone and dolomite. In the East Metropolitan Area, the Platteville consists of four members representing different lithologies and depositional environments (Mossler, 2008). The basal member is a sandy dolostone that typically contains phosphate nodules. The contact between the Platteville and Glenwood formations is considered conformable because of the lack of evidence suggesting a break in deposition in Minnesota (Mossler, 2008).

The Platteville Formation is present in parts of Washington and Ramsey counties. Where present, the formation thickness ranges between approximately 25 and 30 feet (Steenberg et al., 2018). The Platteville crops out at bluffs of the Mississippi River in Ramsey County.

The horizontal hydraulic conductivity estimates, based on discrete interval packer tests, range between 10^{-3} and 10^{-1} feet/day in deep bedrock. Pumping tests in shallow bedrock span from 10^{-1} to hundreds of feet/day. Specific capacity tests in this same interval yield an average estimate of 72 feet/day (Runkel et al., 2003).

Due to the low hydraulic conductivity estimates of the Platteville Formation, the lowest portion of the unit is considered a confining unit. However, the formation is a karstic aquifer where bedrock is shallow and serves as a source of water where secondary porosity is well-developed. The Platteville Formation is a significant karst feature within southern Washington County, where present.

B.3.2.11 Decorah Shale

The Decorah Shale is predominantly a shaley unit; however, it also contains thin beds of fossiliferous limestone that are more prominent at the base (Bauer et al., 2016). It is the youngest Paleozoic rock mapped in the Study Area and is only present in Washington, Dakota, Hennepin, and Ramsey counties. In Washington County, it has a maximum thickness of 40 feet. The Decorah Shale is exposed along bluffs of the Mississippi River in Ramsey County.

Where present in Washington County, the Decorah Shale would be under shallow bedrock conditions. Specific capacity tests in shallow bedrock yield an average horizontal hydraulic conductivity of 60.1 feet/day. Under deep bedrock conditions, the Decorah Shale would be on the order of 10^{-6} feet/day based on measured values in similar strata (Freeze and Cherry, 1979) and is considered a confining unit.

B.3.3 Quaternary geology and hydrostratigraphy

The advance and retreat of glaciers emanating from the Laurentide Ice Sheet resulted in a complex assemblage of surficial deposits across Minnesota. The distribution and thickness of glacial deposits were controlled to some extent by the paleo landscape at the time of deposition. Glacial deposits that have distinct characteristics indicate the source area and timing of the glacial advance. Multiple glacial advances occurred during the Pleistocene Epoch and the sediments left behind (gravel, sand, silt, and clay) make up the vast majority of Quaternary deposits. Glacial lobes that advanced into Minnesota have four source areas (shown in Figure B.7): (1) Riding Mountain Provenance, (2) Winnipeg Provenance, (3) Rainy Provenance, and 4) Superior Provenance. Most of the glacial sediments deposited in the Study Area are associated with the Wisconsinan Superior lobe and the Wisconsinan Grantsburg sublobe.

The Pleistocene units mapped in the Study Area make up a complex suite of sand and gravel aquifers, and fine-grained confining units (Figure B.8a). The fine-grained sediment consists of till or diamicton (poorly sorted deposits consisting of gravel-to-boulder size clasts in a fine-grained matrix deposited directly by glaciers); lacustrine clay, silt, and sand; loess (wind-blown silt); and slack water deposits that overly terrace sand. Sand and gravel deposits are primarily the result of meltwater from advancing and retreating glacial lobes.

Holocene deposits are present throughout the Study Area and primarily occur along surface water bodies. These deposits include:

- Alluvium (deposits resulting from flowing water)
- Peat
- Silt and clay lacustrine (lake) deposits
- Wetland sediment
- Colluvium (deposits resulting from gravity or fallen material)
- Wind-blown sand.

Quaternary deposit thickness varies throughout the Study Area (Figure B.8b) and greater thicknesses occur in bedrock valleys. Bedrock valleys are generally areas of sand and gravel outwash deposits. In Washington County, surficial deposits are less than 300 feet. Thickness less than 50 feet occurs in areas where bedrock is at or near the land surface in southern Washington County.

Hydraulic conductivity data for unconsolidated Quaternary deposits was collected by Tipping et al. (2010) and includes laboratory permeameter, slug, specific capacity, and higher-capacity aquifer tests (Table B.4). The scale of the test is generally related to sediment size. Slug tests are the upper limit for field measurement of fine-grained sediment, while large-scale aquifer tests are typically conducted in sand and gravel aquifers. Vertical hydraulic conductivity in fine-grained sediment is typically measured in a laboratory.

Table B.4. Horizontal hydraulic conductivity (Kh) and vertical hydraulic conductivity (Kv) ranges for Quaternary textures.

Texture	Method	Number of samples	Mean	Minimum	Maximum	Geomean
Horizontal hydraulic conductivity (feet/day)						
Loam, silt rich, silt and clay	Grain size	79	3.45E-01	8.57E-03	3.35E+00	1.39E-01
	Slug test	7	1.43E-02	7.65E-05	9.35E-02	7.74E-04
Loam to clay loam	Grain size	1,155	2.37E-01	2.83E-05	5.45E+00	9.64E-02
	Slug test	17	3.87E-01	5.67E-04	3.83E+00	2.80E-02
Loam to sandy loam	Grain size	325	1.26E+00	2.78E-03	1.42E+01	5.70E-01
	Slug test	34	2.27E+00	2.83E-03	4.30E+01	2.00E-01
Sandy silt	Grain size	38	5.65E-01	1.42E-04	1.13E+01	2.42E-02
	Slug test	18	2.49E+01	1.40E-01	1.50E+02	5.54E+00
Fine sand	Grain size	32	4.81E+00	5.84E-05	3.69E+01	1.61E-01
	Slug test	14	3.91E+00	1.42E-03	2.61E+01	5.11E-01

Texture	Method	Number of samples	Mean	Minimum	Maximum	Geomean
Sand and gravel	Grain size	168	5.47E+01	2.83E-02	3.09E+02	1.92E+01
	Laboratory permeameter	3	2.34E+00	4.30E-01	4.50E+00	1.60E+00
	Aquifer test	118	1.17E+02	4.82E-01	4.15E+02	6.53E+01
	Slug test	215	3.98E+01	5.00E-03	5.40E+02	8.07E+00
	Specific capacity	17	4.07E+01	1.50+00	1.52E+02	2.66E+01
Vertical hydraulic conductivity (feet/day)						
Loam, silt rich, silt and clay	Laboratory permeameter (falling head)	4	1.94E-04	6.80E-05	3.97E-04	1.55E-04
Loam to clay loam	Laboratory permeameter (constant head)	17	1.68E-01	6.24E-05	2.83E+00	7.26E-04
	Laboratory permeameter (falling head)	37	7.14E-02	2.83E-06	1.98E+00	2.19E-04
Loam to sandy loam	Laboratory permeameter (falling head)	14	2.45E-01	1.98E-05	3.40E+00	9.81E-04
Sandy silt	Laboratory permeameter (constant head)	9	8.55E-01	8.50E-04	5.67E+00	8.88E-02
	Laboratory permeameter (falling head)	31	1.07E-01	9.35E-06	1.64E+00	1.73E-03
Fine sand	Laboratory permeameter (constant head)	2	1.70E+00	1.50E+00	1.90E+00	1.69E+00
	Laboratory permeameter (falling head)	1	2.35E-01	2.35E-01	2.35E-01	2.35E-01
Sand and gravel	Laboratory permeameter (falling head)	4	4.27E-01	6.80E-03	1.13E+00	1.22E-01
	Aquifer test	3	6.76E+01	7.00E-01	1.01E+02	1.93E+01

Source: Tipping et al., 2010.

Tipping et al. (2010) noted a potential relationship between hydraulic conductivity and burial depth in fine-grained sediment. Local, site-specific slug tests conducted in till showed decreasing hydraulic conductivity values with increasing burial depth. Visual observation of the till showed an upper, fractured, oxidized zone; and a lower, less-fractured, unoxidized zone. However, when evaluating all the data together, Tipping et al. (2010) did not observe a strong correlation between depth and hydraulic conductivity. Instead, the poor correlation was attributed to several factors that would obscure a correlation between depth and hydraulic conductivity such as a uniform fracture network regardless of depth, relatively thinner till deposits with depth, and a wide variety of till textures in the Twin Cities Metropolitan Area.

B.4 Groundwater recharge

Groundwater recharge primarily occurs from precipitation. However, surface water features can provide a source of water to Quaternary and bedrock aquifers as well.

B.4.1 Precipitation

Precipitation that infiltrates the ground surface and reaches the water table is the primary source of recharge to the groundwater flow system. Groundwater recharge from precipitation varies spatially across the Study Area depending on land cover, evapotranspiration, and hydraulic properties of the soil or bedrock. The amount and distribution of recharge is difficult to quantify on a regional scale, and recharge rates used in groundwater flow models are often assumed as a percentage of precipitation and adjusted during model calibration. Previous groundwater modeling efforts for the Twin Cities Metropolitan Area have used the USGS soil water balance (SWB) code to establish a spatial distribution of recharge from precipitation and temperature. The SWB uses geographic information system (GIS) compatible rectangular grids with user-defined data, including (1) climate data, (2) land-use classification, (3) hydrologic soil group, (4) flow direction, and (5) soil-water capacity to calculate spatial and temporal variations in groundwater recharge (Westenbroek et al., 2010). As the name implies, the SWB uses a soil-water balance approach that consists of the following components:

Sources

- Daily precipitation
- Daily snowmelt (based on temperature)
- Inflow (surface runoff that is routed to downslope grid cells using a digital elevation model).

Sinks

- Interception (precipitation that is trapped at the land surface and evaporated or used by plants)
- Outflow (surface runoff)
- Evapotranspiration (requiring climate data such as daily minimum and maximum air temperatures)
- Change in soil moisture (change in the amount of water stored in the soil for a given grid cell).

Detailed documentation for the SWB model including all required input parameters, equations, and methods used to calculate each component are found in Westenbroek et al. (2010).

The DNR (2019i) provided Wood with SWB input and output files for simulations run between 1999 and 2018. The SWB domain is a rectangular area that covers the Northeast Metro Lakes Groundwater-Flow (NMLG) model domain. With the exception of surface water features, annual recharge rates range between less than 1 to greater than 20 inches in 2018 (Figure B.9). Surface water features that were assigned an open-water land cover type in the SWB model have a recharge value of zero (i.e., does not allow recharge to groundwater).

B.4.2 Surface water sources

Rivers, lakes, streams, and wetlands are also potential sources of recharge depending on surface water elevation relative to the position of the water table. Water chemistry data for Washington County suggest that many of the lakes throughout the county are sources of recharge with the exception of lakes in the northwest, which tend to be more isolated because of an underlying low-permeability layer (Berg, 2019). Surface water bodies that have a water elevation higher than the adjacent water table elevation will be a source of recharge to the aquifer. The amount of recharge is affected by the lakebed conductance and hydraulic conductivity of the receiving formation. During periods of high river stage, water may percolate laterally from a river into the adjacent aquifer (bank storage), which may in turn percolate back into the river as it returns to normal or low-flow conditions. Unlike bank storage that occurs during periods of high stage, recharge from lakes may be sustained over long periods of time. Lake gages are located throughout the Study Area and provide current and/or historical water-level measurements (Figure B.10). Based on lake bathymetry data, most of the lakes overlie glacial deposits. However, deeper lakes in the Study Area extend closer to bedrock, such as White Bear Lake, which may be less than 50 feet above bedrock in the deepest portion of the lake (Berg, 2019).

Surface water elevations at White Bear Lake and adjacent groundwater elevations are shown in Figure B.11 for a 15-year period (2003–2018). In this example, groundwater in Quaternary glacial deposits mimic lake surface water elevations. Lake water levels and groundwater elevations are decreasing between 2003 and 2012, and increasing between 2013 and 2018. This same general trend is seen in the Prairie du Chien; however, water-level fluctuations are more pronounced, perhaps as a response to pumping from nearby wells. Based on data provided by the DNR, annual precipitation was below normal between 2003 and 2012 (with the exception of annual precipitation for 2005, 2007, and 2010), as shown in Figure B.11. The DNR used a gridding procedure to harmonize observations from a dense portion of their high-density precipitation gage network and the data presented in Figure B.11 are representative of the Study Area. However, local variations, such as in White Bear Lake, have occurred (DNR, 2018a, 2018b). In general, precipitation at White Bear Lake was exceptionally high in 2002 (45 inches) and below normal from 2006 to 2012 (with the exception of annual precipitation for 2010 and 2011). The decline in White Bear Lake water levels between 2003 and 2012 is attributed to long-term well pumping in the vicinity of the lake and a period of below-normal precipitation (Jones et al., 2013; S.S. Papadopulos and Associates, 2017; DNR, 2018a, 2018b; Berg, 2019). Annual precipitation between 2013 and 2018 was at or above normal annual precipitation and, as a result, lake levels increased during this period (Berg, 2019).

The impact on lake levels and volume from groundwater withdrawal in the vicinity of White Bear Lake (within five miles) has been evaluated using the transient NMLG model (S.S. Papadopulos and Associates, 2017; DNR, 2018a, 2018b). The results of these efforts have demonstrated some influence on lake levels from nearby pumping; however, the magnitude of response depends on several factors such as the pumping rate, the distance to the lake, and the aquifer being utilized. Additionally, the adverse effects noted are largely a result of pumping from a small number of permitted wells that appear to have a dominant influence on the lake (S.S. Papadopulos and Associates, 2017). Recent modeling efforts have also shown that while current groundwater use complies with Minnesota's sustainability standard, current pumping continues to contribute to water levels falling below the protective elevation for White Bear Lake (DNR, 2018a).

During the same 15-year period, White Bear Lake surface water elevations were generally observed to be higher-than-measured adjacent groundwater elevations, indicating that the groundwater system is receiving net recharge from the lake. Additional studies conducted at White Bear Lake also suggest that the lake is a source of net recharge to groundwater and indicate that the lake is hydraulically connected to the Prairie du Chien aquifer (uppermost bedrock aquifer). It was also shown, however, that groundwater is discharging to the lake along parts of the lake shore (Jones et al., 2013, 2016).

B.5 Groundwater discharge

Water is removed from the groundwater flow system by pumping wells, lakes, major rivers, and smaller streams. Groundwater discharge can also occur from evapotranspiration at springs along bedrock outcrops; and at wetlands along lakes, rivers, and streams. A discussion of discharge from wells, lakes, and rivers is provided below.

B.5.1 Pumping wells

Groundwater is the primary source of potable water for about three-quarters of the population in the Twin Cities Metropolitan Area. In addition to being the primary potable water supply, pumping wells are used to extract groundwater for a variety of purposes, including industrial/commercial, agricultural, construction, and hydraulic control at landfills/waste sites.

Annual withdrawal from all pumping wells (commercial, municipal, industrial, agricultural, and construction) within the Study Area were obtained from the DNR (2019b). The pumping wells were filtered so that only wells pumping greater than 10 million gallons per year were evaluated. Locations of high capacity wells in the Easter Metropolitan Area are shown in Figure B.12. A plot of combined Washington County withdrawal from all high-capacity wells and combined withdrawal from seven East Metropolitan Area municipalities (i.e., Cottage Grove, Lake Elmo, Lakeland, Newport, Oakdale, St. Paul Park, and Woodbury) for a 30-year period is shown in Figure B.13a. The overall trend in withdrawal over time is primarily driven by municipal wells, with most of the withdrawal coming from Woodbury, Cottage Grove, and Oakdale. A significant increase in pumping occurs in the 1990s and early 2000s, which corresponds to a population growth in Washington County during that time (Figure B.13b). Pumping from high-capacity wells peaks in 2007 and then appears to level off or decrease in the past decade (with the exception of 2012). Bedrock aquifers (particularly the Jordan) are heavily utilized in Washington County. Quaternary aquifers are also used but to a lesser extent. The Jordan Sandstone and Quaternary aquifers saw an increase in total gallons extracted between 1988 and 2018, while pumping in the Mt. Simon and Prairie du Chien aquifers has steadily decreased during the same time period.

B.5.2 Baseflow

Natural sustained flow of a stream (i.e., baseflow) in the absence of run-off is largely due to groundwater discharge. Net baseflow at Valley and Browns creeks in Washington County was estimated by the DNR (2019c). Baseflow estimates from data recorded in 2016, 2017, and 2018 at three gaging stations are summarized in Table B.5.

Table B.5. Stream baseflow in Valley Creek and Browns Creek.

Year	2016	2017	2018
Station 37067001 (Valley Creek at Afton)			
Average flow (cfs)	4.8	5.1	NA
Estimated average baseflow (cfs)	4.8	5.0	NA
Station VA0010 (Valley Creek at Putman Boulevard)			
Average flow (cfs)	20	22	19
Estimated average baseflow (cfs)	20	22	18 to 19
Station BR0003 (Browns Creek and Dellwood Road)			
Average flow (cfs)	8.8	8.8	8.5
Estimated average baseflow (cfs)	6.1 to 7.2	6.7 to 7.7	6.2 to 7.2

cfs = cubic feet per second.

Additionally, the Washington County Conservation District gaged streamflow at Trout Brook (near the mouth) between April and October in years 2004 through 2006. During this period, baseflow varied from less than 1 cubic feet per second (estimated from August 2004 streamflow) and 4.5 cubic feet per second (estimated from May and June 2004). Baseflow typically ranged between 1 and 2.5 cubic feet per second during this period (Emmons & Oliver Resources, 2009).

B.5.3 Lakes

Lakes can be points of discharge, which is particularly the case with lower-elevation lakes. When groundwater elevations are higher than lake elevations, the lake receives discharge from the adjacent aquifer. For example, water levels measured at Lake Isabelle, near Hastings, are generally lower than water table elevations measured at an adjacent observation well between 2003 and 2018 (Figure B.14). Periodically, this relationship is reversed (i.e., during periods of high lake levels). The water table fluctuates with lake elevations and there appears to be an increase in both between 2015 and 2018. It is important to note that surface water features determined to be points of discharge can also serve as points of recharge and provide water to the groundwater flow system when the elevation of groundwater drops below that of the water body, and surface water features determined to be a source of recharge can also be points of discharge when water body elevations drop below groundwater elevations. The amount of flow or surface water-groundwater exchange is controlled by the hydraulic conductivity and thickness of lakebed sediment.

B.6 Groundwater flow

Groundwater levels measured at DNR observation wells that are constructed in glacial or bedrock aquifers were plotted and compared to precipitation and pumping data. Many of the wells showed an increasing trend in groundwater levels within the past decade until approximately 2016. This may be in part due to an increase in precipitation; however, this may also be related to pumping.

Bedrock potentiometric surfaces generated by Sanocki et al. (2009) are shown in Figures B.15a–c. The aquifers were grouped as follows:

1. Mt. Simon-Hinckley
2. Wonewoc Sandstone and Tunnel City Group
3. Jordan Sandstone and Prairie du Chien Group.

Elevations shown on Figures B.15a–c represent elevations where groundwater would rise in a tightly cased well. Groundwater flow occurs from higher-to-lower elevations perpendicular to potentiometric surface contours. The potentiometric maps of all aquifers in Washington County show that groundwater in bedrock aquifers (with exception of Mt. Simon) generally flows south-southwest toward the Mississippi River or east toward the St. Croix River from the elongated north-south groundwater high area in northern Washington County, as shown in Figure B.16.

The potentiometric surface for the Mt. Simon Sandstone aquifer is affected by a regional cone of depression in the Metropolitan Area (Figure B.15a). The cone of depression is presumably an effect of long-term, high-capacity pumping from the aquifer (Berg and Pearson, 2013).

Groundwater elevations in the Prairie du Chien are in many areas above the top of bedrock, indicating that groundwater is confined. However, unconfined conditions in the Prairie du Chien were also observed (Figure B.17). Groundwater elevations measured in a Prairie du Chien observation well at Cottage Grove [Minnesota Well Index (MWI) number 817790] between 2017 and 2019 are below the top of bedrock. The well is located along the Mississippi River, where regional groundwater discharge occurs. Areas of shallow depths to bedrock and bedrock aquifers overlain by large bodies of sand and gravel (such as in deep bedrock valleys) tend to be under unconfined conditions, as supported by calculated short travel times and water chemistry data (Tipping, 2011). Groundwater flow is enhanced by secondary porosity (fracture flow and/or dissolution) in shallow bedrock. Although groundwater flow is primarily horizontal, vertical gradients occur at high-capacity wells, areas of regional discharge, and in bedrock confining units.

Due to the complex nature of glacial deposits, groundwater flow in buried sands and gravels are not depicted on a potentiometric map. Shallow unconfined groundwater flow generally follows surface topography and is toward major rivers. In Washington County, the water table ranges between 0 and 20 feet below ground surface (bgs) in the northwest, 0 to 40 ft bgs in the central part of the county, and greater than 50 feet bgs in proximity to the Mississippi and St. Croix rivers (Berg, 2019). According to Berg (2019), groundwater flow through unconsolidated deposits in Washington County generally occurs as follows:

1. Laterally through unconsolidated deposits from areas of recharge to areas of discharge areas (at surface water bodies)
2. Vertically from unconsolidated surficial aquifers to buried unconsolidated aquifers
3. Vertically from surficial or buried aquifers to an underlying bedrock aquifer.

B.7 PFAS source areas and groundwater sampling results

Four source areas for PFAS contamination in the East Metropolitan Area groundwater were identified by the MPCA and MDH: 3M Cottage Grove Disposal Sites, the 3M Woodbury Disposal Site, the Oakdale Disposal Site, and the Washington County Landfill (Figures B.18a–c). There is also evidence suggesting the large flood control project conducted by the Valley Branch Watershed District, known as Project 1007, may have contributed to the distribution of PFAS. Raleigh Creek is one of the surface water bodies that conveys water from the Tri-Lakes area to the St. Croix River as a part of this project. Raleigh Creek flows through the former Oakdale disposal site, potentially conveying PFAS-impacted water to locations downstream where it may have mixed with groundwater.

Groundwater samples were collected from drinking water wells throughout the East Metropolitan Area, as well as greater Minnesota, and analyzed for PFAS. Results of the groundwater samples were compared to the health index (HI) values. Drinking water wells with HI values greater than 1.0 are considered an exceedance and the well is subject to a well advisory. MDH provided a dataset containing the most recent PFAS results for each private drinking water well sampled. Not all the wells were assigned a HI value in the MDH-provided dataset; therefore, a column titled “Wood HI” (Wood Health Index) was created to fill in the missing HIs where possible. The Wood HI was calculated using the same HI calculation used by MDH: the sum of the PFAS constituent concentrations (in parts per billion) divided by their respective (most conservative) health-based value (HBV) or health risk limit (HRL), as shown below.

$$\text{Wood HI} = ((\text{PFOA}/0.035) + (\text{PFOS}/0.015) + (\text{PFBA}/7) + (\text{PFBS}/2) + (\text{PFHxS}/0.047)).$$

A subset of MDH wells within and slightly beyond the 14 affected East Metropolitan Area communities were selected for review during the preparation of this Conceptual Plan. In total, 3,320 wells in the selected extent were sampled for PFAS by MDH and 1,304 samples exceeded the HI value. The Wood HI values were plotted for the East Metropolitan Area wells and are presented in Figures B.17a–c with applicable cross-sections. The wells were divided into five categories (Table B.6) based on the percentage of the HI or Wood HI:

Table B.6. HI values.

Value	Percent of HI value
0.0000–0.25000	Non-detect to 25%
0.25001–0.50000	> 25 to 50%
0.50001–0.75000	> 50 to 75%
0.75001–1.00000	> 75 to 100%
> 1.00000	> 100%

Most of the samples exceeding the HI or Wood HI were in the Jordan, Prairie du Chien, and St. Peter aquifer grouping. A complete list of exceedances by aquifer is presented in Table B.7. Residential wells exceeding the HI were generally located downgradient of the four PFAS source areas. Remediation wells now largely provide hydraulic control of the groundwater migration around the four source areas. A remedial investigation to determine the nature and extent of these source areas has not been conducted.

Table B.7. HI exceedances by aquifer.

Aquifer grouping	Total number of wells exceeding the HI
Eau Claire	2
Jordan, Prairie du Chien, St. Peter	791
Mt. Simon	0
Platteville	3
Quaternary	100
St. Lawrence	0
Unknown[a]	396
Tunnel City-Wonewoc	9

a. The Unknown aquifer group represents wells with either no well log or no information in MWI.

B.8 Data gaps

A great deal of work has been accomplished by others in characterizing the geology and hydrogeology of the East Metropolitan Area. This work includes (but is not limited to):

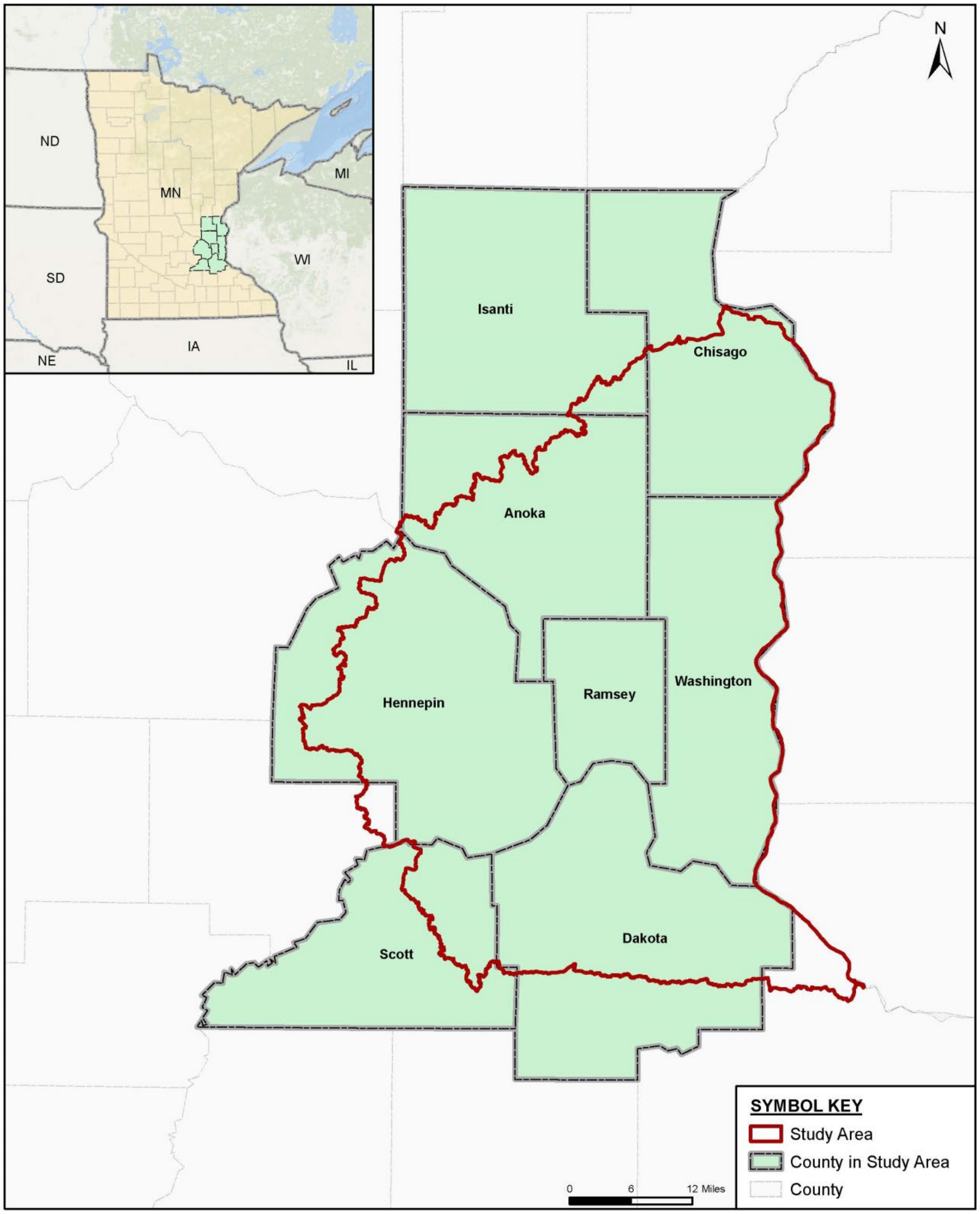
- Detailed mapping of lithostratigraphic units
- Defining and characterizing hydrostratigraphic units
- Generating potentiometric surfaces
- Estimating groundwater recharge and residence times
- Evaluating groundwater and surface water exchanges
- Conducting steady-state and transient groundwater flow modeling
- Evaluating groundwater and surface water chemistry data.

Much of this work has been done on a regional scale where localized heterogeneities are difficult to capture.

Although site-specific data are available, some amount of simplification is necessary when building a groundwater flow model as data gaps are inherent on both regional and local scales. Data gaps include:

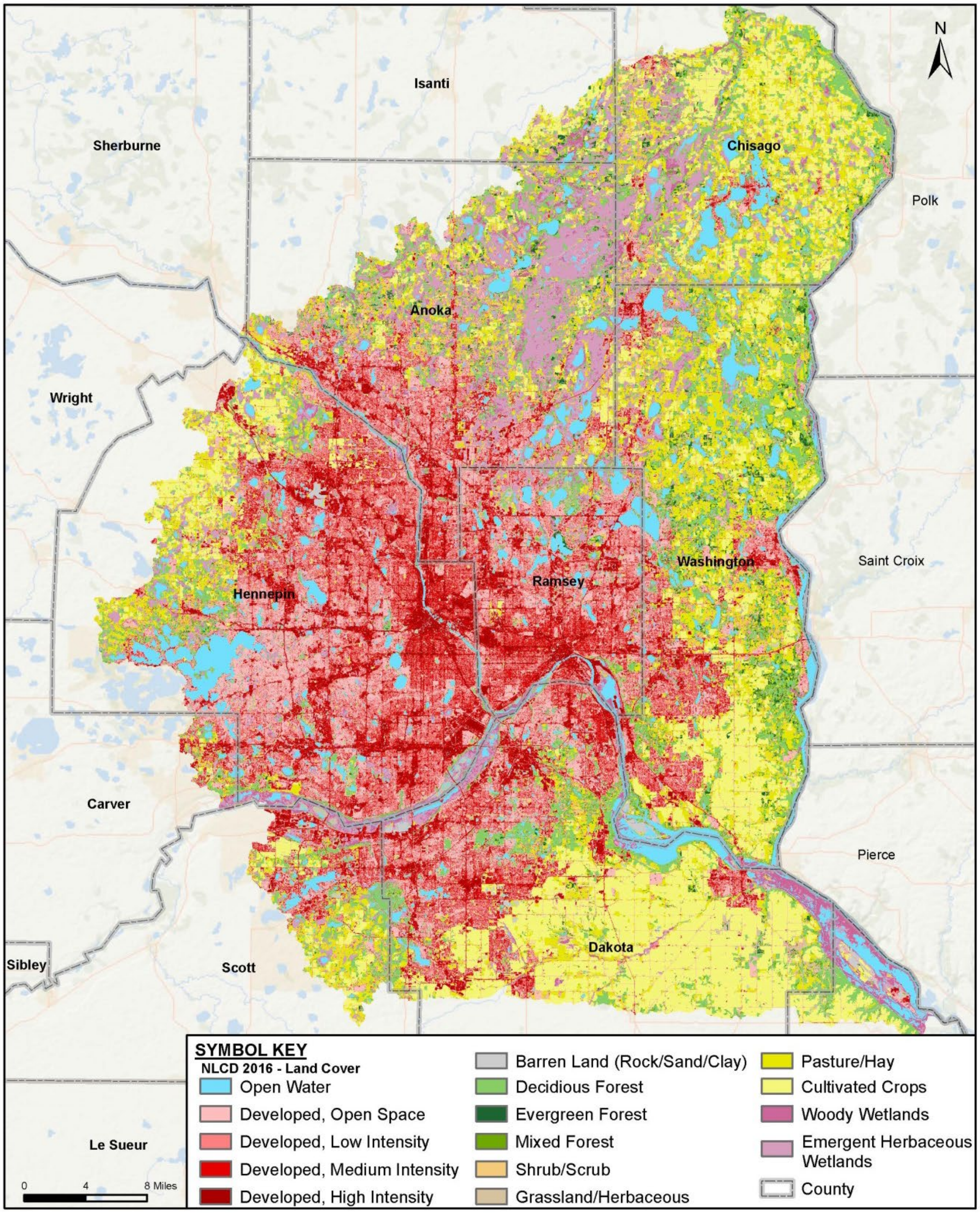
- Heterogeneities within hydrostratigraphic units (particularly in glacial deposits and areas of fractured bedrock or karst development)
- Limitations related to the SWB model, and aerial recharge and runoff estimates
- Surface water elevations where not gaged
- Bottom elevations of rivers, lakes, and streams where bathymetry data are not available
- River and lakebed conductance
- Amount of leakage from surface water bodies
- Limited baseflow calculations
- Limited vertical and spatial distribution of calibration targets
- Limited PFAS plume nature and extent of understanding

Figure B.1. Location of the Study Area.



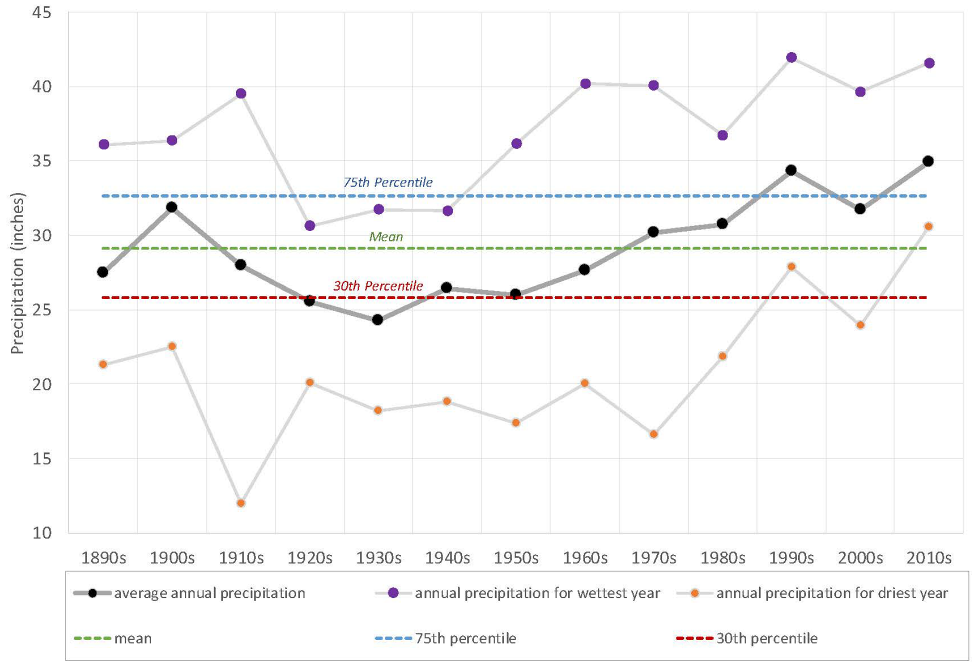
Background imagery service layer credits: Esri, Garmin, GEBCO, National Oceanic and Atmospheric Administration (NOAA) National Geophysical Data Center (NGDC), and other contributors.

Figure B.2. Land use.



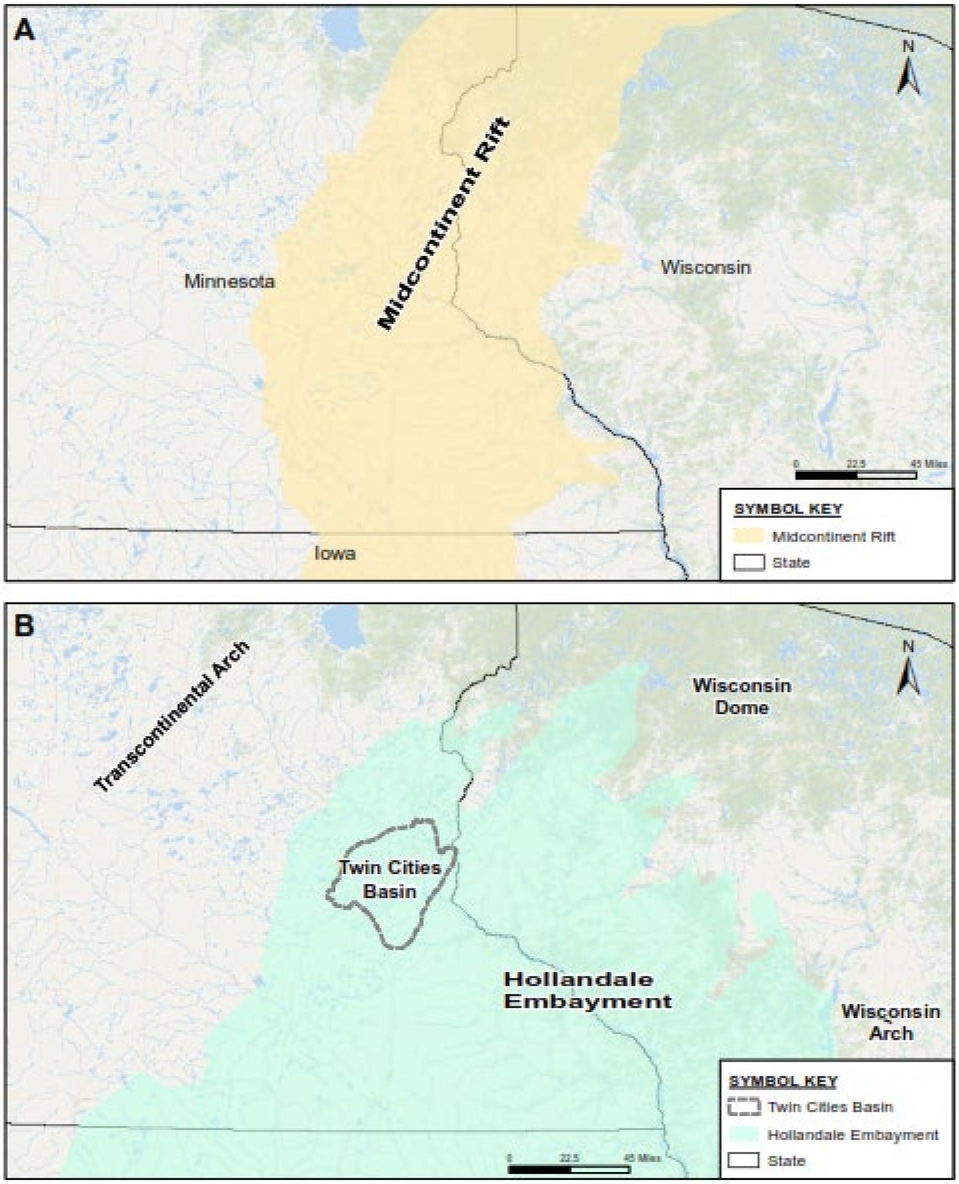
Background imagery service layer credits: Esri, Garmin, GEBCO, NOAA NGDC, and other contributors.

Figure B.3. Annual precipitation by decade.



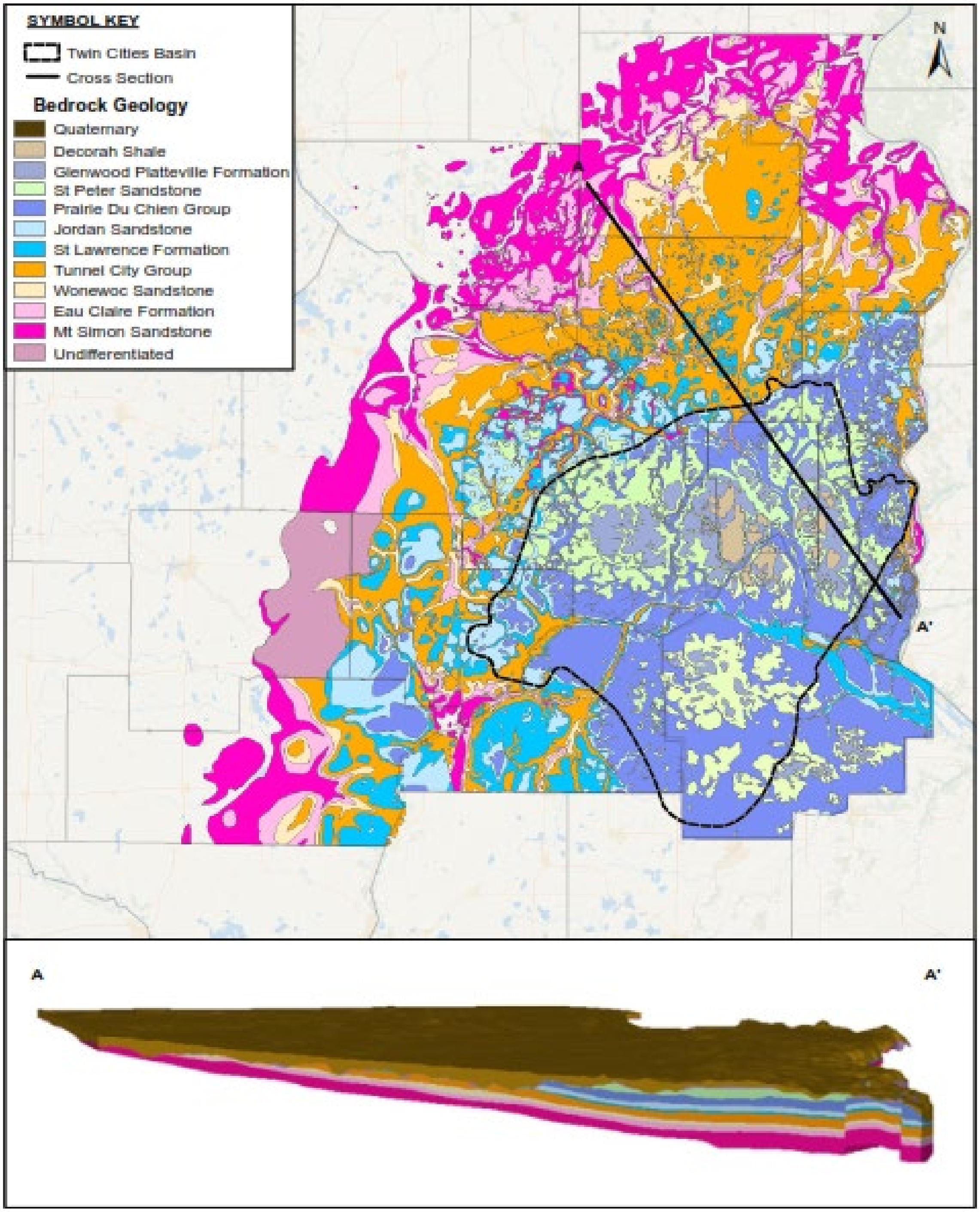
Source: Minnesota Department of Natural Resources MNDNR (2019b)

Figure B.4. Structural setting.



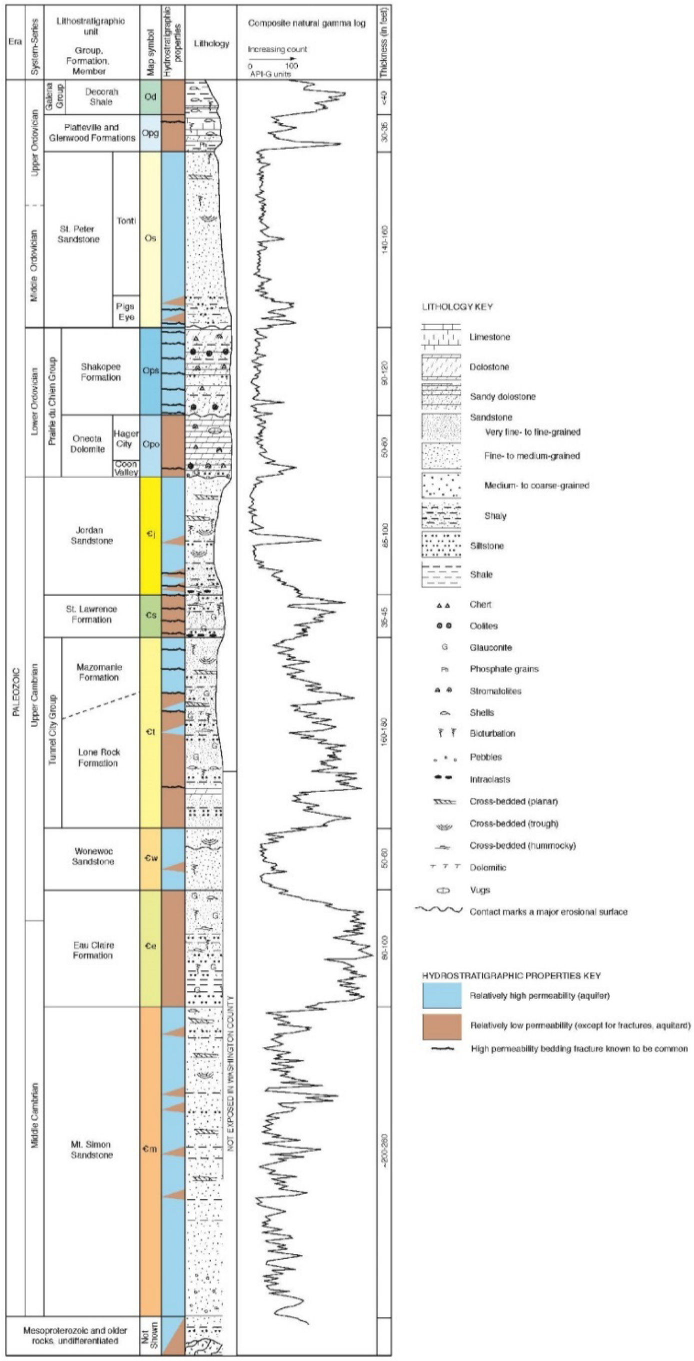
Background imagery service layer credits: Esri, Garmin, GEBCO, NOAA NGDC, and other contributors.

Figure B.5. Paleozoic bedrock geology in the Twin Cities Metropolitan Area.



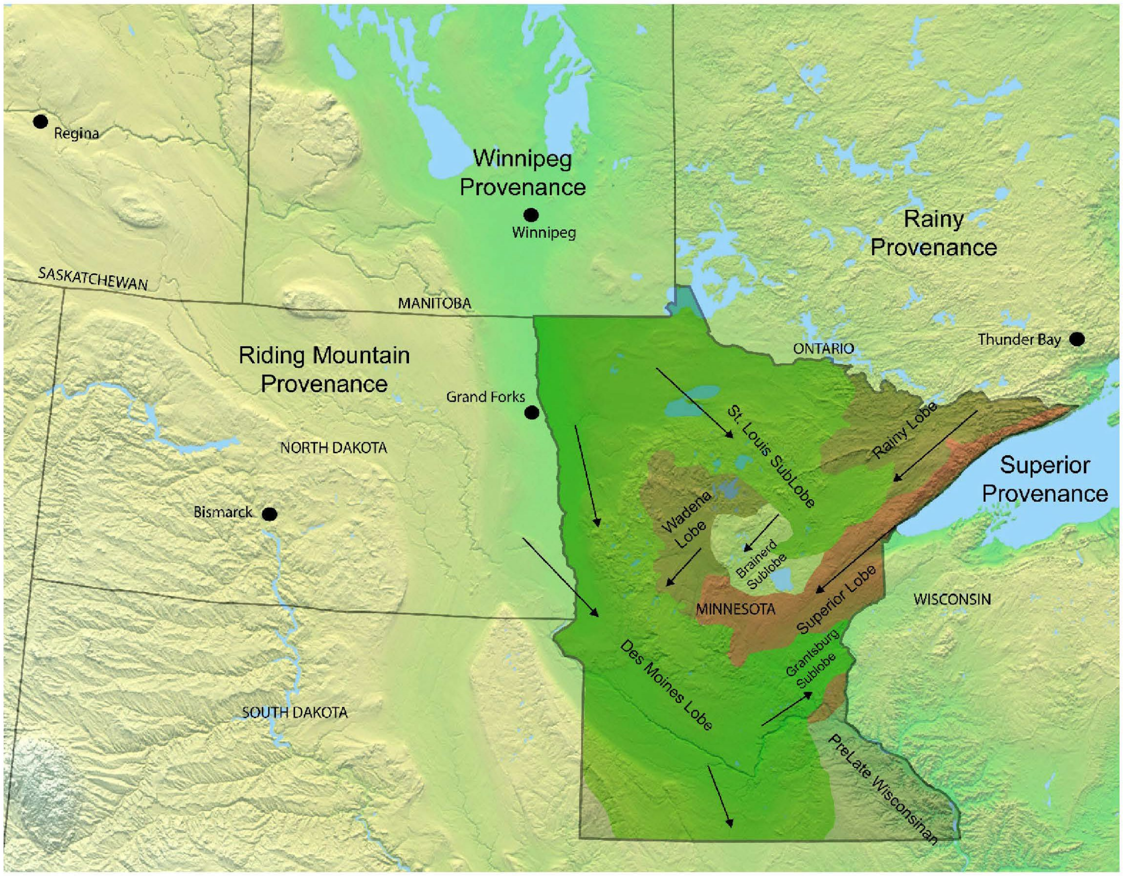
Background imagery service layer credits: Esri, Garmin, GEBCO, NOAA NGDC, and other contributors.

Figure B.6. Representative stratigraphic column for Paleozoic bedrock.



Source: Bauer, Emily J.. (2016). C-39, Geologic Atlas of Washington County, Minnesota. Minnesota Geologica Survey. Retrieved from the University of Minnesota Digital Conservancy, http://hdl.handle.net/11299/178852.

Figure B.7. Global lobe source areas.



Source: Minnesota Geologic Survey, 2019, pebbles in till of Minnesota, available on the web at https://www.mngs.umn.edu/pebbles.htm

Figure B.8a. Generalized surficial geology map.

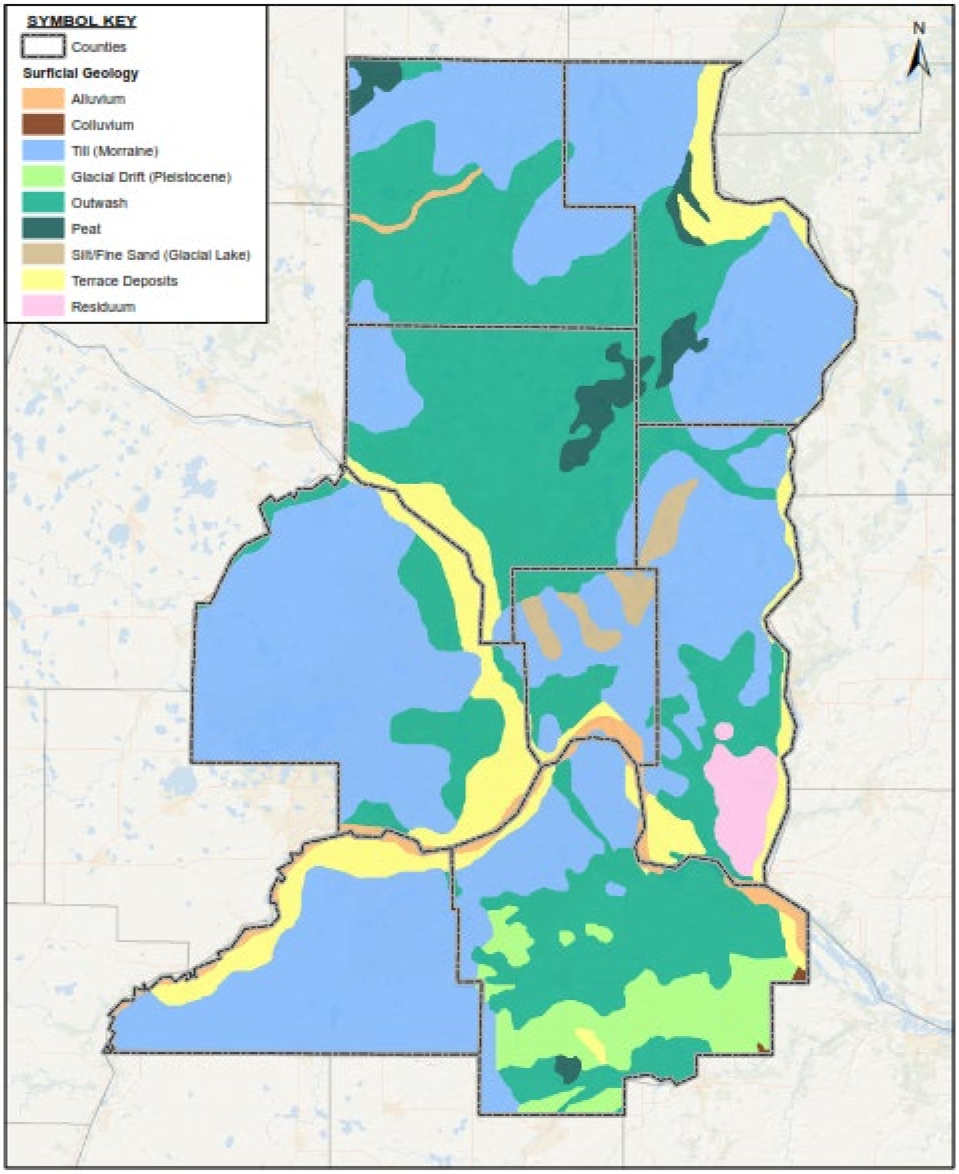


Figure B.8b. Quaternary thickness.

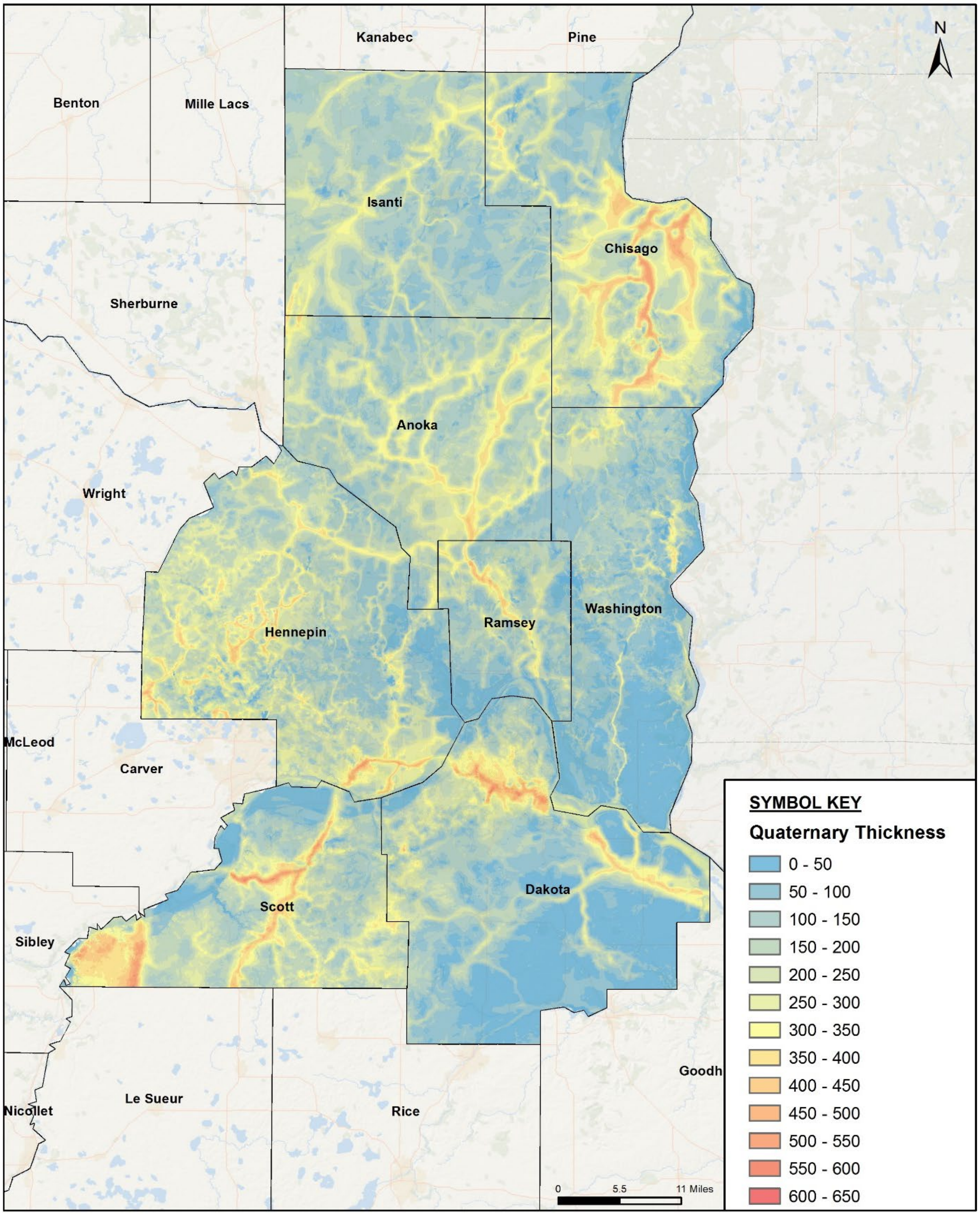
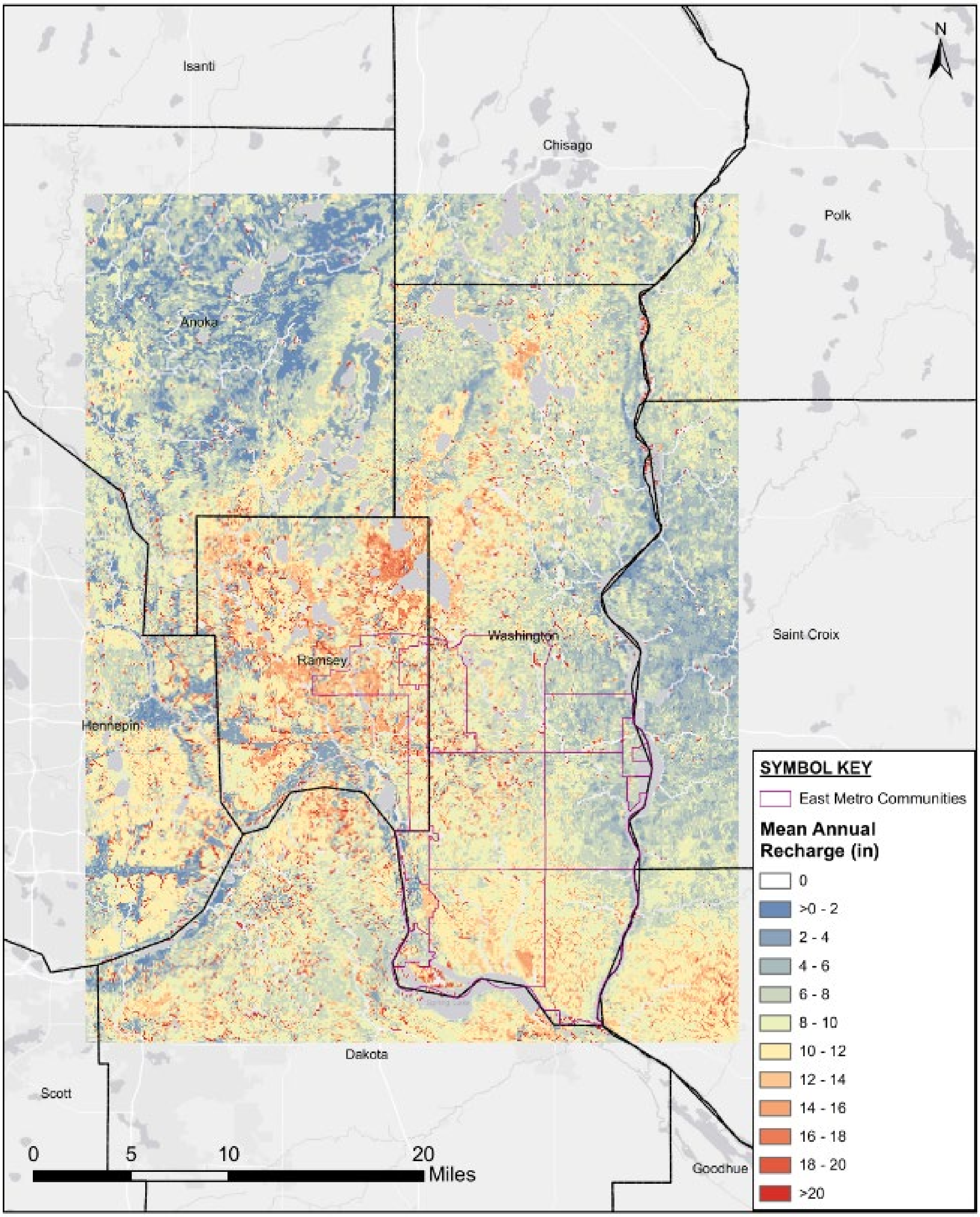
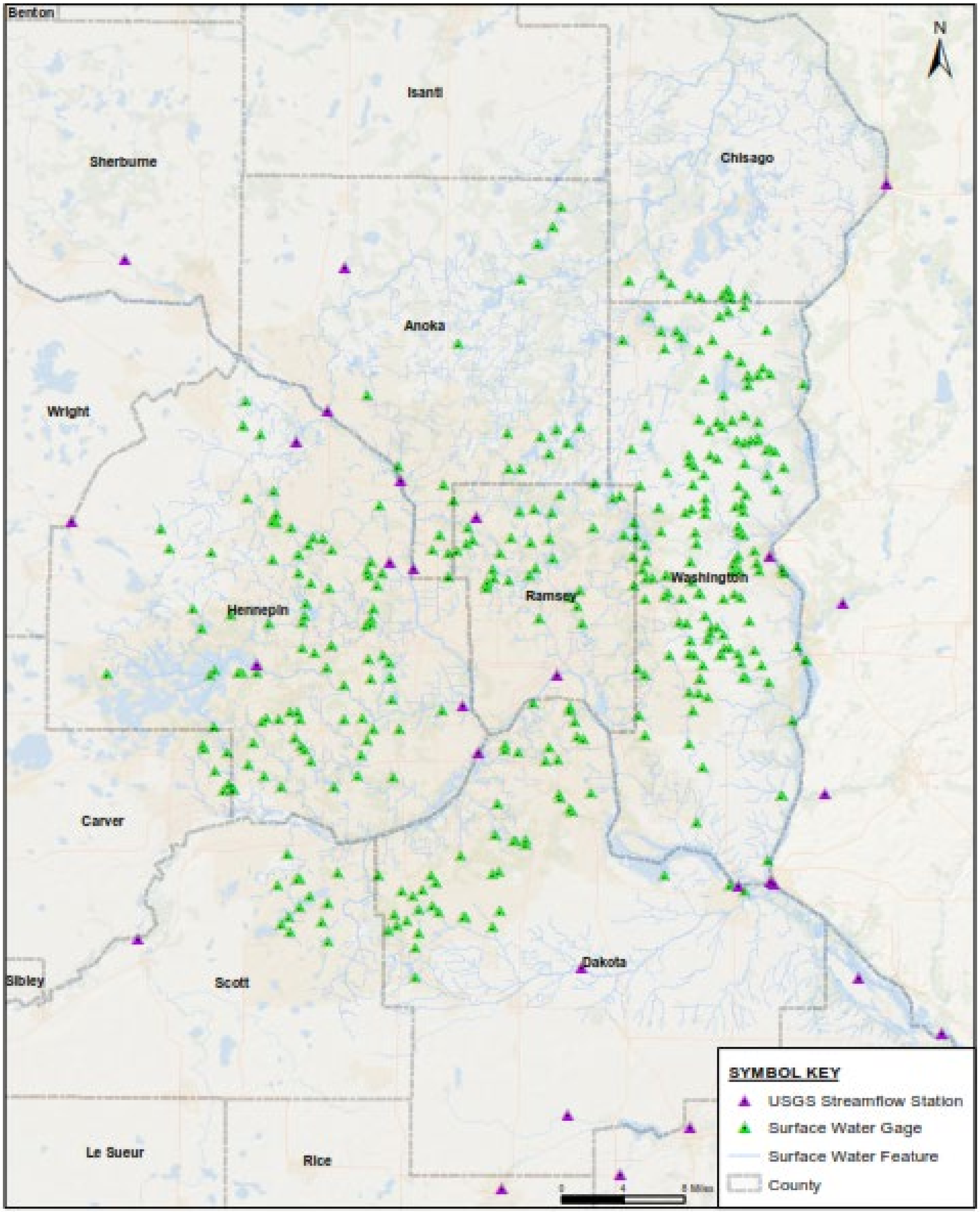


Figure B.9. Recharge in 2018 for Washington County (inches/year).



Background imagery service layer credits: Esri, GEBCO, NOAA, National Geographic, Garmin, HERE, Geonames.org, and other contributors.

Figure B.10. Location of surface water gages.



Background imagery service layer credits: Esri, Garmin, GEBCO, NOAA NGDC, and other contributors.

Figure B.11. Surface water elevations at White Bear Lake, and Quaternary and Prairie du Chien groundwater elevations measured at adjacent observation wells.

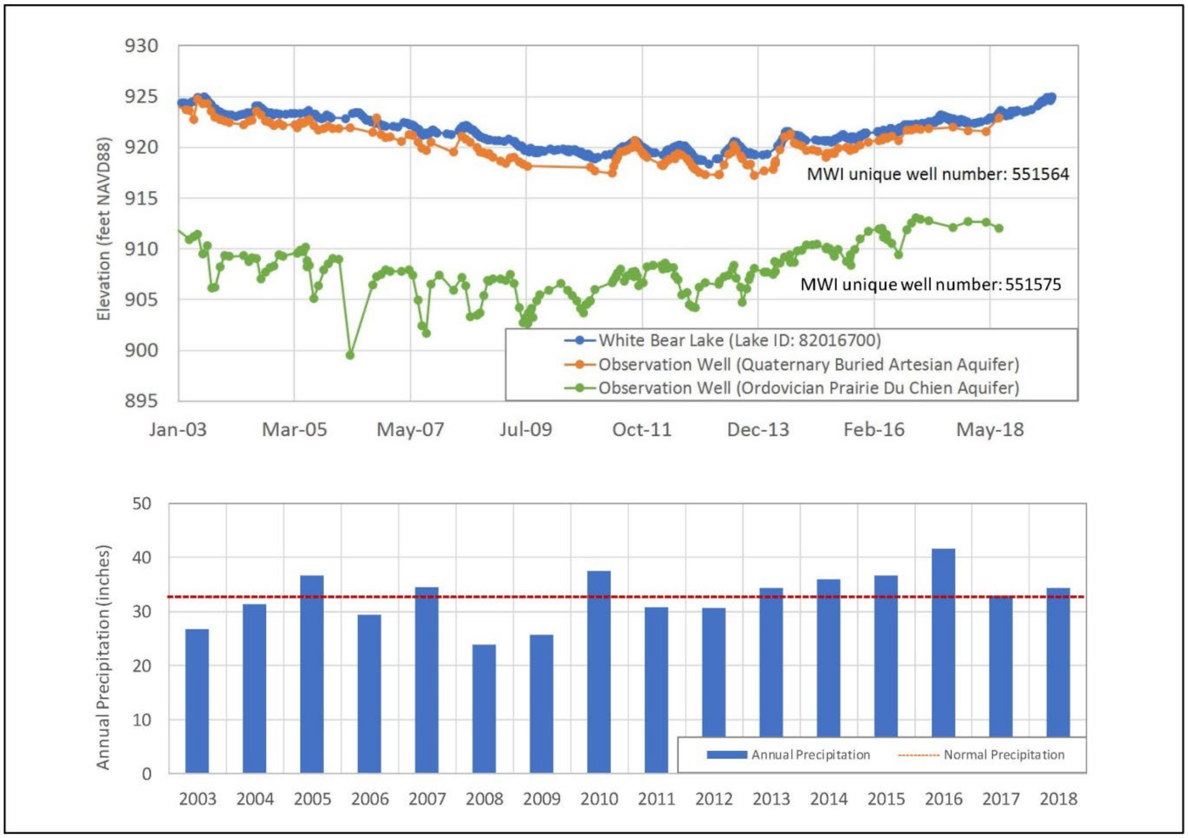


Figure B.12. Map showing locations of high capacity wells (greater than 10 million gallons per year) in the East Metropolitan Area.

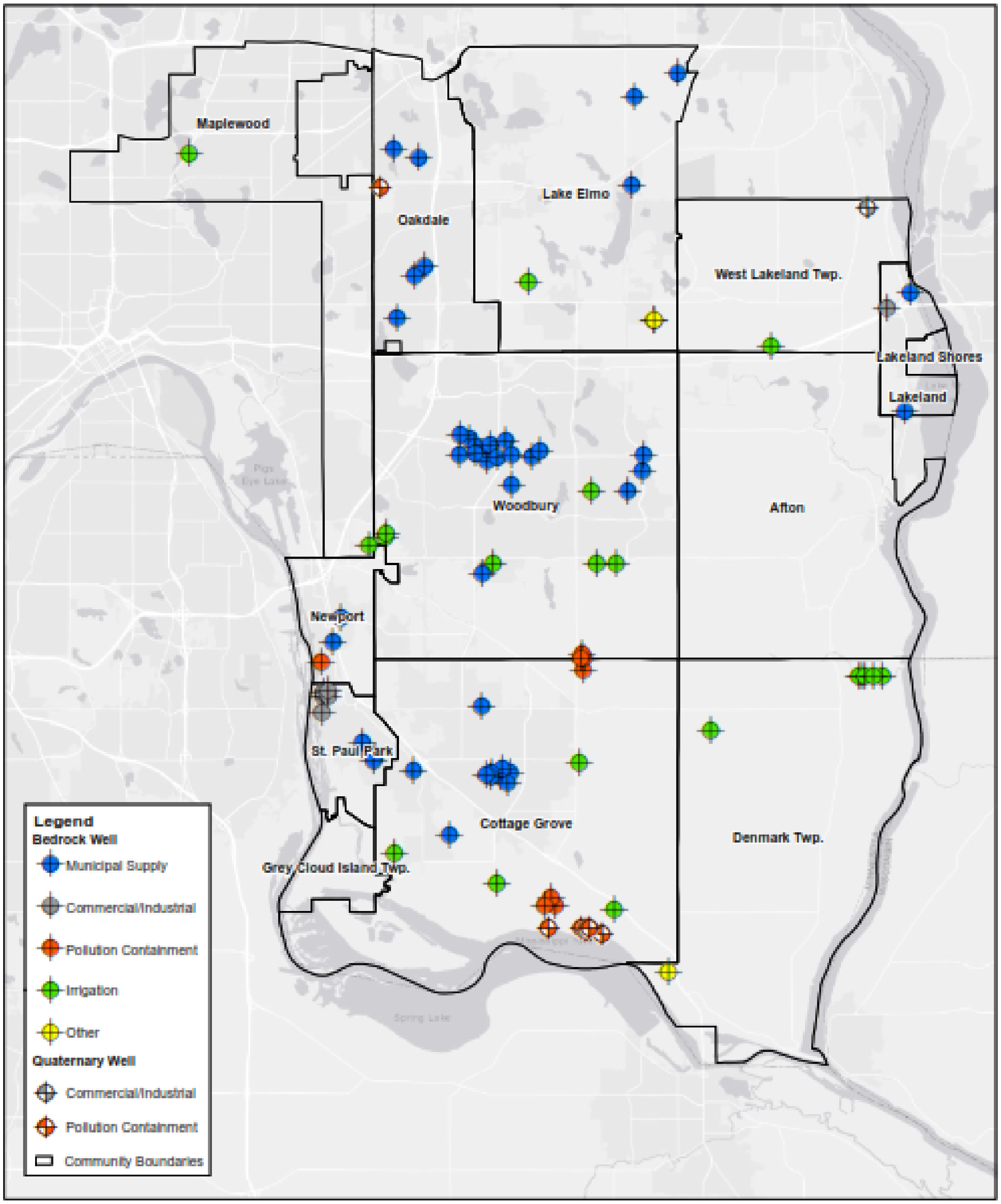


Figure B.13. A) Total groundwater pumped from municipal water supply wells for seven municipalities (Cottage Grove, Lake Elmo, Lakeland, Newport, Oakdale, St. Paul Park, and Woodbury), and B) Washington County population data.

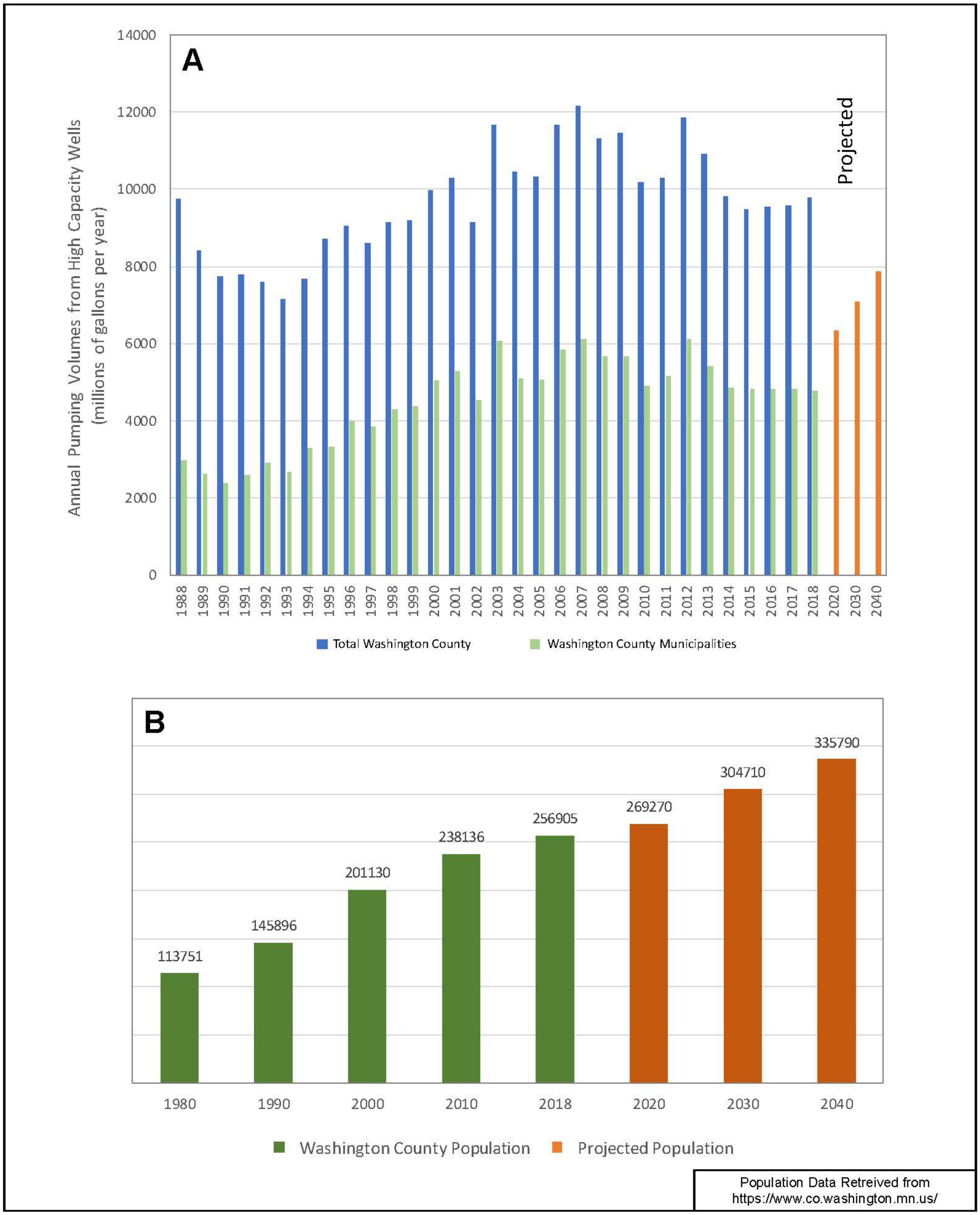


Figure B.14. Lake Isabelle water levels and water table elevation measured in an adjacent observation well.

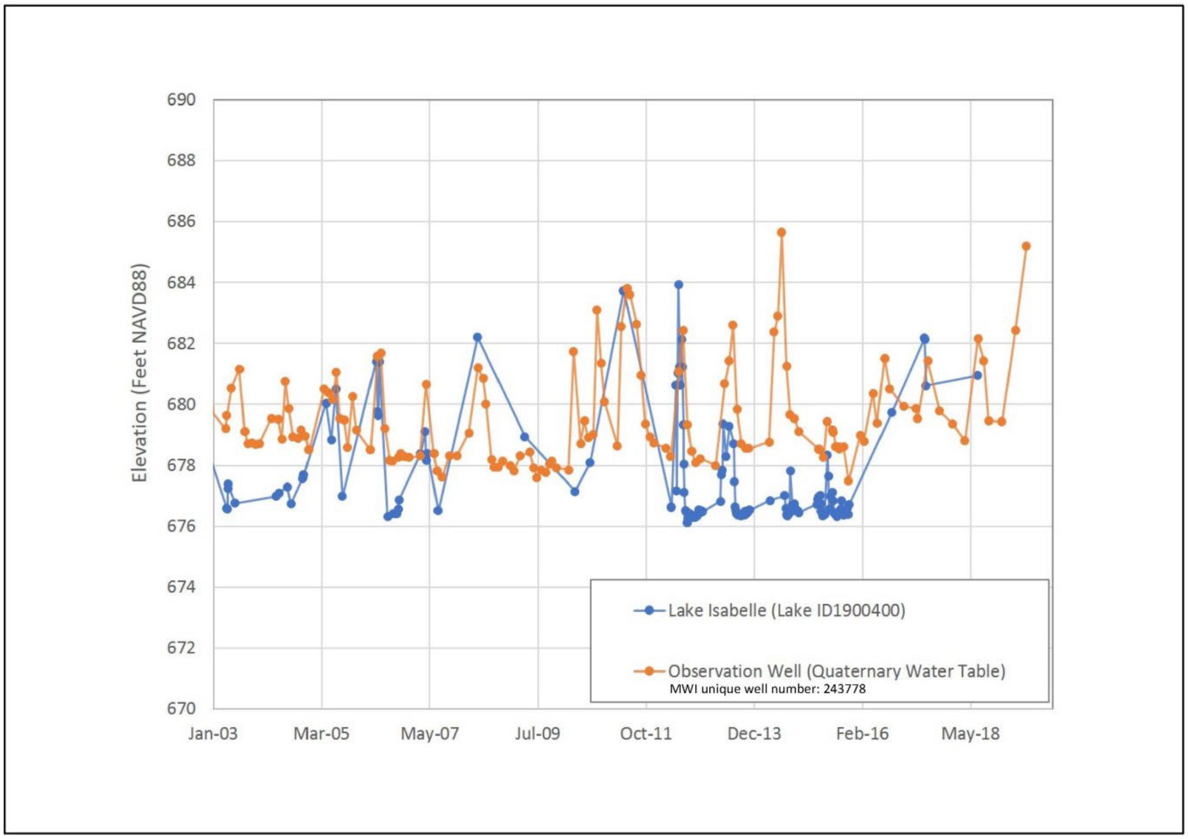


Figure B.15a. Average 2017 potentiometric surfaces for Mt. Simon Sandstone.

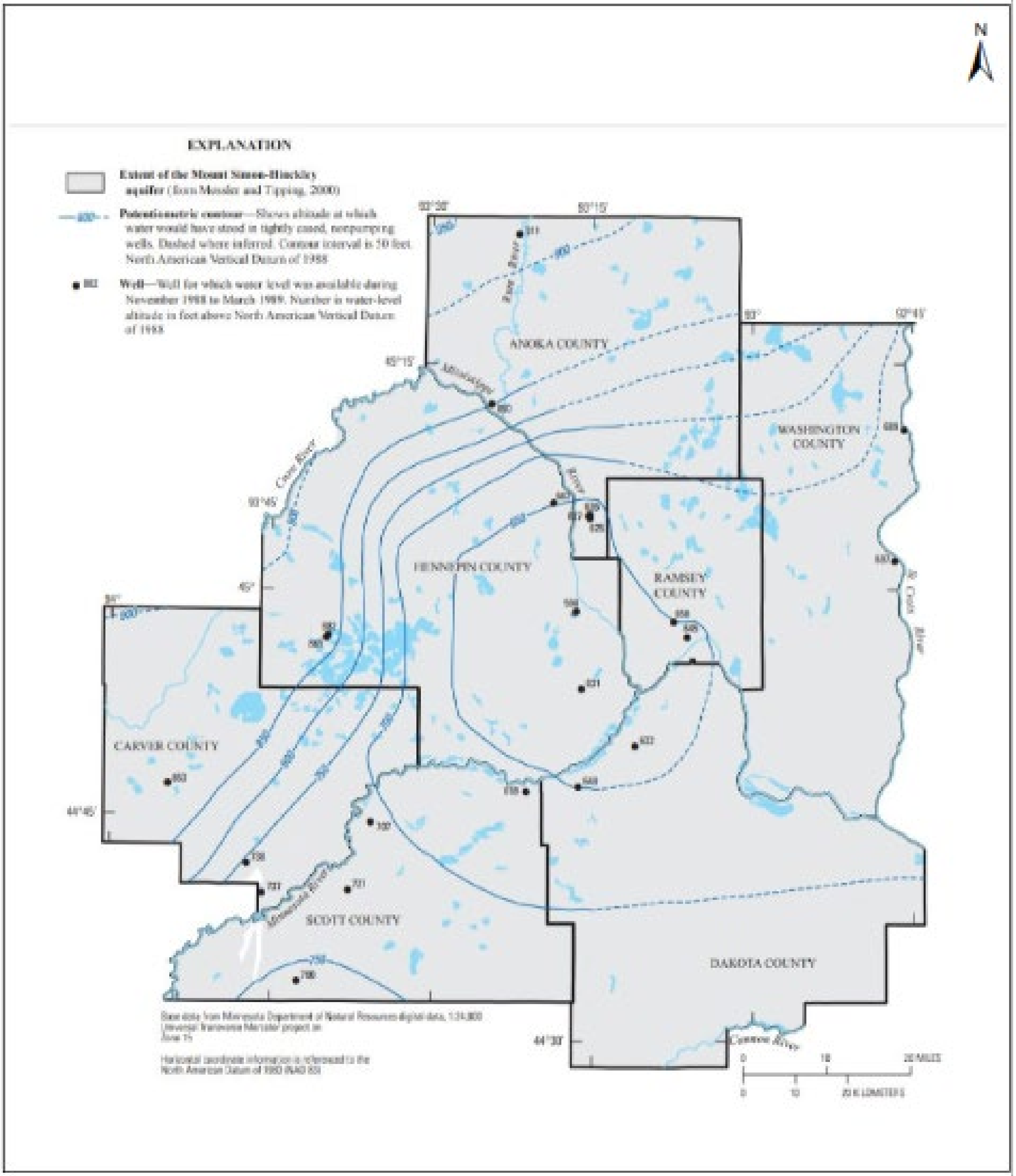


Figure B.15b. Average 2017 potentiometric surfaces for Wonewoc Sandstone and Tunnel City Group.

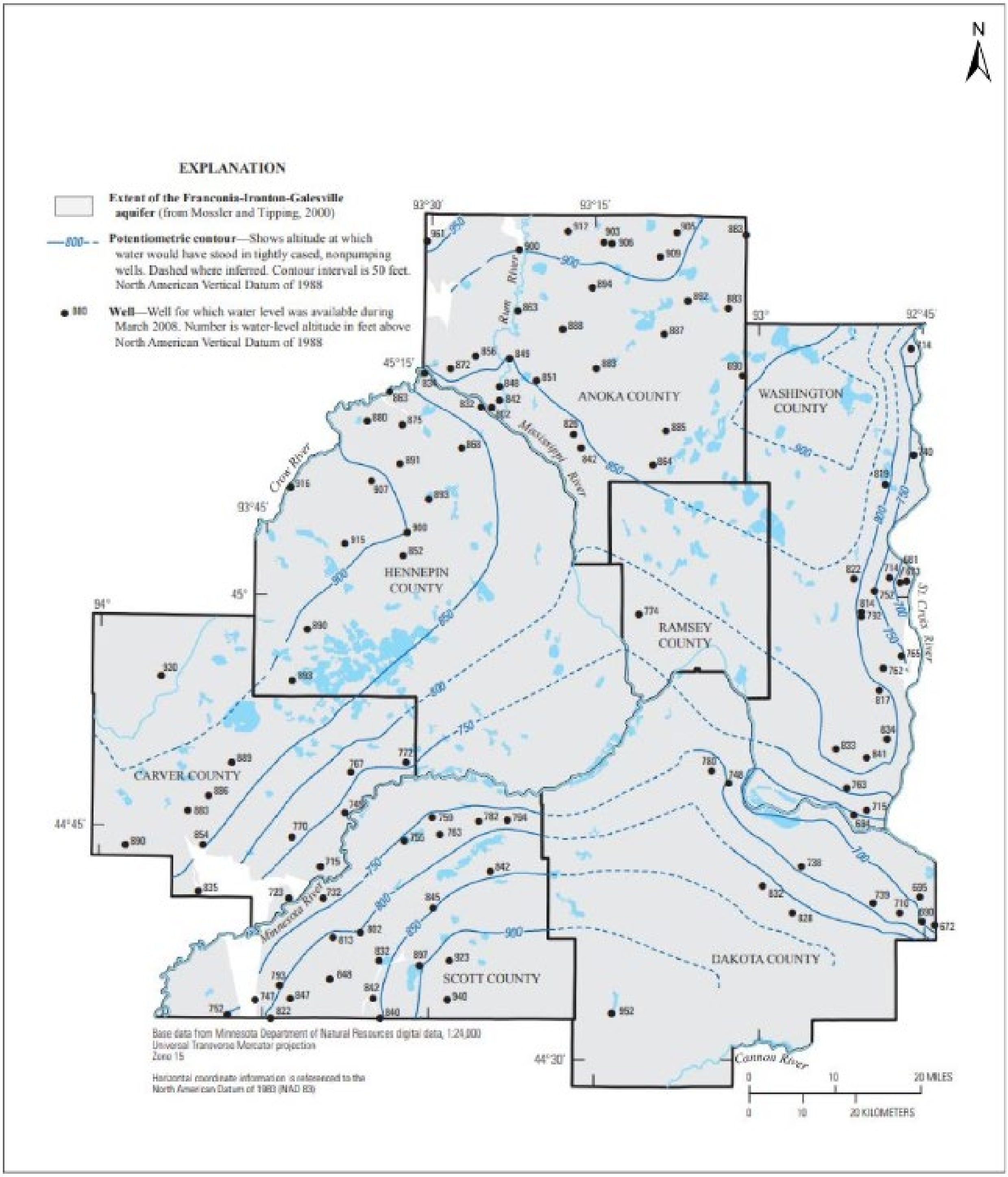


Figure B.15c. Average 2017 potentiometric surfaces for Jordan and Prairie Du Chien aquifers.

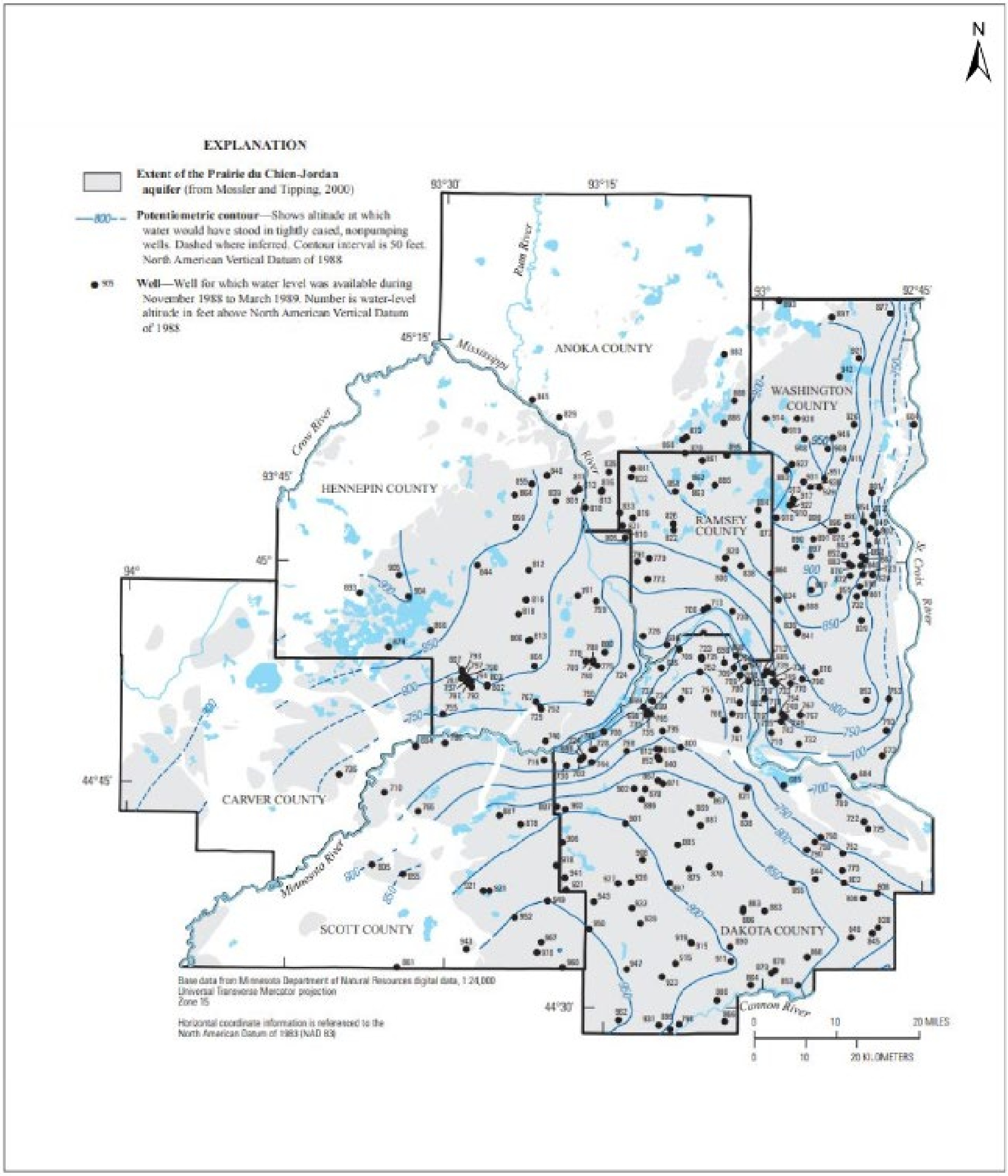


Figure B.16. Washington County potentiometric elevation in Prairie du Chien and Jordan bedrock aquifers (Berg, 2019).

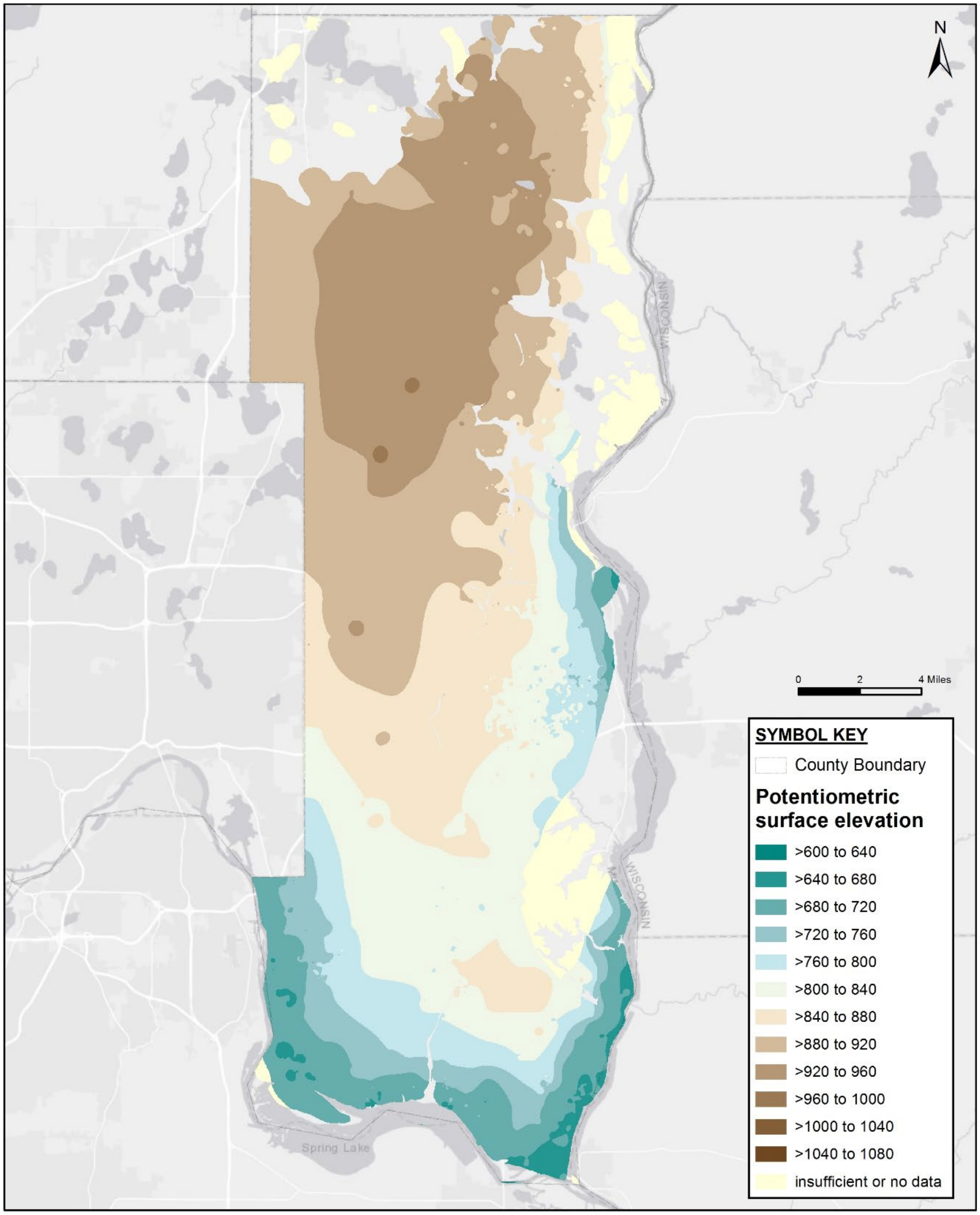


Figure B.17. Groundwater elevation measured in Prairie du Chien and Mt. Simon observation wells at Cottage Grove (MWI unique well numbers 817790 and 789735).

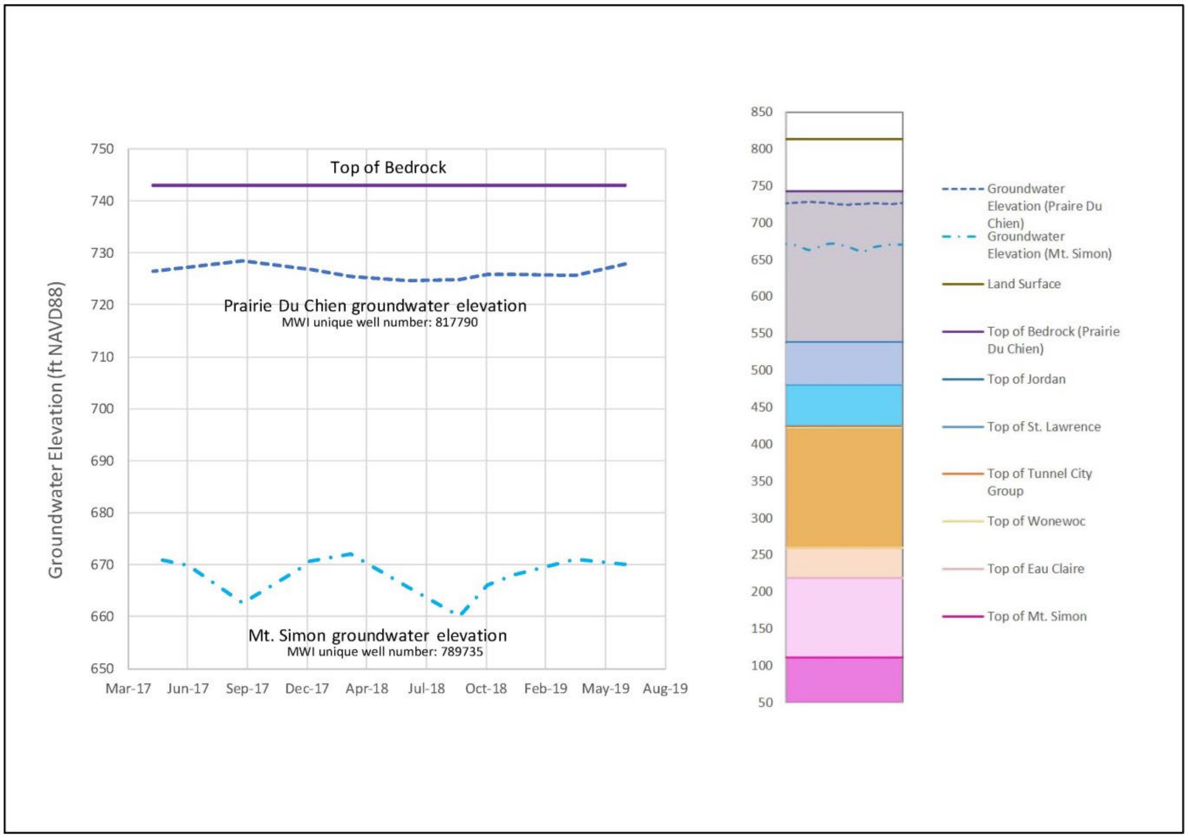
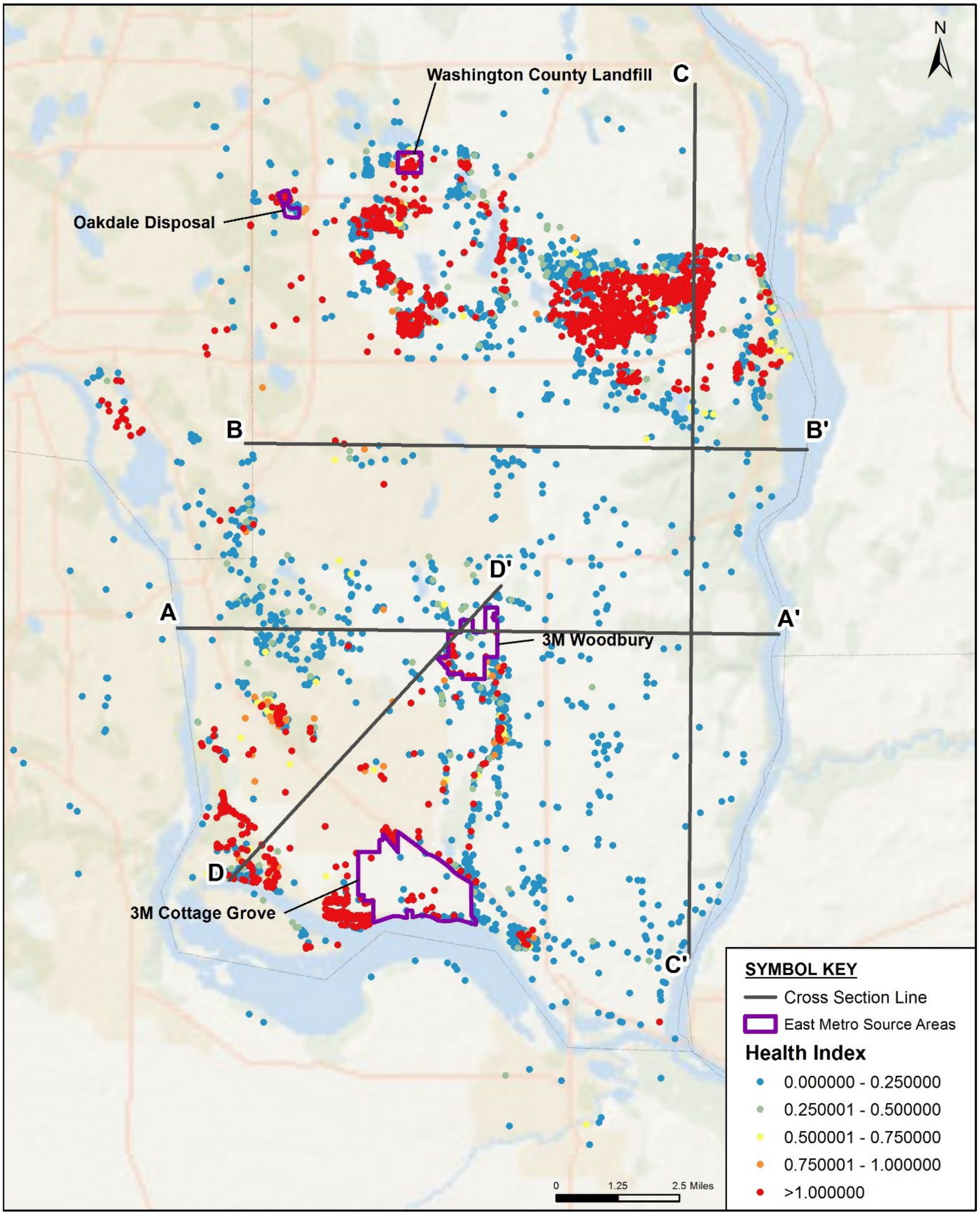


Figure B.18a. Cross-section locations with PFAS source areas and HI values from wells.



Background imagery service layer credits: Esri, GEBCO, NOAA, National Geographic, Garmin, HERE, Geonames.org, and other contributors.

Figure B.18b. Cross-section locations with PFAS source areas and HI values from wells (cont.).

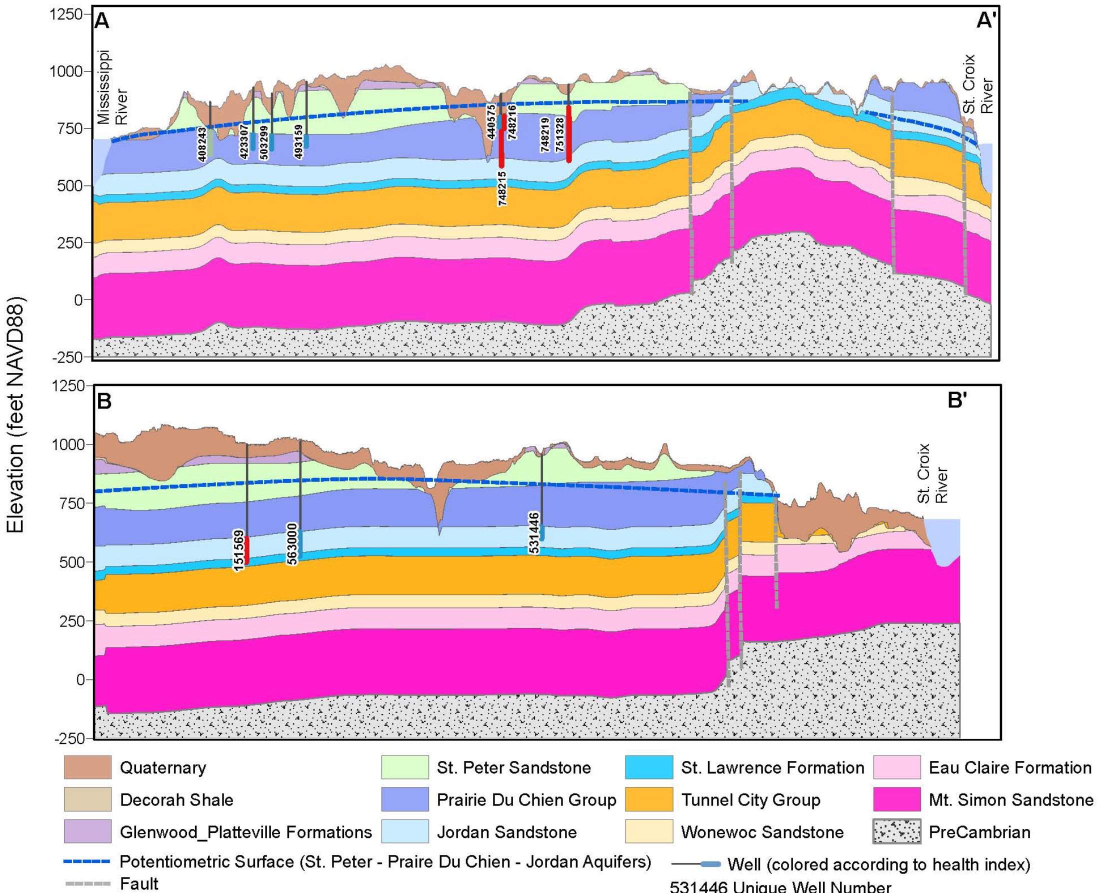


Figure 17. Cross-sections (continued)

Figure B.18c. Cross-section locations with PFAS source areas and HI values from wells (cont.).

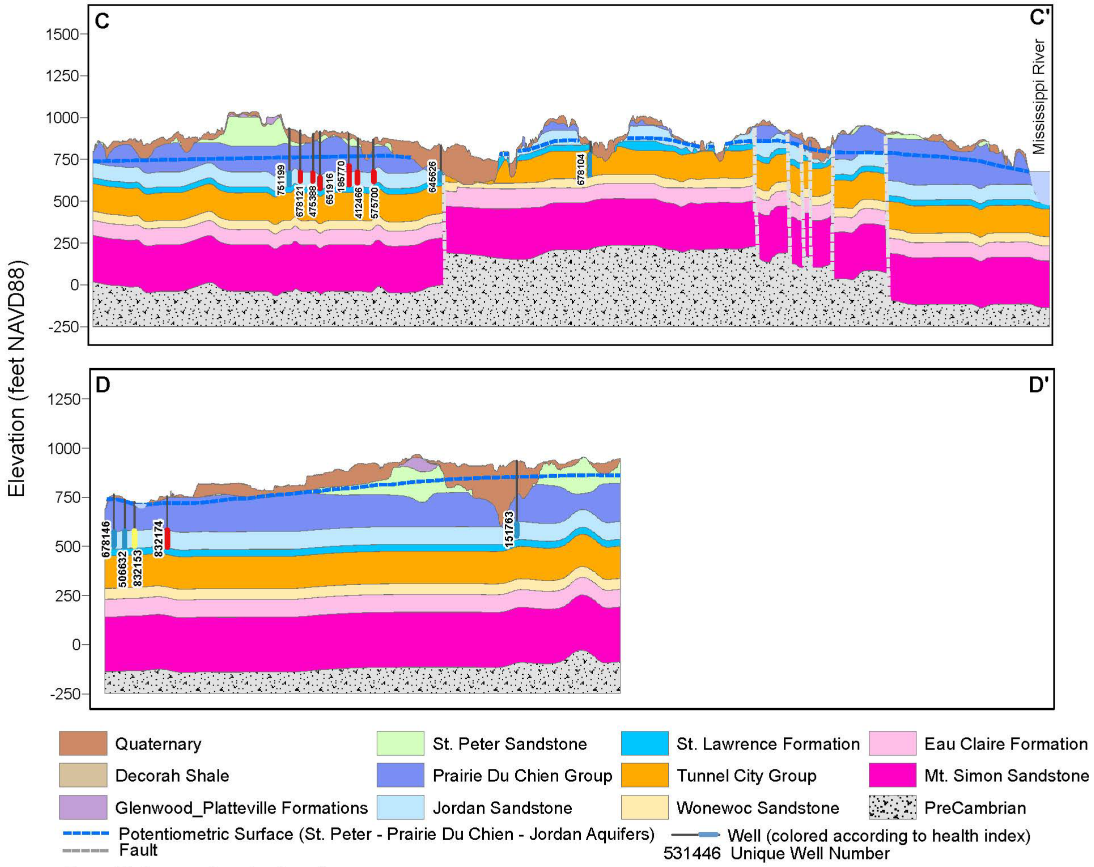


Figure 17. Cross-sections (continued)

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Appendix C. Numerical model description and construction

Groundwater modeling was conducted to support the evaluation of scenarios in this Conceptual Drinking Water Supply Plan (Conceptual Plan). The numerical groundwater flow model was developed to support the evaluation of scenarios that address drinking water quantity and quality for the 14 communities currently known to be affected by per- and polyfluoroalkyl substances (PFAS) contamination in the East Metropolitan Area, now and through 2040.

This appendix provides a summary of the groundwater model setup, calibration, and simulations developed for the East Metropolitan Area. The conceptual site model provided in Appendix B was used as the basis of the numerical groundwater model.

C.1 Introduction

C.1.1 Purpose and scope

The purpose of the groundwater model is to provide insight into the current groundwater flow system, and predict impacts to flow paths and groundwater resources through the year 2040 from the proposed scenarios. These flow paths and quantity estimates are based on projected groundwater recharge/precipitation rates, surface water elevations, and pumping volumes of the proposed scenarios. The year 2040 was selected because it was the time period for which there are population projections in the comprehensive plans and/or water supply plans for each community, which determine drinking water demand.

The objectives of the groundwater model are to:

1. Assess aquifer sustainability and viability of production rates for the proposed scenarios that may involve changes in pumping rates and/or new water supply wells
2. Analyze contaminant flow paths under the different proposed scenarios and climate conditions to determine the potential risk of PFAS contamination at existing and future wellfields
3. Evaluate potential impacts to groundwater resources in response to projected future groundwater use under the different proposed scenarios and climate conditions
4. Communicate model results and technical issues (e.g., flow direction, impacts to current remediation) internally and to stakeholders through visual representations of simulated flow systems.

This groundwater model may also be used in the future to further evaluate projects as they are refined following the development of this Conceptual Plan.

Results of the model predictions, as related to the objectives stated above, are provided in Appendix E of this Conceptual Plan.

C.1.2 Data and sources

The data compiled for the groundwater model were selected in collaboration with several agencies, local government units, and consultants, including the:

- Minnesota Pollution Control Agency
- Minnesota Geological Survey (MGS)
- Minnesota Department of Natural Resources (DNR)
- Minnesota Department of Health
- Metropolitan Council
- United States Geological Survey (USGS).

The data compiled and evaluated for the groundwater model are summarized in Table C.1.

Table C.1. Data compiled for the groundwater model.

Data	Source
3-meter digital elevation model (DEM)	DNR (2019f)
10-meter DEM	USGS (2019c, 2019d)
Lake bathymetry contours	DNR (2019d)
Bedrock elevation digital rasters	MGS (2019)
Surface water elevations at USGS gaging stations	USGS (2019b)
Surface water elevations at lake gaging stations	DNR (2019e)
Stream networks	USGS (2019a)
Potentiometric surfaces	Sanocki et al. (2009), Berg (2016)
Geologic maps for K zonation	Balaban and Hobbs (1990), Meyer and Swanson (1992), Setterholm (2010, 2013), Bauer et al. (2016), Tipping (2019)
Initial hydraulic conductivity estimates/ranges	Runkel et al. (2003), Tipping (2011), DNR (2020), MDH (2020)
Soil water balance (SWB) recharge	DNR (2019g)
Historical and current pumping volumes	DNR (2019a)
Groundwater elevations	DNR (2019c)
Baseflow estimates	DNR (2019b)
Effective porosity	Metropolitan Council (2019)

C.1.3 Previous modeling efforts

Previous groundwater modeling efforts near the current study area serve as a source for input parameters in this groundwater model in some instances (provided in Table C.2). These instances are discussed throughout this appendix.

Table C.2. Summary of previous groundwater modeling efforts.

Model	Additional information
Metro Model 3	• Developed to assist with regional water supply planning • Model domain includes an 11-county area in and around the Twin Cities Metropolitan Area • Grid has a uniform 500-meter x 500-meter cell size • Quasi-3D layers were used to represent confining units not explicitly included in the model (lower St. Peter Sandstone, lower Prairie Du Chien Group, and lower Tunnel City Group) • MODFLOW-NWT code was used for the simulation of groundwater flow • Accounts for temporal variations in aquifer stresses and changes in aquifer storage • SWB model was used to estimate recharge • Unsaturated Zone Flow package was used to simulate recharge in MODFLOW (i.e., a time lag between infiltration and recharge to the water table was accounted for during transient simulations)
Northeast Metro Lakes Groundwater-Flow Model	• Initially developed as a steady-state model by Jones et al. (2017) to assess groundwater and surface water exchanges, and the effects of groundwater withdrawals and precipitation on water levels of lakes in the northeast Twin Cities Metropolitan Area • Transient version of the model was developed by S.S Papadopulos & Associates (2017) to help understand and meet the challenges of sustainable groundwater use, with a focus on White Bear Lake • Additional refinement was performed by the DNR (2018) to incorporate new and updated data • Borrows much from Metro Model 3 but with a finer grid (125 meters x 125 meters), additional layers, and updated model parameters • Includes water budget/levels for several lakes (Lake package)
South Washington County	• Last version was a local refinement of Metro Model 2, with transient pumping capability • Built to evaluate potential impact of Woodbury's East Well Field on baseflow in Valley Creek • Parameter estimation to match a long-term pumping test
Minnesota Department of Health Wellhead Protection Areas	• Delineation of 10-year capture zones within pumped aquifer systems; some include surface drainage areas to vulnerable capture zones • Extent of some Wellhead Protection Areas defined by simple volume mapping technique for fractured aquifers • Local refinements of Metro Model 3 or other models

C.2 Model description and discretization

The groundwater model was developed and calibrated based on average 2016–2018 steady-state conditions using the three-dimensional control volume finite-difference groundwater flow code MODFLOW-USG Transport (Panday et al., 2013). The code was chosen because of the flexibility in the grid design around hydrologic boundaries and the ability to represent discontinuous layers. Additionally, faulted systems can be represented explicitly with MODFLOW-USG because of the model's ability to assign cell connections between different layers along faults. This allows for the continuity of flow between aquifers represented by different layers that are juxtaposed along a fault.

The model was constructed using Groundwater Vistas version 7 (ESI, 2017), a graphical user interface for the construction, simulation, and analysis of numerical groundwater flow models. The software was used as a pre-and post-processor for the three-dimensional MODFLOW-USG numerical model.

The model area contains the entire region shown in Figure C.1. Unlike previous finite-difference MODFLOW codes that use a rectangular grid, the MODFLOW-USG (simplified to MODFLOW elsewhere in this appendix) code uses an unstructured grid that can be fitted to an irregular model boundary without having to inactivate cells outside the model domain. The model domain was discretized (subdivided into smaller areas or cells) into a Voronoi polygon grid using AlgoMesh (HydroAlgorithmics, 2016) and imported into Groundwater Vistas. Since the grid is limited to 2 million nodes for particle tracking simulations, grid refinement was largely constrained to the area of interest. This is evident in Figure C.2a, where the polygon cell sizes vary from the smallest (most discrete) in southern Washington County and near features of interest such as high-capacity wells and rivers, to the largest cell sizes in areas of less interest in the model domain. In southern Washington County, the average polygon cell size is approximately 100 meters (328 feet). In northern Washington County, the average polygon cell size was increased to 500 meters (1,640 feet). In other areas, cell sizes are up to 1,200 meters (3,937 feet), but refinement outside Washington County was applied around high-capacity wells (greater than 10 million gallons per year) and along major rivers.

The top elevation of the model is land surface. The land surface in Minnesota was defined using a 3-meter (10-feet) resolution DEM (DNR, 2019c). The land surface in Wisconsin was defined using a USGS 10-meter (33-feet) resolution DEM (USGS, 2019c, 2019d). Bathymetry data for several lakes in the model domain were provided by the DNR (2019d) and incorporated into the DEM for accurate lake bottom elevations.

The grid was vertically discretized into 18 layers that represent the primary geologic units for the area (Table C.3). Each of the layers, with exception of Layer 6, has a variable thickness.

Table C.3. Model layers.

Layer	Hydrostratigraphic unit
1 through 5	Quaternary sediments
6	Shallow bedrock
7	Platteville-Glenwood Confining Unit
8	St. Peter Sandstone Aquifer
9	Lower St. Peter Confining Unit
10	Prairie Du Chien (Shakopee) Aquifer
11	Prairie Du Chien (Oneota) Confining Unit
12	Jordan Sandstone Aquifer
13	St. Lawrence Confining Unit
14	Upper Tunnel City Aquifer
15	Lower Tunnel City Confining Unit
16	Wonewoc Sandstone Aquifer
17	Eau Claire Confining Unit
18	Mt. Simon Sandstone Aquifer

Quaternary deposits are represented in Layers 1 through 5 (Table C.3). Vertical discretization of the Quaternary sediments was achieved by equally dividing the total quaternary thickness (ground surface through the top of bedrock) into five layers, so that in Washington County the average layer thickness is approximately 6 meters (20 feet).

The top of bedrock is equivalent to the base of Layer 5. Bedrock aquifers and confining units are represented in Layers 6 through 18 (Table C.3). MODFLOW-ready surfaces for bedrock units were created using rasters (i.e., grids) provided by MGS (2019). The bedrock rasters have assigned elevation values only where the bedrock unit is present. Since each model cell needs an assigned elevation to create MODFLOW inputs, areas with no coverage were assigned the elevation of the underlying surface present in those areas. The bedrock layers were constructed from the bottom up. The base elevation of the Mt. Simon Sandstone Aquifer (Layer 18) is equivalent to the top of pre-Cambrian basement rock (present everywhere). The top of the Mt. Simon is the base of the Eau Claire Confining Unit. Where the Mt. Simon is not present, the top elevation of the pre-Cambrian basement rock is equivalent to the base elevation of the Eau Claire. Each overlying bedrock layer (with the exception of Layer 6) was assigned elevations in the manner described above. Cells with thickness less than 0.1 meter (3 feet; where a bedrock unit is not present) were removed from the simulations using MODFLOW settings. The upper 18 meters (59 feet) of bedrock was made into a separate model layer (Layer 6) that represents shallow bedrock that is typically more weathered and fractured, with greater secondary porosity values. Layer 6 replaced the upper 18 meters (59 feet) of bedrock throughout the entire model domain and represents the areas where deeper units subcrop. The remaining layers, Layers 7 through 18, represent individual, competent deeper bedrock units.

C.3 Boundary conditions

Boundary conditions were placed along the edge of the model domain where groundwater was determined to enter or leave the model (perimeter boundaries) and at major rivers, lakes, and perennial streams (surface water boundaries).

An overview of surface water boundaries is presented in Section C.3.1 and an overview of perimeter boundaries is presented in Section C.3.2.

C.3.1 Surface water boundaries

Rivers, lakes, and perennial streams represented in the model were simulated using MODFLOW's RIV package (Figure C.3). This package is a head-dependent boundary in which flow across the boundary is dependent on the difference between a user-supplied head (i.e., stage or elevation) at the boundary and the model's calculated head adjacent to the boundary. Where the model's calculated head is higher than the user-supplied stage, groundwater flows into the river or lake and is removed from the model. If the stage is higher than the adjacent model's calculated head, water flows from the river or lake into the model. The rate of flow into and out of the river or lake (or flux) is also dependent on the hydraulic conductivity of the river or lakebed material, its presumed thickness, and the cross-sectional area of flow between the river or lakebed and the aquifer (referred to as river or lakebed conductance). Stage, bottom elevation, and conductance values assigned to RIV boundary cells are discussed below.

C.3.1.1 Surface water stage

River stages in the St. Croix, Mississippi, and Minnesota rivers were recorded at the USGS gaging stations (USGS, 2019b) and are summarized in Table C.4**.**

Table C.4. USGS gaging stations at St. Croix, Mississippi, and Minnesota rivers

River	USGS station	Location	2016–2018 average stage (meters)	2016–2018 average stage (feet)
St. Croix	5341550	Stillwater, MN	206.62	677.89
St. Croix	5344490	Prescott, WI	206.51	677.53
Mississippi	5344500	Prescott, WI	206.50	677.49
Mississippi	5331580	Hastings, MN (below Lock and Dam #2)	206.60	677.82
Mississippi	5331000	St. Paul, MN	210.13	689.40
Mississippi	5288500	Brooklyn Park, MN	245.01	803.84
Minnesota	5330920	Fort Snelling Park, MN	210.67	691.17

The average stage at each gaging station was calculated for the 2016–2018 timeframe (Table C.4). The St. Croix River stage was estimated by linear interpolation between gaging stations along the mid-line of the river. The river stage north of the Stillwater station was interpolated using the 3-meter (10-feet) DEM surface elevation along the mid-line of the river. The Mississippi River consists of a series of locks and dams that form navigation pools along the river; therefore, the river stage could not be estimated by interpolating between USGS gaging stations. Since pool elevation does not vary considerably annually, the 3-meter (10-feet) DEM was used to assign the river stage at dam locations (with the exception of Lock and Dam #2 at Hastings). The river stage between dams and USGS gaging stations was estimated by linear interpolation. The average 2016–2018 river stage calculated from data recorded at Fort Snelling Park, Minnesota, was assigned to each reach designated for the Minnesota River. Since only a small portion of the river is located within the model domain (approximately 4 miles) and the DEM surface elevation does not change along the centerline of the simulated stretch of the river, the average river stage at Fort Snelling Park was used for each of the boundary cells representing the Minnesota River (i.e., linear interpolation was not applied to these reaches).

Lake data, which include surface water elevations and lake surveys, are available on the DNR LakeFinder website (DNR, 2019e). Monitored lakes that have recorded stage for the 2016–2018 timeframe were assigned an average stage value for that period. Lake stages for unmonitored lakes were determined from the 3-meter (10-feet) DEM.

Perennial streams were identified using the USGS National Hydrography Dataset (USGS, 2019a). Stage data for perennial streams within the model domain are limited. Of the streams represented in the model, only the Vermillion River, the Kinnickinnic River, and Rice Creek have gaging stations with current water level data. With the exception of the Vermillion River, perennial streams represented in the model typically connect to a major river or lake. Stages along perennial streams were estimated by linear interpolation; recorded surface water levels were used where available. For stream segments that start and end at a lake, the stream stage was estimated using the assigned lake stage at the start and end of the stream segment. For streams that did not have a lake at the start of the stream but discharge into a lake or major river, stage along the stream was estimated using linear interpolation between an estimated stage at the head of the stream [based on the 3-meter (10-feet) DEM in Minnesota or the 10-meter (33-feet) DEM in Wisconsin] and the assigned river stage at the mouth of the stream. If a gaging station was located along the stream, the average 2016–2018 calculated stage was also used in the interpolation. The Vermillion River does not connect to a lake or major river and was divided into two segments for assigning stage: an upper segment that stretches between the model boundary near Vermillion and the USGS gaging station at Hastings, and a lower segment that stretches between the

USGS gaging station and where it intersects the model boundary southeast of Hastings. Stage along the upper segment was estimated using linear interpolation between an estimated stage at the start of the stream [based on the 3-meter (10-feet) DEM] and the average 2016–2018 calculated stage at Hastings. Stage along the lower segment was estimated using linear interpolation between calculated stage at Hastings and estimated stage at the end of the stream [based on the 3-meter (10-feet) DEM].

C.3.1.2 Surface water bottom elevation

The bottom elevation of the St. Croix River was assigned based on depth contours provided in an ArcGIS base map (National Geographic Society, 2013). Bathymetry data are not available for the Mississippi and Minnesota rivers; therefore, the river bottom was arbitrarily assigned an elevation 3 meters (10 feet) below stage. The bottom elevation for lakes with bathymetry data incorporated into the 3-meters (10-feet) DEM were assigned a bottom elevation equivalent to the top elevation of the model. Lakes lacking bathymetry data and perennial streams were estimated by using lake depths reported in the DNR LakeFinder (DNR, 2019e), or by subtracting a minimum of 1 meter (3 feet) from the stage where lake and stream depths were not available.

C.3.1.2 Conductance value

The conductance value assigned to the boundary cell restricts the amount of flow between the aquifer and the boundary. Conductance is the product of the hydraulic conductivity of the river or lakebed and the cross-sectional area of the surface water body within the model cell, divided by the river or lakebed thickness. Initial conductance values assigned to major rivers were calculated using an average cell area for the major rivers [approximately 15,000 square meters (161,459 square feet)], a hydraulic conductivity value of 0.1 meter per day (0.3 feet per day) and an assumed thickness of 1 meter (3 feet). The rivers were initially separated into reaches based on large changes in stage (such as at dams), width, or bottom elevation (where available), with designated river reaches not exceeding 8,000 meters (5 miles). However, in order to minimize the number of parameters for calibration, the reaches were combined so that the Mississippi River and the St. Croix River each have three reaches, while the Minnesota River consists of two reaches. Final conductance values for the rivers are provided in Table C.5.

Table C.5. Riverbed conductance for St. Croix, Mississippi, and Minnesota rivers

River	Conductance (square meters per day)	Conductance (square feet per day)
St. Croix	316–15,000	3,401–161,459
Mississippi	50–1,670	538–17,976
Minnesota	154–1,000	1,658–10,764

Lakes were separated into reaches according to the predominant lithology underlying the lake (till, sand, or organic sediment) in order to use an appropriate hydraulic conductivity value for calculating lakebed conductance. Since cells intersecting a lake outside of Washington County vary considerably in size, assigning unique conductance values to account for the various cell sizes would have resulted in numerous reaches. In order to minimize the number of reaches used for calibration, lakebed conductance for all lakes within the model domain were calculated using an average cell area for southern Washington County [approximately 10,000 square meters (107,639 square feet)]. By doing this, lakebed conductance for lakes outside Washington County is underestimated. Hence, simulated RIV lake flux is potentially too small. Calibrated lakebed conductance ranges between 24 and 4,779 square meters per day (258 and 51,441 square feet per day). The lower end of the range applies to lakes overlying till and the upper end of the range applies to lakes overlying sand. The calibrated conductance value applied to lakes overlying organic material is 55 square meters per day (592 square feet per day).

Perennial streams were also separated into reaches according to the predominant lithology underlying the stream for assigning streambed hydraulic conductivity. Since the stream area is much smaller than the boundary cell, the conductance was assigned using the stream length and estimated width within the cell. Calibrated streambed conductance ranges between 83 and 3,000 square meters per day (893 and 32,292 square feet per day). The lower end of the range applies to streams overlying organic material and the upper end of the range applies to streams overlying sand. The calibrated conductance value applied to streams overlying till is 147 square meters per day (1,582 square feet per day).

C.3.2 Perimeter boundaries

General and constant head boundaries were placed along the edge of the model domain where groundwater was determined to enter or leave the model (Figures C.4a–p). A constant head boundary was defined for all model layers on the eastern edge of the model where groundwater flows from the eastern side of the St. Croix River in Wisconsin into the model domain. The general head boundaries were assigned on the southwestern edges of the model in the deep bedrock units, and in the quaternary along the northwestern edge of the model. Locations and associated head values where flux was determined to enter or leave the model are based on monitoring well data, previous modeling efforts, and potentiometric surfaces produced by Sanocki et al. (2009) and Berg (2016).

C.4 Hydraulic conductivity

C.4.1 Quaternary layers

Layers 1 through 5 were zoned according to the lithologies present within each layer. Six zones were used to define hydraulic conductivity in Quaternary layers according to the following groupings (Figures C.5a–e):

- Zone 1 – Areas where the predominant texture is silt, clay, or clay loam
- Zone 2 – Areas where the predominant texture is sandy loam
- Zone 3 – Areas where the predominant texture is undifferentiated or alluvium
- Zone 4 – Areas where both till and sand/gravel are present within the layer
- Zone 5 – Areas where the predominant texture is sand and gravel
- Zone 6 – Areas of no data (primarily in Wisconsin).

Lithologic zones in Washington and Chisago counties were defined using sand and till rasters that are included with the County Geologic Atlas (Setterholm, 2010; Bauer et al., 2016). Point data provided by MGS (Tipping, 2019) were used to define zones in Ramsey, Dakota, and Anoka counties; along with digital quaternary maps included with the County Geologic Atlas (Balaban and Hobbs, 1990; Meyer and Swanson, 1992; Setterholm, 2013). The data used to map hydraulic conductivity zones provide the lithologies present within a layer; however, it does not account for the predominant lithology of the layer. For example, if a model cell encompasses sand, gravel, and till, zone 3 hydraulic conductivity was assigned to that cell; however, the predominant lithology may be either sand and gravel or till. Initial hydraulic conductivity ranges for Quaternary sediment were established using Tipping (2011). Final calibrated hydraulic conductivity values for Quaternary zones are provided in Table C.6.

Table C.6. Horizontal hydraulic conductivity (Kh) and vertical hydraulic conductivity (Kv) of Quaternary layers

Zone	Texture	Kh		Kv	
		(meters/day)	(feet/day)	(meters/day)	(feet/day)
1	Silt, clay, clay loam	1.83E-02	6.00E-02	1.83E-03	6.00E-03
2	Sandy loam	5.00E-01	1.64E+00	5.00E-02	1.64E-01
3	Undifferentiated, alluvium	1.00E+01	3.28E+01	1.00E-01	3.28E-01
4	Sand/gravel and till	8.00E+01	2.62E+02	8.00E+00	2.62E+01
5	Sand and gravel	8.00E+01	2.62E+02	8.00E+00	2.62E+01
6	No data	1.55E+00	5.09E+00	1.33E-01	4.36E-01

C.4.2 Bedrock layers

A uniform hydraulic conductivity was set for each bedrock layer, with the exception of Layer 6. Layer 6 replaces the uppermost 18 meters (59 feet) of bedrock and was assigned properties consistent with fractured bedrock. Hydraulic conductivity zones for the uppermost bedrock in Layer 6 were defined using digital bedrock maps provided with the County Geologic Atlas for each county represented in the model (Figure C.6). Therefore, a zone in Layer 6 represents a bedrock unit directly underlying Quaternary deposits. Average shallow fractured bedrock hydraulic conductivity values were assigned to bedrock units represented by those zones. The shallow bedrock layer could consist of more than one bedrock unit if the uppermost bedrock unit is less than 18 meters (59 feet). Therefore, a wider hydraulic conductivity range was used for calibration that encompasses the uppermost bedrock unit and the underlying bedrock unit. Average hydraulic conductivities assigned to deep and shallow bedrock units are based on aquifer test data within the model domain or published values where local data are not available (Runkel et al., 2003; DNR, 2020; MDH, 2020). Final calibrated hydraulic conductivity values for bedrock units are provided in Table C.7.

Table C.7. Horizontal hydraulic conductivity (Kh) and vertical hydraulic conductivity (Kv) of bedrock layers

Zone	Formation/group	Kh		Kv	
		(meters/day)	(feet/day)	(meters/day)	(feet/day)
7	Decorah Shale (shallow)	8.13E-02	2.67E-01	8.13E-04	2.67E-03
8	Glenwood/Platteville (shallow)	3.00E-02	9.84E-02	3.00E-03	9.84E-03
9	St. Peter Sandstone (shallow)	8.69E+00	2.85E+01	8.69E-01	2.85E+00
10	Prairie Du Chien Group (shallow)	3.06E+01	1.00E+02	3.06E-01	1.00E+00
11	Prairie Du Chien Shakopee (shallow)	1.50E+02	4.92E+02	3.00E+00	9.84E+00
12	Prairie Du Chien Oneota (shallow)	3.37E+00	1.11E+01	3.37E-02	1.11E-01
13	Jordan Sandstone (shallow)	1.00E+01	3.28E+01	1.00E-01	3.28E-01
14	St. Lawrence (shallow)	1.50E+01	4.92E+01	1.50E-02	4.92E-02
15	Tunnel City Group (shallow)	3.00E-01	9.84E-01	3.00E-03	9.84E-03
18	Wonewoc Sandstone (shallow)	3.00E+01	9.84E+01	3.00E+00	9.84E+00
19	Eau Claire (shallow)	2.59E-03	8.50E-03	2.59E-05	8.50E-05
20	Mt. Simon (shallow)	2.00E+01	6.56E+01	1.23E+00	4.03E+00
21	Glenwood/Platteville (deep)	3.45E-04	1.13E-03	3.45E-07	1.13E-06
22	St. Peter Sandstone (deep)	3.00E-01	9.84E-01	3.00E-03	9.84E-03
23	Lower St. Peter Confining Unit (deep)	1.37E-02	4.50E-02	1.37E-04	4.50E-04

Zone	Formation/group	Kh (meters/day)	Kh (feet/day)	Kv (meters/day)	Kv (feet/day)
24	Prairie Du Chien Shakopee (deep)	4.14E+00	1.36E+01	4.14E-02	1.36E-01
25	Prairie Du Chien Oneota (deep)	3.00E+00	9.84E+00	3.00E-02	9.84E-02
26	Jordan Sandstone (deep)	3.00E+00	9.84E+00	3.00E-01	9.84E-01
27	St. Lawrence (deep)	3.00E-02	9.84E-02	3.00E-05	9.84E-05
28	Tunnel City Mozamanie (deep)	8.29E+00	2.72E+01	8.29E-03	2.72E-02
29	Tunnel City Lone Rock (deep)	3.00E-04	9.84E-04	3.00E-06	9.84E-06
30	Wonewoc Sandstone (deep)	3.00E+00	9.84E+00	3.00E-01	9.84E-01
31	Eau Claire (deep)	3.00E-05	9.84E-05	3.00E-07	9.84E-07
32	Mt. Simon (deep)	6.00E+00	1.97E+01	6.00E-01	1.97E+00
33	Wisconsin shallow bedrock	3.00E+00	9.84E+00	3.00E-01	9.84E-01

C.5 Recharge

Areal recharge from precipitation for areas overlapping with the Northeast Metro Lakes Groundwater Flow (NMLG) model domain was estimated by the DNR (2019g) using the USGS SWB model (Westenbroek et al., 2010). Annual recharge rates for 2016, 2017, and 2018 were provided to Wood Environment & Infrastructure Solutions, Inc. (Wood) as raster data in units of inches per day. The rasters were averaged for the three years, converted to meters per day, and because the recharge rate was of finer resolution compared to the groundwater model cells outside of southern Washington County, an average raster value was calculated for each groundwater model cell in ArcGIS. An average recharge value of 0.152 meters (6 inches) per year was assigned to areas outside the NMLG model domain. Recharge was adjusted during calibration using a recharge multiplier. The recharge multiplier for the calibrated model is 0.75. Recharge for the calibrated model is shown in Figure C.7.

C.6 Pumping wells

Groundwater withdrawals from high-capacity wells (wells with permit totals that are greater than 1 million gallons per year) were incorporated into the model as Connected Linear Network (CLN) wells (Panday et al., 2013). The CLN wells, coupled with MODFLOW’s Well package, are capable of simulating the effects of wells that span more than one node (such as multi-aquifer wells).

Annual pumping volumes for high-capacity wells were provided by the DNR (2019a). The location coordinates for the wells were derived from the Minnesota Well Index (MDH, 2019). An average 2016–2018 pumping rate was calculated for each well. A total of 606 wells with permit volumes greater than 1 million gallons per year were imported into the model (Figure C.8). Wells that did not have a designated aquifer were not included in the model. A majority of these wells did not have significant pumping volumes (less than 10 million gallons per year). Wells within 200 meters (656 feet) of the model boundary were also not included. Although many of these wells did have pumping volumes greater than 10 million gallons per year, the wells were removed in order to avoid non-convergence or overlapping boundary conditions. The total wells removed make up less than 1% of the wells located within the model domain that have average 2016–2018 pumping volumes greater than 1 million gallons per year. The total volume not accounted for in the model is approximately 1,200 million gallons per year, and the total volume applied to the model is approximately 32,000 million gallons per year.

Ninety-eight of the simulated wells are pumping from Quaternary aquifers. A majority of pumping in the Quaternary is used for irrigation, pollution containment, and commercial/industrial supplies. The pumping volumes applied to Quaternary aquifers range from less than 1 million gallons per year to greater than 400 million gallons per year. The total volume applied to the model from Quaternary wells is approximately 2,700 million gallons per year. One of the permitted wells located along the Mississippi River in Ramsey County (DNR permit number: 1965-0271) was simulated using MODFLOW's Drain package. The well is used for groundwater dewatering. The average 2016–2018 volume for the well is approximately 576 million gallons per year. Simulating this withdrawal volume using MODFLOW's Well package was causing a long run time and issues with convergence; therefore, the well was converted to a drain and simulated using MODFLOW's Drain package. Construction details such as depth and diameter of the drain are not available. The depth and conductance value applied to the drain is 10 meters (33 feet) and 75 square meters (807 square feet) per day, respectively. Despite the large conductance value, the drain was only able to remove approximately 12% of the actual volume. Since the drain was not considered significant to the model's calibration and predictions, no further effort was made to simulate the full average 2016–2018 volume for the drain.

Bedrock aquifers are heavily utilized for municipal supply but are also utilized for industrial processing, irrigation, and pollution containment. The average pumping volumes applied to bedrock aquifers range between less than 1 gallon to greater than 600 million gallons per year. The maximum pumping applied to bedrock aquifers occurs at a pollution containment well in the Prairie du Chien. Of the simulated bedrock wells, 346 wells have pumping volumes greater than 10 million gallons per year. Ninety-five of the wells have pumping volumes greater than 100 million gallons per year. The total volume applied to bedrock aquifers is approximately 29,000 million gallons per year. A majority of this volume is produced from the Prairie du Chien and Jordan Sandstone aquifers. Approximately 16% of the total volume is produced from deeper aquifers (Tunnel City through Mt. Simon).

MODFLOW's Well package has an automated flow-reduction capability (Niswonger et al., 2011). If the saturated thickness of the model cell containing the CLN well is less than 1%, the pumping rate will be reduced. Seven CLN nodes in the calibrated model had reduced rates. The flow reduction from the seven CLN nodes was spread throughout the model with a combined total reduction of 1,048 cubic meters per day (192 gallons per minute). The flow reduction accounts for less than 1% of the total applied production and is considered negligible. The reduction in rates could be due to several factors, including, but not limited to, inaccurate production rates associated with using average rates and an unknown quality of rate measurements, areas where the aquifer thickness and/or aquifer hydraulic conductivity is not accurately represented in the model, completion intervals represented in the model differ from actual, hydraulic conductivity is homogenous in the model for each bedrock unit and lumped for shallow units, and heterogeneity leading to greater production rates in the areas of these wells may not have been captured.

C.7 Solver

The Sparse Matrix Solver (SMS) was used to solve the system of equations formulated by MODFLOW-USG. The SMS includes the unconfined Newton Raphson linearization option for upstream weighting, as provided in MODFLOW-NWT (Niswonger et al., 2011). Various settings used by the SMS package were adjusted until optimal settings were reached to achieve model convergence and a mass balance error that is less than 0.1%. An explanation of settings is not discussed here as it is beyond the scope of this report; however, the various options available in the SMS package are documented by Panday et al. (2013). Key solver settings for the calibrated model are summarized in Table C.8.

Table C.8. Key solver settings for the calibrated model

Parameter	Setting
Solver	SMS
Head change criterion (meters)	0.0003
Nonlinear method	Delta-Bar-Delta/Newton Raphson linearization
Linear solution method	Preconditioned conjugate gradient
Flow residual tolerance (meters cubed per day)	130

C.8 Calibration

The groundwater flow model was calibrated by adjusting model input parameters until the model simulated head matched average 2016–2018 groundwater elevations (DNR, 2019c) within an acceptable level of accuracy. The groundwater elevations were recorded at DNR observation wells and City of Woodbury observation wells (Table C.9). Additionally, simulated potentiometric surfaces were compared to potentiometric surfaces generated from measured groundwater elevations (Sanocki et al., 2009) as a qualitative evaluation of the simulated head distribution. Parameters adjusted during calibration included hydraulic conductivity, recharge, and river and lakebed conductance. Observed and simulated head at calibration targets is provided in Table C.9.

Table C.9. Observed and simulated head at calibration targets.

Well identification	X	Y	Layer	Observed head (meters)	Computed head (meters)	Residual head (meters)
227977	498129	4990823	1	281.04	281.15	-0.11
243778	512311	4953877	1	207.33	208.89	-0.57
272110	490344	5003193	1	271.49	271.72	-0.23
551575	500438	4990730	1	280.69	282.50	-1.81
591980	485678	4966748	1	221.63	222.41	-0.78
789993	490131	5012062	1	273.80	272.55	1.25
816925	509923	5005835	1	287.47	284.56	2.92
270208	510906	5021186	2	269.35	270.00	-0.65
482154	485678	4966748	2	221.96	222.51	-0.55
623066	512270	4990960	2	266.85	260.31	6.54
675586	513198	4973198	2	249.04	248.66	0.38
208135	490349	5003179	3	269.65	271.63	-1.98
227033	516232	4995471	3	249.00	250.78	-1.77
243178	490130	5012065	3	270.32	272.55	-2.23
243746	497303	4957498	3	230.50	235.29	-4.79
244359	498073	4990791	3	277.07	280.97	-3.90
482156	485749	4966962	3	221.56	221.70	-0.15
623058	498450	4982785	3	292.06	289.65	2.41
783243	509539	5003085	3	288.48	285.48	3.01
208137	490349	5003185	4	269.53	271.63	-2.10

Well identification	X	Y	Layer	Observed head (meters)	Computed head (meters)	Residual head (meters)
809291	496340	4983044	4	257.71	264.55	-6.84
227032	516232	4995471	5	240.27	250.70	-10.43
244346	498447	4982783	5	286.26	287.38	-1.12
763777	507076	5031910	5	264.04	268.64	-4.60
792506	506856	4967627	5	258.45	251.77	6.68
797201	502799	4988571	5	281.26	281.96	-0.70
797202	508493	4977346	5	268.04	267.99	0.046
123527	517936	4974847	6	208.22	210.05	-1.83
195689	509532	5003091	6	288.38	285.43	2.95
195728	513502	5007358	6	283.18	280.23	2.95
551565	507798	4997116	6	291.15	286.26	4.89
551576	501029	5003204	6	279.71	280.21	-0.50
761596	498645	4974804	6	219.20	228.28	-9.08
767633	498759	4973940	6	215.27	219.29	-4.03
799890	506858	4967626	6	258.42	251.75	6.67
799898	512824	5024652	6	266.43	271.95	-5.52
826487	509466	5005300	6	288.23	284.87	3.37
219492	511906	5026490	6	268.39	270.27	-1.89
123548	517940	4974844	6	208.46	210.03	-1.57
200105	488506	4983804	8	259.48	263.27	-3.79
124395	502831	4999575	10	283.49	284.52	-1.03
481807	498135	4990822	10	275.82	279.85	-4.03
551564	500438	4990730	10	278.05	278.51	-0.46
551577	506308	4984368	10	274.42	278.50	-4.07
675583	510867.3	4972215	10	258.14	262.22	-4.08
675585	513197.9	4973200	10	249.10	249.09	0.01
722705	512389.5	4971975	10	255.96	258.08	-2.12
767882	502422	4969799	10	237.13	238.79	-1.66
767883	504469	4970029	10	256.78	250.63	6.15
799899	499982.5	4993553	10	277.87	281.23	-3.36
817790	502791	4960821	10	221.41	212.66	8.76
825069	502796	4988561	10	281.34	281.42	-0.08
200054	501030	4975379	12	245.21	251.92	-6.71
200660	492491	4970981	12	223.40	225.61	-2.21
200874	501102	4981659	12	262.17	267.67	-5.50
206833	488966	4987763	12	257.94	264.31	-6.36
274285	517080	4968726	12	239.04	236.19	2.85
675580	509509.2	4972862	12	259.38	259.54	-0.16
675584	513199	4973199	12	249.27	249.17	0.10
763366	504885	4970704	12	258.33	253.85	4.48
767884	504468	4970040	12	254.15	250.23	3.92

Well identification	X	Y	Layer	Observed head (meters)	Computed head (meters)	Residual head (meters)
767885	502418	4969799	12	236.12	238.65	-2.53
799891	506861	4967626	12	258.03	251.37	6.67
799900	500103	4993452	12	277.89	281.42	-3.53
817789	502840	4960835	12	222.42	212.90	9.52
826486	509464	5005299	12	287.85	284.89	2.97
225652	486332	4988251	12	257.96	263.75	-5.79
244592	517117	4968757	13	221.53	229.14	-7.61
595649	512531.7	4991032	13	263.91	257.41	6.50
800954	506864	4967626	14	250.24	245.98	4.26
791036	500100	4993449	14	268.77	269.79	-1.01
767868	516538	4966106	16	225.78	224.00	1.78
826484	509468	5005298	16	252.61	256.89	-4.28
227031	516232	4995471	16	239.84	250.66	-10.81
603059	517060	4975967	16	233.44	220.10	13.33
225647	500127	4993313	18	219.77	225.79	-6.03
783609	516538	4966103	18	213.44	222.85	-9.41
785579	493532	5001562	18	225.98	236.33	-10.34
789735	502841	4960831	18	203.07	211.00	-7.93

The difference between observed and simulated head is the residual head. A positive residual is a result of a lower model simulated head compared to the observed head and a negative residual is a result of a higher simulated head compared to the observed head. The distribution of residual head is shown in Figures C.9a–l. The average residual head (i.e., mean error) for the calibrated model is -0.88 meters. A perfectly calibrated model would have a mean error of zero; however, a small mean error does not necessarily indicate a well-calibrated model since positive and negative errors can cancel each other out. The negative mean residual for the calibrated model indicates that simulated heads are generally higher than observed heads at calibration targets. The negative mean residual bias can also be observed in a plot of residual versus observed heads at calibration targets (Figure C.10). More of the plotted residuals are negative; however, the points are generally randomly distributed as they should be for a spatially, non-biased calibrated model. The negative bias is reasonable, considering the model is calibrated assuming steady state (long-term constant with time) based on a wet recharge condition that has only been observed for the last five years. Additionally, there is a large negative bias associated with the deeper layers, particularly the Mt. Simon (layer 18). The Mt. Simon experienced historically greater pumping rates compared to the applied average pumping rates from 2016 to 2018. The recovery associated with decreased pumping in the Mt. Simon may not have been achieved in the 2016–2018 time period, which is inherently assumed in the model calibration approach taken.

A plot of simulated versus observed heads at calibration targets is shown in Figure C.11. If the model were perfectly calibrated, the plotted points would fall on a line with a 45-degree slope such that simulated heads would equal observed heads at calibration targets. The less scatter around the line, the better the matching of observed heads with simulated heads, and a theoretically better calibration. The plot of simulated versus observed heads for the calibrated model shows some scatter from the theoretical line. However, the degree of scatter is within acceptable statistical criteria, where the majority of the data fall within the 95% prediction interval, providing confidence in the model calibration (Figure C.11).

The model accuracy was calculated using the scaled root mean square (RMS) error between actual head measurements and model simulated head measurements. The RMS error is the average of the squared differences in measured and simulated heads. The ratio of the RMS error to the total head loss over the model domain is the scaled RMS error. Normally this value should be less than 10% for a well-calibrated model. The scaled RMS for the calibrated model is 5.5%.

A comparison of simulated potentiometric surfaces with those depicted by Sanocki et al (2009; Figures C.12a through C.12e) was used as a qualitative measure of the simulated head distribution. Overall, there is a good match between potentiometric surfaces. The simulated water table and potentiometric surfaces for bedrock aquifers are shown in Figures C.12f through C.12h. The groundwater model simulated the observed groundwater divide in Washington County (Berg, 2019; Sanocki et al, 2009). Groundwater flow in the Quaternary and bedrock aquifers (with exception of Mt. Simon) is generally toward the St. Croix and Mississippi rivers. Lakes and small perennial streams serve as both points of recharge and discharge within the model domain. The model did not simulate the regional cone of depression in the Mt. Simon. Simulated heads in the Mt. Simon were higher than average 2016–2018 measured heads. One possible reason may be due to the model simulating higher leakage than is occurring in areas where shallow bedrock directly overlies the Mt. Simon (primarily in the northern part of the model domain). However, it seems more likely that average 2016–2018 pumping is an inadequate timeframe for calibration to the Mt. Simon head targets (i.e., a longer period of pumping is needed to match simulated and observed heads).

C.8.1 Baseflow

Baseflow was estimated by the DNR (2019b) for two gaging stations along Valley Creek and a gaging station along Browns Creek (Table C.10).

Table C.10. Estimated and model simulated baseflow at Valley and Browns creeks.

Year	2016 (cfs)	2017 (cfs)	2018 (cfs)
Station 37067001 (Valley Creek at Afton)			
Average flow	4.8	5.1	NA
Estimated average baseflow	4.8	5.0	NA
Simulated baseflow		0.77	
Station VA0010 (Valley Creek at Putman Boulevard)			
Average flow	20	22	19
Estimated average baseflow	20	22	18–19
Simulated baseflow		24	
Station BR0003 (Browns Creek and Dellwood Road)			
Average flow	8.8	8.8	8.5
Estimated average baseflow	6.1–7.2	6.7–7.7	6.2–7.2
Simulated baseflow		7.6	

cfs = cubic feet per second, NA = not available.

Baseflow estimates were compared to simulated flows at these locations to further assess the model's calibration. Estimated and simulated baseflows at Valley Creek (Afton) were approximately 5 and 0.77 cubic feet per second, respectively. Estimated and simulated baseflows at Valley Creek (Putman

Boulevard) were approximately 20 and 24 cubic feet per second, respectively. Simulated baseflow at Brown's Creek was 7.6 cubic feet per second compared to the estimated baseflow of approximately 7 cubic feet per second. Additionally, streamflows were measured near the mouth of Trout Brook between 2004 and 2006. Baseflows estimated during this period varied from less than 1 cubic feet per second to 4.5 cubic feet per second, but was on average approximately 1 to 2.5 cubic feet per second (DNR, 2019b; Emmons & Olivier Resources, 2009). Simulated baseflow for Trout Brook was approximately 2.5 cubic feet per second.

C.8.2 Water Balance

The water balance for the model is summarized in Table C.11.

Table C.11. Model water balance.

Boundary condition	Inflow (millions of gallons per day)	Outflow (millions of gallons per day)
Well	0	86.52[a]
Perimeter boundaries	1,001.86	597.60
River	183.96	846.76
Recharge	340.82	0
Total	**1,526.64**	**1,530.88**

a. Includes well simulated as a drain.

A majority of the water entering the model is from groundwater flux along the perimeter of the model. Recharge from precipitation contributes approximately 22% of the total flow into the model, while recharge from surface water boundaries contributes approximately 12% of inflow. Groundwater leaving the model along perimeter boundaries accounts for approximately 39% of the water removed from the model. Discharge along perimeter boundaries primarily occurs in bedrock layers beneath the Mississippi River where head-dependent boundary cells were placed to simulate groundwater flux out of the model domain. Discharge at surface water boundaries removes approximately 55% of water from the model, while pumping wells remove approximately 6%. The water balance error for the model is approximately 0.27%. As shown in Table C.10, a slightly larger amount of water is leaving the model compared to the amount of water entering the model from recharge, rivers, and, flux along perimeter boundaries.

C.9 Effective porosity for particle tracking

Effective porosity values were uniformly applied to each model layer, with the exception of Layer 6 for particle tracking analysis (discussed in Appendix E). Porosity values in Layer 6 were assigned according to the hydraulic conductivity zone (which is based on the uppermost bedrock layer). Porosity values used in the model for predictive scenarios were provided by DNR as a range of values for each formation in written communication. However, the DNR did not provide porosity values for all of the formations represented in the model including the Decorah Shale, Glenwood/Platteville, and Eau Claire confining units. The formations missing values were assigned porosity values using data from the Wisconsin Geological and Natural History Survey (WGNHS, 2020). The lower end of the range of values were selected to provide conservative predictions of transport (lower porosity values results in greater distances traveled over the same amount of time), and then were refined within the ranges to a final set after comparison of particle travel times to arrival of known PFAS contamination at municipal wells in areas near sources (Table C.12). The particle tracking analysis was performed using mod-PATH3DU (S.S. Papadopulos & Associates, 2017).

Table C.12. Effective porosity used for particle tracking analysis.

Hydrostratigraphic unit	Porosity
Quaternary sediments	0.100
Decorah Shale	0.010
Glenwood/Platteville	0.043
St. Peter Sandstone	0.100
Lower St. Peter confining unit	0.100
Prairie du Chien Group	0.010
Jordan Sandstone	0.100
St. Lawrence Formation	0.050
Tunnel City Group	0.060
Wonewoc Sandstone	0.100
Eau Claire Formation	0.130
Mt. Simon Sandstone	0.100

C.10 Model Limitations

The calibrated model is a regional scale model based on average hydraulic parameters and three-year average recharge rates, pumping rates, and river and lake stage values. The model reasonably simulates regional groundwater flow within statistically acceptable criteria. Although the three-dimensional, steady-state groundwater flow model is considered to be calibrated within statistically acceptable criteria and is appropriate for evaluating various pumping scenarios outlined in the Conceptual Plan, there are limitations to the model that should be noted.

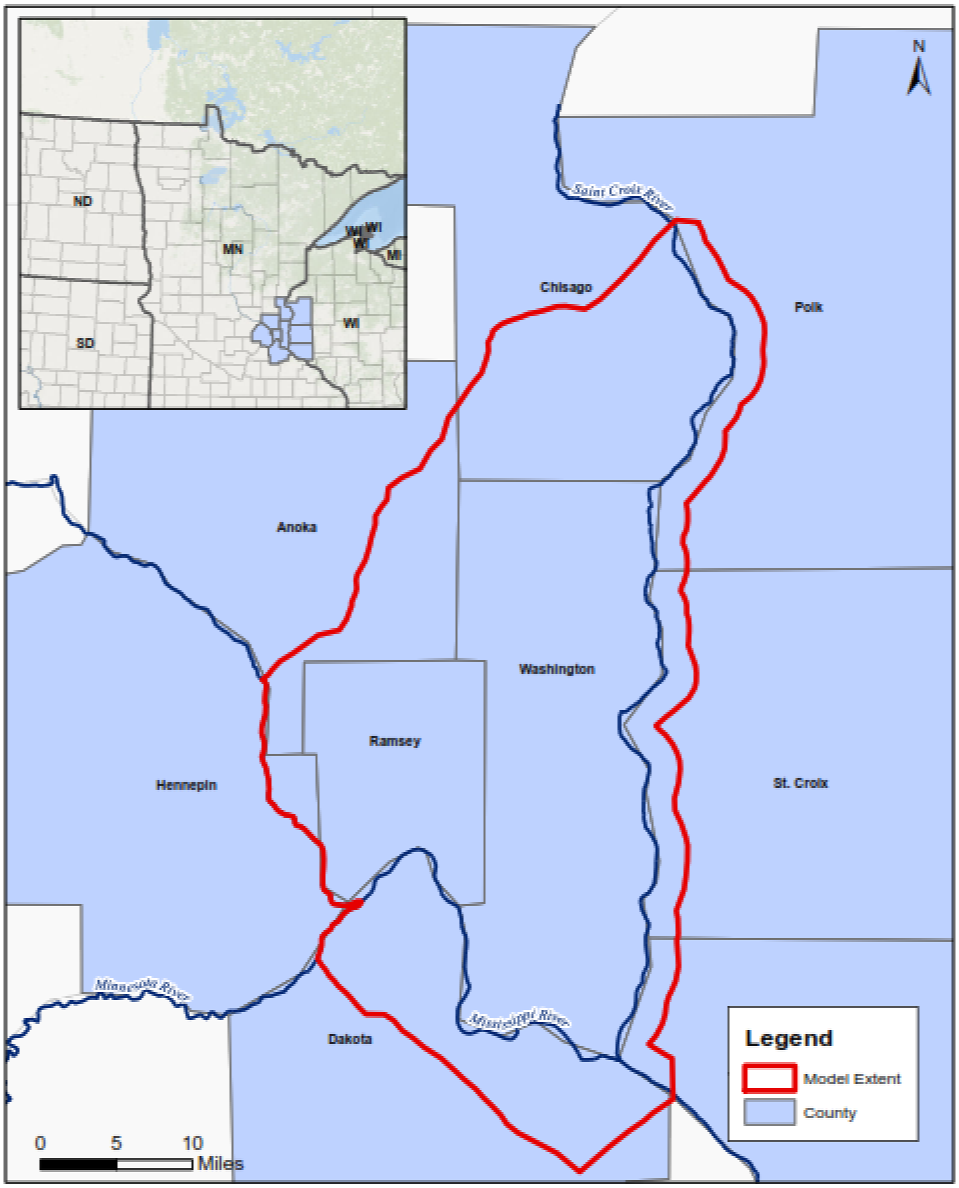
The model is steady-state, developed on a limited set of averaged data over a limited timeframe, and calibrated to annual averages during recent wet conditions that could result in locally different flow patterns at different times of the year. This currently limits the model to matching any predictions related to transient conditions. However, a transient verification/calibration could be implemented, and transient conditions could be simulated with greater confidence.

Bulk average hydraulic parameters (e.g., hydraulic conductivity, porosity) were used in the model for the various layers. Heterogeneities in aquifers and confining units were not accounted for and could result in significantly different yields and associated drawdown on a local scale. This can also limit the understanding of localized flow paths enhanced or reduced by local or sub-regional scale fractures.

There are limitations and a certain amount of error related to the SWB model and estimation of recharge that were used as the source of recharge in the model, and the values are assuming a wet condition.

River and lakebed thickness values and bottom and stage elevations are not known at several lakes and streams within the model domain. Many of these values along with river and lakebed hydraulic conductivity are unknown and could result in locally different inflows and outflows from lakes and river bodies. This can limit the understanding of potential surface water body interactions with groundwater under different pumping conditions.

Figure C.1. Location and extent of the model domain.



Background imagery service layer credits: Esri, Garmin, GEBCO, National Oceanic and Atmospheric Administration (NOAA) National Geophysical Data Center (NGDC), and other contributors.

Figure C.2. Model grid and cross-section through southern Washington County.

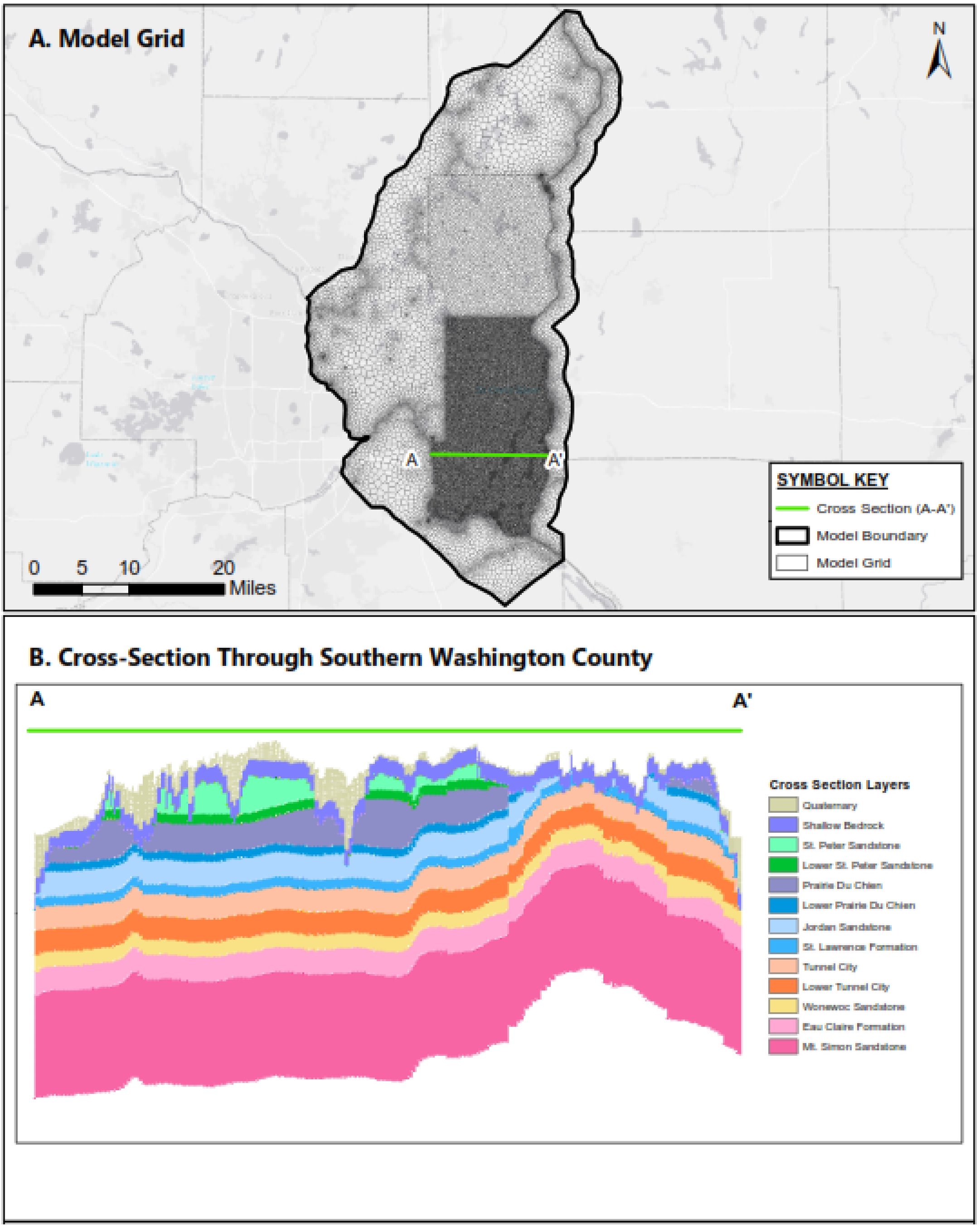


Figure C.3. Rivers, lakes, and perennial streams simulated with MODFLOW's RIV package.

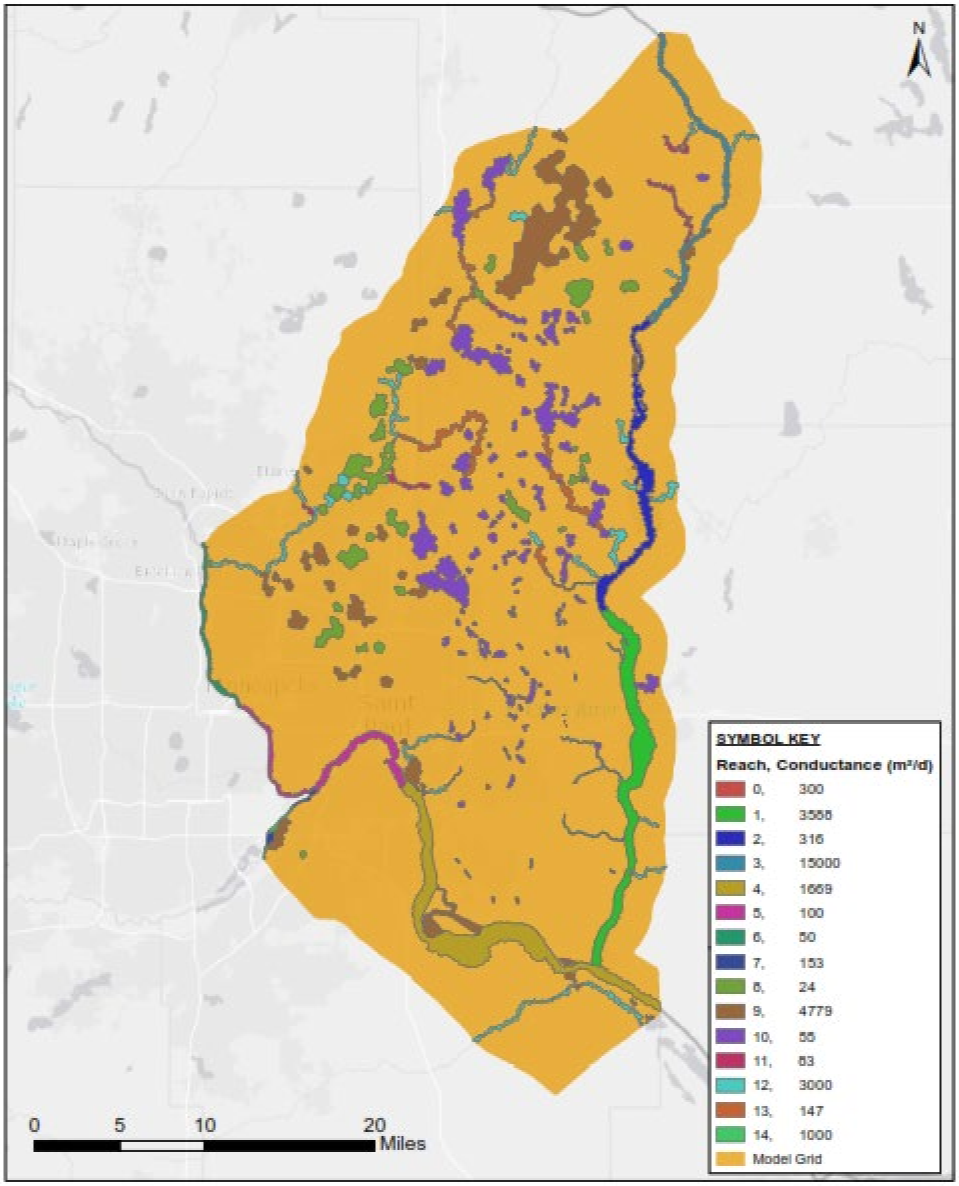


Figure C.4a. Perimeter boundaries in Layer 1 (Quaternary).

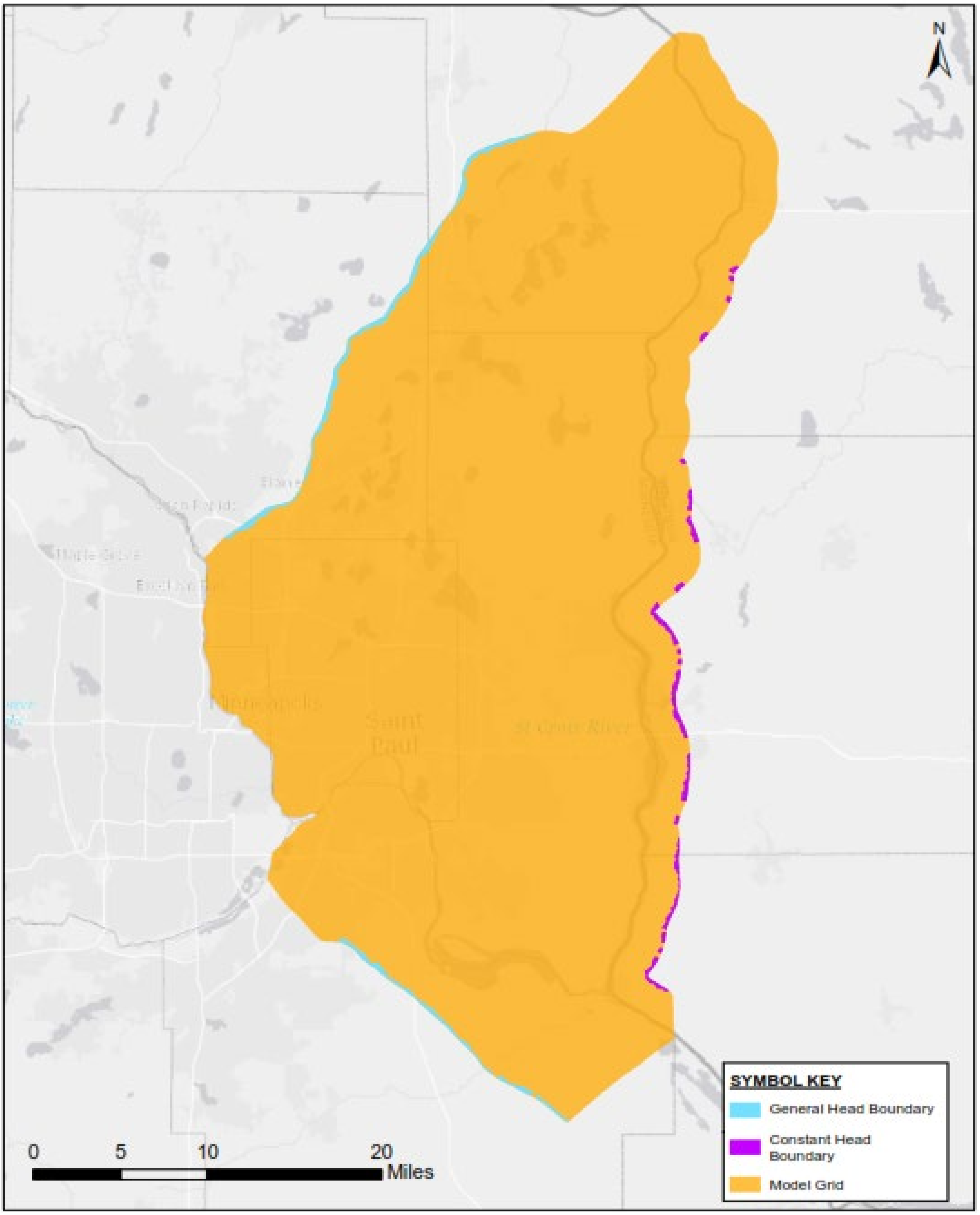


Figure C.4b. Perimeter boundaries in Layer 2 (Quaternary).

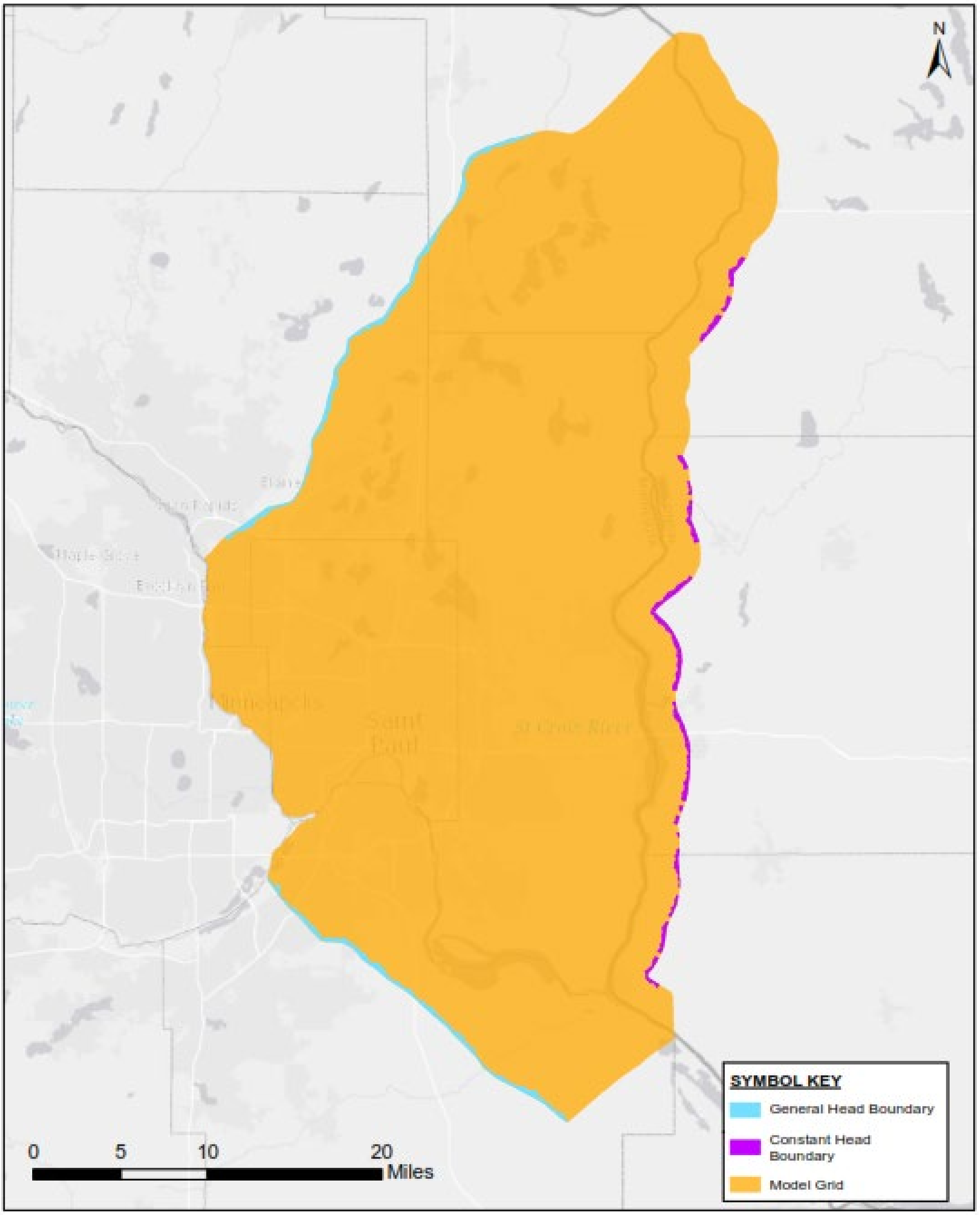


Figure C.4c. Perimeter boundaries in Layer 3 (Quaternary).

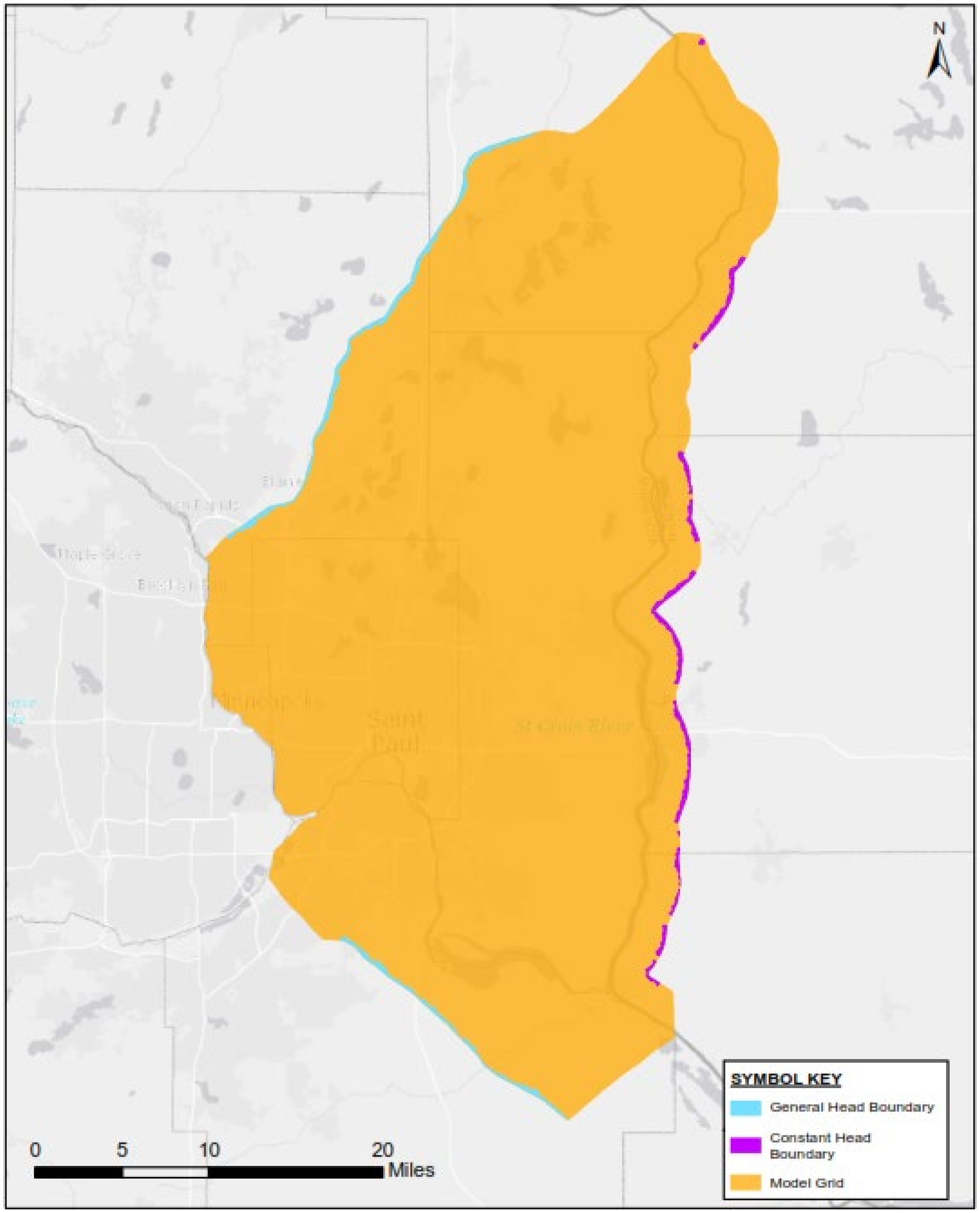


Figure C.4d. Perimeter boundaries in Layer 4 (Quaternary).

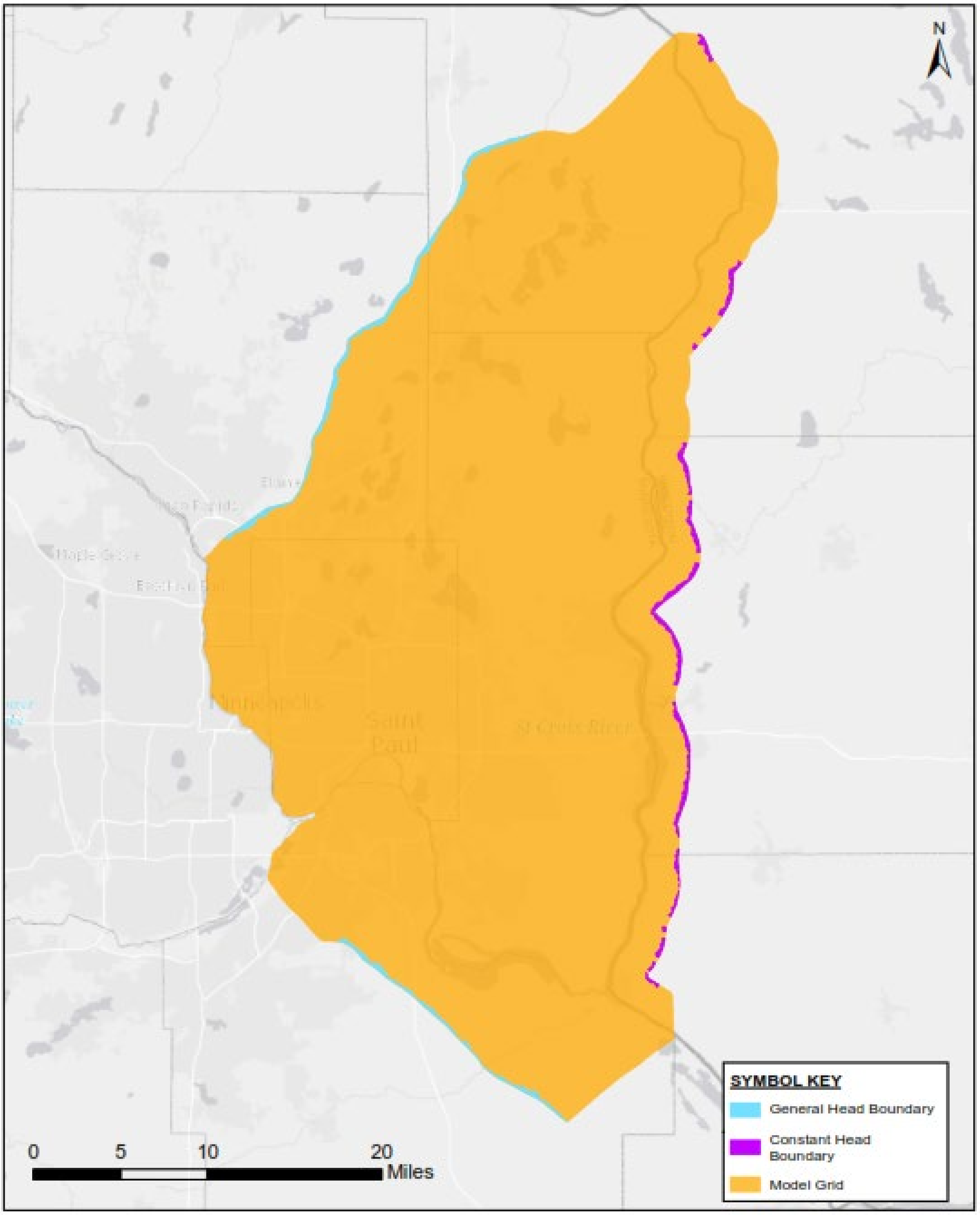
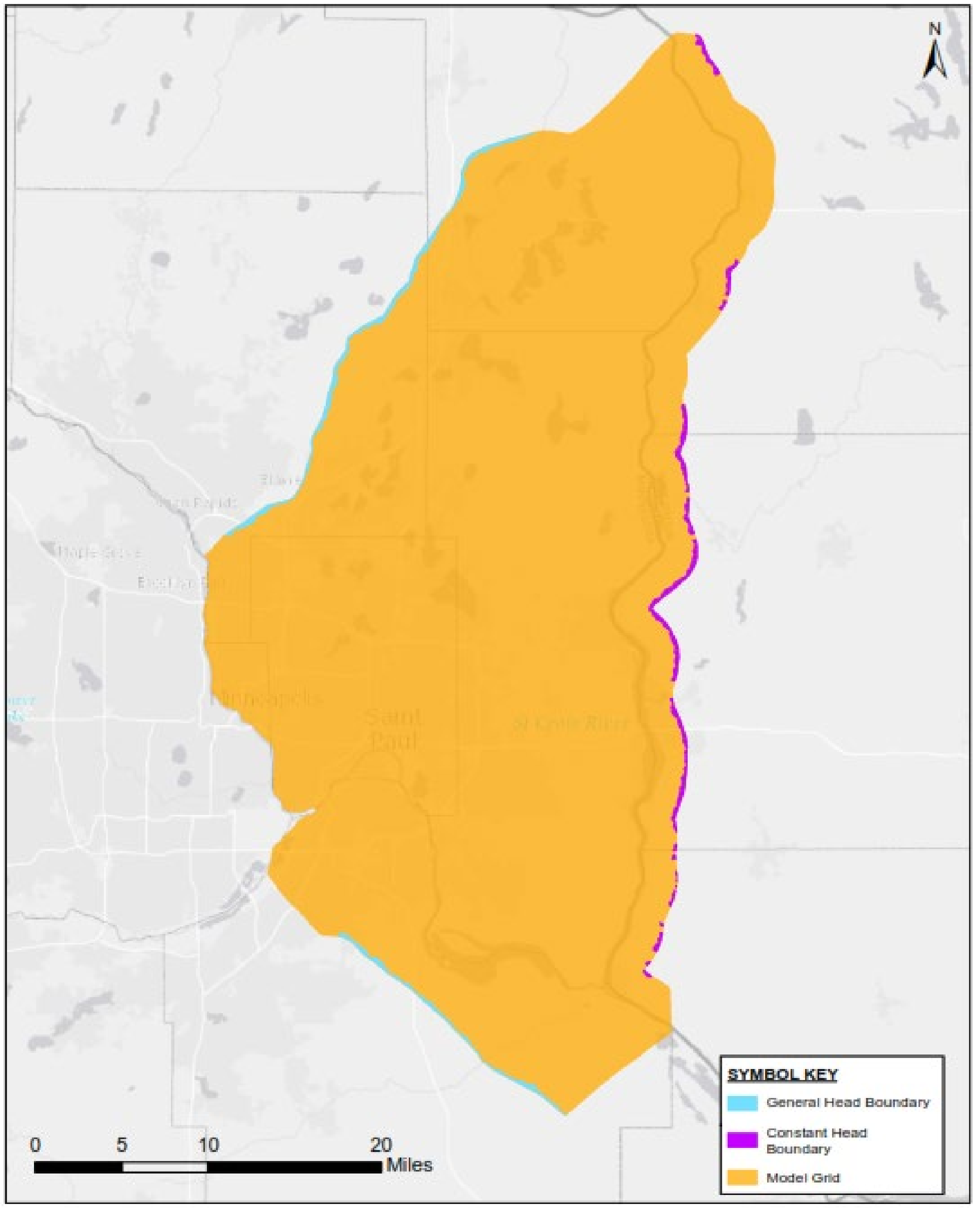


Figure C.4e. Perimeter boundaries in Layer 5 (Quaternary).



Appendix D. Conceptual project list

D.1 Conceptual project list

Table D.1 provides the list of potential conceptual projects identified for each of the 14 communities currently known to be affected by per- and polyfluoroalkyl substances (PFAS) contamination in the East Metropolitan Area of the Twin Cities. This list includes projects that were identified by the Government and the 3M Working Group, the Citizen-Business Group, Subgroup 1, members of the public, and the Co-Trustees.

This list of conceptual projects represents the range of potential solutions for improving drinking water supply for the affected communities in the East Metropolitan Area; however, additional projects may be identified and evaluated at a later date as new information comes to light. As a next step, these potential projects were bundled into scenarios and evaluated using the drinking water distribution and groundwater models (see Chapter 6 of this Conceptual Plan). During scenario development, the conceptual projects presented below may have been modified, combined, and/or expanded; or new projects may have been identified.

Table D.1. List of potential conceptual projects. This list is organized by community-specific projects, multi-community projects, projects for all communities, and other project submissions. The relevant water supply improvement option number (WSIO) and project submission source are also indicated.

Project Number	Community	Project Name	Project Description	WSIO	Source[a]
Community-Specific Projects					
1	Afton	Afton 1/ Individual GAC Filter Systems for Individual Private Wells	As individual private wells are found to have levels of PFAS near or above healthy levels, **install individual granular activated carbon (GAC) filter systems to remove the PFAS**. All properties in Afton have individual private wells. The individual GAC filter system for individual private wells is a cost-effective and flexible solution for the currently small but widely spread number of contaminated wells, and can also easily and cost-effectively be installed if the PFAS contamination moves and affects more wells.	1	Online
2	Afton	Wood-Afton 2a	**Create new small community water systems with treatment:** This conceptual project would create a new small community water system in Afton. The small community water system could be located east of Indian Trail and Tomahawk Drive. The system would supply five homes and require one shared, treated groundwater well. This option would require approximately 1,440 linear feet of 2” diameter polyvinyl chloride (PVC) piping.	2	Wood
3	Afton	Wood-Afton 2b	**Create new small community water systems with treatment:** This conceptual project would create a new small community water system in Afton. This system could be located south of Tomahawk Lane and Tomahawk Drive and would supply eight homes and require one shared, treated groundwater well. This option would require approximately 2,920 linear feet of 2” diameter PVC piping.	2	Wood
4	Afton	Wood-Afton 2c	**Create new small community water systems with treatment:** This conceptual project would create a new small community water system in Afton, which could be located at South Division Street on Croixview Avenue. The system would supply 10 homes and require 2 shared, treated groundwater wells. This option would require approximately 2,640 linear feet of 2” diameter PVC piping.	2	Wood
5	Afton	Wood-Afton 2d	**Create new small community water systems with treatment:** This conceptual project would create a new small community water system in Afton, which could be located on Tomahawk Dive South and Tomahawk Lane South. The system would supply 20 homes and require 2 shared, treated groundwater wells. This option would require approximately 6,480 linear feet of 4” diameter PVC piping.	2	Wood
6	Afton	Wood-Afton 3	**Create a new surface water treatment plant (SWTP) off the St. Croix River:** This conceptual project would create a new water treatment plant (WTP) using surface water from the St. Croix River. While this conceptual project is technically feasible, it is the	8	Wood

Project Number	Community	Project Name	Project Description	WSIO	Source[a]
			least administratively feasible option. Administratively, the permitting challenges with using St. Croix as a water source could take 3–5 years to resolve. The city has also stated that they do not have the resources to support a new WTP. In addition, this option would require Afton to implement a municipal water system. If this were to be considered, this option would need to be compared to the option of connecting to another neighborhood as part of a regional solution. As a result, a SWTP may be infeasible for Afton alone but could be evaluated as part of a regional surface water option considered in the following section.		
7	Cottage Grove	Wood – Cottage Grove 2c	**Connect private wells and non-community public water systems to an existing municipal water system:** This conceptual project would extend waterlines to connect neighborhoods currently on private wells to Cottage Grove's municipal water system. Considerations for this option would be the rate at which neighborhoods could be connected and a cost trade-off analysis with providing point of entry treatment systems (POETS) for individual homes. There also might be a community/resident preference to remain on a private well. The following is a list of potential neighborhoods that could be connected: i. Neighborhood A: This neighborhood is near the intersection of Goodview Avenue South and 70th Street South. A few of these residences have seen health risk index (health index, HI) values over 1 and the remaining homes have had detectible levels of PFAS in their non-municipal wells. The intent would be to connect these homes through the waterlines installed under Expedited Project 100014 – Granada Avenue. ii. Neighborhood B: This neighborhood is located off Grey Cloud Trail near the intersection with 103rd Street South. The majority of the residences in this area have already seen HI values over 1. Serving the area would require approximately 10,500 linear feet of waterline to reach all members of the neighborhood, with additional feet of waterline required to loop the system. This area also includes the golf course which, according to city personnel, will be up for sale soon for future development. Potential complications to consider would be how to loop the system and the crossing under the railroad track. An interim solution could be to install individual POETSs for non-municipal wells. iii. Neighborhood C: This neighborhood incorporates all the residences along Kimbro Avenue including Old Cottage Grove. It would require extensive water line installation to provide service and loop back into the existing system. Connecting to the city's municipal water system may be a long-term solution that would require POETSs for	3	Wood

Project Number	Community	Project Name	Project Description	WSIO	Source[a]
			individual homes in the interim as homes in this area have seen HI values greater than 1. iv. Neighborhood D: This neighborhood is located in southeast Cottage Grove and remains far from the existing municipal water system. The timing of the municipal water system expansion would be an important consideration for this option. Connecting this area could be a possible long-term solution, and an interim solution could be the installation of POETSs or small community water systems with treatment depending on the number of homes in this area seeing HI values greater than 1. v. Neighborhood E: This neighborhood is located on Lower Grey Cloud Island and is similar to Neighborhood D. This option could be a possible long-term solution and an interim solution could be the installation of POETSs or small community water systems with treatment, depending on the number of homes in this area seeing HI values greater than 1. vi. Neighborhood F: This neighborhood is in the Langdon Area, which contains homes that are heavily contaminated with PFAS – 12 of the homes have HI values of 27. A preliminary analysis by the city determined it may not be cost-effective to extend the municipal water system to these homes due to the small number of homes and that other options should be considered.		
8	Cottage Grove	Wood – Cottage Grove 3	**Drill new municipal supply wells in optimized locations:** This conceptual project would drill one or more new municipal supply wells in Cottage Grove. This option is consistent with Cottage Grove's Master Plan to drill new wells in optimized locations to either replace existing municipal supply wells (Wells 1 and 2) or meet future demand. The city currently has sufficient firm capacity [12.8 million gallons per day (mgd)] from their operational wells to meet the 2020 maximum daily demands of 11.5 mgd, assuming these wells maintain an HI value less than 1. However, recent testing has indicated that increased pumping of Well 9 has resulted in increasing HI values. It is anticipated that Well 9 will exceed an HI of 1 within the next testing round or the one after that. This would have an extremely significant impact on the firm capacity of the system due to the required blending needed to achieve the demand values listed above. In addition, the city will need to install additional wells to meet the 2040 maximum daily demands of 14.1 mgd. Ideally, new wells would be located in optimized areas where no PFAS treatment is required; however, there is the potential that new wells will need to be located in an area where PFAS treatment is required. The further evaluation of well locations will be coordinated with groundwater modeling efforts to assist in this determination.	5	Wood

Project Number	Community	Project Name	Project Description	WSIO	Source[a]
9	Cottage Grove	Wood – Cottage Grove 4	**Provide POETSs for private wells and non-community public water systems:** This conceptual project would provide POETSs for private wells and/or non-community public water systems in Cottage Grove. Some neighborhoods listed in Wood – Cottage Grove 2c may be better suited to be on POETSs as a long-term solution or as an interim solution until they can be brought onto the city's municipal water system. Or, it may be found that certain residences that are unable or unwilling to connect to the city's municipal water system can be outfitted with POETSs. This could include homes in Neighborhoods B, C, D, E, and F (as outlined in Wood – Cottage Grove 2c) that are farther away from the existing system and would require more time to connect.	1	Wood
10	Cottage Grove	Wood – Cottage Grove 5	**Create new small community water systems with treatment:** This conceptual project would create one or more small community water systems in Cottage Grove. Potential locations include Neighborhoods C, D, and E, as outlined in Wood – Cottage Grove 2c. There may be a cost advantage to implementing small community water systems for some neighborhoods as opposed to installing individual POETSs. A cost comparison of the two options will determine the most economically feasible option.	2	Wood
11	Cottage Grove	Cottage Grove Municipal Groundwater System Treatment & Supply Plan	This project would include the **construction of two WTPs and associated raw water lines to serve Cottage Grove's existing groundwater supply system**. The WTPs would be located in low and intermediate pressure zones, and would be sized for expansion as additional municipal supply wells are constructed. This project would also include an analysis for connecting impacted rural residential neighborhoods to municipal water.	4	Online
12	Denmark	Wood – Denmark 1	**Provide POETSs for private wells and non-community public water systems:** This conceptual project would provide POETSs for private wells and/or non-community public water systems in Denmark. This option would be a good fit for wells that are not located near a municipal water system, and where the number of private wells does not justify the costs of connecting to an existing municipal water system or implementing a small community water system.	1	Wood
13	Denmark	Wood – Denmark 2	**Create new small community water systems with treatment:** This conceptual project would create one or more small community water systems in Denmark. The small community water systems would be supplied by a shared, treated groundwater well. The consideration for this would be the cost tradeoff of this option as opposed to individual POETSs and resident/community preferences.	2	Wood

Project Number	Community	Project Name	Project Description	WSIO	Source[a]
14	Grey Cloud Island Township	Wood – GCI 1	**Provide POETSs for private wells and non-community public water systems:** This conceptual project would provide POETSs for private wells and/or non-community public water systems in Grey Could Island that have not had these systems installed to date.	1	Wood
15	Grey Cloud Island Township	Wood – GCI 2a	**Create new small community water systems with treatment:** This conceptual project would create a new small community water system in Grey Cloud Island. The small community water system could be located west of Grey Cloud Trail on Grey Cloud Island Drive. The system would supply five homes and require one shared, treated groundwater well. This option would require approximately 1,260 linear feet of 2” diameter PVC piping.	2	Wood
16	Grey Cloud Island Township	Wood – GCI 2b	**Create new small community water systems with treatment:** This conceptual project would create a new small community water system in Grey Cloud Island. The small community water system could be located west of Grey Cloud Trail. The system would supply eight homes and require one shared, treated groundwater well. This option would require approximately 2,240 linear feet of 2” diameter PVC piping.	2	Wood
17	Grey Cloud Island Township	Wood – GCI 2c	**Create new small community water systems with treatment:** This conceptual project would create a new small community water system in Grey Cloud Island. The small community water system could be located west of Pioneer Road on Grey Cloud Island Drive. The system would supply 10 homes and require 2 shared, treated groundwater wells. This option would require approximately 2,490 linear feet of 2” diameter PVC piping.	2	Wood
18	Grey Cloud Island Township	Wood – GCI 2d	**Create new small community water systems with treatment:** This conceptual project would create a new small community water system in Grey Cloud Island. The small community water system could be located west of Pioneer Road on Grey Cloud Island Drive. The system would supply 20 homes and require 2 shared, treated groundwater wells. This option would require approximately 8,500 linear feet of 4” diameter PVC piping.	2	Wood
19	Lake Elmo	Wood – Lake Elmo 1	**Provide treatment of an existing municipal water supply:** This conceptual project would provide treatment of Lake Elmo’s existing municipal water supply. Lake Elmo had previously explored the option to construct a WTP at their existing, unequipped Well 3 that had never been brought online. A study by Bolton & Menk indicated, however, that this was not a cost-effective option relative to drilling a new municipal supply well that did not require treatment and required almost twice the cost of implementing treatment at Well 1. This option of treating existing wells would need to be compared to	4	Wood

Project Number	Community	Project Name	Project Description	WSIO	Source[a]
			the option of drilling new supply wells in optimized locations such as Well 5, which do not require treatment. Considerations for this option would need to be made, such as the impact on White Bear Lake and locating any new wells outside the Special Well and Boring Construction Area. This option would have to be implemented in conjunction with one or more other options since the water supply available from Well 1 and/or Well 3 would not meet future demand.		
20	Lake Elmo	Wood – Lake Elmo 2	**Drill new municipal supply wells in optimized locations:** This conceptual project would drill one or more new municipal supply wells in Lake Elmo. Lake Elmo is currently implementing the results of a study by Bolton & Menk and are drilling a new municipal supply well, Well 5, in the northeast region of the city close to existing Well 4. Based on the study, the city estimates that they will need up to an additional two wells to meet buildout conditions, and the first well will be needed by 2023. If it is found that there are significant restrictions on pumping in the northern region due to the 5-mile proximity to White Bear Lake, Lake Elmo would need to consider the option of drilling new wells farther south, which may potentially require treatment. The Minnesota Department of Health (MDH) has also designated regions of Lake Elmo as Special Well and Boring Construction Areas. Requirements for such areas would need to be followed for all new wells. This option is consistent with Lake Elmo's Comprehensive Water System Planning efforts since 2006 and does not require costs to reconfigure the existing water distribution system.	5	Wood
21	Lake Elmo	Wood – Lake Elmo 3	**Provide POETSs for private wells and non-community public water systems:** This conceptual project would provide POETSs for private wells and/or non-community public waters systems in Lake Elmo. This could include residences that cannot be connected to the city's municipal water system or could be an interim solution until the city is able to bring them onto the municipal water system.	1	Wood
22	Lake Elmo	Wood – Lake Elmo 3e	**Connect private wells and non-community public water systems to an existing municipal water system:** This conceptual project would extend waterlines to connect neighborhoods currently on private wells to Lake Elmo's municipal water system. Lake Elmo has estimated that there are 175 well advisories from PFAS contamination in the southern two-thirds of the community. These wells are located within the 18 developed neighborhoods located within the Special Well and Boring Construction Area. The city plans to connect these existing neighborhoods to the municipal water system. New developments in these areas are required to connect to the municipal water system as they are developed.	3	Wood

Project Number	Community	Project Name	Project Description	WSIO	Source[a]
23	Lake Elmo	Wood – Lake Elmo 4	**Create new small community water systems with treatment:** This conceptual project would create one or more small community water systems in Lake Elmo. This option would be most applicable for neighborhoods where the number of residences is large enough to justify the cost as opposed to installing individual POETSs.	2	Wood
24	Lake Elmo	Sustainable Water Usage Requirements in New Developments	Feedback from Lake Elmo resident states that a solution should incorporate sustainable water use practices and considerations. The comment stated that it is true that the water is contaminated and the City is working towards resolution, the answer cannot simply be "drill another well" for the following reasons: • This solution is very short-sighted. • With the explosive growth in Lake Elmo City staff has indicated that, despite the current water shortage, there have been no requirements for the new developments to use less water/use water more efficiently. • Residences with swimming pools, in-ground sprinklers, and herbicide-reliant yards are filling in all the undeveloped land in and around Lake Elmo which will require more water. • There is already a water shortage, and the population is continuing to grow with no requirements on the developers or homeowners to take a forward-looking, 21st century approach to water usage.	10	Online
25	Lakeland/ Lakeland Shores	Wood – Lakeland/ Lakeland Shores 1a	**Provide treatment of an existing municipal water supply:** This conceptual project would provide treatment of Lakeland's existing municipal water supply. Lakeland could provide treatment at their existing municipal supply wells to address any future PFAS contamination. The city is currently treating the water at each well with pressurized, permanganate coated GAC to address iron and manganese levels. As a result, there is potentially space available and land that can be purchased by the city to add new PFAS treatment technology. There is also a strong financial preference to reuse these treatment systems as they were recently updated.	4	Wood
26	Lakeland/ Lakeland Shores	Wood – Lakeland/ Lakeland Shores 1b	**Provide treatment of an existing municipal water supply:** This conceptual project would provide treatment of Lakeland's existing municipal water supply. Lakeland could install a centralized WTP to address any future PFAS contamination in their two existing municipal supply wells. The WTP would be able to treat water from both wells. In order to convey water to the WTP, a dedicated raw water line would be constructed between the sites, which are 2.3 miles apart. However, these wells are currently not contaminated and do not require treatment for PFAS at this time.	4	Wood

Project Number	Community	Project Name	Project Description	WSIO	Source[a]
27	Lakeland/ Lakeland Shores	Wood – Lakeland/ Lakeland Shores 2	**Drill new municipal supply wells in optimized locations:** This conceptual project would drill one or more new municipal supply wells in Lakeland. If either or both of their existing municipal supply wells were to become contaminated with PFAS, Lakeland could drill new wells in optimized locations where there is no evidence of PFAS contamination. However, there is a moratorium on drilling new wells in the Mt. Simon aquifer and there is uncertainty as to the migration of PFAS from upgradient and/or higher stratigraphy aquifers, given the downgradient position of the city for contamination in West Lakeland. Thus, providing treatment at existing well sites is preferred until additional wells are required. However, if Lakeland became a regional water provider for neighboring communities such as West Lakeland and Afton or portions of Afton, they would need to drill new wells to meet the added demand.	5	Wood
28	Lakeland/ Lakeland Shores	Wood – Lakeland/ Lakeland Shores 3	**Connect private wells and non-community public water systems to an existing municipal water system:** This conceptual project would extend waterlines to connect existing neighborhoods on private wells to Lakeland's municipal water system. Lakeland has connected residents with private wells to their municipal water system each year and will continue to do so. According to the city, many residents that are on the municipal water system have also kept their private wells for irrigation. However, it is unknown if the city will require these residents to seal their wells if they are brought onto the municipal water system as a result of PFAS contamination. If these residences were connected to the city's municipal water system, irrigation demands would need to be considered and water conservation efforts would need to be enforced to minimize peak demands on the existing municipal water system. According to available data for 2015, approximately 206 homes are on private wells. Bringing these private wells onto the city's municipal water system would add 140,300 gallons per day during a maximum-day scenario, which would not require additional well capacity in Year 2020, but would require additional water supply in Year 2040. Total water usage per capita demand is currently at 97 gallons per capita per day, so the installation of smart irrigation controllers would help to reduce overall water consumption and help the city meet the Minnesota Department of Natural Resources (DNR) water conservation goal of 75 gallons per capita per day (DNR, 2018).	3	Wood
29	Lakeland/ Lakeland Shores	Wood – Lakeland/ Lakeland Shores 4	**Provide POETSs for private wells and non-community public water systems:** This conceptual project would provide POETSs for private wells and/or non-community public water systems in Lakeland and/or Lakeland Shores. Providing POETSs would likely only be necessary for two properties north of I-94 and west of State Highway 95. If connected to the municipal water system, the new water line would need to be routed	1	Wood

Project Number	Community	Project Name	Project Description	WSIO	Source[a]
			west under State Highway 95 and a booster pump station would be required as there is a 100-foot elevation difference. In terms of cost/benefit, that option would likely be infeasible for the purpose of serving only two households. Therefore, POETSs are the most-likely final solution for these households.		
30	Maplewood	Wood – Maplewood	**Connect private wells and non-community public water systems to an existing municipal water system:** This conceptual project would extend waterlines to connect residences currently on private wells in Maplewood to St. Paul Regional Water Services (SPRWS). This option would be primarily for those wells south of I-494.	3	Wood
31	Maplewood	Wood – Maplewood 2	**Provide POETSs for private wells and non-community public water systems:** This conceptual project would provide POETSs for private wells and/or non-community public water systems in Maplewood. This option would be most applicable for private wells that could not be connected to SPRWS.	1	Wood
32	Newport	Wood – Newport 1a	**Provide treatment of an existing municipal water supply:** This conceptual project would provide treatment of Newport's existing municipal water supply. Approved treatment technologies (such as GAC) could be implemented at each of the existing supply wells to address any future PFAS contamination. Considerations for available space need to be made. While Well 1 has available space, there is limited space available at Well 2. However, the Minnesota Department of Transportation owns a parcel southwest of Well 2 that they have offered to the city in the past, which may be a site to consider acquiring for future treatment. Otherwise, the city may need to consider purchasing other available land for WTPs.	4	Wood
33	Newport	Wood – Newport 1b	**Provide treatment of an existing municipal water system:** This conceptual project would provide treatment of Newport's existing municipal water supply. A centralized WTP could be constructed to treat water from both municipal supply wells as the distance between them is approximately 3,000 linear feet. However, the new raw water transmission main would need to cross Highway 61. It may be possible to repurpose the 8" water main that crosses Highway 61 at Glenn Road as a raw water transmission main between the two well sites. A new 600-linear-foot, 8" water main along 7th Avenue between 12th Street and 13th Street is necessary on the west side of the highway to reestablish looped water mains.	4	Wood
34	Newport	Wood – Newport 2	**Drill new municipal supply wells in optimized locations:** This conceptual project would drill one or more new municipal supply wells for Newport. Newport does not require new municipal supply wells to meet current or projected potable water demands through 2040. However, if either or both of their existing municipal supply wells were to become contaminated with PFAS, Newport could drill new wells in optimized locations	5	Wood

Project Number	Community	Project Name	Project Description	WSIO	Source[a]
			where there is no evidence of PFAS contamination. However, because there is uncertainty as to the migration of PFAS from upgradient and/or higher-stratigraphy aquifers, and the location of future contamination is unknown, it is preferred to provide treatment at the existing well sites until additional wells are required. New wells would also be required if Newport were ever to become a supply of clean drinking water to meet additional demand.		
35	Newport	Newport 3/ Municipal Water Service Area Expansion	**Expand city water service area to replace private wells**.	3	Online
36	Newport	Wood – Newport 4	**Provide POETSs for private wells and non-community public water systems:** This conceptual project would provide POETSs for private wells and/or non-community public water systems in Newport. This option would be most applicable for those residences that cannot be connected to the city's municipal water system. POETSs could be considered for 14 residences in the southeast corner. However, there is a Cottage Grove water main that extends into this area to service the TEN-E Packaging Plant, so there is potential that Cottage Grove could serve the residents in this area as well (see the Wood – Cottage Grove – Newport 1 project).	1	Wood
37	Newport	Wood – Newport 5	**Create new small community water systems with treatment:** This conceptual project would create one or more new small community water systems in Newport. Newport is actively connecting as many residents as possible to the city's municipal water system. However, for those areas where connection is infeasible, a small community water system could be installed. A small community water system would be feasible for the 14 residences in the southeast corner of the city, if treatment is required in the future.	2	Wood
38	Newport	Monitor Newport Municipal Wells, Filter if Needed	**Regularly monitor Newport's two municipal wells, prepare action plan (for filtering, temporary supply from interconnect, etc.) in case of exceedance, and implement action plan if needed**.	N/A	Online
39	Newport	Newport Looping	**Loop pressure zones within Newport to improve resilience in the event of a supply disruption**.	N/A	Online
40	Oakdale	Wood- Oakdale 1b	**Provide treatment of an existing municipal water supply and drill new municipal supply wells in optimized locations:** This conceptual project would provide treatment of	4, 5	Wood

Project Number	Community	Project Name	Project Description	WSIO	Source[a]
			municipal supply wells in Oakdale. This option would expand the existing GAC WTP at the Public Works location and add new wells in the area to replace the four affected wells, essentially creating a new well field and centralized WTP.		
41	Oakdale	Wood-Oakdale 1c	**Provide treatment of an existing municipal water supply:** This conceptual project would provide treatment of Oakdale's existing municipal water supply. Oakdale took Well 6 out of service due to high iron and manganese levels; however, according to available data, it is not contaminated with PFAS. Providing treatment at Well 6 could either replace some of the contaminated well(s) or provide for future demand in the North Pressure Zone. If Well 6 were to serve other areas of Oakdale, infrastructure changes would be required.	4	Wood
42	Oakdale	Wood-Oakdale 2	**Drill new municipal supply wells in optimized locations:** This conceptual project would drill one or more new municipal supply wells in Oakdale. According to available data and similar to Lake Elmo, the northern region of the city has detectable levels of PFAS, but HI values are less than 1. An option may be to drill new wells in the northern region to supply the southern region. However, considerations for this option would need to be made regarding additional water quality parameters such as iron and manganese, and the potential impacts on White Bear Lake and/or the well restrictions for those located within a 5-mile radius of White Bear Lake. Furthermore, wells in the northern zone are currently only able to supply the north pressure zone of the city's municipal water system and water supply to other zones would require infrastructure changes.	5	Wood
43	Oakdale	Wood-Oakdale 3	**Connect private wells and non-community public water systems to an existing municipal water system:** This conceptual project would extend waterlines to connect neighborhoods currently on private wells to Oakdale's municipal water system. The residential neighborhood of Olsen Lake could be easily connected to the city's municipal water system.	3	Wood
44	Oakdale	Wood-Oakdale 4	**Provide POETSs for private wells and non-community public water systems:** This conceptual project would provide POETSs for private wells and/or non-community in Oakland. This option would be most applicable for those residences with PFAS-impacted private wells that cannot be brought onto the city's municipal water system.	1	Wood
45	Oakdale	Wood-Oakdale 5	**Create new small community water systems with treatment:** This conceptual project would create a new small community water system in Oakdale. The residential neighborhood of Olsen Lake is the only pocket of homes in Oakdale that appear suitable for a small community water system. However, this option is less feasible than connecting these homes to the existing municipal water system.	2	Wood

Project Number	Community	Project Name	Project Description	WSIO	Source[a]
46	Oakdale	Wood-Oakdale 6	**Connect a subset of a community to SPRWS:** This conceptual project would connect Oakdale to SPRWS. However, there are concerns with water quality, cost, taste, public acceptability, etc. Oakdale does have 16” and 12” trunk water mains within one mile of the Maplewood border that could be used to convey SPRWS’s water throughout its water system.	7	Wood
47	Prairie Island Indian Community	Wood-PIIC 2	**Provide POETSs for private wells and non-community public water systems:** This conceptual project would drill a new well and provide POETSs for every new residence planned for this community. The Prairie Island Indian Community is currently planning 71 homes and a commercial development in this area.	1, 5	Wood
48	St. Paul Park	Wood-St. Paul Park 1	**Provide treatment of an existing municipal water supply:** This conceptual project would provide treatment of St. Paul Park’s existing municipal water supply. The city is currently installing a temporary 2,200 gallons per minute (gpm) WTP to treat water from Wells 3 and 4, with the intent to serve Well 2 at a future date.	4	Wood
49	St. Paul Park	Wood-St. Paul Park 2	**Drill new municipal supply wells in optimized locations:** This conceptual project would drill a new municipal supply well for St. Paul Park. Once St. Paul Park’s WTP is online and the existing municipal supply wells can be utilized at their full potential, the city should have sufficient firm capacity (1.73 mgd) to provide for their 2040 maximum daily demands (1.7 mgd) with their largest well out of service. However, if the city plans on taking more than one well off-line for maintenance, an additional municipal supply well will be required to meet firm capacity. It is assumed that any new wells will require PFAS treatment due to the extent of the observed contamination in the area. The city had previously done a feasibility study looking at deeper wells that used the Mt. Simon-Hinckley aquifer. However, there is a moratorium on this aquifer in the Metropolitan Area and DNR seldom approves permits to pump groundwater from it. In addition, the Mt. Simon-Hinckley aquifer is known to produce water with high concentrations of radium that may require treatment for this contaminant.	5	Wood
50	St. Paul Park	Wood-St. Paul Park 3a	**Connect private wells and non-community public water systems to an existing municipal water system:** This conceptual project would extend waterlines to connect neighborhoods on private wells to St. Paul Park’s municipal water system. Very few private wells are left in St. Paul Park, but those that remain, particularly the homes on the south side of the city, could be connected to the city’s system.	3	Wood
51	St. Paul Park	Wood-St. Paul Park 3b	**Connect private wells and non-community public water systems to an existing municipal water system:** This conceptual project would extend waterlines to connect	3	Wood

Project Number	Community	Project Name	Project Description	WSIO	Source[a]
			new developments to St. Paul Park's municipal water system, such as the new Forest Edge housing development.		
52	St. Paul Park	Wood-St. Paul Park 3c	**Connect private wells and non-community public water systems to an existing municipal water system:** This conceptual project would extend waterlines to connect new developments to St. Paul Park's municipal water system, such as the vacant parcels at the south end of St. Paul Park that are owned by the railroad but may get developed if sold.	3	Wood
53	St. Paul Park	Wood-St. Paul Park 4	**Provide POETSs for private wells and non-community public water systems:** This conceptual project would provide POETSs for private wells and/or non-community public water systems in St. Paul Park. Two homes north of the State Highway 61 are currently on private wells and, if they were to become contaminated with PFAS, could be given POETSs as a short-term measure. There is no benefit to create a small community water system for two homes; however, there is a potential for these homes to connect to Cottage Grove's municipal water system in the future if Cottage Grove extended their waterlines.	1	Wood
54	West Lakeland	Wood-West Lakeland 1	**Provide POETSs for private wells and non-community public water systems:** This conceptual project would provide POETSs for private wells and/or non-community public water systems in West Lakeland. POETSs are already being implemented and the interim solution is providing residents with bottled water. There will be a cost tradeoff between this option and implementing small community water systems for these residences.	1	Wood
55	West Lakeland	Wood-West Lakeland 2a	**Create new small community water systems with treatment:** This conceptual project would create a new small community water system in West Lakeland, which could be located south of Nordic Avenue on Nordic Circle. This system would supply five homes and require one shared, treated groundwater well. This option would require approximately 1,430 linear feet of 2" diameter PVC piping. A consideration for implementing this solution would be the cost tradeoff of this option as opposed to individual POETSs and resident/community preference.	2	Wood
56	West Lakeland	Wood-West Lakeland 2b	**Create new small community water systems with treatment:** This conceptual project would create a new small community water system in West Lakeland, which could be located east of Neal Ave on 4th Street. This system would supply eight homes and require one shared, treated groundwater well. This option would require approximately 2,520 linear feet of 2" diameter PVC piping.	2	Wood

Project Number	Community	Project Name	Project Description	WSIO	Source[a]
57	West Lakeland	Wood-West Lakeland 2c	**Create new small community water systems with treatment:** This conceptual project would create a new small community water system in West Lakeland, which could be located east of Neal Avenue on 6th Street. This system would supply 10 homes and require 2 shared, treated groundwater wells. This option would require approximately 2,490 linear feet of 2" diameter PVC piping.	2	Wood
58	West Lakeland	Wood-West Lakeland 2d	**Create new small community water systems with treatment:** This conceptual project would create a new small community water system in West Lakeland, which could be located north of 10th Street on Paris Avenue. This system would supply 20 homes and require 2 shared, treated groundwater wells. This option would require approximately 5,120 linear feet of 4" diameter PVC piping.	2	Wood
59	West Lakeland	Wood-West Lakeland 3	**Drill new municipal supply wells in optimized locations:** This conceptual project would drill one or more new municipal supply wells for West Lakeland. West Lakeland could establish a municipal water system by drilling new wells with WTPs and installing a new distribution system. A consideration is that the township does not currently have the resources to support a WTP or a large-scale distribution system. In addition, cost and blending water are two very large concerns for residents.	5	Wood
60	Woodbury	Wood-Woodbury 1b	**Connect private wells and non-community public water systems to an existing municipal water system:** This conceptual project would extend waterlines to connect neighborhoods currently on private wells to Woodbury's municipal water system. This may potentially include the southwestern region of Woodbury; however, so far, this area has not been considered to be connected to the city's municipal water system due to the large lot sizes.	3	Wood
61	Woodbury	Wood-Woodbury 2	**Provide POETSs for private wells and non-community public water systems:** This conceptual project would provide POETSs for private wells and/or non-community public water systems in Woodbury. This option would be most applicable for remote areas that either could not be served by the city's municipal water system or considered as an interim solution until they could be served. It is recommended that these POETSs would serve the entire house.	1	Wood
62	Woodbury	Wood-Woodbury 4	**Drill new municipal supply wells in optimized locations:** This conceptual project would drill one or more new municipal supply wells in Woodbury. The city's proposed plan is to construct any new wells required to meet future demands in the South Well Field. This evaluation, in conjunction with the groundwater model, will help identify if there are any optimal locations for new wells that would require no PFAS treatment in the South Well Field and other available areas within the city. As previously mentioned, while the	5	Wood

Project Number	Community	Project Name	Project Description	WSIO	Source[a]
			individual well capacities indicate the city should be able to meet future demands, running all Tamarack wells simultaneously effectively reduces the pumping capacity of each well, which has not been measured at this time. As a result, it is likely that at least one new high-capacity well will be required to meet projected water demand. However, depending upon the extent of PFAS contamination, the location of new wells may or may not be within Woodbury and/or require treatment.		
63	Woodbury	Wood-Woodbury 5a	**Create new small community water systems with treatment:** This conceptual project would create one or more small community water systems in Woodbury. Potential locations could be in the southeastern region where development is least likely and land use will remain mostly rural. This region is also the location of the 3M disposal site. Therefore, a new groundwater well would either need to be located upgradient from the 3M disposal site or treatment may be necessary. Another consideration for this option would be the potential impacts on the head waters of Valley Creek for which the State has implemented pumping restrictions on the city's eastern wells. Furthermore, as part of their City Plan, Woodbury plans to develop this area in the future and extend their municipal water system to these residents.	2	Wood
64	Woodbury	Wood-Woodbury 5b	**Create new small community water systems with treatment:** This conceptual project would create one or more small community water systems in Woodbury. Potential locations could be in the southwestern region, which is developed with large residential lots but is not connected to Woodbury's municipal water system.	2	Wood
65	Woodbury	Municipal Water for Salem Meadows Neighborhood, Woodbury, MN	**Replace private wells, and eliminate the need for private reverse osmosis water treatment systems, by extending municipal water into the Salem Meadows neighborhood in Woodbury, MN.**	3	Online
66	Woodbury	Two (2) Treatment Plant Solutions (Tamarack and South Well Fields)	**Two WTP solutions (Tamarack and South Well Fields)** • Would be a groundwater-based system. • Tamarack WTP to treat Tamarack Well Field. South WTP to treat South Well Field wells and new wells installed in the Woodbury South Well Field to meet growth demands. • Would consider costs and logistics to construct a raw water pipeline from the East Well Field to the South Well Field.	4, 5	Online

Project Number	Community	Project Name	Project Description	WSIO	Source[a]
			• Would include PFAS treatment with consideration of or some combination thereof at both WTPs: ◦ Treatment of iron and manganese ◦ Lime softening ◦ PFAS treatment (GAC or ion exchange).		
67	Woodbury	Woodbury Centralized Treatment	**Centralized treatment (one WTP):** • Would be a groundwater-based system. • WTP location is flexible but should consider centralized location in southern portion of Woodbury for potential service connections to neighboring community(ies). • Would include costs and logistics to construct raw water pipeline from the Tamarack East Well Fields and South Well Fields to the centralized WTP location. • Would include PFAS treatment with consideration of or some combination thereof: ◦ Treatment of iron and manganese ◦ Lime softening ◦ PFAS treatment (GAC or ion exchange). • Would include and assumes growth in demand for the new wells installed in Woodbury's South Well Fields.	4, 5	Online
68	Woodbury	Woodbury Three (3) Plant Solutions	**Three WTP solutions (one PFAS WTP located near each City of Woodbury Well Field for full system treatment):** • Would include treatment of iron and manganese and GAC or ion exchange. • Would include new wells to meet City of Woodbury growth. • Would not include softening.	4, 5	Online
Multi-Community Projects					
69	Afton – Lakeland	Wood Afton-Lakeland 1	**Create a new regional public water system through interconnects with neighboring communities:** This conceptual project would connect Afton to Lakeland's municipal water system. In order to connect to a neighboring system such as Lakeland, Afton would need to install a municipal water system. Lakeland had previously offered to serve the downtown area and bordering communities of Afton; however, the City of Afton is hesitant to implement a municipal water system if it is owned and operated by another community because of concerns regarding what a regional agreement would entail and what the cost would mean to residents. However, the City of Afton is more receptive to this idea instead of owning, operating, and maintaining their own WTP due to the availability of resources. In addition, if Afton and Lakeland were to interconnect, the City of Lakeland would need to drill new wells to meet the additional demand. Varying	6	Wood

Project Number	Community	Project Name	Project Description	WSIO	Source[a]
			topography (100+ feet) between Lakeland and neighboring communities would have to be considered and pump stations may be required.		
70	Afton – Woodbury	Wood Afton-Woodbury 1	**Create a new regional public water system through interconnects with neighboring communities:** This conceptual project would connect Afton to Woodbury's municipal water system. Afton could tie into the neighboring system of Woodbury by extending a water main along Hudson Road South to the area of contaminated non-municipal wells on the north end of the city.	6	Wood
71	Cottage Grove – Denmark	Wood – Cottage Grove – Denmark 1	**Create a new regional public water system through interconnects with neighboring communities:** This conceptual project would connect Denmark to Cottage Grove's municipal water system. If Cottage Grove were to extend their municipal water system to serve the eastern region, it would provide a connection point with Denmark. If a regional groundwater WTP or supply facility and distribution system were to be constructed in Denmark, this interconnect would provide an additional water supply for Cottage Grove.	6	Wood
72	Cottage Grove – Grey Cloud Island	Wood – Cottage Grove – Grey Cloud Island 1	**Create a new regional public water system through interconnects with neighboring communities:** This conceptual project would connect Grey Cloud Island to Cottage Grove's municipal water system. Extending Cottage Grove's existing municipal water system to Grey Cloud Island would require several miles of new water mains to be installed in both Cottage Grove and Grey Cloud Island, since Grey Cloud Island does not currently have a municipal water system and the two communities are partially separated from each other by a fork of the Mississippi River with limited utility pathways and a railroad. A municipal water system in Grey Cloud Island may not be feasible as a standalone project from a constructability standpoint. However, expansion of the Cottage Grove municipal water system to a residential area along Grey Cloud Trail South on the southern Cottage Grove/Grey Cloud Island border (as outlined in Cottage Grove 2c Neighborhood B) could provide a more convenient pathway to connect Grey Cloud Island to Cottage Grove's municipal water system.	6	Wood
73	Cottage Grove – Newport	Wood – Cottage Grove – Newport 1	**Create a new regional public water system through interconnects with neighboring communities:** This conceptual project would expand an interconnect between Cottage Grove and Newport. Newport currently has a packaging plant located in the southeast corner that is being supplied by Cottage Grove's municipal water system. This existing interconnect could be expanded to supply the small neighborhood on Oakridge Drive. If Newport's municipal supply wells were to become contaminated with PFAS, they could extend Cottage Grove's water main to connect to their municipal water system via a	6	Wood

Project Number	Community	Project Name	Project Description	WSIO	Source[a]
			3,600-foot water main. However, considerations regarding looping in the distribution system and managing pressure zones would need to be made.		
74	Cottage Grove – St. Paul Park	Wood-Cottage Grove – St. Paul Park 1a	**Create a new regional public water system through interconnects with neighboring communities:** This conceptual project would connect a portion of St. Paul Park to Cottage Grove's municipal water system. St. Paul Park could connect the two homes mentioned in Wood-St. Paul Park 4 to Cottage Grove's municipal water system, since Cottage Grove plans to connect the adjoining neighborhoods through their Expedited Project 100014 and extending lines to their proposed Neighborhood A (see Wood-Cottage Grove 2c).	6	Wood
75	Cottage Grove – St. Paul Park	Wood-Cottage Grove – St. Paul Park 1b	**Create a new regional public water system through interconnects with neighboring communities:** This conceptual project would expand an interconnect between Cottage Grove and St. Paul Park. Cottage Grove could provide water to St. Paul Park by utilizing their existing interconnect, which has an estimated capacity of 350 gpm. This is approximately 40% of St. Paul Park's current maximum daily demand if Cottage Grove has a sufficient water supply. This interconnect is currently for emergency use only; however, if the existing 350-gpm interconnect and the 2,200-gpm WTP in St. Paul Park were operational, this would allow St. Paul Park to meet their current 2020 and future 2040 demands (unless more than one well was taken off-line at a time).	6	Wood
76	Cottage Grove – Woodbury	Wood Cottage Grove – Woodbury 1a	**Create a new regional public water system through interconnects with neighboring communities:** This conceptual project would connect portions of Woodbury to Cottage Grove's municipal water system. There is no existing interconnect between Cottage Grove and Woodbury; however, Cottage Grove could extend lines to supply treated water to the southwest region of Woodbury. This would require new water distribution infrastructure to be installed in Woodbury.	6	Wood
77	Cottage Grove – Woodbury	Wood Cottage Grove 6d – Woodbury 1b	**Create a new regional public water system through interconnects with neighboring communities:** This conceptual project would connect portions of Cottage Grove to Woodbury's municipal water system. Woodbury could extend their water lines south to provide the northeastern region of Cottage Grove with treated water. This option would require new water supply infrastructure to be installed in both Cottage Grove and Woodbury. In addition, Woodbury would need to provide treatment at their existing municipal supply wells and new municipal supply wells (potentially with treatment) would be required to meet the additional demand.	6	Wood

Project Number	Community	Project Name	Project Description	WSIO	Source[a]
78	Grey Cloud Island Township – St. Paul Park	Wood – Grey Cloud Island – St. Paul Park 1	**Create a new regional water public water through interconnects with neighboring communities:** This conceptual project would connect portions of Grey Cloud Island to St. Paul Park's municipal water system. Grey Cloud Island could connect to St. Paul Park's municipal water system to supply water to the northern portion of Grey Cloud Island along Grey Cloud Trail South. This would require treatment and expansion of St. Paul Park's municipal water system (in progress) in order to meet future demands of St. Paul Park and Grey Cloud Island. New water lines would also need to be installed in Grey Cloud Island along Grey Cloud Trail South to serve the northern residents.	6	Wood
79	Lake Elmo – Oakdale	Wood – Lake Elmo-Oakdale 1	**Create a new regional public water system through interconnects with neighboring communities:** This conceptual project would create an interconnect between Lake Elmo and Oakdale. Lake Elmo had previously evaluated an interconnect with Oakdale in a study by Bolton & Menk but found that the cost to reconfigure their current municipal water system exceeded the cost of drilling a new well. Two existing interconnects between Lake Elmo and Oakdale could supply 0.58 mgd of clean water or receive treated water. The capacity of these interconnects would need to be verified to determine if an interconnect is a viable option from a regional standpoint. In addition, the difference in hydraulic grade may require booster pump station(s) to deliver water from Lake Elmo to Oakdale.	6	Wood
80	Lake Elmo – Oakdale	15th Street North Water Main	Lake Elmo has a water main along Inwood Avenue – County 13 – with a water tower. Oakdale has a water main on 15th Street North ending at the border with Lake Elmo. Connecting these two water mains by a pipe running east to west along 15th Street North will provide public water availability in the future. The Armstrong Farm has donated their development rights to the Minnesota Land Trust and planted over 65,000 trees – there will be no further subdivisions on 15th Street North.	6	Online
81	Lake Elmo – West Lakeland	Wood – Lake Elmo-West Lakeland 1	**Create a new regional public water system through interconnects with neighboring communities:** This conceptual project would connect West Lakeland to Lake Elmo's municipal water system. However, Lake Elmo's demands would need to be met prior to providing water and new infrastructure would need to be installed to provide West Lakeland with a municipal water system.	6	Wood
82	Lake Elmo – Woodbury	Wood – Lake Elmo-Woodbury 1	**Create a new regional public water system through interconnects with neighboring communities:** This conceptual project would create an interconnect between Lake Elmo and Woodbury to supply clean water or receive treated water. Considerations for differences in system pressure and crossing I-94 would need to be made, which may make this a less technically feasible option than other neighboring communities.	6	Wood

Project Number	Community	Project Name	Project Description	WSIO	Source[a]
83	Lakeland/Lakeland Shores – West Lakeland	Wood – Lakeland/ Lakeland Shores – West Lakeland 1	**Create a new regional public water system through interconnects with neighboring communities:** This conceptual project would connect West Lakeland to Lakeland's municipal water system. Under this option, Lakeland has the potential to become a provider of treated groundwater to the neighboring community of West Lakeland. This could include both the southern half of West Lakeland, which has experienced extensive PFAS contamination; as well as the northern half, which was previously contaminated by a trichloroethylene plume. West Lakeland seemed very open about the possibility of receiving water from Lakeland; however, West Lakeland would need to install a municipal water system. If Lakeland became a regional water provider for neighboring communities such as West Lakeland and Afton or portions of Afton, they would need to drill new wells to meet demand. Varying topography (100+ feet) between Lakeland and neighboring communities would have to be considered, and additional elevated storage and pump stations may be required.	6	Wood
84	Maplewood – Newport	Wood – Maplewood – Newport 1	**Create a new regional public water system through interconnects with neighboring communities:** This conceptual project would connect portions of Maplewood to Newport's municipal water system. This would be most applicable for Maplewood residences with non-municipal wells that cannot be connected to SPRWS or do not want a POETS installed.	6	Wood
85	Maplewood – Woodbury	Wood – Maplewood – Woodbury 1	**Create a new regional public water system through interconnects with neighboring communities:** This conceptual project would connect portions of Maplewood to Woodbury's municipal water system. This is most applicable for Maplewood residences with non-municipal wells that cannot be connected to SPRWS or do not want a POETS installed.	6	Wood
86	Newport – St. Paul Park	Newport-Saint Paul Park Water Interconnect	**Cross-connect municipal water supplies to improve resilience in event of supply disruption.**	6	Online
87	Newport – Woodbury	Newport-Woodbury Water Interconnect	**Cross-connect municipal water supplies to improve resilience in event of supply disruption.**	6	Online
88	Oakdale – Woodbury	Wood-Oakdale-Woodbury 1	**Create a new regional public water system through interconnects with neighboring communities:** This conceptual project would create an interconnect between Oakdale and Woodbury. Oakdale currently has a 2.88 mgd interconnect with Woodbury that is	6	Wood

Project Number	Community	Project Name	Project Description	WSIO	Source[a]
			capable of meeting the city's current water supply gap for both a 2020 maximum daily demand (1.7 mgd needed) and a 2040 maximum daily demand (2.7 mgd needed). Considerations for this option would be any required infrastructure upgrades to accommodate differences in hydraulic conditions and new infrastructure to convey the water supply.		
89	Prairie Island Indian Community – Lake Elmo	Wood-PIIC-Lake Elmo 1	**Create a new regional public water system through interconnects with neighboring communities:** This conceptual project would connect Prairie Island Indian Community to Lake Elmo's municipal water system. This option would require that Lake Elmo extend their water lines out to Manning Avenue. A new water distribution system would also need to be installed to convey Lake Elmo's water.	6	Wood
90	Prairie Island Indian Community – Lakeland	Wood-PIIC-Lakeland 1	**Create a new regional public water system through interconnects with neighboring communities:** This conceptual project would connect Prairie Island Indian Community to Lakeland's municipal water system. In the case that Lakeland became a regional water supplier that supplied West Lakeland, Prairie Island Indian Community could connect to Lakeland's municipal water system through West Lakeland's infrastructure. This option will require a new distribution system in West Lakeland as well as in Prairie Island Indian Community for the future development.	6	Wood
91	Prairie Island Indian Community – West Lakeland	Wood-PIIC-West Lakeland 1	**Create a new regional public water system through interconnects with neighboring communities:** This conceptual project would create an interconnect between Prairie Island Indian Community and West Lakeland. Prairie Island Indian Community could supply water to West Lakeland. A new water distribution system would need to be installed to convey the treated water in both communities. A new well in Prairie Island Indian Community would also be needed to provide redundancy for a centralized treatment and distribution system, and the wells would need to meet Minnesota's Well Code. This would require a new distribution system in West Lakeland as well as in Prairie Island Indian Community for future development.	6	Wood
92	Prairie Island Indian Community – Woodbury	Wood-PIIC-Woodbury 1	**Create a new regional public water system through interconnects with neighboring communities:** This conceptual project would connect Prairie Island Indian Community to Woodbury's municipal water system. However, Woodbury's municipal water system would require treatment and the extension of their water distribution system lines. Additional wells within Woodbury may also be required to meet Prairie Island Indian Community's demands. The challenges associated with this option would be the installation of water lines across the Manning Avenue and the I-94 interchange.	6	Wood

Project Number	Community	Project Name	Project Description	WSIO	Source[a]
93	West Lakeland – Afton	Wood-West Lakeland-Afton 1	**Create a new regional public water system through interconnects with neighboring communities:** This conceptual project would create an interconnect between West Lakeland and Afton. If Afton developed a municipal water system to provide water to their northern region, West Lakeland could tie into Afton's system. West Lakeland would need to install new infrastructure.	6	Wood
94	Cottage Grove, Grey Cloud Island, Lake Elmo, Newport, Oakdale, St. Paul Park, and Woodbury	Wood Surface Water Regional 3	**Connect subsets of communities to St. Paul regional Water Services:** This conceptual project would connect the western communities to SPRWS by routing water through existing municipal water systems of neighboring communities. This would not be a standalone option for any one community and would require participation of multiple communities to take advantage of the cost savings. However, water quality and cost considerations regarding water age and potential water rates should be made.	7	Wood
Project for All Communities					
95	All Communities	Wood Surface Water Regional 1	**Create a new SWTP on the Mississippi River:** This conceptual project would add a SWTP on the Mississippi River to provide treated water to all communities of the East Metropolitan Area. This would not be a standalone option for any given community as it would require participation from multiple communities for cost-sharing purposes. Considerations for the location of the new SWTP would be the proximity of the two refineries and the wastewater treatment plant that discharges to the Mississippi River, and the additional treatment required. Additionally, infrastructure upgrades and installations to convey treated water would need to be considered and evaluated.	8	Wood
96	All Communities	Wood Surface Water Regional 2	**Create new SWTPs on the Mississippi River and the St. Croix River:** This conceptual project would supply all communities of the East Metropolitan Area with treated water from one SWTP on the St. Croix River and one SWTP on the Mississippi River. This would not be a standalone option for any one community as it would require participation from multiple communities for cost-sharing purposes. Considerations for the implementation of the St. Croix SWTP would be the permitting and regulatory review and approval process of various state and federal agencies. Considerations for the location of the new SWTP would be the proximity of the two refineries and the wastewater treatment plant that discharges to the Mississippi River, and the additional treatment required. Additionally, infrastructure upgrades and installations to convey treated water would need to be considered and evaluated.	8	Wood

Project Number	Community	Project Name	Project Description	WSIO	Source[a]
97	All Communities	Wood Groundwater Regional 1	**Create a new groundwater WTP:** This conceptual project would connect communities to a centralized groundwater WTP and distribution system. Further evaluation is required to optimize regional WTP(s) and potential location(s) across the East Metropolitan Area, as well as coordination with the groundwater model to optimize new well locations. Existing municipal supply wells will be evaluated to determine how they can be incorporated into this option.	6	Wood
Other Project Submissions					
98	All Communities	Reverse Osmosis Filtration	**All homes should be given reverse osmosis filtration filters:** This is the only way to ensure all perfluorinated chemicals (PFCs) and perfluorooctanoic acids (PFOAs) are removed.	1	Online
99	All Communities	Non-Community Public Water Systems	**MDH wants to ensure that the non-community public water system supply wells are being addressed:** MDH has compiled a list of those supply wells that have been impacted by PFAS contamination and that should be considered in future scenario evaluations.	1	Online
100	All Communities	Washington County Parks	**The county would like to ensure county parks have continued access to safe drinking water:** There are four existing county parks and one regional trail within the PFAS-affected area. Our parks receive many thousands of visitors each year and there is also a planned county park on Grey Cloud Island that is heavily impacted by PFAS in private wells. The larger solutions for the Conceptual Water Supply Plan may in fact result in water systems that are close enough to consider connecting in park facilities. If that is not the case, at a minimum, the treatment of water within these facilities, as needed, can and should be considered to ensure safe drinking water.	1	Online
101	All Communities	Water Testing and Treatment Endowment	**Endowment to fund ongoing testing and water supply maintenance, and upgrades for all areas covered by the settlement**.	N/A	Online
102	All Communities	Managed Aquifer Recharge	**Managed aquifer recharge includes both passive approaches where treated water is directed to unconfined aquifers, and an active approach wherein treated water is injected and recovered through wells:** This is also called aquifer storage and recovery (ASR). Both methods are used around the world and have been implemented in Minnesota. For communities affected by perfluorooctanesulfonic acid (PFOS) and PFOA, a bubble of clean water could be injected into the flow field of existing wells and be drawn upon for public water supply. This would also displace and redirect polluted water that may be flowing to the pumping center. An interdisciplinary team led by the Water Resources Center (WRC) is currently evaluating the engineering, hydrogeologic,	N/A	Online

Project Number	Community	Project Name	Project Description	WSIO	Source[a]
			economic, and policy benefits of and barriers to aquifer recharge in four places in Minnesota and one of those study areas is Washington County. The team will produce recommendations for recharge and how the State might proceed if recharge is the economic and practical approach.		
103	Washington County	Washington County Aquifer Augmentation District (WCAAD)	**This water supply option would establish a WCAAD, built on the premise of targeted ASR principles.** Normal aquifer recharge projects are typically designed to replenish water in an aquifer, but under this plan groundwater recharge is used for dilution and dispersion, the two primary means of contaminant attenuation these past decades, which would be used to lower in-situ PFC concentrations in the bedrock aquifers. In essence, it is a water flooding of the bedrock aquifers where recharge water increases potentiometric levels and augments groundwater flow, and serves as flushing of the resident PFC impacted groundwater with fresh (treated) water. This would be accomplished through the installation of both vertical injection wells and horizontal wells, or an underground injection aqueduct down the spine of the county's groundwater divide. Several ASR injection systems would need to be installed, based on the current understanding of groundwater impacts. A horizontal injection system could transect the groundwater divide running from the Washington County Landfill in Lake Elmo in the north and southward through eastern Woodbury and south of the Woodbury Disposal Site, and then deviate southeast to the 3M Cottage Grove Plant. The source water would be treated Mississippi River water. To address PFC-impacted wells in West Lakeland Township and northern Afton, a second ASR injection system would be installed utilizing St. Croix River water. A third ASR system would be installed in the southeast portion of the county with Mississippi River water to augment the bedrock aquifer in St. Paul Park and Grey Cloud Island, and running east to the 3M Cottage Grove plant. Under this system, largely, individual residences and municipalities would continue to own and maintain their current water distribution systems, a major cost in developing new infrastructure. The county would establish and run the ASR district.	N/A	Online

a. Wood = projects initially identified by Wood Environment & Infrastructure Solutions, Inc. and subsequently refined using input from the work groups and Subgroup 1. Online = projects submitted via the online project portal located on the Minnesota 3M Settlement website (https://3msettlement.state.mn.us/) between 8/6/2019 and 9/4/2019.

References

DNR. 2018. Minnesota Water Conservation Report 2018. November. Available: https://files.dnr.state.mn.us/waters/watermgmt_section/water_conservation/2018-water-conservation-report.pdf