Final Report

Regional Groundwater Recharge and Stormwater Capture and Reuse Study

North and East Metro Study Area

May 2016

METROPOLITAN COUNCIL

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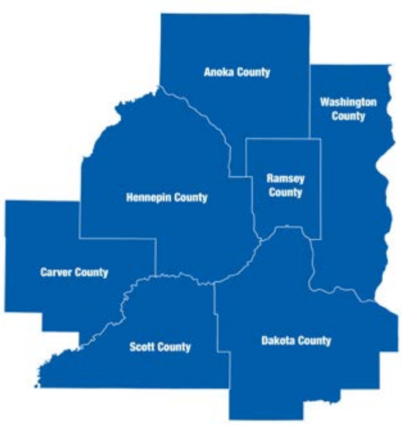

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About this Report

The 2005 Minnesota Legislature directed the Metropolitan Council to “carry out planning activities addressing the water supply needs of the metropolitan area,” including the development of a Twin Cities Metropolitan Area Master Water Supply Plan (Minn. Stat., Sec. 473.1565). After completing that plan, the Council took on many technical and outreach projects that strengthen local and regional water supply planning efforts. These projects have also elevated the importance of water supply in local comprehensive planning, which is carried out by local communities.

This study is one of several being led by the Metropolitan Council to support an update to the Master Plan and other activities identified by the 2005 Minnesota Legislature to address the water supply needs of the seven-county metropolitan area. This study is funded from the Clean Water Legacy Fund (Minn. Laws 2013 Ch. 137, Art. 2, Sec. 9).

The Metropolitan Council retained HDR to complete this technical study of two broad approaches to the regional sustainability of water resources in the north and east part of the Metropolitan Area. This study has been carried out with input from and engagement with local stakeholders, including other agencies, municipalities and watershed districts/water management organizations.

Recommended Citation

Metropolitan Council. 2016. *Regional Groundwater Recharge and Stormwater Reuse Study (North and East Metro Study Area) – Draft Report*. Prepared by HDR. Metropolitan Council: Saint Paul.

CLEAN WATER LAND & LEGACY AMENDMENT

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Executive Summary

This regional study evaluates the potential to enhance groundwater recharge and evaluates the potential for stormwater to serve as either a source for enhanced recharge or a non-potable water supply in the North and East Metro area. This study is one of several being led by the Metropolitan Council (Council) to support an update to the Water Supply Master Plan and other activities identified by the 2005 Minnesota Legislature to address the water supply needs of the seven-county metropolitan area.

Background

Groundwater is the principal source for water supply for municipalities in the Metropolitan Area. The ratio of groundwater use to surface water use for municipal supply has increased over the last several decades and currently groundwater use measures approximately three times that of surface water use in the region (Metropolitan Council, 2015a). Groundwater modeling done by the Council projects that continued development of groundwater sources to meet future demands may have an adverse effect on resources, and conversely indicates benefit to the regional aquifers if demand on groundwater is reduced (Metropolitan Council, 2015b).

Enhancing groundwater sources through enhanced groundwater recharge or development of alternative sources, like the capture and use of stormwater for non-potable supply, can improve the reliability of the region's water supply. Having diversified water sources can support projected population growth and economic development of the region, and improve the flexibility of its water supply.

Scope of the Regional Study

This report summarizes the study of enhanced aquifer recharge and stormwater capture and reuse potential for the North and East Metro Study Area. The study area boundary (shown in the attached figure) was designed to match the North and East Groundwater Management Area as defined by the Minnesota Department of Natural Resources (MnDNR, 2015). It covers all of Washington and Ramsey Counties, and portions of Anoka and Hennepin Counties.

The scope of the regional study includes two components: Enhanced Recharge, and Stormwater Capture and Reuse. Similar studies, including those that evaluate alternative drinking water sources, were conducted for other regions in the metropolitan area and are summarized in separate reports.

This study is a first look at supplementing water sources and enhancing bedrock aquifer recharge on a regional scale in this part of the metropolitan area. It is a desktop study, intended only to assess the potential for enhanced recharge and stormwater reuse, and to provide the Council and communities in the region technical information that can be used in future planning and implementation efforts. The study is not intended to prescribe solutions for specific locations within the study area.

Enhanced Groundwater Recharge

This study included a regional assessment of enhanced groundwater recharge in the North and East Metro area. Enhanced groundwater recharge is an integrated approach to water management that could provide benefit to regional aquifers. The purpose of the study was to perform an initial screening of the study area to identify areas where water applied at the surface would have the highest potential to recharge bedrock aquifers based on specific hydrogeologic, land use, drinking water protection, and other specific criteria. Emphasis was given to recharge of permeable bedrock formations as the majority of the groundwater used in the North and East Metro study area for municipal supply comes from these sources. The study is intended to serve as a planning-level assessment of regional-scale enhanced recharge opportunities in the study area and as a basis of technical information for others to use in more detailed, site-specific analyses.

The analysis was completed as a desktop study, and as such no subsurface investigations were performed. Assessment of the impact of enhanced recharge on groundwater levels was not included in the scope of this study, but is a recommended step in further study of enhanced recharge opportunities. Other potential benefits of enhanced groundwater recharge, such as its impact on sensitive surface water features, were also not specifically evaluated as part of the study.

Findings

- Nearly 13,000 acres, or approximately three percent of the study area, were classified as having good potential for groundwater recharge based on study criteria.
- An additional 49,000 acres were classified as having limited potential for groundwater recharge based on study criteria, but where a more detailed study of local conditions may result in a more favorable assessment.
- Most of the areas classified as having either good or limited potential are in the eastern and southern portions of the study area, and are concentrated in Afton, Cottage Grove, Denmark Township, May Township, Stillwater Township, and West Lakeland Township.
- Reasonable opportunities for enhanced recharge may also exist in portions of Grant, Lake Elmo, Scandia, and Woodbury.
- Much of the western and northern portions of the study area are classified as having poor potential for enhanced groundwater recharge, primarily due to low hydraulic conductivity, shallow water table, land development, or a combination of these factors.
- A significant amount of area classified as having good potential for enhanced recharge lies in portions of Washington County where known contamination exists.
- Most of the area classified as having good potential for enhanced recharge lies outside areas that are projected to experience significant aquifer drawdown with continued groundwater pumping. This is mainly due to the lack of undeveloped land in these areas, which is a limiting criterion in the analysis.
- Estimated costs for constructed recharge basins range from $1.7 million to $4.6 million for 10-acre basins, and from $13 million to $35 million for 80-acre basins, not including source water treatment, land acquisition or water quality monitoring.

Recommendations

- MDH, MPCA, and local watershed management districts should be consulted for the latest guidance for planning, design and implementation of recharge basins.
- Further analysis and planning studies would be required to assess the feasibility of constructing enhanced recharge facilities, including hydrogeologic analysis, subsurface investigations and site review for candidate sites.
- More investigation into the nature and extent of contaminant plumes is recommended if specific parcels are identified for enhanced recharge projects.
- Modeling studies should be performed to analyze groundwater mounding potential and the recharge contribution to unconsolidated and bedrock aquifers at potential enhanced recharge sites.

- Water quality, source water treatment, and monitoring requirements should be fully evaluated for each specific recharge site as these can have a significant impact on project costs.
- Potential impacts to vulnerable drinking water supplies and the movement of contaminant plumes should be assessed. Groundwater travel time from proposed recharge basin sites to public water supply wells and contaminant plumes should be examined.
- Source water quantity, variability and reliability should be fully evaluated on a site-specific basis.
- Monitoring requirements should be developed for long-term evaluation of groundwater quality and mounding.
- Individual threatened and endangered species and any associated construction requirements would need to be identified in coordination with the MnDNR on a site-specific basis.

Stormwater Capture and Reuse

Stormwater capture and reuse refers to the large-scale diversion and collection of stormwater runoff for beneficial use. In this part of the country treated drinking water is often used for urban irrigation, driving peak summertime demands. There is potential to reduce groundwater withdrawals and demands for treated potable water supplies through capture, retention and reuse of stormwater.

The purpose of the stormwater capture and reuse study was to conduct a preliminary assessment of stormwater capture and reuse systems as a way to offset demand on groundwater sources for non-potable uses, and to quantify the potential to use captured stormwater as a source for enhanced recharge in the North and East Metro Study Area. The study is intended to serve as a planning-level assessment of the potential to offset groundwater use with stormwater reuse and as a basis of technical information for others to consider in more detailed, site-specific analyses.

The study focused on existing high-volume, non-potable uses identified through both MnDNR appropriation permit records and municipal water sales data. Cost information and implementation discussions were based on reuse mainly for urban irrigation applications. Smaller scale opportunities for on-site rainwater harvesting, such as the use of residential rain barrels or single property systems, were not evaluated as part of this regional study. The study did not consider the potential for stormwater reuse to supply future developments or needs.

Findings

- The average annual non-winter runoff for the entire study area was calculated to be 89,981 million gallons (MG). Total groundwater use for 180 high-volume, non-potable uses identified in the study area totaled 5,018 MG, or 5.6% of non-winter runoff in 2010.
- Of the 180 high-volume, non-potable groundwater users identified in the study, 73 percent could potentially capture and reuse stormwater as an alternative to groundwater use. These sites were estimated to have stormwater run-on (surface runoff from upstream areas that flow to a specific site or area) that exceeds 2 times their annual water use, and could be further evaluated for stormwater capture and reuse feasibility.
- Stormwater run-on to fifteen of the sites classified as having good or limited potential for enhanced groundwater recharge based on study criteria amounts to approximately 4,200 MG per year, or 11.5 MG per day, on average.

- Estimated costs for stormwater capture and reuse (irrigation) systems range from $2.5-$10 per 1,000 gallons for 10,000 gallon systems to $0.28-$0.45 per 1,000 gallons for one million-gallon systems, not including source water treatment, water quality monitoring, land acquisition or irrigation equipment.

Recommendations

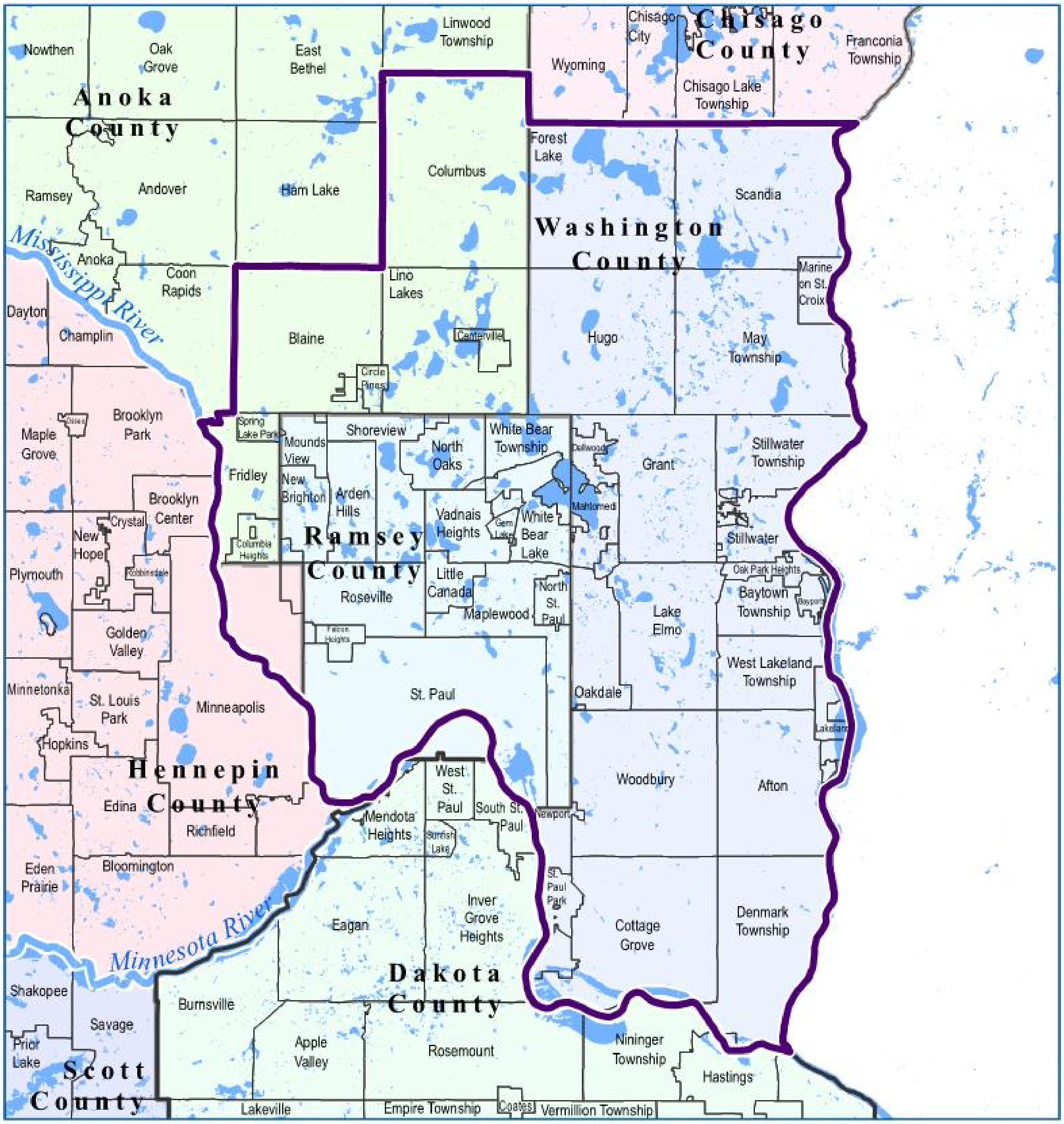
- MDH, MPCA, and MnDNR, along with municipalities and local watershed management districts should be consulted for the latest guidance for planning, design and implementation of stormwater reuse systems.
- Water quality and water treatment requirements should be fully evaluated for each specific reuse application as treatment requirements can have a significant impact on project costs.
- A detailed analysis of local hydrology and stormwater availability at specific sites should be conducted to further characterize source availability and evaluate storage, bypass, and back-up source requirements.
- Diversion of stormwater from storm sewer or other conveyance systems and the potential impact of reduced flow on downstream conditions should be evaluated.

Related Water Planning Studies

This study is one of a number of studies and technical evaluations the Council is completing to support water supply planning and sustainability in the region. In December 2014 the Council published a report titled, "*Feasibility Assessment of Approaches to Water Sustainability in the Northeast Metro*". The study evaluated approaches to drinking water supply in the northeastern part of the Twin Cities, including a sub-group of the communities in the North and East Metro study area in the vicinity of White Bear Lake. The Council is also working on a study to evaluate the financial implications of combining certain components of municipal water supply and distribution systems in another sub-group of communities in the northern part of the study area. Results from that study are expected in 2016.

Metropolitan Council
Regional Groundwater Recharge and Stormwater Reuse Study

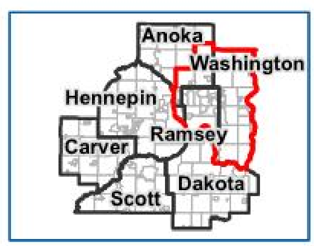
North and East Metro Study Area



Legend

- Study Area
- County Boundary
- City/Township Boundary
- Waterbody

0 35,000 Feet



Sources: Met Council, NHD, DNR

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Introduction

The Metropolitan Council (Council) contracted with HDR to study water supply diversification alternatives in various regions of the seven-county metropolitan area. This Regional Groundwater Recharge and Stormwater Reuse Study report summarizes the study of the North and East Study Area (study area). The scope of the study includes a desktop-level assessment of enhanced groundwater recharge and stormwater capture and reuse. Information used in the study was obtained from available sources. No subsurface investigations or engineering design were performed.

The study area boundary was designed to match the North and East Groundwater Management Area as defined by the Minnesota Department of Natural Resources (MnDNR, 2015). It covers all of Washington and Ramsey Counties, and portions of southeastern Anoka County and the portion of Hennepin County that lies east of the Mississippi River. The study area is shown in Figure 1.

The enhanced groundwater recharge and stormwater capture and reuse components of this regional study are being applied to other regions, or study areas, in the metropolitan area. Although there may be some refinement in scope for a specific study area related to resource availability or other conditions, the same general approach to the analyses can be applied to various regions. Detailed results of the analyses for other regions are summarized in separate reports.

Background

Reliable sources of abundant and high quality water have been critical to development of the Twin Cities region. Population growth and expanding development are increasing demands on water supplies in the region (Metropolitan Council, 2015b). The metropolitan area is focusing greater attention on sustainable water supplies to meet these needs.

Groundwater modeling done by the Council shows that continued development of groundwater sources to meet future demands will have an adverse effect on resources, and conversely shows benefit to regional aquifers if demand on groundwater is reduced (Metropolitan Council, 2015b).

This study is one of a number of studies and technical evaluations the Council is completing to support water supply planning and sustainability in the region. These include, "*Feasibility Assessment of Approaches to Water Sustainability in the Northeast Metro*" published by the Council in December 2014. The study evaluated approaches to drinking water supply in the northeastern part of the Twin Cities, including a sub-group of the communities in the North and East Metro study area in the vicinity of White Bear Lake. The Council is also working on a study to evaluate the financial implications of combining certain components of municipal water supply and distribution systems in another sub-group of communities in the northern part of the study area. Results from that study are expected in 2016.

The focus on the North and East Metro Study Area resulted from a 2014 Clean Water Fund appropriation to the Council, which was intended to fund the investigation of the "feasibility of collecting and treating storm water in the North and East Metro Groundwater Management Area to enhance surface waters and groundwater recharge."

The results of the study can help the Council and the communities in the sub-region better understand enhanced recharge and stormwater reuse as approaches to augment groundwater resources or reduce groundwater demands.

Enhanced Groundwater Recharge

Introduction

Groundwater recharge is defined as the inflow of water to a groundwater reservoir from the land surface. Natural groundwater recharge usually refers to the natural infiltration of precipitation to the water table (USGS, 2015). Enhanced groundwater recharge refers to engineered systems designed to infiltrate surface water into the zone of saturation, with the express purpose of increasing the amount of groundwater stored in the aquifer.

The objective of the enhanced groundwater recharge study was to perform an initial screening of the study area to identify areas where water applied at the surface would have the highest potential to recharge bedrock aquifers. The analysis was completed by compiling and analyzing existing surface and subsurface data and comparing it to a set of criteria. Emphasis was given to recharge of permeable bedrock formations as the majority of the groundwater used in the North and East Metro study area for municipal supply comes from these sources. Other potential benefits of enhanced recharge, such as its impact on sensitive surface water features, were not specifically evaluated as part of the study.

Methodology and results of the enhanced groundwater recharge study are described in the following sections. General concepts related to enhanced recharge, including implementation of groundwater recharge projects, are also discussed. Suggestions for data refinements that would facilitate more detailed analysis of location-specific recharge opportunities within the study area are also provided. Although the recharge criteria and analysis did not identify a specific water source for groundwater recharge, an assessment of stormwater as a potential recharge water source is considered in a subsequent section of this report.

Recharge and Infiltration

Recharge and infiltration are similar processes in that both refer to the hydrologic process by which water at the surface enters and percolates through the soil. Recharge refers to the water that infiltrates past the root zone, into the saturated zone, and eventually reaches groundwater sources. Not all water that infiltrates will necessarily recharge the water table.

Although there are state and local policies that encourage or require infiltration as a stormwater management practice, these policies are designed primarily to manage runoff rate and volume and protect the quality of receiving water bodies. While some portion of infiltrated stormwater can and may eventually reach the water table, aquifer recharge is not generally the primary goal of most stormwater management practices. For example, Minnesota's Minimal Impact Design Standards (MIDS) encourages a low-impact development approach to stormwater management, where water is kept on the landscape, mimicking pre-development hydrology. Under the MIDS guidelines, infiltration is used to offset the hydrologic effects of creating new or redeveloped impervious area (MPCA, 2015a). While groundwater recharge can be an incidental benefit of the low-impact development approach, it is not usually the primary driver for the practice. Enhanced groundwater recharge at the scale that is considered in this study is typically done with constructed facilities that have the specific purpose of increasing the recharge to groundwater supplies.

Benefits of Enhanced Groundwater Recharge

The objective of this study was to evaluate the potential to enhance groundwater recharge to drinking water aquifers in the study area. In addition to the direct benefit to aquifers, enhanced groundwater recharge can provide other water resource benefits. The following list describes potential benefits to surface water from enhanced groundwater recharge:

- Enhanced recharge near surface water bodies can offset the lateral drawdown effects of pumping from nearby wells.
- Enhanced recharge near surface water bodies can offset the loss of water due to lower potentiometric heads in underlying aquifers. Surface water bodies can be losing water from deeper portions while receiving recharge from groundwater in shallow portions.
- Enhanced recharge near surface water bodies can improve the quality of the water that ultimately recharges the surface water body (as opposed to direct overland flow to the surface water body).
- Enhanced recharge can raise the water table over the long-term, reversing the lowering of water levels in surface water bodies.

Stormwater is a potential recharge water source. Capturing stormwater for enhanced recharge may provide benefit not only to bedrock aquifers, but also the unconsolidated aquifers and surface water bodies that are vulnerable to changes in groundwater level. A key component to enhancing recharge to any groundwater resource is providing a net addition of water to the system, which could be accomplished by capturing stormwater runoff before it leaves the local watershed.

North and East Metro Area Enhanced Groundwater Recharge Study

Methodology

The methodology for the enhanced groundwater recharge study included the collection and processing of existing data sets, the development of criteria to assess the potential for enhanced groundwater recharge on a regional scale, and the evaluation of the data against the established criteria. These steps are described in detail in this section.

Data Collection

Data relevant to infiltration and recharge criteria were collected from various sources including publicly-available Geographic Information System (GIS) datasets from local, state and national agencies. Data were placed into several categories including geology/hydrogeology, land use/natural resources, and drinking water protection. Table 1 shows the datasets that were collected and used in the study.

Table 1. Data Sources and Datasets for Enhanced Recharge Study

Data Source	Dataset(s) Used	Reference
Geology/Hydrogeology		
United States Department of Agriculture Natural Resources Conservation Service (NRCS) Soil Survey Geographic Database	Vertical infiltration rate data for soils, top 5 feet	(NRCS, 2014)
	Parent material for soils	(NRCS, 2014)
Minnesota Geological Survey (MGS)	Hydraulic conductivity for unconsolidated zone	(Tipping, 2011)
	Bedrock geology	(Mossler, 2013)
Metropolitan Council Environmental Services (MCES)	Water table elevation	(Barr Engineering, 2010)
Land Use and Natural Resources		
MCES	Current (2010) land use	(MCES, 2011)
	Future (2030) land use	(MCES, 2014)
Minnesota Department of Natural Resources (MnDNR)	Calcareous Fens, Trout Streams, Native Plant Communities, Aquatic Management Areas, Game Refuges, Wildlife Management Areas, Federal Land/Easement, Scientific and Natural Areas, State Parks, USDA NRCS Easement, Nature Conservancy, T&E Species Areas, Regional Natural Resource Areas	(MnDNR, 2014a)
Drinking Water Protection		
Minnesota Department of Health (MDH)	Drinking Water Supply Management Area (DWSMA) vulnerability	(MDH, 2014)

Data Processing

Although most datasets were incorporated into the study in their original form, processing of some datasets was required to reach project goals. Specific modifications to the datasets include the following:

- Calculation of the average vertical infiltration rate of the top 5 feet of soil;
- Calculation of hydraulic conductivity of the unconsolidated formation; and
- Calculation of the depth to the water table.

Average Vertical Infiltration Rate: NRCS provides a vertical infiltration rate (k_{satr}) for multiple depths within the top 5 feet of soil. An average vertical infiltration rate was assigned at each location where k_{satr} data is available. This was done by calculating a weighted average of all k_{satr} values provided for the top 5 feet of soil at each location.

Hydraulic Conductivity: Data prepared by Tipping (2011) were used to determine a representative value of hydraulic conductivity for the unconsolidated formation. The source data includes values for hydraulic conductivity at 20 foot intervals on a 250 meter grid. The values were assigned based on interpolations from existing well and boring logs. To determine a composite value to represent hydraulic conductivity of the overburden the harmonic mean of the values along the vertical column for each grid point was computed. This value was then applied to a 250 square meter area around each grid point. If the entire vertical profile of a grid cell was given an intermediate value of 10.05 ft/day by Tipping (2011) due to insufficient lithologic data, HDR cross-checked these areas for permeable parent material to determine aquifer recharge feasibility and factored that assessment into the Tier 2 criteria.

Depth to Water: The depth to water table was calculated using water table elevations obtained from the datasets prepared for the Metro Model 3 groundwater model. These point elevations were subtracted from ground surface elevation data estimated using the National Elevation Dataset (NED) 30m developed by USGS. Dataset processing is summarized in Table 2.

Table 2. Processing of Datasets for Enhanced Recharge Study

Data Source	Processed Dataset(s)	Processing Required
Geology/Hydrogeology		
NRCS	Vertical infiltration rate (k_{satr})	The average vertical infiltration rate was calculated using a weighted average of all k_{satr} values in the top 5 feet of soil at a given location.
MGS	Hydraulic conductivity data for unconsolidated zone	A composite hydraulic conductivity value was calculated by taking the harmonic mean of the hydraulic conductivity of each 20-ft elevation interval created by Tipping (2011) at each grid cell.
MCES	Water table elevation	Depth to water table was calculated by subtracting the water table elevations given by Barr Engineering (2010) from the National Elevation Dataset (NED 30m).

Criteria Development

Criteria were developed to evaluate the potential for enhanced groundwater recharge within the study area. Three levels of criteria were developed for each dataset:

- *Tier 1* criteria indicate areas that have may have good potential for enhanced groundwater recharge.
- *Tier 2* criteria indicate areas where there may be limited potential for enhanced groundwater recharge.
- *Tier 3* criteria indicate areas where there is poor potential for enhanced groundwater recharge.

The enhanced groundwater recharge criteria are presented in Table 3. Rationale for the criteria is presented in Table 4. Individual datasets used in the evaluation are depicted on Figures A1-1 through A1-9 in Appendix A1. Geology, hydrogeology, and land use criteria were partially developed with input from the Metropolitan Council Environmental Services (MCES), Minnesota Pollution Control Agency (MPCA), Minnesota Department of Natural Resources (MnDNR), Minnesota Board of Water and Soil Resources (BWSR), United States Geological Survey (USGS), and Minnesota Geological Survey (MGS). Drinking water protection criteria were developed with input from the Minnesota Department of Health (MDH).[1]

Table 3. Criteria for Evaluation of Enhanced Recharge Areas

Criteria	Tier 1	Tier 2	Tier 3	Figure Reference (see Appendix A1)
Geology/Hydrogeology				
Vertical Infiltration Rate (k_{satr}) - Top 5 feet (NRCS)	>5in/hr	0.5 - 5 in/hr	<0.5 in/hr	Figure A1-1
Parent Material (NRCS)	N/A	(see Composite Hydraulic Conductivity, below)	N/A	Figure A1-2
Composite Hydraulic Conductivity (MGS)	>10 ft/day	1 - 10 ft/day, or Insufficient data but permeable parent material (glaciofluvial sediments, outwash)	<1 ft/day	Figure A1-3

[1] Individual meetings with agency and local government representatives were held to discuss the methodology and draft evaluation criteria. Final criteria were developed with input from agency and local government representatives received at a workshop held in January 2015.

Criteria	Tier 1	Tier 2	Tier 3	Figure Reference (see Appendix A1)
Depth to Water Table	>50 feet	≥15 feet	<15 feet	Figure A1-4
Uppermost Bedrock (MGS)	Prairie du Chien and older	St. Peter and older	Galena, Decorah, Platteville, Glenwood	Figure A1-5
Land Use/Natural Resources				
Current Land Use - 2010 (MCES)	Agricultural, parks, undeveloped areas	Agricultural, parks, undeveloped areas	All types other than agricultural, parks, undeveloped areas	Figure A1-6
Future Land Use – 2030 (MCES)	(2030 land use was not used for the analysis; a figure was generated for discussion purposes)			Figure A1-7
Sensitive Natural Resource Areas (MnDNR)	Not within: Calcareous Fens, Trout Streams, NPC, AMA, WMA, Federal Land/Easement, SNA, State Parks, USDA NRCS Easement, Nature Conservancy, RNRA, T&E Species Areas, Game Refuge[1]	Not within: Calcareous Fens, Trout Streams, NPC, AMA, WMA, Federal Land/Easement, SNA, State Parks, USDA NRCS Easement, Nature Conservancy, RNRA	Within: Calcareous Fens, Trout Streams, NPC, AMA, WMA, Federal Land/Easement, SNA, State Parks, USDA NRCS Easement, Nature Conservancy, RNRA	Figure A1-8
Drinking Water Protection				
High or Very High Vulnerability DWSMA and <100 ft to Prairie du Chien (MDH)	Outside the limits of a vulnerable DWSMA	Outside the limits of a vulnerable DWSMA	Within the limits of a vulnerable DWSMA and < 100 ft to the	Figure A1-9

Notes:

[1] *NPC = Native Plant Communities; AMA = Aquatic Management Areas; WMA = Wildlife Management Area; SNA = Scientific and Natural Area; USDA NRCS = United States Department of Agriculture Natural Resource Conservation Service; RNRA = Regional Natural Resource Area; T&E = threatened and endangered.*

Table 4. Rationale for Enhanced Recharge Criteria

Criteria	Rationale
Geology/Hydrogeology	
Vertical Infiltration Rate - Top 5 feet (NRCS)	• 5 in/hr (or greater) was chosen as the Tier 1 criterion for vertical infiltration; 5 in/hr is generally considered to be a lower threshold limit for rapid infiltration basins. • 0.5 - 5 in/hr was chosen as the Tier 2 criterion, representing a site with limited potential for a rapid infiltration basin; • 0.5 in/hr, the criterion for Tier 3 areas, represents a site with poor potential for an infiltration basin. It is a slightly more conservative screening value than the 0.2 in/hr minimum recommended in the Minnesota Stormwater Manual (MPCA, 2015b) for infiltration basins.
Parent Material (NRCS)	• Parent material was used to cross-check for permeability the areas where composite hydraulic conductivity data (Tipping, 2011) is insufficient. If permeable parent material is indicated, the grid cell was deemed Tier 2 (limited potential) for recharge. • Coarse-grained materials such as glaciofluvial sediments and outwash are deemed feasible for transmitting water for recharge.
Composite Hydraulic Conductivity (MGS)	• 10 ft/day (or greater) was chosen as the Tier 1 criterion for hydraulic conductivity representing formation material that is conductive enough to receive recharge water from a rapid infiltration basin without excessive mounding. • 1 - 10 ft/day was chosen as the Tier 2 criterion for a site with limited potential for enhanced recharge. • < 1 ft/day was chosen as the Tier 3 criterion and represents a site with poor potential for enhanced groundwater recharge. The hydraulic conductivity of the formation materials in these areas is considered too low and recharge from infiltration basins would likely cause excessive mounding.
Depth to Water Table (MCES)	• 50 feet (or greater) unsaturated thickness was chosen as the Tier 1 criterion for infiltration. • 15 feet was chosen as the Tier 2 criterion, representing a reasonable minimum unsaturated thickness over which water from an infiltration basin can build a sufficient vertical gradient to effectively drive infiltration. Higher water tables will require higher transmissivity to accommodate mounding.
Uppermost Bedrock (MGS)	• Subcropping Prairie du Chien and older bedrock aquifers are deemed Tier 1 (most feasible) for receiving recharge since they typically have sufficient permeability (i.e., could be effectively recharged) and are heavily pumped. • Subcropping St. Peter and older aquifers are deemed Tier 2 since the basal St. Peter may contain a lower confining layer that could hinder recharge to lower aquifers. • Subcropping Galena, Decorah, Platteville, and Glenwood formations are typically considered to be either 1) a confining unit, or 2) not typically used for water supply, and are deemed Tier 3 (unfeasible) for receiving recharge.

Criteria	Rationale
Land Use/Natural Resources	
Current Land Use (MCES)	• Agricultural, parks, and undeveloped areas may have land available and are considered Tier 1 and Tier 2 for locating large infiltration basins. • All other types of land use are considered Tier 3 since the land is already developed.
Natural Resource Areas (MnDNR)	• Calcareous Fens, Trout Streams, NPC, AMA, WMA, Federal Land/Easement, SNA, State Parks, USDA NRCS Easement, Nature Conservancy, and RNRA are Tier 3 for locating infiltration basins since they are sensitive and/or protected natural resources. • T&E Species Areas and Game Refuges are considered Tier 2 (generally feasible) for locating infiltration basins at this time based on low potential for impact to those areas.
Drinking Water Protection	
High or Very High Vulnerability DWSMA and <100 ft to fractured bedrock (MDH)	Considered to be Tier 3 (unfeasible). MDH guidance (MDH, 2007) specifies stormwater infiltration should not occur where less than 100 feet of unconsolidated sediments separate fractured bedrock (e.g., Prairie du Chien dolomite) from the ground surface within a vulnerable DWSMA. This guidance is in place to protect vulnerable public supply wells from potential pathogens.

Data Calculation

The datasets were imported into GIS and new subsets of data were identified at the intersection of specific criteria. Polygons were created to identify the areas where specific features or portions of features from the various datasets overlapped. These areas represent the results of the enhanced recharge study, and were classified as follows:

- *Tier 1* subsets from each of the various datasets were merged to show the areas where all of the Tier 1 criteria were met. These areas may have good potential for enhanced groundwater.
- *Tier 2* subsets from each of the various datasets were merged to show the areas where all of the Tier 2 criteria were met. These are areas where there may be limited potential for enhanced groundwater recharge. However, it is possible that local conditions are more favorable than what is indicated in the regional datasets for the Tier 2 areas.
- *Tier 3* areas are those not classified as Tier 1 or Tier 2, indicating that there is poor potential for enhanced groundwater recharge. For an area to be classified as Tier 3, any one of the criteria for a Tier 3 recharge location needed to be met.

Results

Two approaches were used to evaluate the recharge potential in the study area. The first approach used hydrogeological criteria to identify areas where water could infiltrate and potentially reach a bedrock drinking water aquifer, without consideration for the current land use or other human- or environmental-influenced limitations. The second approach expanded the hydrogeological approach to incorporate land use, sensitive natural resource areas, and drinking water protection areas into the data calculation. GIS-based maps were generated for each approach. Figure 2 shows the results using only the hydrogeological criteria, and Figure 3 shows the results using all criteria. Each figure includes a summary of the criteria used to generate the figures.

The total Tier 1 and Tier 2 area using all (expanded) criteria is summarized in Table 5, with breakdowns of the Tier 1 and Tier 2 areas by municipality shown in Table 6. Much of the western and northern portions of the study area are classified as Tier 3, primarily due to low hydraulic conductivity, shallow water table, land development, or a combination of these factors. Most of the Tier 1 and Tier 2 areas are in the eastern and southern portions of the study area, and are concentrated in Afton, Cottage Grove, Denmark Township, May Township, Stillwater Township, and West Lakeland Township. These locations have considerable amounts of agricultural and undeveloped land that could potentially support the development of regional-scale recharge basins. Reasonable opportunities for enhanced recharge also exist in portions of Grant, Lake Elmo, Scandia, and Woodbury.

Table 5. Tier 1 and Tier 2 Areas in the Study Area for Enhanced Recharge Using All Criteria

Enhanced Recharge	Acres	% of Study Area
Tier 1 Area	12,866	2.7%
Tier 2 Area	48,614	10%

Table 6. Tier 1 and Tier 2 Areas for Enhanced Recharge in Municipalities Using All Criteria

Municipality	Tier 1 Recharge Area (acres)	Tier 2 Recharge Area (acres)	Municipality	Tier 1 Recharge Area (acres)	Tier 2 Recharge Area (acres)
Afton	1,187	5,909	Marine on St. Croix	95	316
Arden Hills	0	1	May Township	1,309	4,109
Bayport	144	265	Minneapolis	0	37
Baytown Township	351	1,643	New Brighton	0	40
Birchwood Village	0	0	Newport	5	185
Columbia Heights	0	5	North Oaks	0	2

Municipality	Tier 1 Recharge Area (acres)	Tier 2 Recharge Area (acres)	Municipality	Tier 1 Recharge Area (acres)	Tier 2 Recharge Area (acres)
Cottage Grove	3,132	7,425	North St. Paul	0	5
Dellwood	0	15	Oak Park Heights	16	104
Denmark Township	1,751	6,761	Oakdale	7	143
Forest Lake	0	39	Pine Springs	0	34
Fridley	0	61	Roseville	0	138
Gem Lake	0	30	Scandia	711	2,943
Grant	296	2,392	Shoreview	0	48
Grey Cloud Island Township	169	373	St. Marys Point	0	65
Hastings	0	12	St. Paul	4	755
Hugo	12	392	St. Paul Park	32	458
Lake Elmo	366	2,474	Stillwater	20	271
Lake St. Croix Beach	0	58	Stillwater Township	1,734	3,613
Lakeland	0	296	Vadnais Heights	0	88
Lakeland Shores	0	19	West Lakeland Township	1,291	3,241
Lino Lakes	0	42	White Bear Lake	0	100
Little Canada	15	78	White Bear Township	0	178
Mahtomedi	0	51	Woodbury	170	2,850
Maplewood	50	548			

Table 7 lists the Tier 1 and Tier 2 areas by watershed jurisdiction. Nine watershed jurisdictions have over 1,000 acres of Tier 1 or Tier 2 area. The greatest amount of this area is in Carnelian/Marine Watershed District, Lower St. Croix Watershed Management Organization, South Washington County Watershed District, and Valley Branch Watershed District, each of which has over 5,000 acres of Tier 1 or Tier 2 area. The boundaries of the watershed jurisdictions are shown on Figure 4 along with the Tier 1, Tier 2, and Tier 3 areas for enhanced recharge using all criteria. A discussion of the role of the municipality or watershed organization in the development of recharge basins is provided in the following section, Enhanced Groundwater Recharge Implementation.

Table 7. Tier 1 and Tier 2 Areas for Enhanced Recharge in Watersheds Using All Criteria

Watershed Jurisdiction	Tier 1 Recharge Area (acres)	Tier 2 Recharge Area (acres)
Browns Creek Watershed District	335	2,430
Capitol Region Watershed District	2	377
Carnelian/Marine Watershed District	2,420	5,273
Forest Lake/Comfort Lake Watershed District	79	283
Grass Lake Watershed Management Organization	0	92
Lower St. Croix Watershed Management Organization	2,459	9,574
Marine-on-St. Croix Watershed Management Organization	1,023	3,988
Middle St. Croix Watershed Management Organization	1,118	3,305
Mississippi River Watershed Management Organization	0	37
(Orphan - northeast corner of Washington County)	238	1,102
Ramsey/Washington/Metro Watershed District	63	1,113
Rice Creek Watershed District	21	949
Six Cities Watershed Management Organization	0	56
South Washington County Watershed District	2,919	9,260
Vadnais Lake Area Watershed Management Organization	0	219
Valley Branch Watershed District	2,189	10,557

Although this study did not incorporate presence of soil and groundwater contamination into the criteria for enhanced recharge, it is important to note the location of contaminated and potentially contaminated areas. Contamination datasets were gathered from public sources and are summarized in Table 8. The provided datasets consist of either point locations (e.g., pollution containment wells) or polygons (e.g., contaminant plumes), and are shown on Figure 5 with the Tier 1, Tier 2, and Tier 3 areas for enhanced recharge using all criteria. A significant amount of Tier 1 and Tier 2 area is in portions of Washington County where known contamination exists. Development of recharge basins should closely consider contaminated areas; this is discussed further in the following section, Enhanced Groundwater Recharge Implementation.

Table 8. Contamination Datasets Mapped for Enhanced Recharge Study

Data Source	Dataset(s) Used	Reference
MDH	Special Well and Boring Construction Areas (SWBCAs) generally define the footprint of areas with relatively high concentrations of contaminants. SWBCAs are provided as polygons.	(MDH, 2015a)
MDH, US Army c/o Wenck and Associates	Large, known contaminant plumes, including 3M perfluorochemicals (PFCs) (2014 mapping), Baytown Township (2014 mapping), Lakeland/Lakeland Shores (2014 mapping), and Twin Cities Army Ammunition Plant (TCAAP) (2013 mapping). Plumes are provided as polygons.	(MDH, 2015b) (Wenck, 2015)
MnDNR	Pollution containment wells listed in the State Water Use Database System (SWUDS) indicate areas of potential contamination. Provided as point locations.	(MnDNR, 2014b)
Minnesota Pollution Control	What's In My Neighborhood? sites database indicate areas of potential contamination. Included are: landfills, leak sites, multiple activity sites, petroleum brownfields, tank sites, and voluntary investigation and cleanup sites. Provided as point locations.	(MPCA, 2014a)
Minnesota Department of Agriculture (MDA)	Agricultural spill investigation boundaries indicate potentially contaminated areas. Provided as polygons.	(MDA, 2014)

From the standpoint of groundwater supply, enhanced recharge could potentially benefit areas of greatest drawdown in a drinking water aquifer. Aquifer drawdown was not specifically used as a criterion for enhanced recharge in this study, but could be taken into consideration in prioritizing areas for further investigation. In the North and East Metro Study Area, the Prairie du Chien-Jordan aquifer is the primary drinking water supply aquifer. Figure 6 shows the Tier 1, Tier 2, and Tier 3 areas for enhanced recharge (using all criteria) with projected 2040 groundwater drawdown in the Prairie du Chien aquifer estimated using the Metro Model 3 groundwater model (Metropolitan Council, 2015b). Most Tier 1 and Tier 2 areas are not in locations of significant projected drawdown, primarily because pumping demands and corresponding groundwater drawdown tends to be more pronounced in highly developed areas which are generally classified as Tier 3 because of existing land use. The opportunities for enhanced recharge in areas projected to see over ten feet of additional drawdown in 2040 are primarily in Woodbury and Cottage Grove. Some areas, such as Hugo and White Bear Lake, are projected to see greater than ten feet of additional drawdown in 2040 but may have limited opportunities for enhanced recharge.

As Figure 6 indicates, most Tier 1 and Tier 2 recharge areas are in locations where the Prairie du Chien-Jordan is projected to see between zero and ten feet of additional drawdown in 2040.

Enhanced Groundwater Recharge Implementation

Enhanced Recharge Methods

Enhanced recharge is the focused infiltration of water from the surface into the zone of saturation with the express purpose of recharging an aquifer(s) using an engineered system. There are three basic methods of enhanced recharge including surface infiltration basins, sub-surface infiltration systems, and direct aquifer injection.

Surface infiltration systems are variously termed recharge basins, infiltration basins, and rapid infiltration basins. These are basins or systems located on the ground surface that allow water to infiltrate from an open basin into the unsaturated zoned. Sub-surface infiltration systems, which include infiltration trenches, galleries, or shafts, deliver water directly into the unsaturated zone and allow infiltration down to the water table. These types of systems can be useful when preserving the surface land use is desirable, as in open space or park space, for example.

The third method of enhanced recharge, direct injection of recharge water into an aquifer using injection wells, was excluded from consideration in this study. However, the following overview of the regulation of injection wells provides important contextual information.

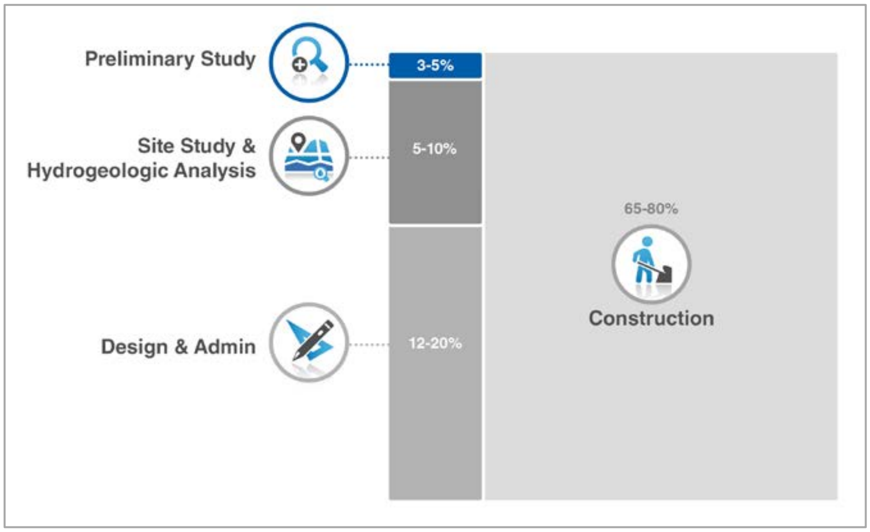
Injection wells are regulated by the EPA through the Underground Injection Control (UIC) program, which classifies wells into six types, or classes (Class I – Class VI). Because the State of Minnesota has not assumed primary enforcement authority for federal UIC regulations, EPA Region 5 directly implements the UIC program for regulating underground injection in Minnesota and for all Tribal lands in the state.

Although MDH does not directly regulate underground injection in Minnesota, the agency administers the state well code (Minnesota Administrative Rules Chapter 4725. 2050), which generally prohibits the injection of fluids into a boring or well, which would include the injection of recharge water for artificial groundwater recharge. There are currently no known systems in Minnesota that inject treated stormwater into an aquifer for enhanced recharge.

Enhanced Groundwater Recharge Project Development

This study represents a preliminary comparison of the hydrogeologic characteristics with criteria that would indicate the potential for enhanced recharge on a regional scale. Further analysis and planning studies would be required to assess the feasibility of constructing enhanced recharge facilities including hydrogeologic analysis and site assessments for candidate sites. Implementation would also require permitting and detailed engineering design. Chart 1 illustrates the phases required to further assess, design, and ultimately construct an enhanced recharge system, and the relative costs associated with each phase. Planning level analyses, regulatory and permitting considerations, and construction costs are discussed in subsequent sections.

Chart 1. Enhanced Recharge Project Implementation Phases and Associated Costs



Site Study and Hydrogeologic Analysis

Planning for recharge systems should include a more detailed analysis of site-specific conditions, including hydrogeology, water quality, source water availability and characteristics, institutional and legal considerations, and operational requirements.

Geology and hydrogeology of specific areas proposed for enhanced recharge should be investigated on a more focused, local scale. Much of the geology and hydrogeology data used in this analysis resulted from regional-scale studies, modeling, and data sets. A site-specific study that assesses the suitability of the site, a soils investigation, and a detailed hydrogeologic analysis should be performed for candidate groundwater recharge sites. The drilling of soil borings and installation of monitoring wells will provide information needed to design a recharge basin, including the depth to groundwater and groundwater flow direction, hydraulic conductivity and transmissivity of the aquifer, presence or absence of confining layers, infiltration rate, and background groundwater quality. There is potential that recharge water may not reach targeted groundwater resources, perhaps due to the presence of impermeable strata, or horizontal ‘short-circuiting’ of groundwater flow to a surface water body. Modeling studies should be performed to assess groundwater mounding potential and the recharge contribution to unconsolidated and bedrock aquifers. A certain minimum vertical distance between the seasonally high water table (or bedrock surface) and the bottom of the basin would need to be maintained in order for the recharge basin to drain properly and to provide a zone of treatment. MPCA (2015b) requires at least 3 feet of vertical separation, and local authorities may require greater separation depths.

Existing groundwater contamination may also limit the potential to perform groundwater recharge at specific sites. A closer examination of past and present contaminated areas should be performed, as these were not used as specific screening criteria, and the movement of contaminant plumes in the study area is a concern. The contaminant information used in this study included the State Water Use Database System (SWUDS) and MPCA and MDA inventories, which are primarily provided as point locations, and Special Well and Boring Construction Areas (SWBCAs) and large contaminant plumes, which are provided as polygons.

These were meant to indicate potentially contaminated areas that would require further investigation. Smaller contaminant plumes exist that were not identified in this regional study. More investigation into the nature and extent of contaminant plumes is recommended if specific parcels are identified for recharge projects. MDH and MPCA should be consulted to confirm that recharge basins are not located within a SWBCA or other drinking water protection area, or in the vicinity of a contaminant plume. Potential impacts on vulnerable drinking water supplies and the movement of contaminant plumes should be assessed, and travel times from the recharge basin to nearby public water supply wells and contaminant plumes should be estimated.

Source water quality and quantity should also be further evaluated. Source water quality and potential movement and treatment of source water through the subsurface will determine the overall feasibility of, and treatment and monitoring requirements for, specific recharge applications. Source water quantity and reliability will factor into the recharge basin feasibility and design.

While this study included general identification of threatened and endangered (T&E) species areas, the individual species and potential construction requirements associated with the species would need to be identified in coordination with the MnDNR on a site-specific basis. The planning phase for a recharge basin should include a T&E record search and the findings reviewed by the MnDNR. The MnDNR may require a Determination of Effects if T&E species are indicated in the project area. Criteria used for the determination may include:

- Presence/absence of appropriate habitat;
- Presence/absence of species observations within the project area;
- Potential to avoid and minimize impacts through timing restrictions and best management practices; and
- Level of potential impact in relation to known species populations.

Some habitats may be off-limits to construction in T&E species areas, whereas other areas may be acceptable if certain mitigation measures are taken. The MnDNR would ultimately decide whether construction of a recharge basin would be allowed in a T&E species area, and would be the approving body for any potential mitigation measures.

Regulations and Permitting

Recharge basins are regulated by local water management districts, cities (or counties), and the MPCA as part of the Stormwater Program. This program administers both the federal Clean Water Act and the State Disposal System. The program includes three types of stormwater permits: the Municipal Separate Storm Sewer System (MS4) permit, the Construction Stormwater Permit, and the Industrial Stormwater Permit. These permits are required for projects disturbing more than one acre. MPCA's Stormwater Program website (MPCA, 2014b) describes permit requirements related to infiltration practices and provides more information about these types of permits. MPCA's Stormwater Manual contains guidance and requirements for design, construction, and operation of recharge basins. Watershed management organizations and districts may have local regulatory authority over the construction of recharge basins. Permits are typically obtained through the city within which the site is located, and cities may include infiltration guidance from their respective watershed district. The districts typically rely on MPCA and MDH guidance but may have additional criteria based upon their own requirements and needs.

Should a proposed site for a recharge basin lie within a Wellhead Protection Area (WHPA) or a Drinking Water Supply Management Area (DWSMA), MDH should be consulted for the latest guidance. MDH does not regulate the construction or management of recharge basins but has published guidance (MDH, 2007) related to infiltration of stormwater and encourages care in planning these types of projects, especially within a vulnerable DWSMA. A vulnerable DWSMA involves criteria such as overlying a sub-cropping fractured or karst aquifer with less than 100 feet of overburden, the land use of the basin's watershed, and contaminants of concern in the stormwater. In addition, MDH designates SWBCAs in areas where groundwater contamination has, or may, result in risks to the public health. Although the SWBCA rules pertain to drilling or modification of public and private water supply wells, and monitoring wells, MDH should be consulted about proposed recharge basin sites that lie within these areas.

Enhanced Recharge Implementation Costs

Conceptual level costs were developed for a range of recharge basin sizes and design considerations. These costs, shown in Table 9, show a low range and a high range of capital costs for surface recharge basins. The low range costs were based on a traditional above-ground recharge basin conceptual design. The high range costs were based on a recharge basin system with sub-surface distribution chambers. A detailed breakdown of the costs for representative recharge basin sizes and design concepts as well as cost assumptions are included in Appendix A2.

Table 9. Estimated Capital Cost for Recharge basins

Recharge Basin Area (acres)	Cost [1]
10	$1,700,000 - $4,600,000
20	$3,400,000- $9,000,000
40	$6,700,000- $17,800,000
60	$9,900,000 - $26,700,000
80	$13,300,000 - $35,500,000

Notes:

[1] *Costs include construction costs, construction contingency (30%), and engineering, permitting, and administrative costs (20%). Costs do not include land acquisition or landscaping improvements other than site restoration.*

Costs will vary depending on a number of considerations, including:

- Type and final design of recharge basin;
- Local site conditions;
- Soil amendment requirements;
- Type of recharge system (traditional recharge basin, trenched system, buried chamber system);
- Source water conveyance to the site;
- Source water treatment requirements;
- Land or property acquisition costs; and
- Regulatory and permitting requirements.

Operations and maintenance costs were not included in these cost estimates, but should be considered when evaluating the type of system for implementation. Operations costs may be related to pumping, treatment system operation, and water quality sample collection and analysis. Maintenance costs may include inspection and maintenance of pipelines, regular upkeep of the recharge basins, and landscaping maintenance. Rehabilitation of recharge basins may be necessary over the life of the facility. This may include replacement of the sand or native soil layers to restore infiltration capacity lost to clogging by plant or bacterial growth for surface systems, or replacement of the chamber systems for those types of facilities.

Enhanced Groundwater Recharge Study Summary

The purpose and findings of this regional study are summarized in this section along with recommendations for further study of enhanced recharge opportunities.

Study Purpose

The purpose of the enhanced groundwater recharge study was to perform an initial screening of the North and East Metro Study Area to identify areas where water applied at the surface would have the highest potential to recharge bedrock aquifers based on specific hydrogeologic, land use, drinking water protection, and other specific criteria. Emphasis was given to recharge of permeable bedrock formations as the majority of the groundwater used in the North and East Metro study area for municipal supply comes from these sources. The study is intended to serve as a planning-level assessment of regional-scale enhanced recharge opportunities in the study area and as a basis of technical information for others to use in more detailed, site-specific analyses.

The analysis was completed as a desktop study, and as such no subsurface investigations were performed. Assessment of the impact of enhanced recharge on groundwater levels was not included in the scope of this study, but is a recommended step in further study of enhanced recharge opportunities. Other potential benefits of enhanced groundwater recharge, such as its impact on sensitive surface water features, were also not specifically evaluated as part of the study.

Study Findings

- Nearly 13,000 acres, or approximately three percent of the study area, were classified as having good potential for groundwater recharge based on study criteria.
- An additional 49,000 acres were classified as having limited potential for groundwater recharge based on study criteria, but where a more detailed study of local conditions may result in a more favorable assessment.
- Most of the areas classified as having either good or limited potential are in the eastern and southern portions of the study area, and are concentrated in Afton, Cottage Grove, Denmark Township, May Township, Stillwater Township, and West Lakeland Township.
- Reasonable opportunities for enhanced recharge may also exist in portions of Grant, Lake Elmo, Scandia, and Woodbury.
- Much of the western and northern portions of the study area are classified as having poor potential for enhanced groundwater recharge, primarily due to low hydraulic conductivity, shallow water table, land development, or a combination of these factors.
- A significant amount of area classified as having good potential for enhanced recharge lies in portions of Washington County where known contamination exists.

- Most of the area classified as having good potential for enhanced recharge lies outside areas that are projected to experience significant aquifer drawdown with continued groundwater pumping. This is mainly due to the lack of undeveloped land in these areas, which is a limiting criterion in the analysis.
- Estimated costs for constructed recharge basins range from $1.7 million to $4.6 million for 10-acre basins, and from $13 million to $35 million for 80-acre basins, not including source water treatment, land acquisition or water quality monitoring.

Study Recommendations

- MDH, MPCA, and local watershed management districts should be consulted for the latest guidance for planning, design and implementation of recharge basins.
- Further analysis and planning studies would be required to assess the feasibility of constructing enhanced recharge facilities, including hydrogeologic analysis, subsurface investigations and site review for candidate sites.
- More investigation into the nature and extent of contaminant plumes is recommended if specific parcels are identified for enhanced recharge projects.
- Modeling studies should be performed to analyze groundwater mounding potential and the recharge contribution to unconsolidated and bedrock aquifers at potential enhanced recharge sites.
- Water quality, source water treatment, and monitoring requirements should be fully evaluated for each specific recharge site as these can have a significant impact on project costs.
- Potential impacts to vulnerable drinking water supplies and the movement of contaminant plumes should be assessed. Groundwater travel time from proposed recharge basin sites to public water supply wells and contaminant plumes should be examined.
- Source water quantity, variability and reliability should be fully evaluated on a site-specific basis.
- Monitoring requirements should be developed for long-term evaluation of groundwater quality and mounding.
- Individual threatened and endangered species and any associated construction requirements would need to be identified in coordination with the MnDNR on a site-specific basis.

Stormwater Capture and Reuse

Introduction

Stormwater capture and reuse in this study refers to the diversion and collection of stormwater runoff for large-scale non-potable reuse applications. The objective of this component of the regional study was to evaluate the potential for stormwater reuse to offset the demand for groundwater from high volume non-potable uses (both municipal customers and private appropriation permit holders) and to quantify the potential to use captured stormwater as a source for enhanced groundwater recharge. Smaller scale opportunities for on-site rainwater harvesting, such as the use of residential rain barrels or other on-site systems, were not evaluated as part of this regional study. The study did not consider the potential for stormwater reuse to supply future developments or needs.

Analysis methods and results of the stormwater capture and reuse study are described in the following sections. Suggestions for data refinements that would facilitate detailed analysis of location-specific opportunities for stormwater capture and reuse, along with considerations for implementation and general cost information are also provided. Detailed information supporting the analyses is included in Appendix A3.

North and East Metro Area Stormwater Capture and Reuse Study

Methodology

The analysis of stormwater capture and reuse included an overall comparison of the total annual stormwater runoff volume and groundwater use in the study area, and a general assessment of stormwater availability at specific locations that use a high volume of water for non-potable applications. The analysis does not evaluate the appropriateness of captured stormwater for water uses at individual locations, or several conditionally-dependent factors that would ultimately define the potential for stormwater to meet specific demands. However, it does provide a relative assessment of a study area's potential to meet some portion of demands for non-potable use with stormwater.

An initial comparison of the total annual non-winter[2] runoff volume and the total groundwater use in the study area was made to assess the overall potential of using stormwater to offset groundwater demands.

Stormwater runoff volumes were calculated for all subwatersheds in the study area with a modified Rational Method, using the 30-year[3] average annual (non-winter) rainfall, runoff coefficients, and the area of each subwatershed. The subwatershed volumes were then aggregated to estimate runoff for the entire study area. These estimates were then compared with tabulated groundwater use to determine the overall balance of runoff to groundwater use in the study area.

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[2] The annual non-winter runoff period is defined as the period from March 15 to November 31.

[3] The 30-year average (1981-2010) of non-winter (March 15 to November 30) precipitation from the six National Centers for Environmental Information (NCEI) rain gage stations within the study area (NCEI, 2015).

A subsequent analysis of stormwater run-on at specific reported high-volume use locations in the study area provided an assessment of the potential to capture and reuse stormwater as an alternative to groundwater use. High-volume users in the study area were identified by reviewing the MnDNR SWUDS database, Water Emergency and Conservation Plans (WECP or “Water Supply Plans”), and water sales data provided by municipalities within the study area. These uses were then screened to identify non-potable uses related to urban irrigation, major crop irrigation, and industrial processing. Water use for these users was tabulated. These sites were then mapped, and the drainage area to each site was delineated using ArcHydro tools within ArcGIS to determine the stormwater run-on volume that could be available for capture in proximity to each user. Computed run-on volumes were compared with historic water use for the list of users to estimate the potential groundwater offset that could be achieved with stormwater capture and use at these sites.

In addition to the stormwater computations for high-volume use sites, the stormwater run-on volumes to sites identified as meeting either Tier 1 or Tier 2 criteria for enhanced recharge (in the previous section of this report) were computed. The fifteen sites with the highest run-on volume were summarized and tabulated for the study.

More detailed information on the methodology and an example are included in Appendix A3.

Results

Stormwater Runoff in the Study Area

To help define the scale of potential for stormwater capture and reuse in the study area, the average annual non-winter stormwater runoff for the entire area was compared with total groundwater use for the entire area. Land cover types and average annual precipitation were used as inputs to a modified Rational Method for runoff calculation. Year 2010 land use data obtained from the Council (Figure A1-6) were correlated to similar Minnesota Land Cover Classification System (MLCCS) classes to determine runoff coefficients for use in the calculation. The average annual non-winter runoff for the entire study area was calculated to be 89,981 million gallons (MG)[4].

[4] Assumptions and parameters used in the rational method calculation are included in Appendix A3.

Non-Potable Water Use from Groundwater Sources in the Study Area

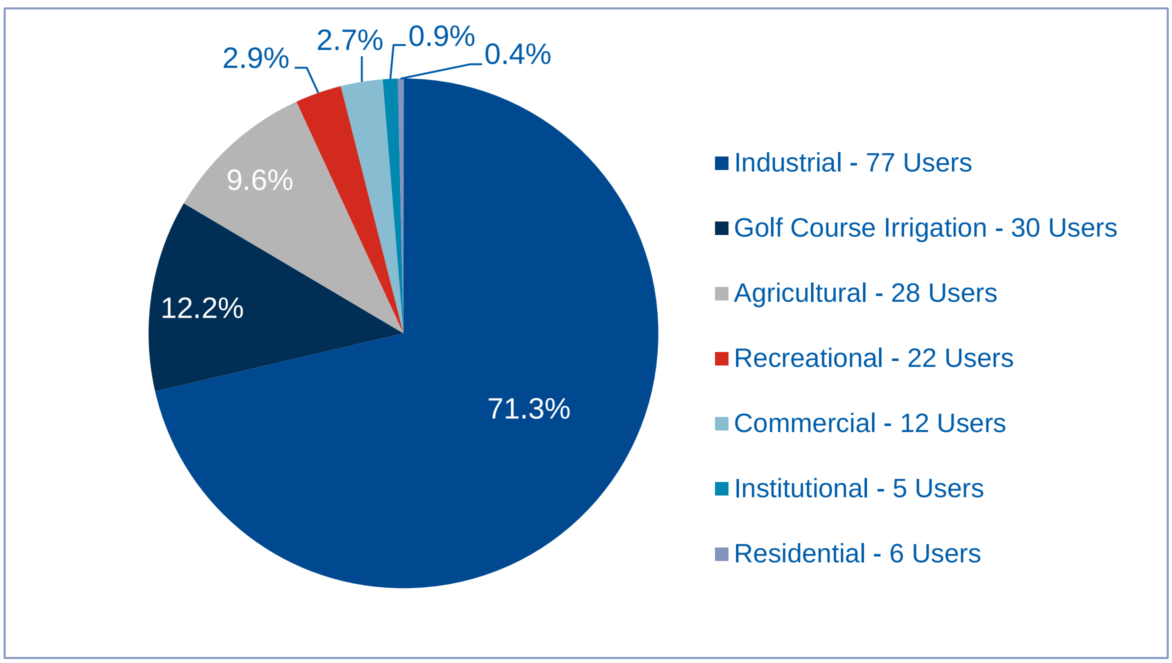
The reported 2010[5] groundwater use for the study area, as tabulated from permit records in the MnDNR SWUDS database, was approximately 28,000 MG. This represents all permitted water withdrawals[6] (both potable and non-potable) within the study area.

Non-potable water users in the study area, which include non-crop irrigation, major crop irrigation, and industrial processing uses, were identified from the MnDNR SWUDS database. Non-crop irrigation uses include golf courses, landscaping, and athletic fields. Major crop irrigation uses include nurseries and large farms. Industrial processing uses include agricultural processing, once-through cooling, sand and gravel washing, and other industrial uses. Groundwater withdrawals from the 109 users in these three use categories totaled 4,047 MG.

In addition to the MnDNR appropriations permit holders, 71 high-volume municipal customers who use water for non-potable uses were identified. The total reported water demand from these users was 971 MG in 2010.

Combining the appropriation permit holders and municipal customers, 180 high-volume, non-potable water users were identified. Total use in 2010 by these high-volume water users was 5,018 MG. Chart 2 shows a breakdown of high-volume, non-potable uses by category in the study area.

Chart 2. 2010 Non-Potable High-Volume Water Users within the North and East Metro Study Area



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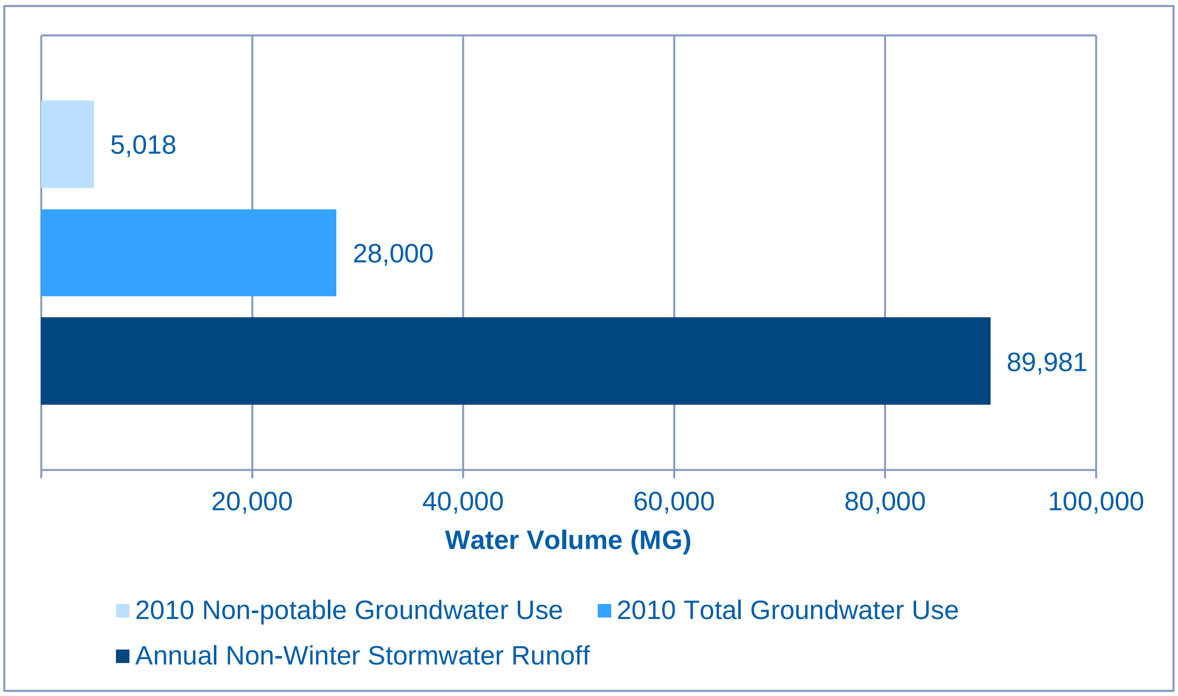
[5] 2010 was the most recent common year that SWUDS data, census data, water use data, and land use data were available at the time the analysis was conducted.

[6] Water withdrawals that exceed the established threshold of 10,000 gallons per day or 1 million gallons per year must obtain an appropriation permit from the MnDNR.

Comparison of Stormwater Runoff and Groundwater Use in the Study Area

Chart 3 shows a summary of non-winter stormwater runoff, total groundwater use, and identified high-volume non-potable groundwater use for the study area. Total reported groundwater use in the study area (28,000 MG) amounted to 31 percent of average annual non-winter runoff. The reported volume for high-volume non-potable uses amounted to 5.6 percent of average annual non-winter runoff estimated for the study area for 2010. Based on this general comparison, it appears feasible that some volume of non-potable use groundwater demand could be offset with stormwater capture and reuse.

Chart 3. Summary of Stormwater Runoff and Groundwater Use within the North and East Metro Study Area



Stormwater and Enhanced Groundwater Recharge in the Study Area

In addition to the 180 high-volume, non-potable water users identified from SWUDS and municipal water use data, fifteen other sites identified as meeting Tier 1 or Tier 2 criteria for enhanced groundwater recharge in the previous section of this report were included to determine the stormwater run-on volume potentially available for enhanced recharge at these sites. These fifteen sites were selected for meeting various hydrogeological, land use, and other criteria.

Estimating Stormwater Run-on to Potential Use Sites

In total, 195 potential stormwater capture and reuse sites were identified. These sites are mapped in Figure 7. Table 10 summarizes the sites by identification source category.

Table 10. Potential Sites for Stormwater Capture and Reuse in the North and East Metro Study Area

Site Identification Source	Number of Sites
MnDNR SWUDS	109
WECP/City Water Sales	71
Enhanced Groundwater Recharge Sites	15
Total	**195**

Drainage areas were delineated to determine the annual non-winter stormwater run-on volume that could be available for capture in proximity to each of the 195 sites described above. Potential water use sites and modeled drainage areas are shown in Figure A3-1 in Appendix A3.

Computed run-on volumes were compared with historic water use for each of the high-volume, non-potable water use sites to estimate the groundwater offset that could potentially be achieved with stormwater capture and reuse. Average annual non-winter stormwater run-on to the 180 high-volume, non-potable use sites was modeled to be nearly 40,000 MG. To assess the general feasibility of stormwater supply for these uses, a comparison of average annual non-winter run-on to annual non-potable demand was made at each of the 180 sites. At 147 of the 180 sites (82%), total run-on volume exceeded water use. At 132 of the 180 sites (73%), run-on volume was more than twice the annual water use, showing a high potential for stormwater capture and reuse. A comparison of annual run-on volume to water use is summarized in Table 11.

Table 11. Site-Specific Comparison of Run-on Volume with Non-Potable Use

Comparison of Run-on to Use	Number of Sites	2010 Water Use (MG)
Water Users with Annual Run-on > 1x Annual Water Use	147 (82%)	2,525
Water Users with Annual Run-on > 2x Annual Water Use	132 (73%)	2,245

The actual volume of stormwater run-on to a site that would be available for capture and reuse will depend on several factors including the timing of rain events, the portion of flow that is intercepted or infiltrated upstream of collection, and how much storage is provided to retain water until it is needed.

Assuming stormwater could be captured and stored to supply non-potable demands at half of the sites where run-on is estimated to be greater than two times the annual water use (at half of the 132 sites identified), then approximately 1,122 MG per year in groundwater use could be offset with stormwater reuse.

Stormwater run-on volumes were also calculated for fifteen of the enhanced groundwater recharge sites identified in the previous section of this report as meeting Tier 1 and Tier 2 criteria to evaluate the feasibility of using stormwater as a recharge source. The total annual non-winter stormwater run-on to the fifteen sites averages nearly 6,500 MG per year. The amount of run-on that could be captured for infiltration will depend on the size and design of recharge sites. For this analysis it was assumed that 65% of the run-on to a recharge site could be captured and infiltrated, (roughly corresponding to capture of 1-inch storm events). This results in approximately 4,200 MG per year, or 11.5 MG per day, on average, that could be applied for groundwater recharge. The recharge analysis determined that these sites had good or moderate potential for aquifer recharge. However, the actual volume that would infiltrate and reach the groundwater aquifer at each site would depend on a number of factors including local soil conditions, geology and hydrogeology, recharge basin size and operation, and other site considerations.

A comparison of stormwater run-on volume to potential use or application and groundwater offset is shown in Table 12.

Table 12. Summary of Stormwater Run-on at Potential Use Sites

Users	Number	Average Annual Stormwater Run-on (MG) [1]	Potential Annual Groundwater Offset (MG)
High-Volume Non-Potable Water Users	180	39,672	1,122 [2]
Enhanced Recharge Sites	15	6,477	4,210 [3]
Total	**195**	**46,149**	**5,332**

Notes:

[1] *Some sites are located upstream of other sites with larger drainage areas, so their run-on volume was removed from the total to avoid double-counting.*

[2] *Assumes 50% of groundwater demand can be met with captured stormwater at the high-volume use sites where run-on is greater than two times annual use.*

[3] *Assumes 65% of the total volume of non-winter stormwater run-on to regional enhanced recharge basins is captured and infiltrated.*

Stormwater Capture and Reuse Implementation

Although stormwater can be captured for reuse for a variety of applications, including industrial uses, greywater uses, and even potable uses, the following discussion is focused on large-scale stormwater capture systems for outdoor urban irrigation uses. These typically include athletic field irrigation, or large-scale landscape irrigation for commercial, industrial or institutional campuses. Reuse for other applications will have varying requirements for storage, source augmentation, treatment, permitting and design.

Stormwater Capture and Reuse System Components

The most widespread non-potable use for stormwater is irrigation, which accounts for approximately 34 percent of all water use in the United States (McPherson, 2015). Stormwater capture and reuse systems for outdoor irrigation typically include collection, storage, treatment, pumping, controls and bypass components. The size and extent of each component will depend on the intended application, site characteristics, and local regulatory and permitting requirements.

Collection or diversion of stormwater from conveyance systems includes pipe networks consisting of a series of catch basins and stormwater pipes, and ditch systems. Before moving from conveyance into storage, stormwater collected for reuse will typically pass through an in-line screen to remove leaves, twigs, and other debris.

Storage typically occurs in one of three forms including pond storage, below-ground storage, and above-ground storage. Each type has advantages and disadvantages in terms of costs, land use, aesthetics, and maintenance requirements. Storage is sized to balance supply needs with variability in rain events, and must also take into consideration site constraints. Storage may also provide solids settling ahead of other treatment. An overflow system to direct runoff volumes in excess of available storage should be designed into capture and reuse systems. Because of the variable nature of rain events, back-up connections to other water supplies should be provided, as well as controls systems to monitor storage and manage pumping operations.

In systems that irrigate unrestricted access areas (or areas that are open to human use, like athletic fields or parks), treatment may also include filtration, followed by a disinfection process. Disinfection may consist of UV radiation and/or chlorination to neutralize pathogens. More detail on system components and features are discussed in Appendix A3.

Stormwater Capture and Reuse Project Development

Planning Level Analyses

Planning for stormwater capture and reuse systems should include more detailed analysis of site-specific conditions, reuse applications, and requirements for implementation.

Further analysis of any of the stormwater capture and reuse sites included in the study could include a refined evaluation of the volume of stormwater run-on at individual sites. A more detailed analysis should consider site-specific factors including local precipitation trends, evapotranspiration, soil types and antecedent soil moisture conditions, and seasonal variability related to timing of use. The Minnesota Stormwater Manual, Stormwater Re-use and Rainwater Harvesting Section (MPCA, 2015c) presents a synthetic analysis that could serve as guidance for a more detailed evaluation of irrigation-related use.

The analysis considers the capture and storage of a specific rain event, the timing between rain events and irrigation application rates to estimate the total portion of annual run-on that can be captured and used for irrigation. The need for bypass or overflow connections to existing conveyance systems should also be addressed.

Diversion of stormwater from conveyance and the impact of potentially reduced flow on downstream conditions should also be considered. Analysis of historic or natural flow patterns in the drainage area, the impact of land development on runoff volume and rate, and the percentage of drainage area to be captured, as well as a more detailed assessment of downstream receiving waters can help assess whether stormwater diversions will have net positive or net negative impacts on downstream flows and uses.

Use-specific considerations, including water quality requirements, and application rate and period should be factored into more detailed analyses of potential applications. Other factors related to infrastructure requirements, including the sizing of the storage or containment facilities, site constraints, application areas, and overflow location and capacity, among others, should be assessed in more detailed study phases and to support implementation.

Water Quality

The quality of the source water is a major consideration in evaluating reuse systems. Stormwater may pick up any number of contaminants as it runs off the land surface. These contaminants include debris, chemical contaminants, and microbiological contaminants. Some concerns associated with the reuse of stormwater for non-potable uses include the potential for human exposure to pathogens; cross-contamination of potable water supply, ingestion of crops potentially contaminated with pathogens, concerns with mosquito breeding, and contaminated pond sediment.

Typical concentrations of urban stormwater constituents are listed in Table 13. The concentration of specific contaminants will vary with storm event, land use, and location, and data collection and monitoring should be used to determine the actual concentration of any constituent in a given watershed (Gulliver, et al, 2010).

Table 13 Concentrations of Stormwater Constituents

Constituent	Twin Cities, MN (Minneapolis – St. Paul) [1]	U.S. Cities (median for all sites) [2]
Total Suspended Solids (TSS) (mg/L)	184	100
Volatile Sustpended Solids (VSS) (mg/L)	66	N/A
Total Phosphorous (TP) (mg/L)	0.58	0.33
Dissolved Phosphorous) (DP) (mg/L)	0.2	0.12
Chemical Oxygen Demand (COD) (mg/L)	169	65
Biochemical Oxygen Demand (BOD) (mg/L)	N/A	9
Total Kjeldahl Nitrogen (TKN) (mg/L)	2.62	1.5
Nitrate Nitrogen (NO3-N) (mg/L)	0.53	0.68
Ammonium (NH4) (mg/L)	N/A	N/A

Constituent	Twin Cities, MN (Minneapolis – St. Paul) [1]	U.S. Cities (median for all sites) [2]
Total Lead (mg/L)	0.060	0.144
Total Zinc (mg/L)	N/A	0.160
Total Copper (mg/L)	N/A	0.034
Total Cadmium (mg/L)	N/A	N/A
Coliforms #/100mL	N/A	21,000

Notes:

[1] *Source: (Stradelmann and Brezonik, 2002).*

[2] *Source: (USEPA, 1983).*

Treatment requirements for captured stormwater will depend on the quality of the source water and the intended use or application. For non-potable reuse of stormwater, the largest public health concern is the exposure of humans to pathogenic bacteria (i.e. Giardia, Cryptosporidium, and Salmonella) and viruses. Treatment requirements can vary depending on whether the application has restricted or unrestricted public access or whether there is the potential for human contact with the reused stormwater. Restricted stormwater reuse applications are defined by areas to which access can be controlled (private golf courses, cemeteries, highway medians). Unrestricted access area reuse applications include irrigation in parks, playgrounds, school yards, and residential areas. To limit the public health risk and exposure to pollutants, projects in unrestricted access areas will have more stringent water quality standards than projects in restricted access areas.

In Minnesota, the MPCA has developed draft water quality guidelines for stormwater reuse systems used for irrigation in areas with public (unrestricted) access. In these areas the draft guidelines should be considered preliminary and used for discussion with governing agencies to solicit additional comments (MPCA, 2015c). Water quality guidelines are aimed at minimizing negative impacts to public health, plant health, and irrigation system function. State water quality guidelines for public access areas (related to outdoor irrigation) are summarized in Table 14.

Table 14. Summary of State of Minnesota Water Quality Guidelines for Irrigation

Water Quality Parameter	Water Quality Guideline – Public Access Areas
E. coli	126 E. coli/100 mL
Turbidity	2-3 NTU
TSS	5 mg/L
pH	6-9
Chloride	500 mg/L
Zinc	2 mg/L (long-term); 10 mg/L (short-term)
Copper	0.2 mg/L (long-term); 5 mg/L (short-term)

Source: (MPCA, 2015c).

Regulations & Permitting

Currently, the State of Minnesota does not have a specific code applicable to stormwater capture and reuse. In 2011, the Council developed the Stormwater Reuse Guide (Metropolitan Council, 2011) to aid cities, engineers, and homeowners in planning and evaluating stormwater harvesting and reuse projects. In addition, the Minnesota Department of Health published guidance (MDH, 2007) related to infiltration of stormwater in 2007, and encourages care in planning these types of projects, especially within vulnerable drinking water supply management areas. Several different agencies will likely need to permit any project planned for implementation. A summary of potentially applicable permits is summarized in Table 15.

Table 15. Summary of Potential Permitting Requirements for Stormwater Reuse Projects

Agency/Regulatory Authority	Summary of Requirements
Municipal permit (by City)	Any stormwater reuse project implemented may require permits from the city in which they are located. Municipal permits may be zoning permits, conditional use permits, municipal storm drain connection permits, and municipal construction permits. The Minnesota Plumbing Code has additional requirements and standards that may limit the uses, construction materials, and professional standards for plumbers installing systems.
U.S. Army Corps of Engineers	Section 404 of the Clean Water Act regulates the discharge of dredged and/or fill material in waters of the U.S. Under Section 10 of the Rivers and Harbors Act of 1899, the USACE regulates work in navigable waters of the U.S. Section 401 of the Clean Water Act requires any applicant for a Section 404 permit to obtain Water Quality Certification from the State to certify that discharge from fill materials will be in compliance with the State’s applicable Water Quality Standards.
MPCA NPDES/SDS Permit)	Any project that disturbs more than 1 acre of soil or discharges to a special or impaired water is required to apply for a National Pollutant Discharge Elimination System / State Disposal System (NPDES/SDS) Construction Stormwater Permit. Additionally, any reuse of stormwater for construction-related activities, such as dust control, must comply with stormwater management requirements contained in the Stormwater Pollution Prevention Plan (SWPPP).
Public Drainage Systems	Any time a public drainage system is created, repaired, improved, extended, abandoned, transferred to another drainage system, or water is impounded or ponded, a petition must be filed for the project, as described by Minnesota Statute 103E. The drainage system may be under the jurisdiction of one of several drainage authorities. The most common are county boards of commissioners, a joint county drainage authority, or a watershed district board of managers. When a drainage system is located within an organized Watershed District, it becomes the drainage authority for the project. Within the Twin Cities seven-county metro area, local governments outside of organized Watershed Districts are required to participate in a Watershed Management Organization (WMO), per Minnesota Statutes 103B.201 to 103B.255. WMOs are required to manage surface water. When a drainage system is not located within a Watershed District, WMO, or municipality, the county board of commissioners or joint county drainage authority has jurisdiction over the drainage project.

Agency/Regulatory Authority	Summary of Requirements
Mn DNR Appropriations Permits	Use of any water of the state (surface water or groundwater) requires an appropriation permit if the withdrawal exceeds 10,000 gallons per day or 1 million gallons per year. If stormwater use will exceed these thresholds, then an appropriation permit will be required. In addition, if a supplemental source of water is needed to provide additional supply during periods of low rainfall or excessive irrigation or other use, a groundwater or surface water appropriation permit would be required if minimum thresholds are met.
Minnesota Department of Health (MDH) / County Health Department	If the reuse of the harvested stormwater has the potential for human exposure, the MDH should be contacted to ensure the use will not cause a public health nuisance. MDH would need to grant approval for this reuse of the stormwater.
Metropolitan Council Environmental Services (MCES) Industrial Waste Discharge Permit	Industrial users discharging into public sewers shall apply for or update an industrial discharge permit, unless MCES determines that the wastewater has an insignificant impact on public sewers. If the stormwater reuse application is classified as industrial, and discharge meets the permit criteria, a MCES Industrial Discharge Permit would be required.
MPCA and MCES Sanitary Sewer Extension Permit	If any modifications are made to existing public sanitary sewers as a part of a stormwater reuse project, a Sanitary Sewer Extension Permit would be required from the MPCA and MCES.
Minnesota Department of Agriculture	If the reuse of the stormwater is meant for commercial operations, including nurseries and grain, vegetable, or fruit producers, the Minnesota Department of Agriculture may need to review or issue a permit for the project.

Stormwater Capture and Reuse Implementation Costs

Costs associated with stormwater capture and reuse systems for irrigation can vary greatly depending on a number of factors including the application or intended use, proximity to conveyance, storage requirements and design, site conditions and constraints, treatment and pumping costs, and the need for landscaping and other features.

For this study, conceptual costs for stormwater capture and reuse systems were tabulated for a range of storage volumes and include both underground storage and pond storage systems suitable for urban irrigation applications. These costs are summarized in Table 16. Capital costs include conveyance, primary stormwater treatment, storage and pumping components as well as engineering, administration, and contingencies. Costs do not include land acquisition, as these vary greatly depending on location, advanced treatment system costs, or the cost for irrigation systems. Approximate requirements for land area and estimated annual O&M costs for each system size are listed. More information on the basis for these costs can be found in Appendix A3.

Table 16. Conceptual Cost for Stormwater Capture and Reuse Systems

	Stormwater Capture Pond Systems		Underground Storage System			
Storage Volume (gallons)	**Capital Cost [1]**	**Land Area Required (acres)**	**Capital Cost [1]**	**Land Area Required (acres)**	**Capital Cost per Gallon Storage ($/1,000 gallon)**	**Annual O&M costs**
10,000	-	-	$25,000 - $100,000	0.01 – 0.05	$2.5 - $10	$200 - $1,000
50,000	$50,000 - $100,000	0.35 – 0.5	$125,000 - $250,000	0.05 – 0.1	$1 - $5	$600 - $2,500
150,000	$80,000 - $160,000	0.5 – 0.75	$200,000 - $400,000	0.15 – 0.25	$0.50 - $2.70	$1,500 - $3,500
250,000	$100,000 - $200,000	0.75 – 1	$300,000 - $600,000	0.2 – 0.5	$0.40 - $2.40	$2,000 - $5,000
500,000	$150,000 - $275,000	1 – 1.5	$500,000 - $1,500,000	0.55 – 0.75	$0.30 - $3.00	$4,000 - $8,000
1,000,000	$275,000 - $450,000	1.75 – 2.25	-	-	$0.28 - $0.45	$8,000 - $15,000

Notes:

[1] *Costs include construction costs, contingency (30%), and engineering, permitting, and administration costs (20%). Costs do not include land acquisition or landscaping improvements other than site restoration.*

Costs will vary depending on a number of considerations, including:

- Local site conditions;
- Type and final design of storage;
- Proximity of source water, conveyance and pumping needs;

- Treatment requirements;
- Land or property acquisition costs; and
- Regulatory and permitting requirements.

For small stormwater reuse projects that require less than 10,000 gallons of storage, it is typically more feasible to store stormwater for reuse in a manufactured tank rather than constructing a pond. For larger stormwater reuse projects requiring more than 50,000 gallons of storage, it is typically more economical to construct a stormwater pond than it is to build an underground storage system. However, depending on zoning requirements or the need or desire to maintain open space, construction of a large underground system may more appealing than construction of a stormwater pond or above ground system. When possible, modifying an existing stormwater pond rather than constructing a new pond for storage can result in a cost savings.

Operations and maintenance costs were not included in these cost estimates, but should be considered when evaluating the type of system for implementation. Typically, stormwater reuse systems will require regular operation and maintenance of the equipment and system components including:

- Regular inspection and testing of valves and all operational structures;
- Monthly inspection of biofilm and for accumulation of sediment in filters;
- Annually testing of control equipment at spring start-up, or as recommended by manufacturer;
- Settings to control the timing of operations if systems must limit human exposure for untreated or minimally treated stormwater;
- An annual winterization schedule for draining pumping and distribution systems required to take the system off-line; and
- An O&M plan, including a detailed site plan that shows the locations of the distribution system, potable connection, backflow prevention devices, valves and types of valves, drain plug, and cleanout sump.

Examples of Local Stormwater Capture and Use Systems

While stormwater reuse facilities are still a relatively new concept in Minnesota, several projects have been constructed and provide good examples for others in the state. These include:

St. Anthony Village Water Reuse Facility. The facility collects stormwater from 15.4 acres of land and filter backwash water from the city's water treatment plant. The runoff and backwash water is stored in a 500,000 gallon underground reservoir. Water from the reservoir is used to irrigate a 20-acre site including a municipal park and St. Anthony's City Hall campus. Total reported costs for this project were $1.5 million (University of Minnesota Extension, 2013).

Oneka Ridge Golf Course. This project was recently constructed in Hugo, Minnesota to collect stormwater runoff from 1,000 acres of land upstream of Bald Eagle Lake to irrigate the 116-acre golf course. Stormwater is collected in a new stormwater pond. The project is expected to capture approximately 32.5 million gallons of water per year for irrigation and underground infiltration, while the water volume of Bald Eagle Lake, downstream of the project, is estimated to decrease by only 0.3 percent. The total reported cost for this project was just under $700,000 (Rice Creek Watershed District, 2015).

Shakopee Mdewakanton Sioux Reuse System. This system in Prior Lake, Minnesota collects stormwater runoff from a 390-acre drainage area and effluent from a 0.5 MGD wastewater treatment plant and provides irrigation water for the 120-acre Meadows at Mystic Lake Golf Course. The golf course aims to reduce their annual groundwater demand for irrigation use of 52 million gallons per year through the 5.5 million gallons of stormwater runoff per year and the 0.5 MGD WWTP effluent (Bolton and Menk, 2009).

Stormwater Capture and Reuse Study Summary

The purpose and findings of this regional study are summarized in this section along with recommendations for further study and development of stormwater reuse projects.

Study Purpose

The purpose of the stormwater capture and reuse study was to conduct a preliminary assessment of stormwater capture and reuse systems as a way to offset demand on groundwater sources for non-potable uses, and to quantify the potential to use captured stormwater as a source for enhanced recharge in the North and East Metro Study Area. The study is intended to serve as a planning-level assessment of the potential to offset groundwater use with stormwater reuse and as a basis of technical information for others to consider in more detailed, site-specific analyses.

Stormwater capture and reuse in this study refers to the diversion and collection of stormwater runoff for large-scale reuse applications. The study focused on existing high-volume, non-potable uses identified through both MnDNR appropriation permit records and municipal water sales data. Cost information and implementation discussions were based on reuse mainly for urban irrigation applications. Smaller scale opportunities for on-site rainwater harvesting, such as the use of residential rain barrels or other on-site systems, were not evaluated as part of this regional study. The study did not consider the potential for stormwater reuse to supply future developments or needs.

Study Findings

- The average annual non-winter runoff for the entire study area was calculated to be 89,981 million gallons (MG). Total groundwater use for 180 high-volume, non-potable uses identified in the study area totaled 5,018 MG, or 5.6% of non-winter runoff in 2010.
- Of the 180 high-volume, non-potable groundwater users identified in the study, 73 percent could potentially capture and reuse stormwater as an alternative to groundwater use. These sites were estimated to have stormwater run-on (surface runoff that is received at a specific downstream point or area) that exceeds 2 times their annual water use, and could be further evaluated for stormwater capture and reuse feasibility.
- Stormwater run-on to fifteen of the sites classified as having good or limited potential for enhanced groundwater recharge based on study criteria amounts to approximately 4,200 MG per year, or 11.5 MG per day, on average.
- Estimated costs for stormwater capture and reuse (irrigation) systems range from $2.5-$10 per 1,000 gallons for 10,000 gallon systems to $0.28-$0.45 per 1,000 gallons for one million-gallon systems, not including source water treatment, water quality monitoring, land acquisition or irrigation equipment.

Study Recommendations

- MDH, MPCA, and MnDNR, along with municipalities and local watershed management districts should be consulted for the latest guidance for planning, design and implementation of stormwater reuse systems.
- Water quality and water treatment requirements should be fully evaluated for each specific reuse application as treatment requirements can have a significant impact on project costs.
- A detailed analysis of local hydrology and stormwater availability at specific sites should be conducted to further characterize source availability and evaluate storage, bypass, and back-up source requirements.
- Diversion of stormwater from storm sewer or other conveyance systems and the potential impact of reduced flow on downstream conditions should be evaluated.

Glossary

Aquifer	Rock or sediment that is saturated and able to transmit economic quantities of water to wells and surface waters. Minnesota Administrative Rules 6115.0630 defines aquifer as any water-bearing bed or stratum of earth or rock capable of yielding groundwater in sufficient quantities that can be extracted.
Digital Elevation Model (DEM)	A digital model of a terrain's surface, constructed from surface elevation data generally acquired by airplane or satellites using remote-sensing techniques such as photogrammetry and LiDAR, or by land surveying.
Drawdown	The lowering of the water table in and around a pumping well. It is the difference between the pumping water level and the original water level.
Drinking Water Supply Management Area	A drinking water supply management area (DWSMA) is the Minnesota Department of Health approved surface and subsurface area surrounding a public water supply well that completely contains the scientifically calculated wellhead protection area and is managed by the entity identified in a wellhead protection plan. The boundaries of the drinking water supply management area are delineated by identifiable physical features, landmarks or political and administrative boundaries.
Enhanced Recharge	Engineered systems designed to infiltrate surface water into the zone of saturation, with the express purpose of augmenting natural recharge of an aquifer(s).
Groundwater	Water stored in the pore spaces of rock and unconsolidated deposits found in the saturated zone of an aquifer (compare to surface water). Minnesota Administrative Rules 6115.0630 defines groundwater as subsurface water in the saturated zone. The saturated zone may contain water under atmospheric pressure (water table condition), or greater than atmospheric pressure (artesian condition).
Hydraulic Conductivity	A measure of the permeability of the porous media. It is commonly measured in feet per day (ft/day).
Infiltration	• The seepage of water from land surface down below the root zone. This water may move horizontally through the soil toward nearby streams, wetlands, and lakes – becoming baseflow. Or this water may move vertically down to recharge deeper regional aquifers. • The seepage of groundwater into sewer pipes through cracks or joints in the pipes.
Infrastructure	Fixed facilities, such as sewer lines and roadways; permanent structures.
Metro Model	The Twin Cities metropolitan area regional groundwater flow model. The current modeling effort builds upon the Minnesota Pollution Control Agency's 2000 *Metro Model*. The current Metro Model (version 3) is used to evaluate the groundwater impacts of current and

	projected groundwater withdrawals. Information provided by the Metro Model helps set regional goals, screen for future risks, and evaluate/compare the regional impact of different water supply approaches.
Non-winter Runoff	The rainfall, snowmelt, or irrigation water flowing that has not evaporated or infiltrated into the soil, but flows over the ground surface during the period of March 15 through November 31.
Non-potable Water User	A public or private entity that obtains treated municipal water for uses other than human consumption.
Open Space	Public and private land that is generally natural in character. It may support agricultural production, or provide outdoor recreational opportunities, or protect cultural and natural resources. It contains relatively few buildings or other human-made structures. Depending on the location and surrounding land use, open space can range in size from a small city plaza or neighborhood park of several hundred square feet, corridors linking neighborhoods of several acres to pasture, croplands or natural areas and parks covering thousands of acres.
Rainwater Harvesting	The practice of collecting rain water from impermeable surfaces, such as rooftops, and storing it for future on-site uses.
Recharge	The natural or manmade infiltration of surface water into the zone of saturation. Also, the portion of infiltration that moves from the unsaturated sediment below the root zone into the underlying zone of saturation. (See also enhanced recharge. The movement of groundwater into a surface water body such as a stream or lake.
Reuse	The collection and use of water that is reclaimed for specific, direct, and beneficial uses. The term is also used to describe water that is collected on-site and utilized in a new application. (See also stormwater reuse.)
Runoff	The rainfall, snowmelt, or irrigation water flowing that has not evaporated or infiltrated into the soil, but flows over the ground surface.
Run-on	The rainfall, snowmelt, or irrigation water flowing over the ground surface (i.e., runoff) that is received at a specific downstream point or location.
Special Well and Boring Construction Area	• A Special Well and Boring Construction Area is sometimes also called a well advisory. It is a mechanism which provides for controls on the drilling or alteration of public and private water supply wells, and monitoring wells in an area where groundwater contamination has, or may, result in risks to the public health. • The purposes of a Special Well and Boring Construction Area 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.

Stormwater	Surplus surface water generated by rainfall that does not seep into the earth but flows overland to flowing or stagnant bodies of water. (See also runoff.) Minnesota Department of Natural Resources defines stormwater more specifically as runoff from impervious surfaces.
Stormwater Reuse	The collection and use of stormwater runoff that is reclaimed for specific, direct, and beneficial uses. The term is also used to describe water that is collected on-site and utilized in a new application. It is also called rainwater harvesting, rainwater recycling, or rainwater reclamation. Minnesota Department of Natural Resources more specifically defines stormwater reuse as the secondary use of water for a purpose other than what it was originally appropriated for.
Subwatershed	A portion of a watershed that still meets the definition of a watershed in that all of the water that is under it or drains off of it goes into the same place.
Surface Water	Water on the earth's surface exposed to the atmosphere such as rivers, lakes and creeks (compare with groundwater).
Treated Wastewater	The effluent from a wastewater treatment plant after the wastewater has been treated. Treated wastewater that is discharged either to the surface or subsurface must meet the requirements of the National Pollutant Discharge Elimination System (NPDES)/State Disposal System (SDS) permit.
Unconfined Aquifer	Aquifer without a confining layer at the top and a lack of pressure that allows the water level to easily rise and fall.
Unsaturated Zone	Area below the land surface that contains a mixture of air and water.
Wastewater	Water carrying waste from domestic, commercial, or industrial facilities together with other waters that may inadvertently enter the sewer system through infiltration and inflow.
Wastewater Treatment Plant	A facility designed for the collection, removal, treatment, and disposal of wastewater generated within a service area.
Watershed	The area of land where all of the water that is under it or drains off of it goes into the same place.
Water Table	The elevation at which the pore water pressure is at atmospheric pressure.

Acronyms and Short Forms

AMA	Aquatic Management Area
BWSR	Board of Water and Soil Resources
Council	Metropolitan Council
DEM	Digital Elevation Model
DWSMA	Drinking Water Supply Management Area
EPA	U.S. Environmental Protection Agency
ft/day	Feet per day
GIS	Geographic Information System
in/hr	Inches per hour
MCES	Metropolitan Council Environmental Services
MDA	Minnesota Department of Agriculture
MDH	Minnesota Department of Health
MG	Millions of U.S. gallons
MGD	Million gallons per day
mg/L	Milligrams per liter
MGS	Minnesota Geological Survey
mi^2	Square mile
MIDS	Minimal impact design standards
MnDNR	Minnesota Department of Natural Resources
MLCCS	Minnesota Land Cover Classification System
MPCA	Minnesota Pollution Control Agency
MS4	Municipal Separate Storm Sewer System
NED	National Elevation Dataset
NPC	Native Plant Communities
NPDES	National Pollutant Discharge Elimination System
NRCS	National Resource Conservation Service
NTU	Nephelometric turbidity unit
O&M	Operation and maintenance
PFCs	Perfluorochemicals
RNRA	Regional Natural Resource Area
SDS	State Disposal System
SNA	Scientific and Natural Area
SWBCA	Special Well and Boring Construction Area
SWUDS	State Water Use Database System

TCAAP	Twin Cities Army Ammunition Plant
TDS	Total dissolved solids
T&E	Threatened and Endangered (species)
TSS	Total suspended solids
UIC	Underground Injection Control
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
VIC	Voluntary Investigation and Cleanup
WD	Watershed district
WECP	Water Emergency and Conservation Plan
WHPA	Wellhead Protection Area
WMA	Wildlife Management Area
WMO	Watershed Management Organization
WWTP	Wastewater treatment plant

References

Barr Engineering. 2010. Evaluation of groundwater and surface-water interaction: guidance for resource assessment, Twin Cities metropolitan area, Minnesota. Prepared for Metropolitan Council, June 2010. 27p. plus GIS files.

Bolton and Menk, Inc. 2009. City Engineers Association of Minnesota. CEAM Annual Conference. *http://ceam.org/vertical/Sites/%7BD96B0887-4D81-47D5-AA86-9D2FB8BC0796%7D/uploads/%7BA01ADDBD-B953-4CBC-9AE9-359B260657A5%7D.PDF*. Website accessed April 30, 2015

Gulliver, J. S., Erickson, A. J., & Weiss, P. T. 2013. Optimizing Stormwater Treatment Practices: A Handbook of Assessment and Maintenance. Minneapolis: Springer Science+Business Media.

McPherson, L. 2014. Taking the Rains: Examining Stormwater Collection and Treatment Methods for Reuse. WaterWorld, Volume 30, Issue 4. April 1.

Metropolitan Council. 2011. Stormwater Reuse Guide. Metropolitan Council: St. Paul, MN.

Metropolitan Council. 2015a. Water Resources Policy Plan. Metropolitan Council: St. Paul, MN.

Metropolitan Council. 2015b. Twin Cities Metropolitan Area Master Water Supply Plan. Metropolitan Council: St. Paul, MN.

Metropolitan Council Environmental Services (MCES). 2011. FTP server, GIS file download, *ftp://gisftp.metc.state.mn.us/*. Website accessed September 2011.

Metropolitan Council Environmental Services (MCES). 2014. Regional planned land use – Twin Cities metropolitan area, GIS file download, *http://www.datafinder.org/metadata/PlannedLandUse.html*. Website accessed March 12, 2014.

Minnesota Department of Agriculture (MDA). 2014. What's in my neighborhood? Agricultural interactive mapping, GIS file download, *http://www.mda.state.mn.us/chemicals/spills/incidentresponse/neighborhood.aspx*. Website accessed May 8, 2014.

Minnesota Department of Health (MDH). 2007. Evaluating proposed stormwater infiltration projects in vulnerable wellhead protection areas, July.

Minnesota Department of Health (MDH). 2014. Source water protection maps and geospatial data, GIS file download, *http://www.health.state.mn.us/divs/eh/water/swp/maps/*. Website accessed March 19, 2014.

Minnesota Department of Health (MDH). 2015a. GIS shapefile containing SWBCAs, email from John Freitag (MDH) to HDR on August 24, 2015.

Minnesota Department of Health (MDH). 2015b. GIS shapefiles containing plume locations for 3M PFCs, Baytown Township, Lakeland and Lakeland Shores, 2014 mapping results, email from Virginia Yingling (MDH) to HDR on November 30, 2015.

Minnesota Department of Natural Resources (MnDNR). 2014a. The DNR data deli, GIS file download, *http://deli.dnr.state.mn.us/*. Website accessed April 9, 2014.

Minnesota Department of Natural Resources (MnDNR). 2014b. Water use – water appropriations permit program, GIS file download, *http://www.dnr.state.mn.us/waters/watermgmt_section/appropriations/wateruse.html*. Website accessed April 24, 2014.

Minnesota Department of Natural Resources (MnDNR). 2015. Draft North & East Metro Groundwater Management Area Plan. MnDNR: St. Paul, MN. February 2.

Minnesota Pollution Control Agency (MPCA). 2014a. Spatial data, what's in my neighborhood?, GIS file download, *http://www.pca.state.mn.us/index.php/data/spatial-data.html*. Website accessed March 20, 2014.

Minnesota Pollution Control Agency (MPCA). 2014b. Stormwater program. *http://www.pca.state.mn.us/index.php/water/water-types-and-programs/stormwater/index.html*. Website accessed November 5, 2014.

Minnesota Pollution Control Agency (MPCA). 2015a. Minimal impact design standards. *http://www.pca.state.mn.us/index.php/water/water-types-and-programs/stormwater/stormwater-minimal-impact-design-standards-mids.html*. Website accessed September 22, 2015.

Minnesota Pollution Control Agency (MPCA). 2015b. Design criteria for infiltration basin. Minnesota Stormwater Manual: *http://stormwater.pca.state.mn.us/index.php/Design_criteria_for_Infiltration_basin*. Website accessed December 24, 2015.

Minnesota Pollution Control Agency (MPCA). 2015c. Stormwater re-use and rainwater harvesting. Minnesota Stormwater Manual: *http://stormwater.pca.state.mn.us/index.php/Stormwater_re-use_and_rainwater_harvesting*. Website accessed March 16, 2015.

Minnesota Pollution Control Agency (MPCA). 2015d. Design criteria for stormwater ponds. Minnesota Stormwater Manual: *http://stormwater.pca.state.mn.us/index.php/Design_criteria_for_stormwater_ponds*. Website accessed March 16, 2015.

Mossler, J.H. 2013. Bedrock geology of the Twin Cities ten-county metropolitan area, Minnesota. M-194 miscellaneous map series. Minnesota Geological Survey. GIS file download, http://hdl.handle.net/11299/154925. Website accessed March 28, 2014.

National Centers for Environmental Information (NCEI). 2015. Rainfall records, *http://www.ncdc.noaa.gov*. Website accessed September 28, 2015.

The Office of the Revisor of Statutes. 2008. 7050.0223: Specific water quality standards for Class 3 waters of the state; industrial consumption. The Office of the Revisor of Statutes: *https://www.revisor.mn.gov/rules/?id=7050.0223*. Website accessed April 15, 2015.

Rice Creek Watershed District (RCWD). 2014. Oneka Ridge Golf Course water re-use irrigation project. Rice Creek Watershed District: *http://www.ricecreek.org/index.asp?SEC=31ABD821-A665-4BD3-BD8C-94D2358D5FE0&DE=F968FCD9-42ED-4D64-ABD5-B58EB8BF0715&Type=B_PR*. Website accessed April 15, 2015.

Stradelmann, T.H. and P.L. Brezonik. 2002. Analysis and predictive models of stormwater runoff volumes, loads, and pollutant concentrations from watersheds in the Twin Cities (Minnesota, USA) metropolitan area. Water Res. 36: 1743-1757.

Tipping, R.G. 2011. Distribution of vertical recharge to upper bedrock aquifers, Twin Cities metropolitan area. Prepared for Metropolitan Council, November 9, 2011. 105 p. plus GIS files.

University of Minnesota Extension. 2013. Underground stormwater treatment & rain harvesting systems, stormwater reuse project examples, *http://www.extension.umn.edu/environment/stormwater/components/Jan14pdfs/PHProjectExamplesHDS01142013.pdf*.

U.S. Department of Agriculture, Natural Resources Conservation Service (NRCS). 2014. Geospatial data gateway, GIS file download, *http://datagateway.nrcs.usda.gov/*. Website accessed April 10, 2014.

United Stated Environmental Protection Agency (USEPA). 1983. Water quality standards handbook. Washington, D.C.: United Stated Environmental Protection Agency.

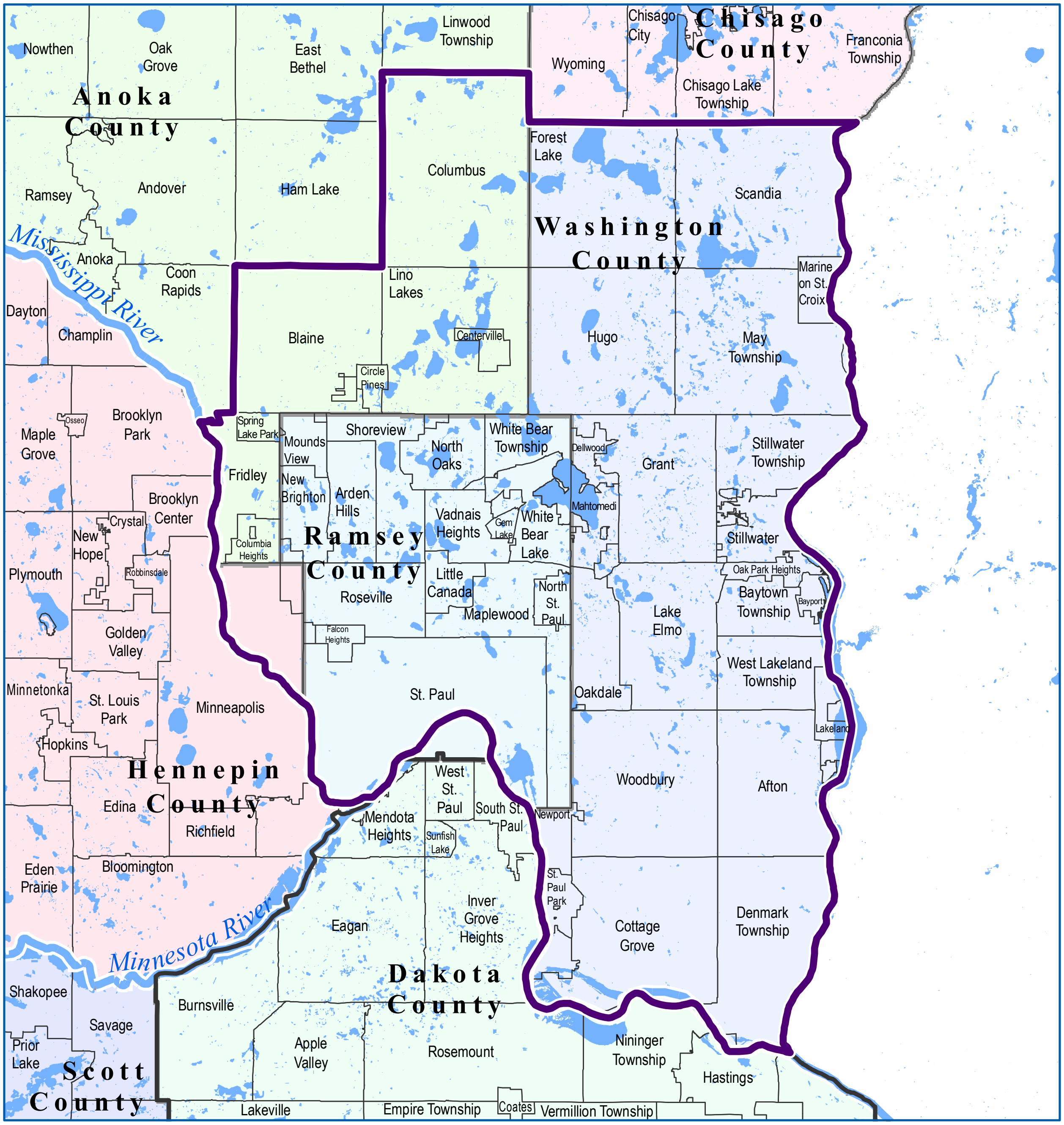
United States Geologic Survey (USGS), 2015. Water science glossary of terms. *http://water.usgs.gov/edu/dictionary.html*. Website accessed on 12/28/15.

Wenck and Associates (Wenck), 2015. GIS shapefile containing 2013 TCAAP plume locations, email from Jordan Shuck (Wenck) to HDR on November 19, 2015.

Figures

Metropolitan Council
Regional Groundwater Recharge and Stormwater Reuse Study

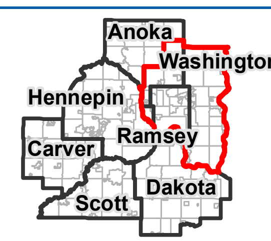
Figure 1
North and East Metro Study Area



Legend

- Study Area
- County Boundary
- City/Township Boundary
- Waterbody

0 — 35,000 Feet



Sources: Met Council, NHD, DNR

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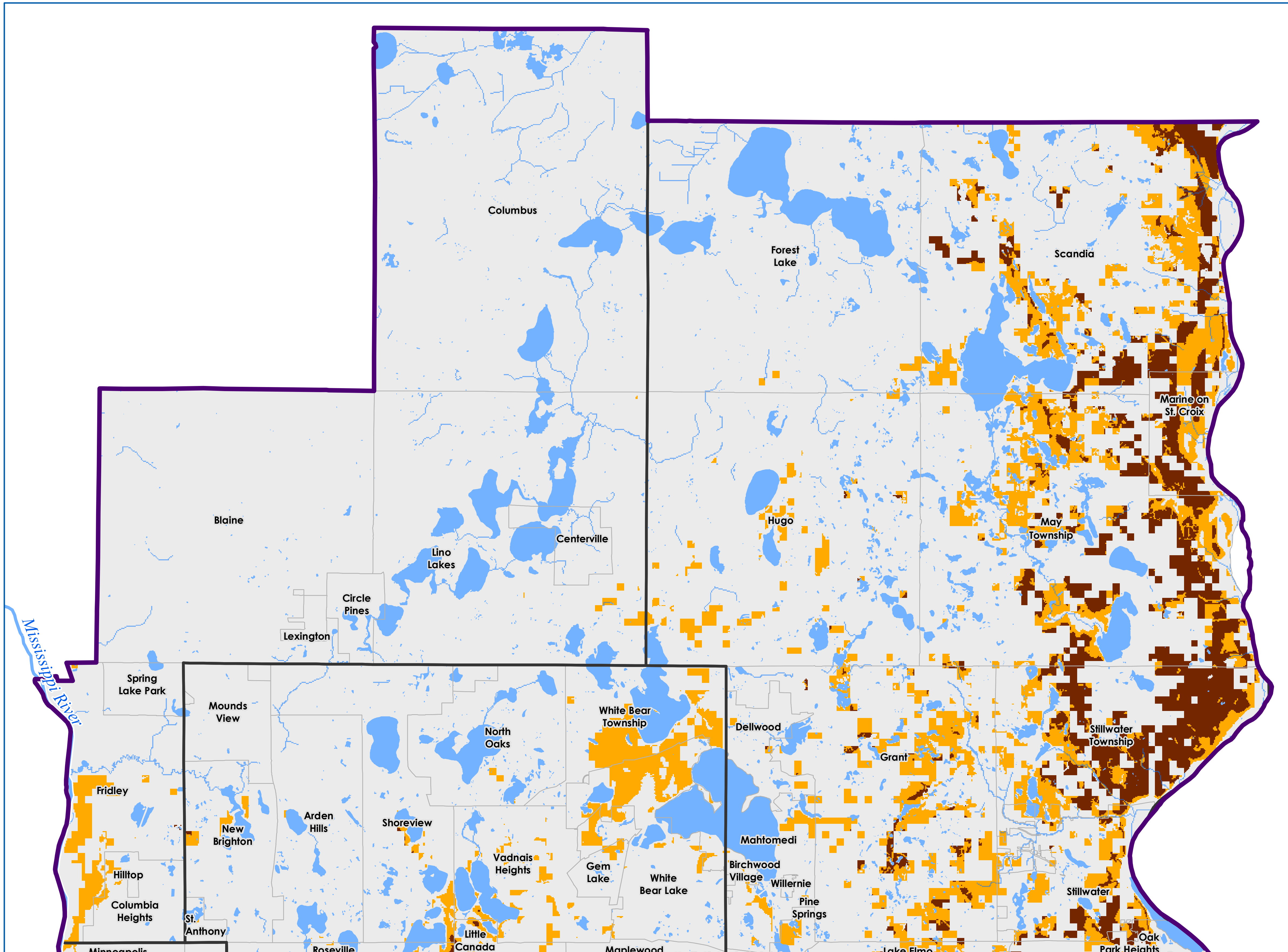
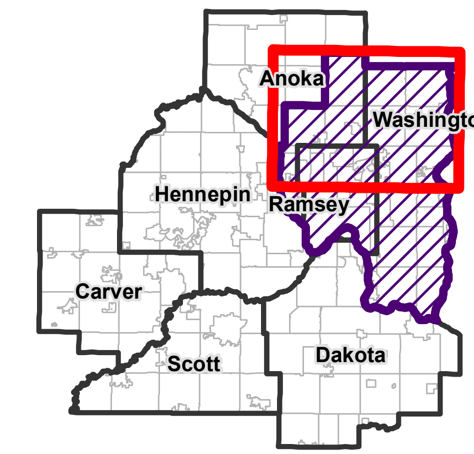
Metropolitan Council
Regional Groundwater Recharge and Stormwater Reuse Study

Figure 2 (1 of 2)
Potential Areas for Enhanced Recharge to Bedrock Drinking Water Aquifers (Hydrogeological Criteria)
North and East Study Area





Legend

- Study Area
- Tier 1 Area
- Tier 2 Area
- Tier 3 Area
- County Boundary
- City/Township Boundary

Enhanced recharge areas are based on hydrogeological criteria only.

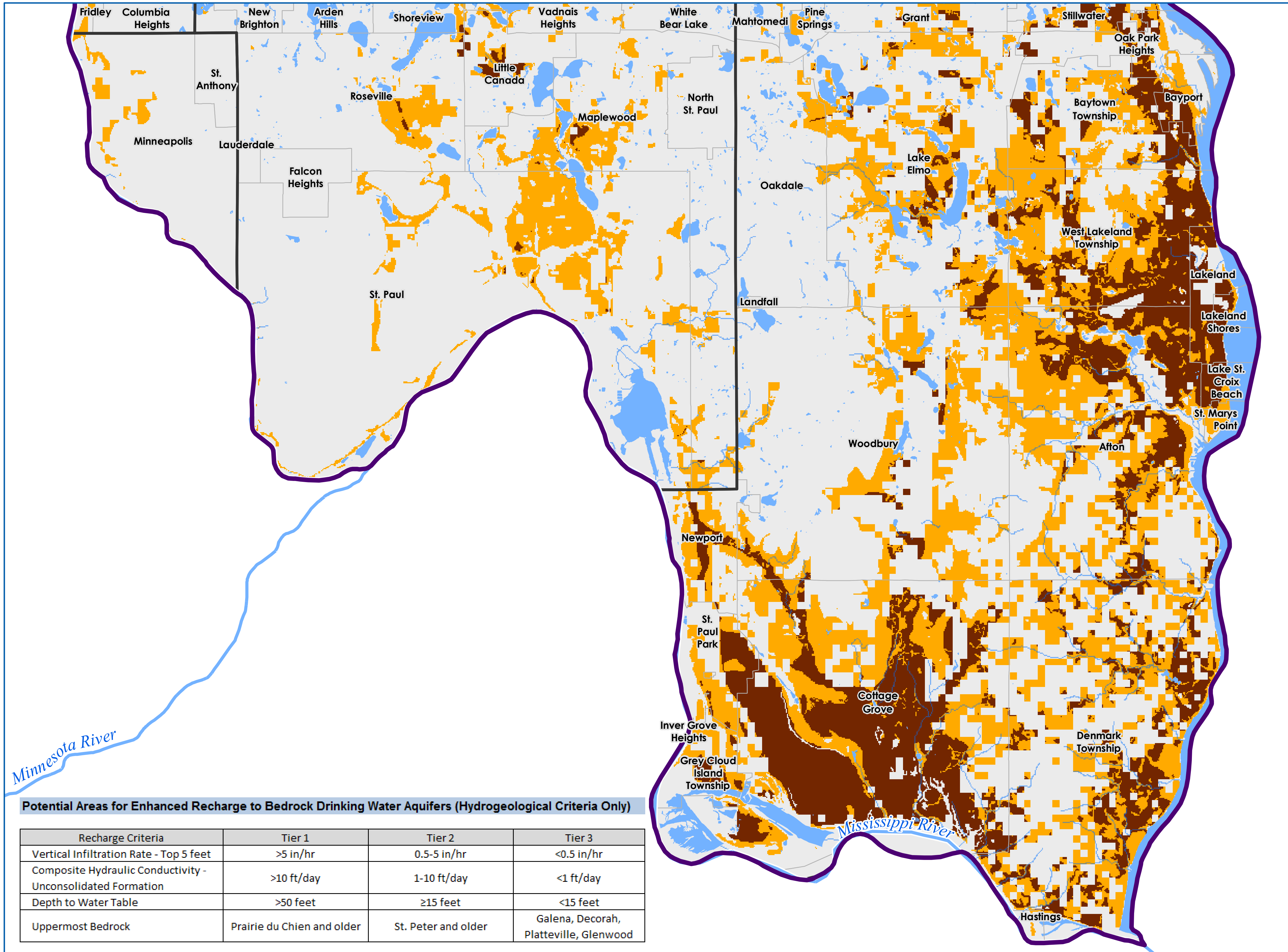
Sources: USDA NRCS, NHD, DNR

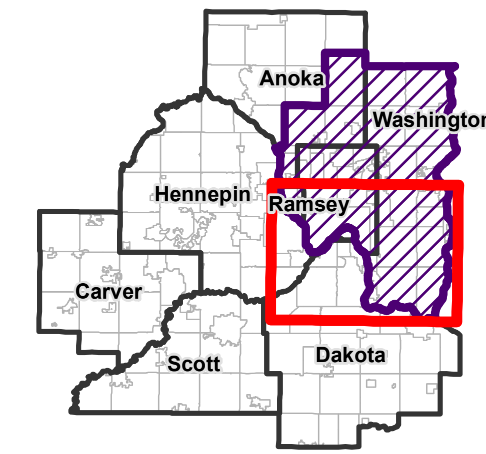
0 — 12,000 Feet

Figure 2 (2 of 2)

Potential Areas for Enhanced Recharge to Bedrock Drinking Water Aquifers (Hydrogeological Criteria)

North and East Study Area





Legend

- Study Area
- Tier 1 Area
- Tier 2 Area
- Tier 3 Area
- County Boundary
- City/Township Boundary

Enhanced recharge areas are based on hydrogeological criteria only.

Potential Areas for Enhanced Recharge to Bedrock Drinking Water Aquifers (Hydrogeological Criteria Only)

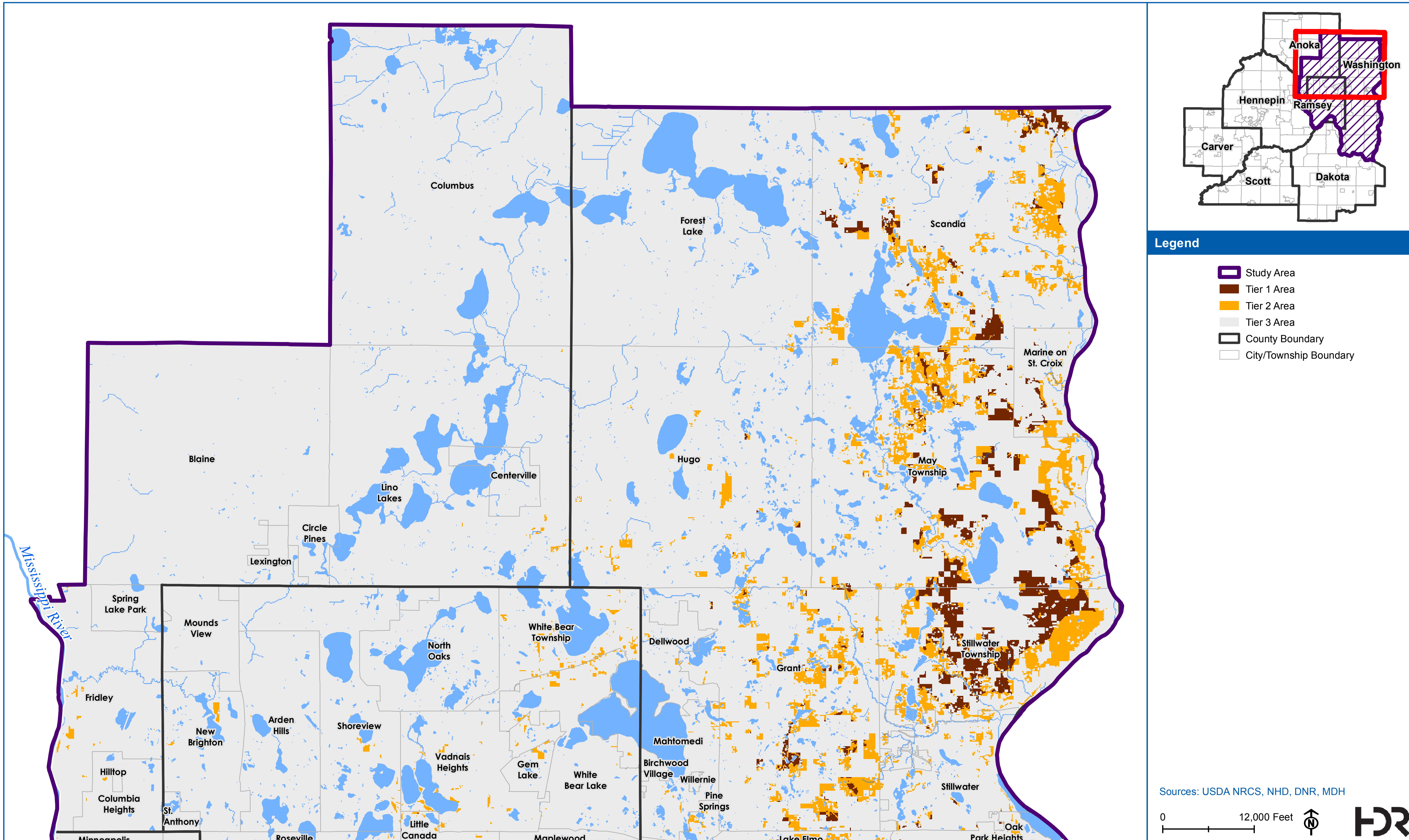
Recharge Criteria	Tier 1	Tier 2	Tier 3
Vertical Infiltration Rate - Top 5 feet	>5 in/hr	0.5-5 in/hr	<0.5 in/hr
Composite Hydraulic Conductivity - Unconsolidated Formation	>10 ft/day	1-10 ft/day	<1 ft/day
Depth to Water Table	>50 feet	≥15 feet	<15 feet
Uppermost Bedrock	Prairie du Chien and older	St. Peter and older	Galena, Decorah, Platteville, Glenwood

Sources: USDA NRCS, NHD, DNR

0 12,000 Feet

Metropolitan Council
Regional Groundwater Recharge and Stormwater Reuse Study

Figure 3 (1 of 2)
Potential Areas for Enhanced Recharge to Bedrock Drinking Water Aquifers (All Criteria)
North and East Study Area



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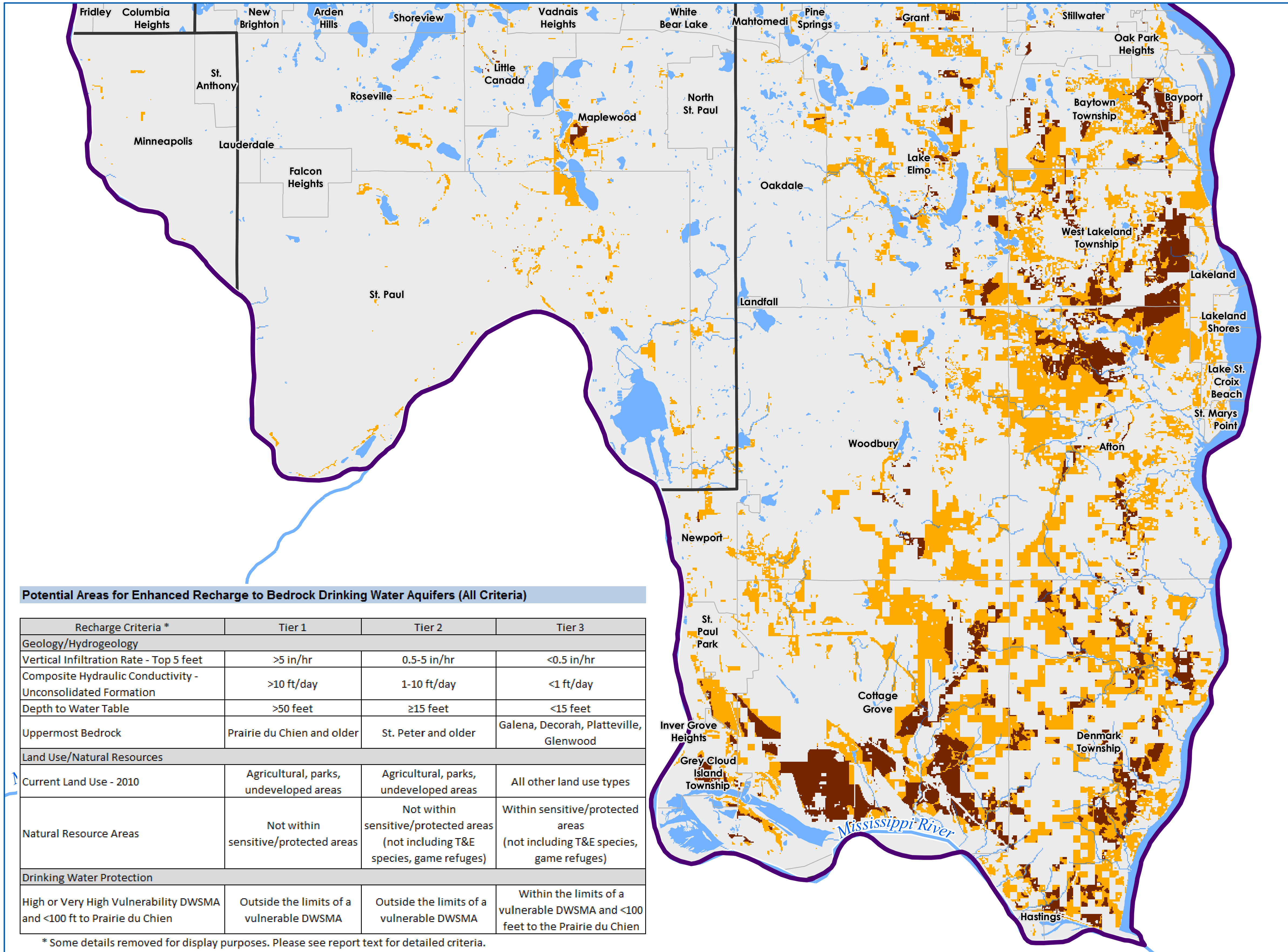
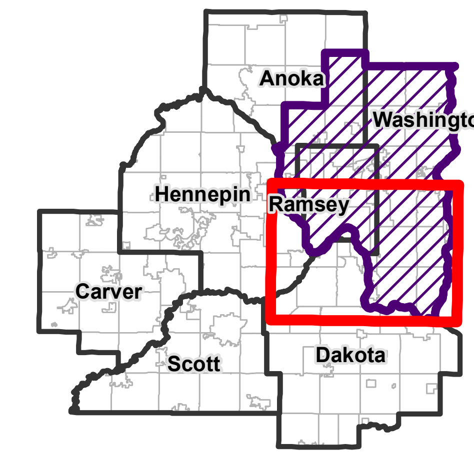
Metropolitan Council
Regional Groundwater Recharge and Stormwater Reuse Study

Figure 3 (2 of 2)
Potential Areas for Enhanced Recharge to Bedrock Drinking Water Aquifers (All Criteria)
North and East Study Area





Potential Areas for Enhanced Recharge to Bedrock Drinking Water Aquifers (All Criteria)

Recharge Criteria *	Tier 1	Tier 2	Tier 3
Geology/Hydrogeology			
Vertical Infiltration Rate - Top 5 feet	>5 in/hr	0.5-5 in/hr	<0.5 in/hr
Composite Hydraulic Conductivity - Unconsolidated Formation	>10 ft/day	1-10 ft/day	<1 ft/day
Depth to Water Table	>50 feet	≥15 feet	<15 feet
Uppermost Bedrock	Prairie du Chien and older	St. Peter and older	Galena, Decorah, Platteville, Glenwood
Land Use/Natural Resources			
Current Land Use - 2010	Agricultural, parks, undeveloped areas	Agricultural, parks, undeveloped areas	All other land use types
Natural Resource Areas	Not within sensitive/protected areas	Not within sensitive/protected areas (not including T&E species, game refuges)	Within sensitive/protected areas (not including T&E species, game refuges)
Drinking Water Protection			
High or Very High Vulnerability DWSMA and <100 ft to Prairie du Chien	Outside the limits of a vulnerable DWSMA	Outside the limits of a vulnerable DWSMA	Within the limits of a vulnerable DWSMA and <100 feet to the Prairie du Chien

* Some details removed for display purposes. Please see report text for detailed criteria.

Sources: USDA NRCS, NHD, DNR, MDH

HDR

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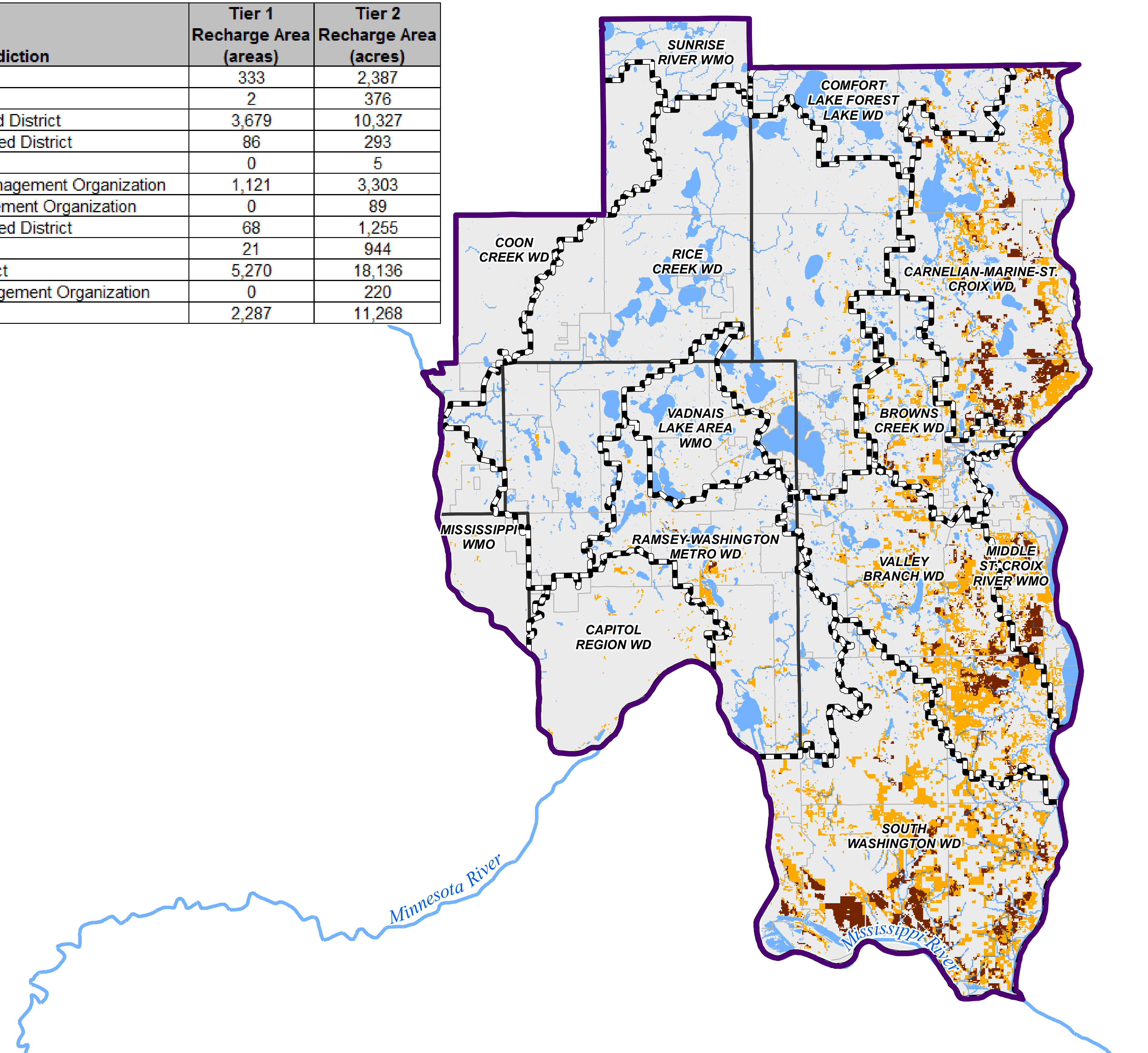
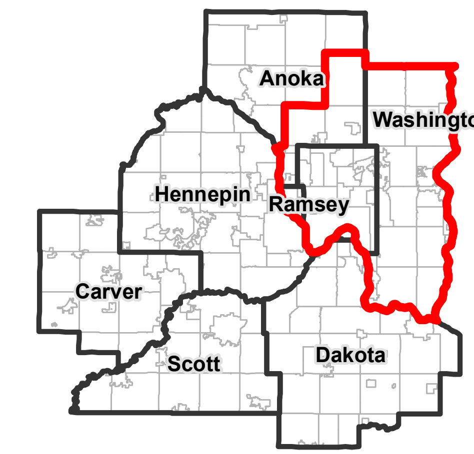
Metropolitan Council
Regional Groundwater Recharge and Stormwater Reuse Study

Figure 4
Enhanced Recharge Areas within Watershed Jurisdictions
North and East Study Area

Watershed Jurisdiction	Tier 1 Recharge Area (areas)	Tier 2 Recharge Area (acres)
Browns Creek Watershed District	333	2,387
Capitol Region Watershed District	2	376
Carnelian-Marine-St Croix Watershed District	3,679	10,327
Comfort Lake / Forest Lake Watershed District	86	293
Coon Creek Watershed District	0	5
Middle St Croix River Watershed Management Organization	1,121	3,303
Mississippi River Watershed Management Organization	0	89
Ramsey/Washington/Metro Watershed District	68	1,255
Rice Creek Watershed District	21	944
South Washington Watershed District	5,270	18,136
Vadnais Lake Area Watershed Management Organization	0	220
Valley Branch Watershed District	2,287	11,268





Legend

- Watershed Jurisdiction
- Study Area
- Tier 1 Area
- Tier 2 Area
- Tier 3 Area
- County Boundary
- City/Township Boundary

Sources: USDA NRCS, NHD, DNR

0 25,000 Feet

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Metropolitan Council
Regional Groundwater Recharge and Stormwater Reuse Study

Figure 5
Potential Contamination and Recharge Areas
North and East Study Area

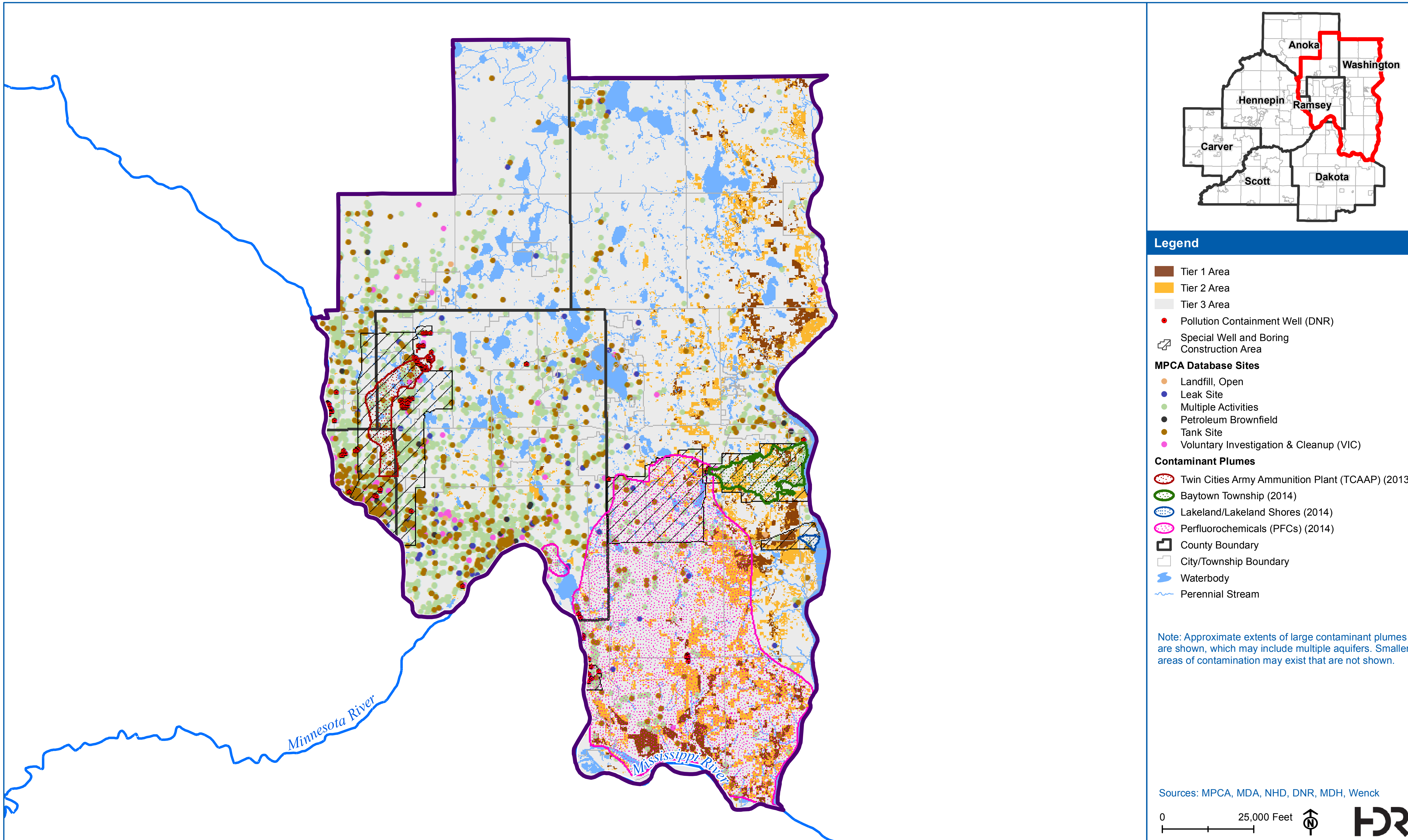

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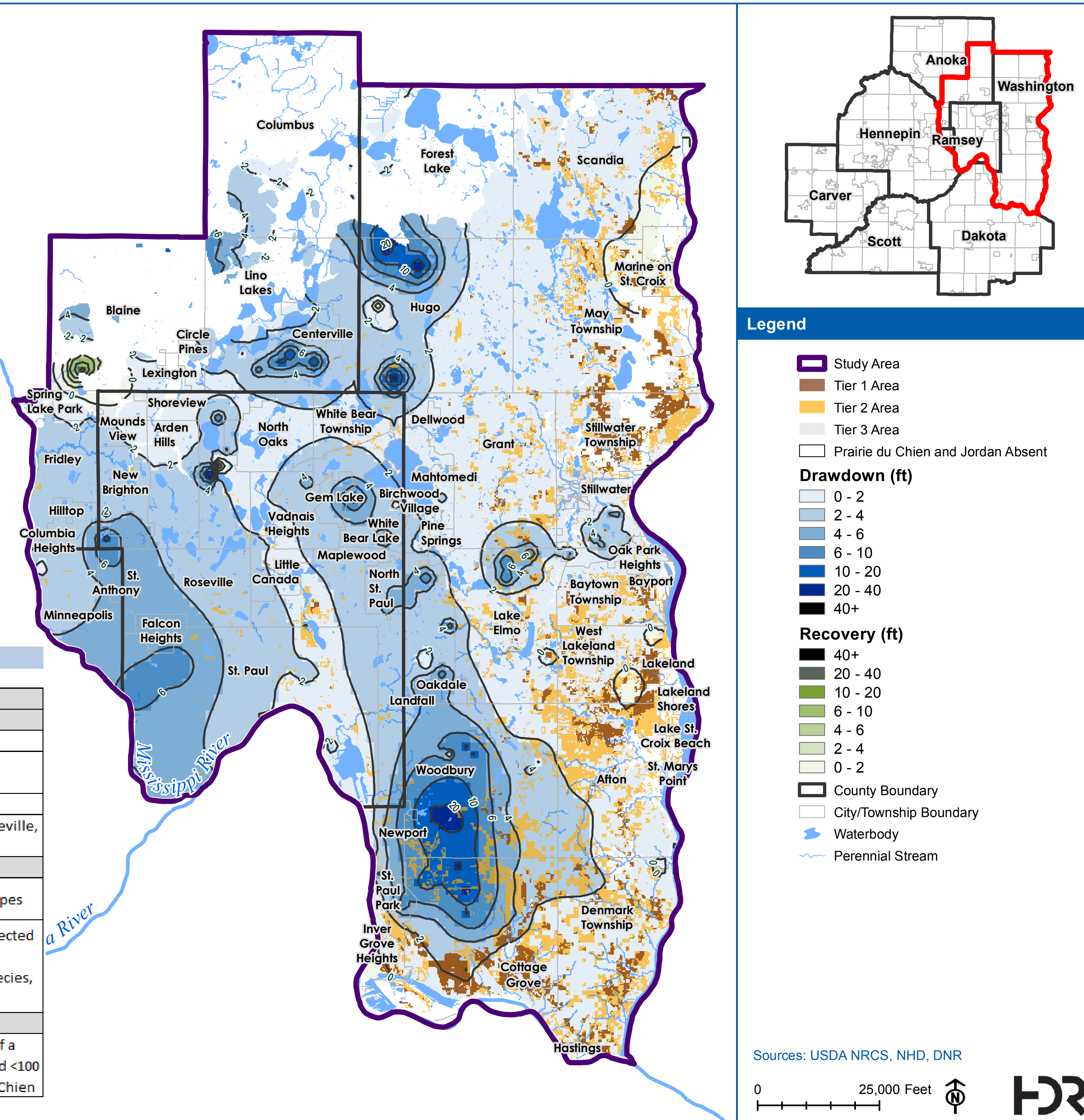
Figure 6
2040 Model-projected Drawdown and Recharge Areas
North and East Study Area

Figure shows the difference between modeled heads from current pumping (based on 1995-2005 reported water use) and modeled heads for 2040 continued development of groundwater sources, for the Prairie du Chien-Jordan Aquifer.



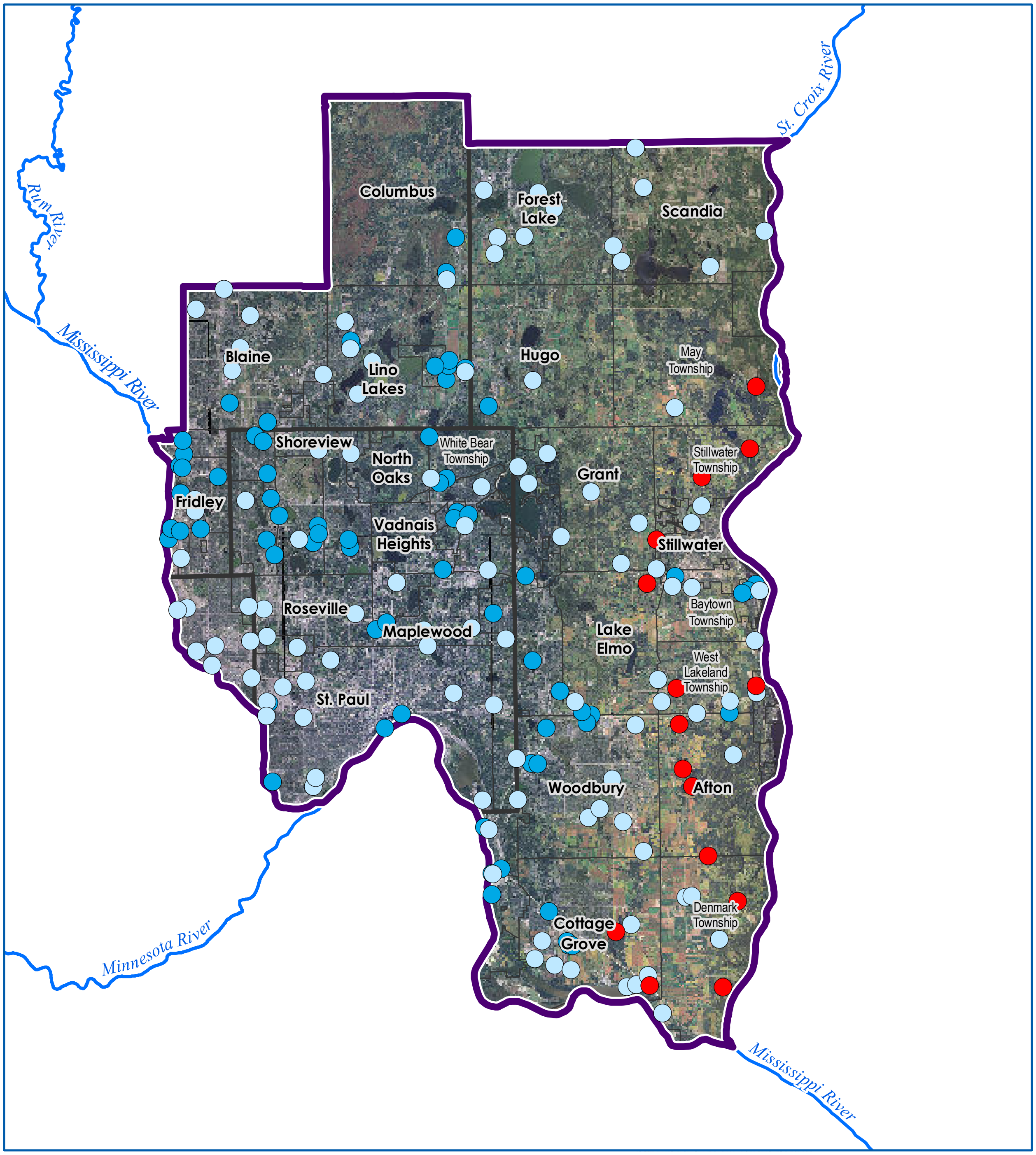
Potential Areas for Enhanced Recharge to Bedrock Drinking Water Aquifers (All Criteria)

Recharge Criteria *	Tier 1	Tier 2	Tier 3
Geology/Hydrogeology			
Vertical Infiltration Rate - Top 5 feet	>5 in/hr	0.5-5 in/hr	<0.5 in/hr
Composite Hydraulic Conductivity - Unconsolidated Formation	>10 ft/day	1-10 ft/day	<1 ft/day
Depth to Water Table	>50 feet	≥15 feet	<15 feet
Uppermost Bedrock	Prairie du Chien and older	St. Peter and older	Galena, Decorah, Platteville, Glenwood
Land Use/Natural Resources			
Current Land Use - 2010	Agricultural, parks, undeveloped areas	Agricultural, parks, undeveloped areas	All other land use types
Natural Resource Areas	Not within sensitive/protected areas	Not within sensitive/protected areas (not including T&E species, game refuges)	Within sensitive/protected areas (not including T&E species, game refuges)
Drinking Water Protection			
High or Very High Vulnerability DWSMA and <100 ft to Prairie du Chien	Outside the limits of a vulnerable DWSMA	Outside the limits of a vulnerable DWSMA	Within the limits of a vulnerable DWSMA and <100 feet to the Prairie du Chien

* Some details removed for display purposes. Please see report text for detailed criteria.

Metropolitan Council
Regional Groundwater Recharge and Stormwater Reuse Study

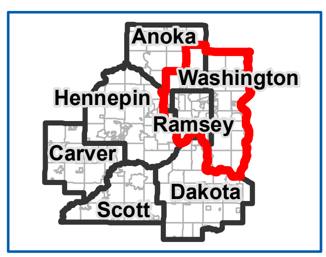
Figure 7
Modeled Sites for Stormwater Reuse & Recharge North and East Metro Study Area



Legend

Data Source
- DNR SWUDs
- Municipal Water Sales/Water Supply Plans
- Enhanced Recharge
- Study Area
- County Boundary
- City/Township Boundary

0 5 Miles



Sources: Met Council, DNR

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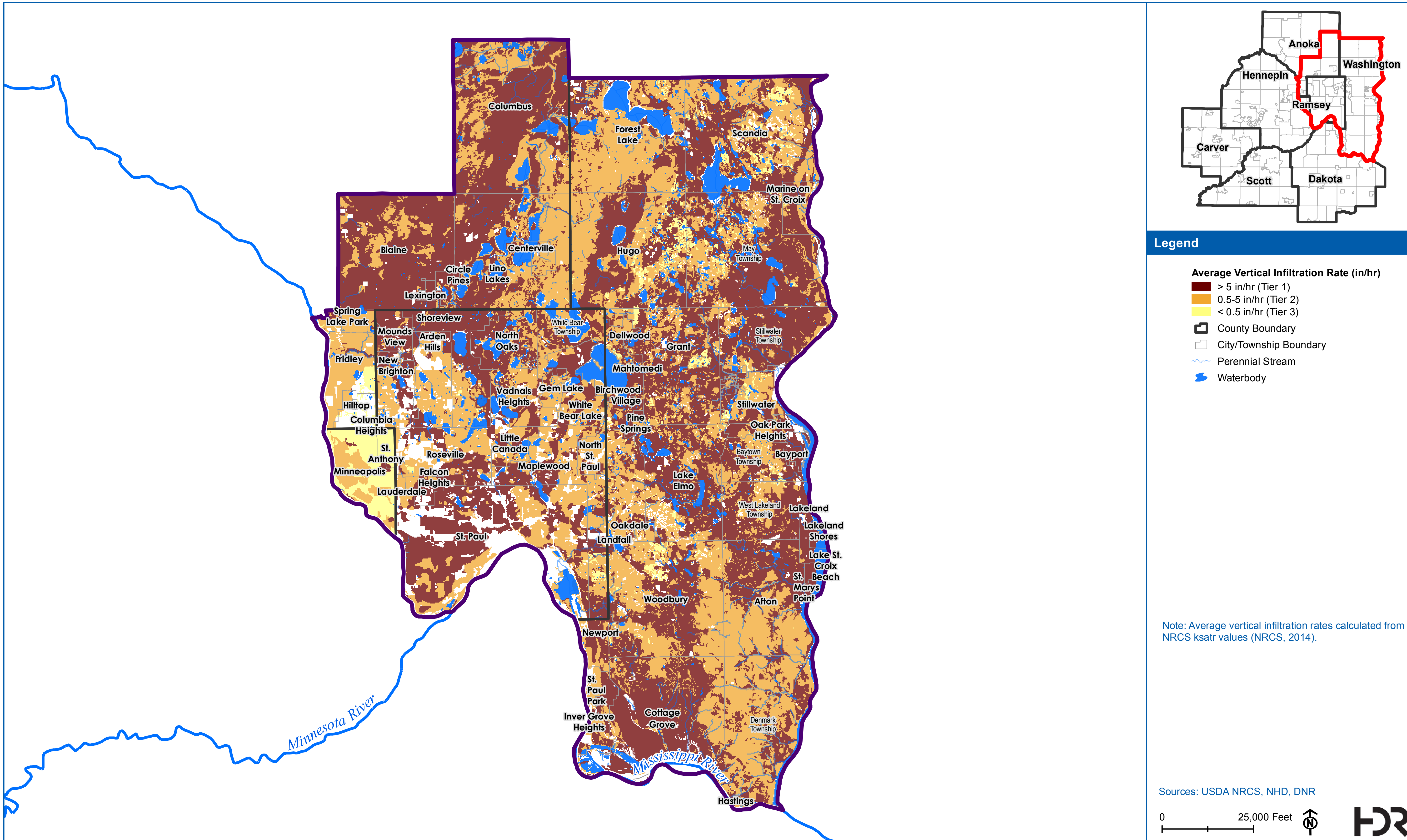
Appendix A1: Enhanced Recharge Study Figures

Metropolitan Council
Regional Groundwater Recharge and Stormwater Reuse Study

Figure A1-1
Average Vertical Infiltration Rate (Top 5 feet)
North and East Study Area



Note: Average vertical infiltration rates calculated from NRCS ksatr values (NRCS, 2014).

Sources: USDA NRCS, NHD, DNR

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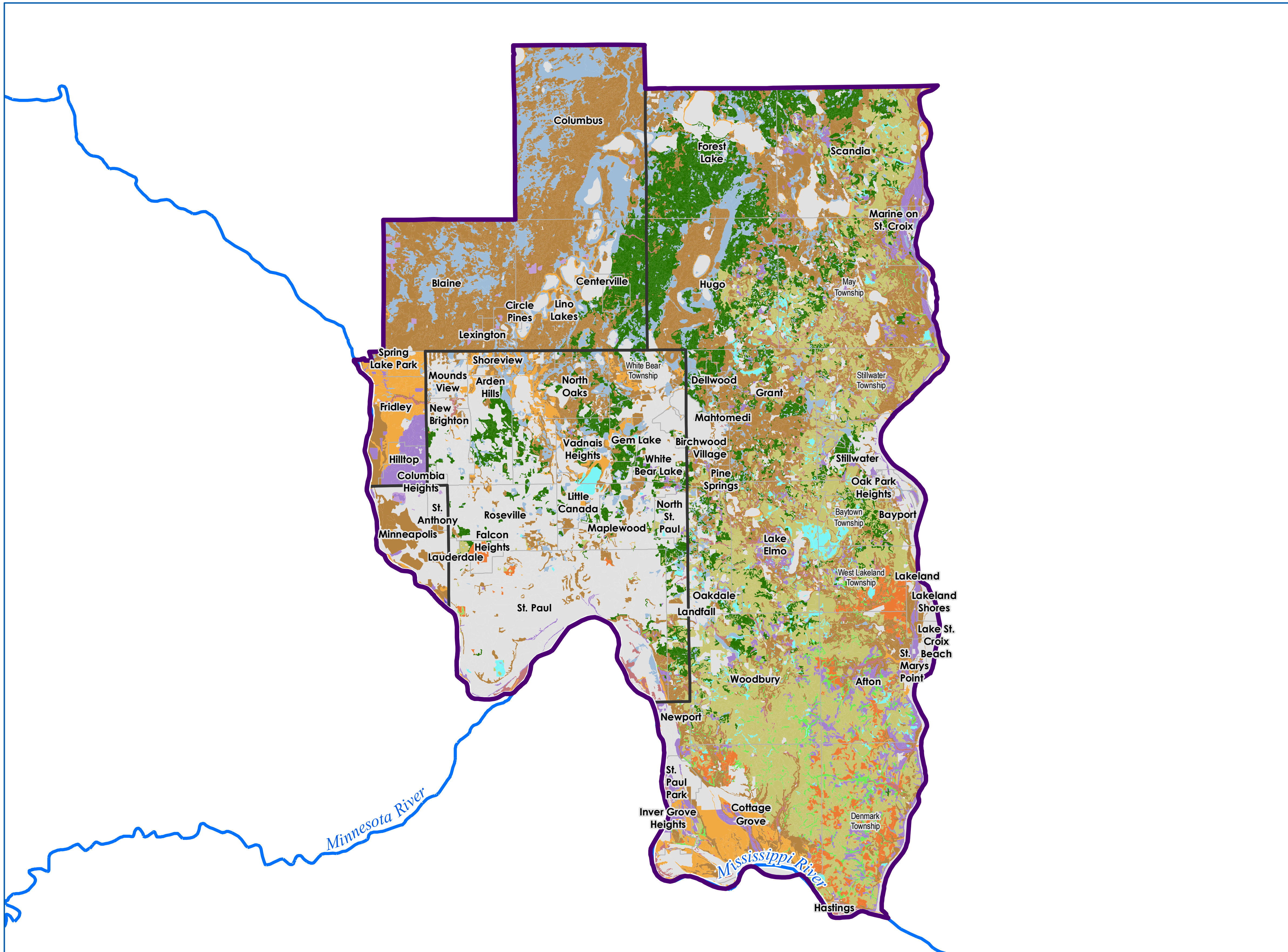
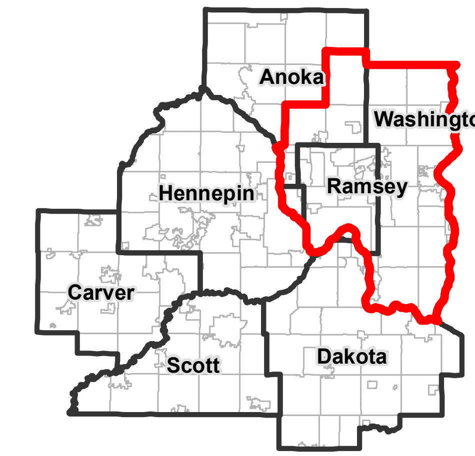
Metropolitan Council
Regional Groundwater Recharge and Stormwater Reuse Study

Figure A1-2
Soil Parent Material
North and East Study Area





Legend

Tier 2 Parent Material
- Glaciofluvial Sediments
- Outwash
- Variable Sandy Material

Tier 3 Parent Material
- Alluvium
- Colluvium
- Glaciolacustrine Sediments
- Lacustrine Sediments
- Limestone and Sandstone Bedrock
- Loess
- Organic Material
- Till
- Variable Loamy Material
- Variable Soil Material
- Unknown Parent Material
- County Boundary
- City/Township Boundary

Note: Tier 1 recharge criteria does not incorporate soil parent material.

Sources: USDA NRCS, NHD, DNR

0 25,000 Feet

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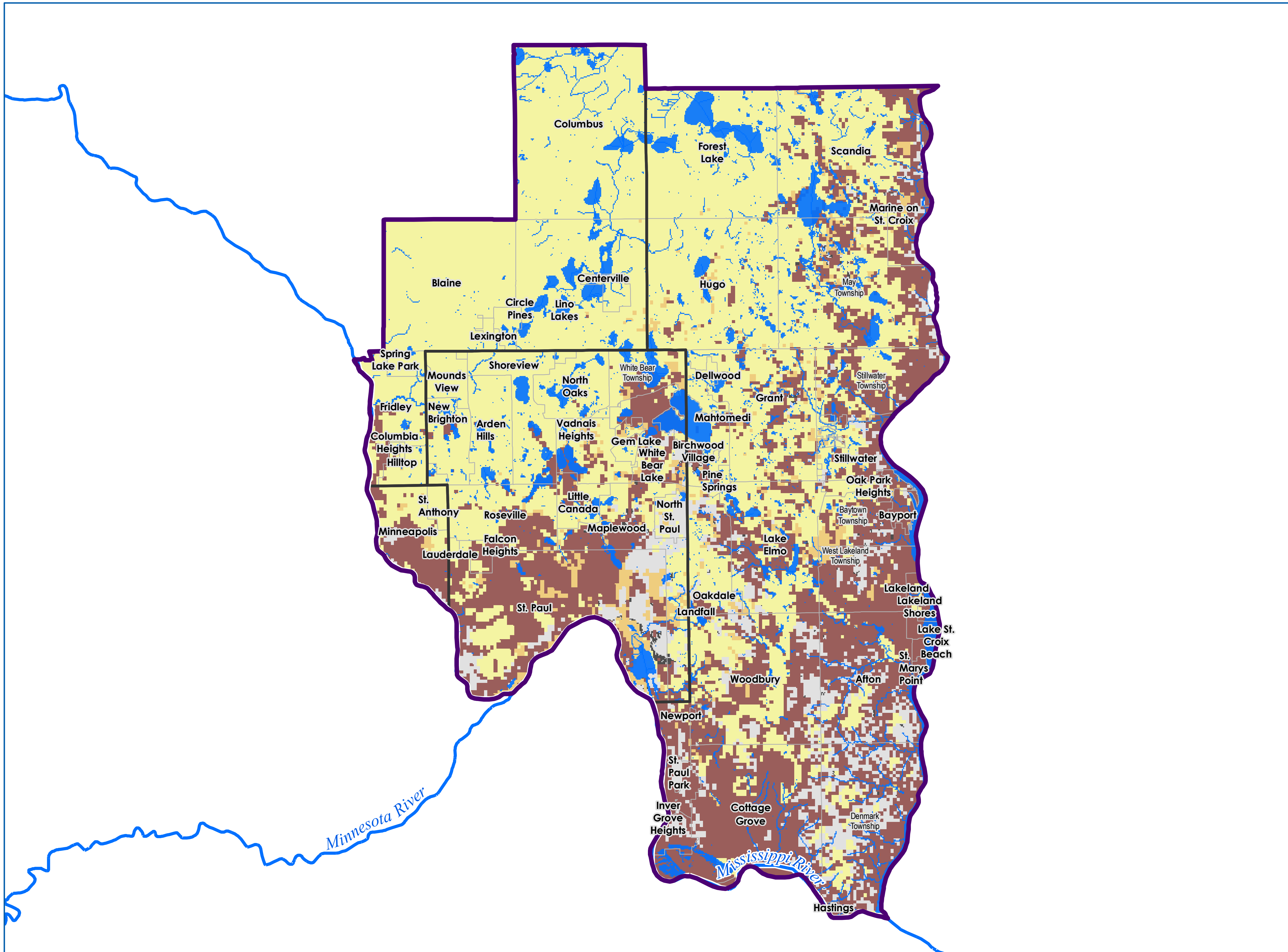
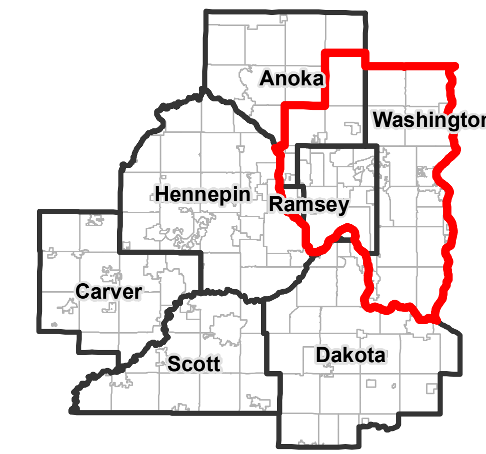
Metropolitan Council
Regional Groundwater Recharge and Stormwater Reuse Study

Figure A1-3
Composite Hydraulic Conductivity - Unconsolidated Formation
North and East Study Area





Legend

Hydraulic Conductivity (ft/day)

- > 10 (Tier 1)
- 1-10 (Tier 2)
- < 1 (Tier 3)
- Insufficient Data (Permeable Parent Material)
- Insufficient Data
- County Boundary
- City/Township Boundary
- Waterbody
- Perennial Stream

Note: Composite hydraulic conductivity calculated from Tipping (2011).

Sources: MGS Tipping, NHD, DNR

0 25,000 Feet

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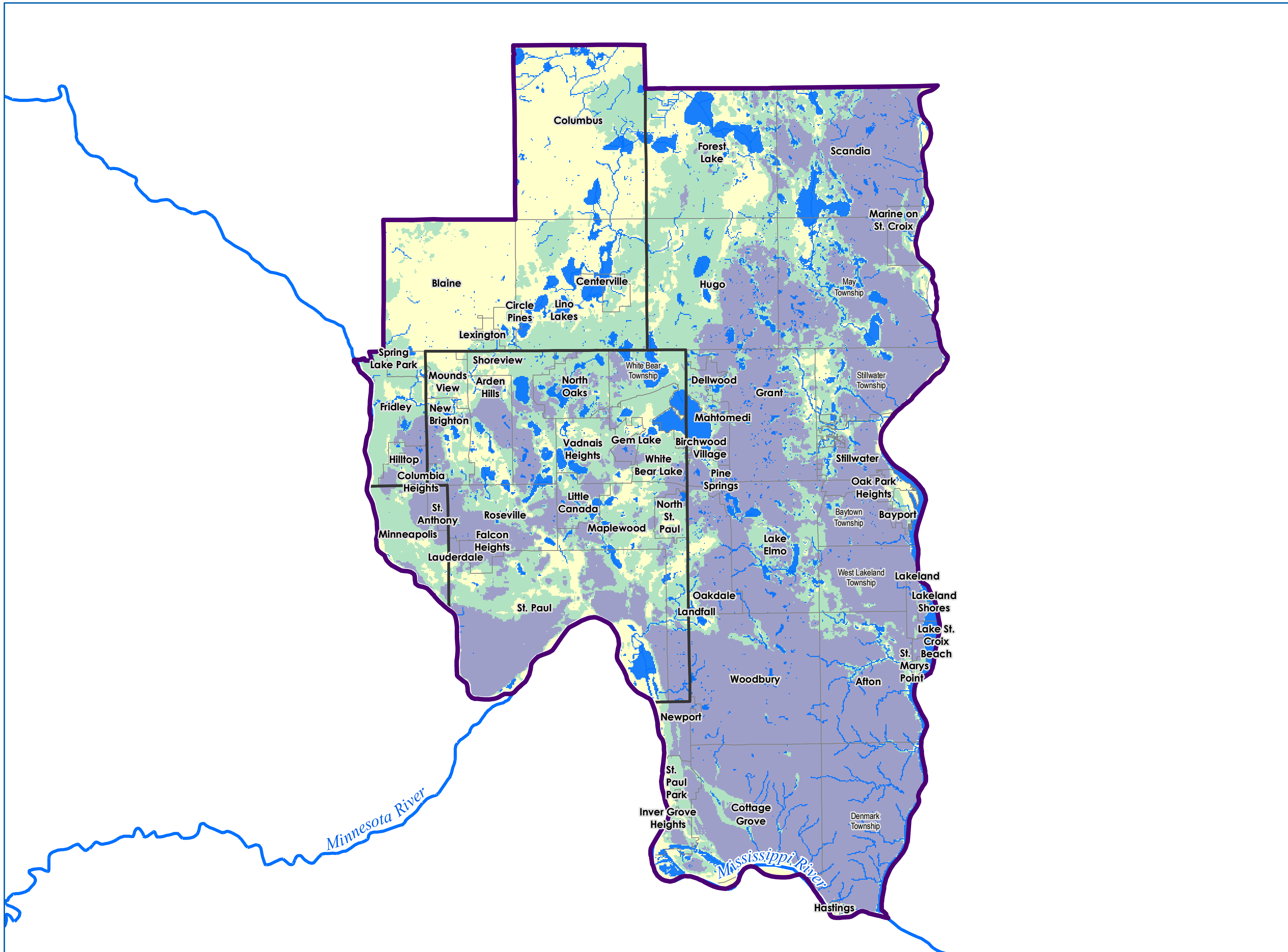
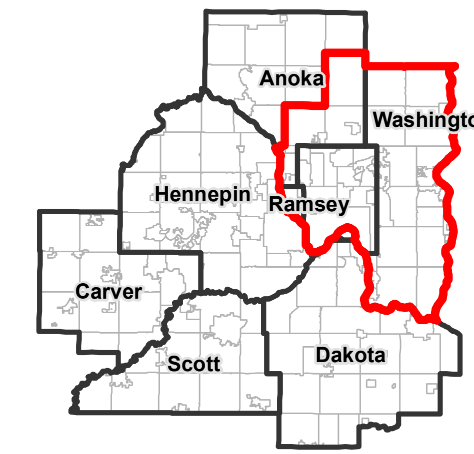
Metropolitan Council
Regional Groundwater Recharge and Stormwater Reuse Study

Figure A1-4
Depth to Regional Water Table
North and East Study Area





Legend

Depth to Water Table (ft)
- > 50 (Tier 1)
- 15-50 (Tier 2)
- < 15 (Tier 3)
- County Boundary
- City/Township Boundary
- Waterbody
- Perennial Stream

Note: Depth to regional water table calculated from NED surface elevations and regional water table elevations (Barr, 2010).

Sources: Barr, NHD, DNR

0 25,000 Feet

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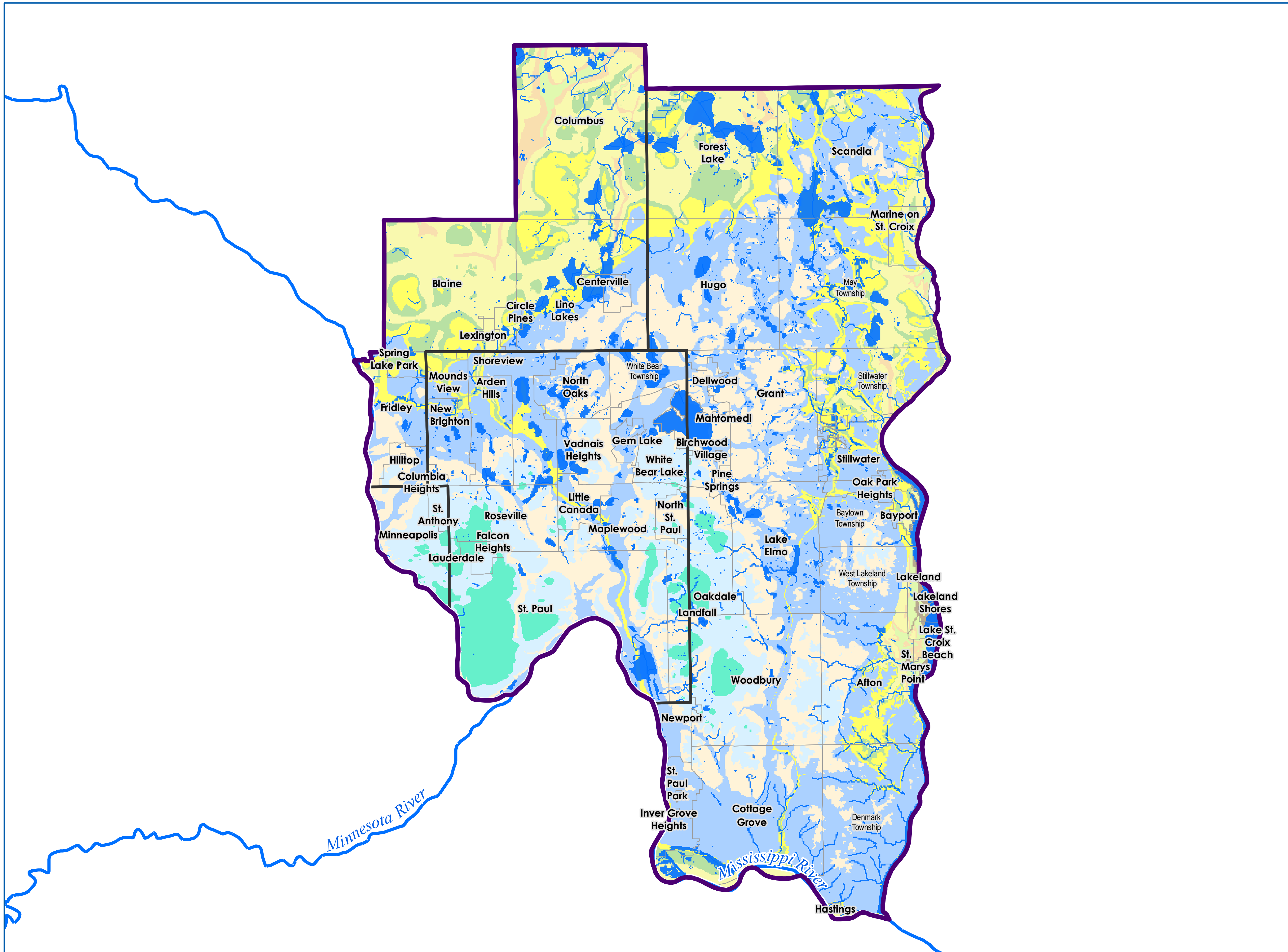
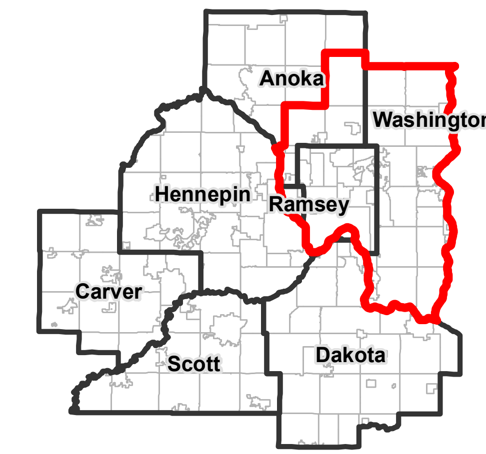
Metropolitan Council
Regional Groundwater Recharge and Stormwater Reuse Study

Figure A1-5
Bedrock Geology
North and East Study Area





Legend

Paleozoic Rocks

Young → Old

Tier 3
- Galena and Decorah Formations
- Platteville and Glenwood Fms

Tier 2
- St. Peter Sandstone

Tier 1
- Prairie du Chien Group
- Jordan Sandstone
- St. Lawrence Formation
- Tunnel City Group
- Wonewoc Sandstone
- Eau Claire Formation
- Mt. Simon Sandstone
- Precambrian Sedimentary Rocks

- County Boundary
- City/Township Boundary
- Waterbody
- Perennial Stream

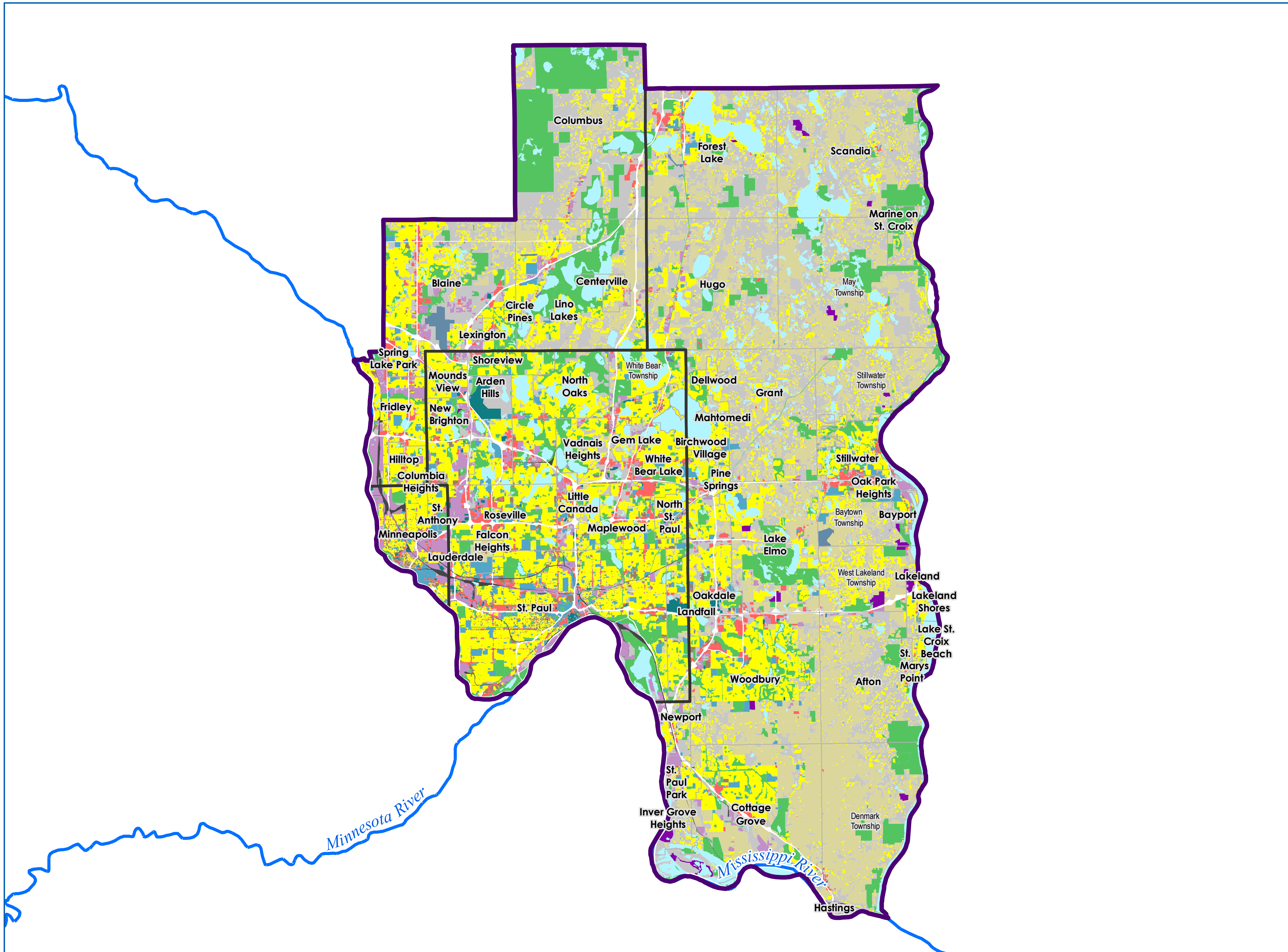
Note: Bedrock geology reproduced from Mossler (2013).

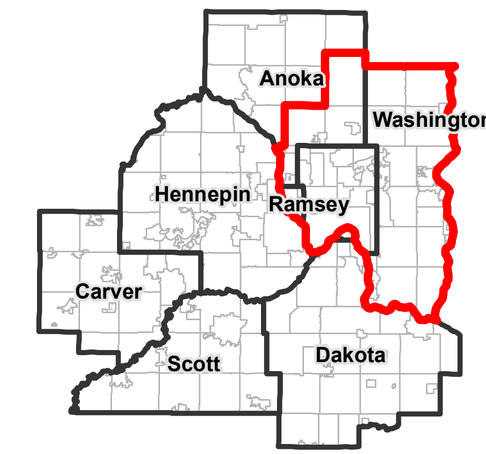
Sources: MGS, NHD, DNR

0 25,000 Feet

Metropolitan Council
Regional Groundwater Recharge and Stormwater Reuse Study

Figure A1-6
2010 Land Use
North and East Study Area





Legend

Tier 1 & 2
- Agricultural
- Park and Recreation
- Undeveloped

Tier 3
- Single Family Residential
- Multifamily Residential
- Commercial
- Extractive
- Industrial
- Institutional
- Mixed Use
- Rights-of-Way (i.e., Roads)
- Railway (inc. LRT)
- Airport
- Open Water
- County Boundary
- City/Township Boundary

Note: Land use mapping provided by Metropolitan Council Environmental Services (2011).

Sources: Met Council, NHD, DNR

0 25,000 Feet

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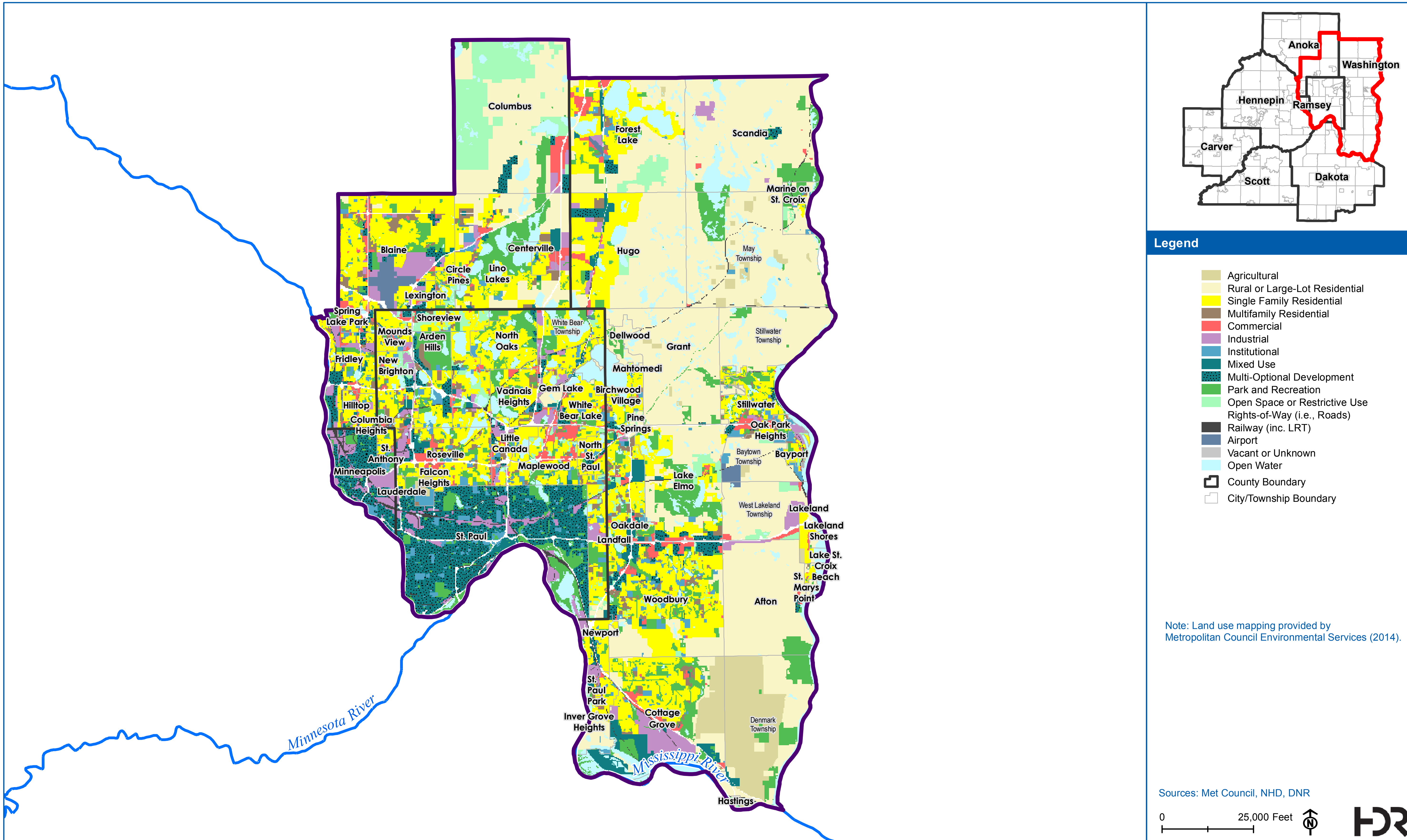
Metropolitan Council
Regional Groundwater Recharge and Stormwater Reuse Study

Figure A1-7
2030 Land Use
North and East Study Area



Note: Land use mapping provided by Metropolitan Council Environmental Services (2014).

Sources: Met Council, NHD, DNR

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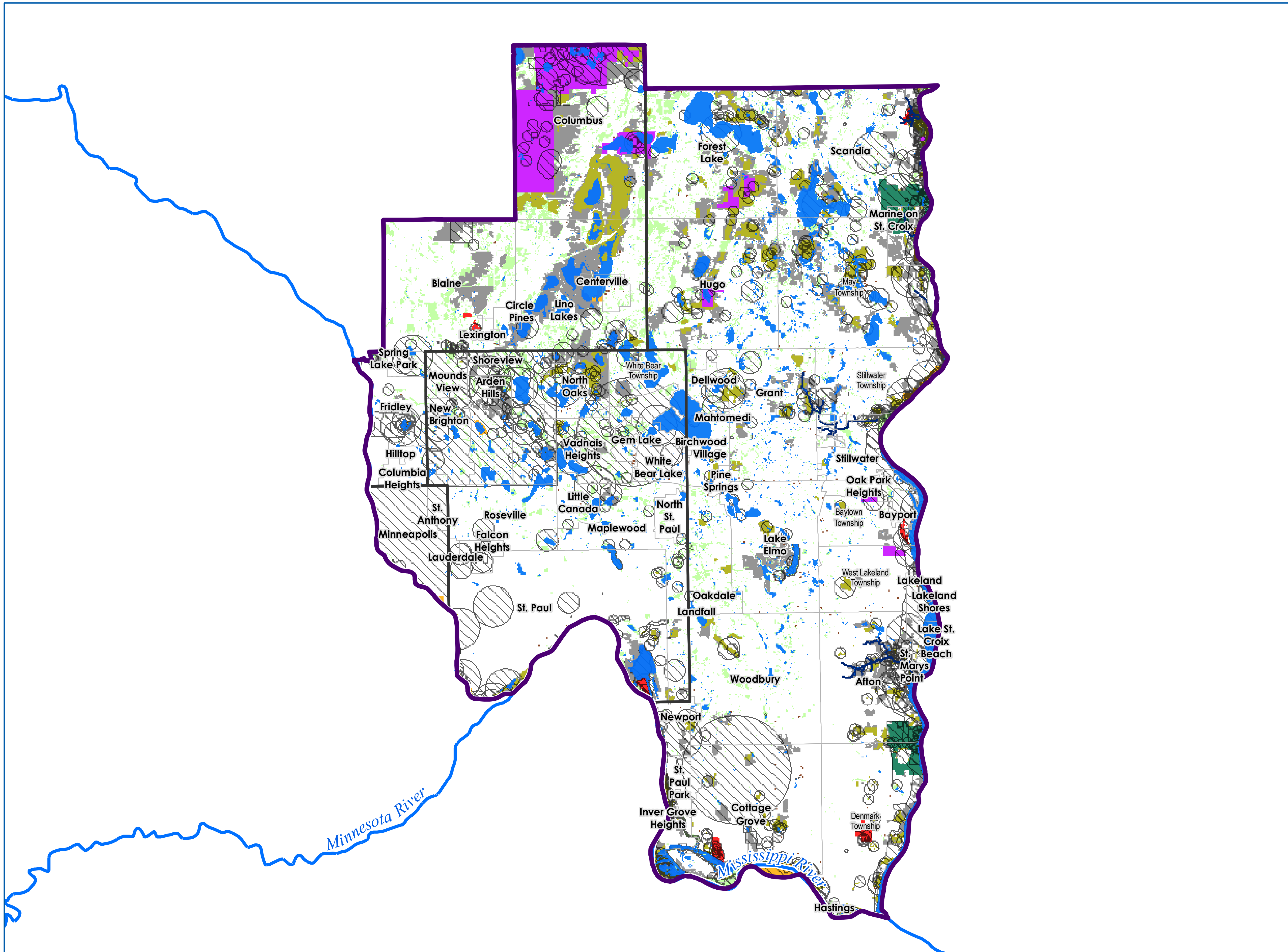
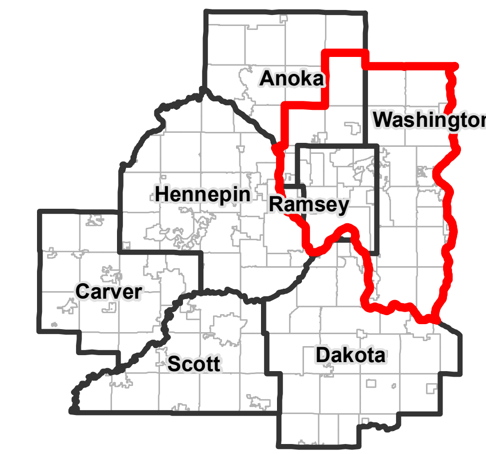
Figure A1-8
Sensitive Natural Resources
North and East Study Area





Legend

Tier 3
- Calcareous Fen
- Designated Trout Stream
- Native Plant Community
- Aquatic Management Area
- Wildlife Management Area
- Federal Land / Easement
- Scientific & Natural Area
- State Park
- USDA NRCS Easement
- Regional Natural Resource Area
- The Nature Conservancy

Tier 2
- Potential T&E Species Area
- Game Refuge

- County Boundary
- City/Township Boundary
- Waterbody
- NWI Wetland

Tier 1:
Areas not designated as Tier 2 or Tier 3

Note: Sensitive natural resources mapping provided by MnDNR (2014 a).

Sources: MPCA, NHD, DNR

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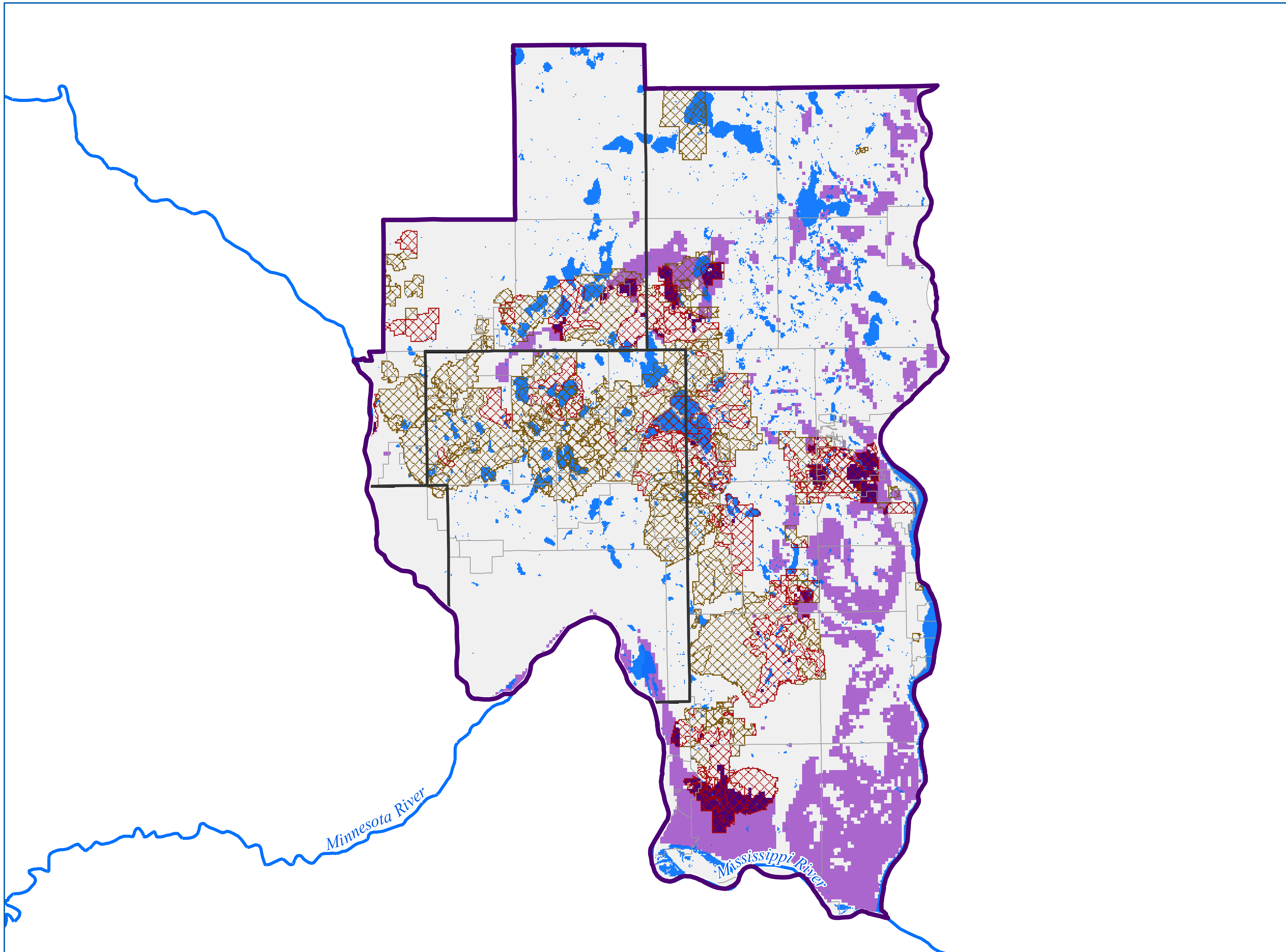
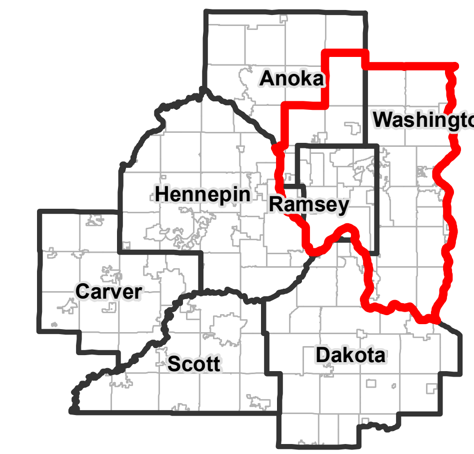
Metropolitan Council
Regional Groundwater Recharge and Stormwater Reuse Study

Figure A1-9
Drinking Water Protection
North and East Study Area





Legend

- DWSMA
- Vulnerable DWSMA
- Depth to Prairie du Chien < 100'
- Prairie du Chien not Subcropping
- Tier 3 *Within a Vulnerable DWSMA AND Depth to Prairie du Chien < 100'*
- County Boundary
- City/Township Boundary

All non-Tier 3 areas meet Tier 1 and Tier 2 criteria.

Sources: MDH, NHD, DNR

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Appendix A2: Enhanced Groundwater Recharge Facility Costs

Enhanced Groundwater Recharge Facility Costs

Capital cost estimates for recharge basins were based on construction costs obtained from recent bids on similar types of construction in Minnesota, quoted unit costs from RS Means, and unit costs from HDR historical costs on similar projects.

Conceptual level costs were developed for a range of recharge basin sizes and design concepts, including a traditional above-ground recharge basin and a system with sub-surface distribution chambers. Detailed breakdowns of representative costs for a 20-acre surface recharge basin and a 20-acre subsurface recharge basin are shown in the Table A2-1 and A2-2.

Assumptions used to develop the costs are listed below.

Capital Cost Items

- **Mobilization/Demobilization** – approximately 2% of construction subtotal cost.
- **Clearing and Grubbing** – Assumed ¼ of the site needs to be cleared and grubbed.
- **Topsoil stripping & haul off-site** – 12” deep across the entire site.
- **Coarse graded sand** – 12” thick for basin bottoms, 1.2 tons per cubic yard.
- **Embankment for Berms – hauled in** – 3 feet high berms, 12 feet wide at top, 3:1 side slopes for entire embankment.
- **Crushed Surfacing Top Course** – 6” thick for 12’ wide access road, entire length of access roads, 1.4 tons per cubic yard.
- **Facility Piping** – Buried 8” ductile iron pipe to deliver water around the site and to each infiltration subbasin or subsurface gallery.
- **Distribution Header** – 18” perforated corrugated steel pipe set at grade in each basin for distribution of flow.
- **Control Valve** – 8 inch valve at each basin controlled by the local control panel operating by PLC on a set operational schedule.
- **Security Fence** – Fencing to surround the site
- **Landscaping** – approximately 2% of construction subtotal cost
- **Instrumentation and Electrical** – All instrumentation and control facilities on the site.
- **Power** – Power drop to extend power to the site.
- **Filtration System** – Contech StormFilter® media filtration system
- **Pumps** – 2000 GPM pumps, 60 HP, 8” discharge
- **Precast Concrete Vault for Control Structure** – 8’ x 14’ x 7’ concrete vault for control structure
- **Control Valve** – 8” valve at each basin controlled by the local control panel operation by PLC on a set operational schedule.
- **Flow Meter** – Circuit Sensor Flow Meter for 8” pipe
- **Water Quality Monitoring** – Monitoring Well installation and initial startup (background) monitoring including lab analysis.
- **Silt Fence** - Assumed same quantity as Security Fencing
- **Seeding** – Area of the site minus aggregate access road or sand surfaces in recharge basins
- **Seed Mixture** – 70 pounds per acre of Seeding
- **Mulch** – 2 tons per acre of Seeding
- **Fertilizer** – 200 pounds per acre of Seeding

Indirect Cost Items

- **Construction Contingency** – 30 percent of construction subtotal
- **Engineering, Permitting, and Administration** – Engineering, permitting costs and fees, and costs incurred by owner for administration and management of the project were estimated to be 20 percent of construction subtotal.

Excluded Costs

- Costs do not include property acquisition, construction management, surveying costs, operations and maintenance, or rehabilitation costs.

Table A2-1. Cost Estimate – 20-Acre Surface Recharge Basin

Description	Qty	Unit	Unit Cost	Cost
Mobilization/Demobilization	1	LS	$45,000.00	$45,000
Clearing & Grubbing	5	ACRE	$10,000.00	$50,000
Common Excavation	95,187	CY	$4.98	$474,031
Haul Excavated Material Off-site	92,643	CY	$4.36	$403,923
Topsoil Replacement	2,544	CY	$6.49	$16,511
Coarse Graded Sand	28,556	TON	$12.50	$356,950
Crushed Surfacing Top Course	2,374	TON	$15.00	$35,610
Geotextile Fabric	15,264	SY	$1.50	$22,896
Facility Piping (8" DIP)	3,440	LF	$60.00	$206,400
Distribution Header (18" perforated HDPE)	6,500	LF	$30.00	$195,000
Control Valve	20	EA	$4,000.00	$80,000
Security Fence	3,950	LF	$30.00	$118,500
Landscaping	1	LS	$45,000.00	$45,000
Instrumentation and Electrical	1	LS	$75,000.00	$75,000
Power	1	LS	$20,000.00	$20,000
Filtration System	1	LS	$25,000.00	$25,000
Pumps (2000 GPM)	3	EA	$15,528.00	$46,584
Precast Concrete Vault for Control Structure, 8'x14'x7' high	1	EA	$10,200.00	$10,200
Control Valve, 8" diameter	1	EA	$10,050.00	$10,050
Flow Meter, 8" diameter	1	EA	$1,300.00	$1,300
Silt Fence	3,950	LF	$1.00	$3,950
Seeding	3.2	ACRE	$100.00	$315
Seed Mixture	221	LB	$2.00	$442
Mulch	6.3	TON	$100.00	$631

Description	Qty	Unit	Unit Cost	Cost
Fertilizer	0.315	TON	$800.00	$252
Subtotal A				**$2,243,545**
Construction Contingency (30%)				$673,064
Subtotal Construction Cost				**$2,916,609**
Engineering, Permitting, Admin (20%)				$448,700
Total Capital Costs				**$3,365,309**

Table A2-2. Cost Estimate – 20 Acre Sub-Surface Recharge System

Description	Qty	Unit	Unit Cost	Cost
Mobilization/Demobilization	1	LS	$120,000.00	$120,000
Clearing & Grubbing	5	ACRE	$10,000.00	$50,000
Common Excavation	101,909	CY	$4.98	$507,507
Haul Excavated Material Off-Site	71,336	CY	$4.36	$311,025
Topsoil Replacement	30,573	CY	$6.49	$198,419
Angular Stone	69,854	TON	$12.00	$838,248
Crushed Surfacing Top Course	1,157	TON	$15.00	$17,355
Facility Piping (8" DIP)	1,200	LF	$60.00	$72,000
Infiltration Chambers (12" H x 34" W)	237,600	LF	$14.09	$3,347,784
Inspection Port	99	EA	$200.00	$19,800
Control Valve	20	EA	$4,000.00	$80,000
Security Fence	3,950	LF	$30.00	$118,500
Landscaping	1	LS	$120,000.00	$120,000
Instrumentation and Electrical	1	LS	$75,000.00	$75,000
Power	1	LS	$20,000.00	$20,000
Filtration System	1	LS	$25,000.00	$25,000
Pumps (2000 GPM)	3	EA	$15,528.00	$46,584
Precast Concrete Vault for Control Structure, 8'x14'x7' high	1	EA	$10,200.00	$10,200
Control Valve, 8" diameter	1	EA	$10,050.00	$10,050
Flow Meter, 8" diameter	1	EA	$1,300.00	$1,300
Silt Fence	3,950	LF	$1.00	$3,950
Seeding	19.0	ACRE	$100.00	$1,898
Seed Mixture	1,329	LB	$2.00	$2,657
Mulch	38.0	TON	$100.00	$3,796

Description	Qty	Unit	Unit Cost	Cost
Fertilizer	1.90	TON	$800.00	$1,518
Subtotal A				**$6,002,591**
Construction Contingency (30%)				$1,800,777
Subtotal Construction Cost				**$7,803,368**
Engineering, Permitting, Admin (20%)				$1,200,500
Total Capital Costs				**$9,003,868**

Appendix A3: Stormwater Capture and Reuse

Methodology and Analysis

To assess the potential for stormwater capture and reuse within the study area, a simple comparison of the total non-winter runoff volume and the total groundwater demands was computed. Stormwater runoff volume for the study area was calculated using the Rational Method, applying runoff coefficients based on land use classifications for the study area. Runoff volumes were calculated for subwatersheds within a study area, and then summed to estimate runoff for the entire study area.

Non-winter months were defined as the period March 15 through November 31. To determine runoff potential, 2010 Land Use Information provided by Met Council data were correlated to similar Minnesota Land Cover Classification System (MLCCS) classes to determine appropriate runoff coefficients. The Rational Method was then used to estimate the expected average annual non-winter runoff for the entire study area, where annual Runoff (R_{annual}) is equal to:

R_{annual} = $\sum [(P*P_j*R_v)/12](A)$, where
R_{annual} = Total annual non-winter runoff from the study area drainage area, acre-ft.
P = Depth of rainfall in inches per year (29.3 inches[1])
P_j = Fraction of rainfall events that produce runoff (set to 0.9)
R_v = Runoff coefficient (ranges from 0.0 to 1.0 based on land cover)
A = Cover type area (acres)

For example, if watershed "A" has an area (A) = 1,000 acres**:**

Using the Met Council 2010 Generalized Land Use data, Watershed "A" has 400 acres of Single Family Detached residential land use, 300 acres of Multifamily residential land use, 100 acres of Industrial and Utility land use, and 200 acres of Agricultural land use. The Met Council land use types were correlated with the Minnesota Land Cover Classification System to determine runoff coefficients for those land uses. Thus, runoff coefficients (R_v) were determined for those four land uses are:

R_v (Single-Family Detached Residential) = 0.392
R_v (Multifamily Residential) = 0.617
R_v (Industrial and Utility) = 0.91
R_v (Agricultural) = 0.30

Thus, the weighted runoff coefficient (R_v) for the entire Watershed "A" is:

R_v (Watershed A) = [(400 acres*0.392) + (300 acres*0.617) + (100 acres*0.91) + (200 acres*0.30)]/1000 acres = **0.493**

Annual non-winter precipitation (P) was calculated using a 30-year average of non-winter precipitation, from March 15 – November 30 between 1981 and 2010. This annual precipitation (P) = **29.3 inches**

[1] Depth of Rainfall is the 30-year average (1981-2010) of non-winter (March 15 to November 30) precipitation from the six National Centers for Environmental Information (NCEI) rain gage stations within the study area (NCEI, 2015).

Thus, using the modified Rational Method equation,

Annual Runoff (R_{annual}) = [(29.3 inches*0.9*0.493)/(12 inch/foot)] * 1,000 acres = **1,083.37 ac-ft**

Water use data from the MnDNR SWUDS database was used to quantify total annual groundwater use for the study area. A comparison of total annual non-winter runoff to average groundwater demand provides a gross assessment of the stormwater supply to groundwater demand for the study area. The difference between the two volumes is a theoretical estimate of the maximum potential groundwater offset provided by stormwater runoff. This gross estimate does not take into account water uses appropriate for captured stormwater, or several conditionally-dependent factors that would ultimately define the potential for stormwater to meet specific demands. However, it does provide a relative assessment of a study area's potential to meet some portion of demands for non-potable use with stormwater. A comparison of non-potable uses in the MnDNR SWUDS and municipal use data to non-winter runoff volume further defines the potential for beneficial use of stormwater in the study area.

The refined analysis compared high-volume uses within the study area to specific, local sub-watershed runoff volumes. These uses included both permitted groundwater users obtained from the MnDNR SWUDS database, and municipal users identified from data obtained from communities in the study area. Uses were screened to identify uses associated with non-potable use, such as urban irrigation, major crop irrigation, and industrial processing. Average annual demands were tabulated for each user.

For each identified location, a drainage area was delineated using the LiDAR-based digital elevation model within ArcHydro (ESRI) with standard GIS-based watershed delineation methods. A drainage area spill point was assigned to each of the 195 sites. These spill points were selected to represent the furthest downslope location on a stormwater conveyance (either a ditch or storm sewer) within each of the drainage areas. These drainage areas (shown on Figure A3-1), in addition to land use/land cover and average regional precipitation data were used to determine the average non-winter runoff to each site. Where the drainage area of one water use site was located within the drainage area of another water use site, the overall run-on volume was calculated for the furthest downstream site to eliminate double-counting of volumes.

Results were tabulated showing stormwater runoff to specific sites and average annual water use at specific sites within the study area. A supply to demand ratio was calculated to assess the general potential for stormwater to satisfy some portion of groundwater demand at each site.

The results of the enhanced recharge analysis were incorporated into the stormwater analysis. Areas identified as meeting Tier 1 or Tier 2 criteria were included as sites for potential reuse of stormwater. Drainage areas for each potential enhanced recharge area were delineated (see Figure A3-1), and total annual non-winter runoff to these sites was computed as described earlier.

More detailed analysis of stormwater reuse potential should consider site-specific factors including local precipitation trends, evapotranspiration, soil types and antecedent soil moisture conditions, and seasonal variability related to timing of use. Use-specific considerations, including water quality requirements, and application rate and period should be factored into more detailed analyses of potential applications. Other factors related to infrastructure requirements, including the sizing of the storage or containment facilities, site constraints, application areas, and overflow location and capacity, among others, should be assessed during future study phases, or in support of implementation.

Stormwater Reuse Applications

Stormwater may be captured and reused for both non-potable and potable uses. Non-potable uses for stormwater are generally easier to implement and permit. The most widespread non-potable use for stormwater is irrigation, which accounts for approximately 34 percent of all water use in the United States (McPherson, 2014). Other non-potable uses of stormwater include toilet flushing and clothes washing. Common applications for these uses may include schools or other institutional facilities. Reuse of stormwater for potable use is possible but requires a high degree of treatment to meet drinking water standards.

In the industrial environment, generally, 80 to 90 percent of water is used for cooling and process water. Industrial uses of stormwater can be complex and expensive to implement due to quality requirements. The intended use for the industrial application dictates the treatment process and monitoring requirements. Stormwater reused in industrial applications may need to meet certain pH, conductivity, temperature, TSS, and TDS standards.

Stormwater Capture and Reuse System Features

Stormwater capture and reuse systems commonly include collection, filtration, disinfection, storage, pumping, and bypass components. The size and extent of each component will depend on the intended application, site characteristics, and local regulatory and permitting requirements.

Collection systems may vary depending on how stormwater is collected. In this study, collection of stormwater from conveyance systems was considered. These included pipe networks consisting of a series of catch basins and stormwater pipes, and ditch systems. It is also possible to collect runoff from rooftops, although these types of systems were not considered for the regional-scale systems considered in this report.

After collecting in the storm sewer network, collected stormwater usually passes through an in-line screen to remove leaves, twigs, and other debris before entering a storage component. In addition, additional solids removal may be accomplished through the addition of a pre-treatment forebay where solids are allowed to settle out before entering storage. Storage typically occurs in one of three forms including pond storage, below-ground storage, and above-ground storage, described in more detail below. Advantages and disadvantages of each type of system are summarized in Table A3-1.

- **Pond storage system.** Ponds should be designed in accordance with the Minnesota Stormwater Manual (MPCA, 2015d). A typical pond stores water three to five feet deep and normally maintains a permanent storage volume to provide water quality treatment. For stormwater reuse, a pond should be constructed so that the bottom is relatively impermeable. Soil testing is required to determine whether the existing material is suitable or whether the pond needs to be supplemented with a clay pond liner. Ponds should be located in areas with limited public access or provided with a fence to reduce the risk of drowning.
- **Below-ground storage tanks.** For smaller underground storage tanks, materials such as polypropylene, fiberglass, and concrete are commonly used. Large underground storage tanks are typically constructed of concrete. Other considerations for the design of underground storage tanks include designing around utilities and infrastructure, water tables, expansive soils, and high-traffic areas at the ground surface.

- **Above-ground storage tanks.** For above-ground tanks, foundations must be designed to carry the weight of the full tank. Foundations must be located away from natural drainage pathways. Above-ground storage tanks are most effective when collecting water from roofs, as water would need to be pumped into the tank when it is collected from the ground.

Table A3-1. Types of Stormwater Storage Systems

Type	Advantages	Disadvantages
Pond	Low Capital Costs Low Maintenance Costs Ponds provide dual purpose	Public safety concerns if unfenced Mosquito breeding habitat Storage losses due to evaporation Storage could limit flood protection capacity
Below-Ground Storage	Concealed from view Space at ground surface remains available for other uses	Higher capital costs Higher maintenance costs Stronger structure needed if located underneath parking area
Above-Ground Storage	Moderate capital costs Moderate maintenance costs	Aesthetic issues Usually only feasible for collection from the roofs of buildings

Source: (Metropolitan Council, 2011).

Storage elements can act as sedimentation basins to further remove particles from the stormwater. Fine filtration can be included at the effluent of the storage system to prevent clogging or fouling of irrigation equipment. In systems that irrigate unrestricted access areas, the stormwater will usually pass through a filter, followed by a disinfection process. Disinfection may consist of UV radiation and/or chlorination to neutralize pathogens that could impact public health.

An emergency spillway or overflow should be designed on any type of storage system to divert flow from conveyance, or allow storage to overflow when storage components are full. The emergency spillway or overflow may consist of a pipe or weir that discharges flow to the downstream stormwater conveyance system.

A stormwater reuse system typically requires a pumping system to move water from the collection or storage location to the use point, and to boost pressure for application. Stormwater should be sufficiently filtered to eliminate the risk of damaging pumping equipment prior to distribution.

Controls incorporated into stormwater capture and reuse systems will provide storage level monitoring to control pumping operations and storage fill/diversion operations, as well as source control. Systems may be designed to draw storage levels down in advance of storm events, to drain storage for maintenance, or to take systems off line. Level monitoring will also control diversion to overflow, as storage volumes fill during rain events. Consideration should also be given to either automatic or manual control of source switching, including proper cross contamination control, to use alternate supplies when storage volumes are depleted.

Cost Estimating Considerations

Estimated costs for construction of stormwater capture and reuse systems for urban irrigation applications were developed for this analysis. Capital costs include conveyance, primary treatment, storage and pumping components as well as engineering, legal, administration, and design contingencies. Costs do not include land acquisition or development costs. However, requirements for land area for each system size were estimated.

Costs were developed in part through a review of literature on other stormwater reuse systems constructed throughout the United States. In the review of literature, the majority of stormwater reuse ponds were developed by modifying an existing stormwater pond. Costs for constructing a new stormwater reuse pond were developed by calculating the quantities and costs of three different sized hypothetical stormwater reuse pond designs. In the hypothetical designs, the stormwater reuse ponds were assumed to be five feet deep with 4:1 side slopes, have a 12-inch thick clay liner, 6-inch thick topsoil stripping and replacement, close proximity to existing stormwater conveyance, security fencing around the entire pond with gate access, and appropriate connection to an existing irrigation system. Costs for pond systems were based on construction costs obtained from recent bids on similar types of construction in Minnesota, quoted unit costs from RS Means, and unit costs from HDR historical costs on similar projects.

Some of the cost items associated with constructing stormwater storage ponds are associated with the existing soil conditions and whether or not the pond requires a clay liner, clearing and grubbing, excavation and hauling, proximity to the stormwater source, security, existing or new irrigation system, treatment and pumping costs, and landscaping and recreational features.

Costs for below ground and above ground storage systems, including manufactured tanks, cisterns, or constructed concrete chamber-type facilities were developed using historical costs on similar projects. Cost curves were developed to estimate costs for a range of system sizes.

For underground storage systems, cost items with the highest variability include excavation and hauling, conveyance of stormwater to the storage system, manufactured or cast-in-place storage system, paving materials at the surface, existing or new irrigation system, and treatment/pumping costs.

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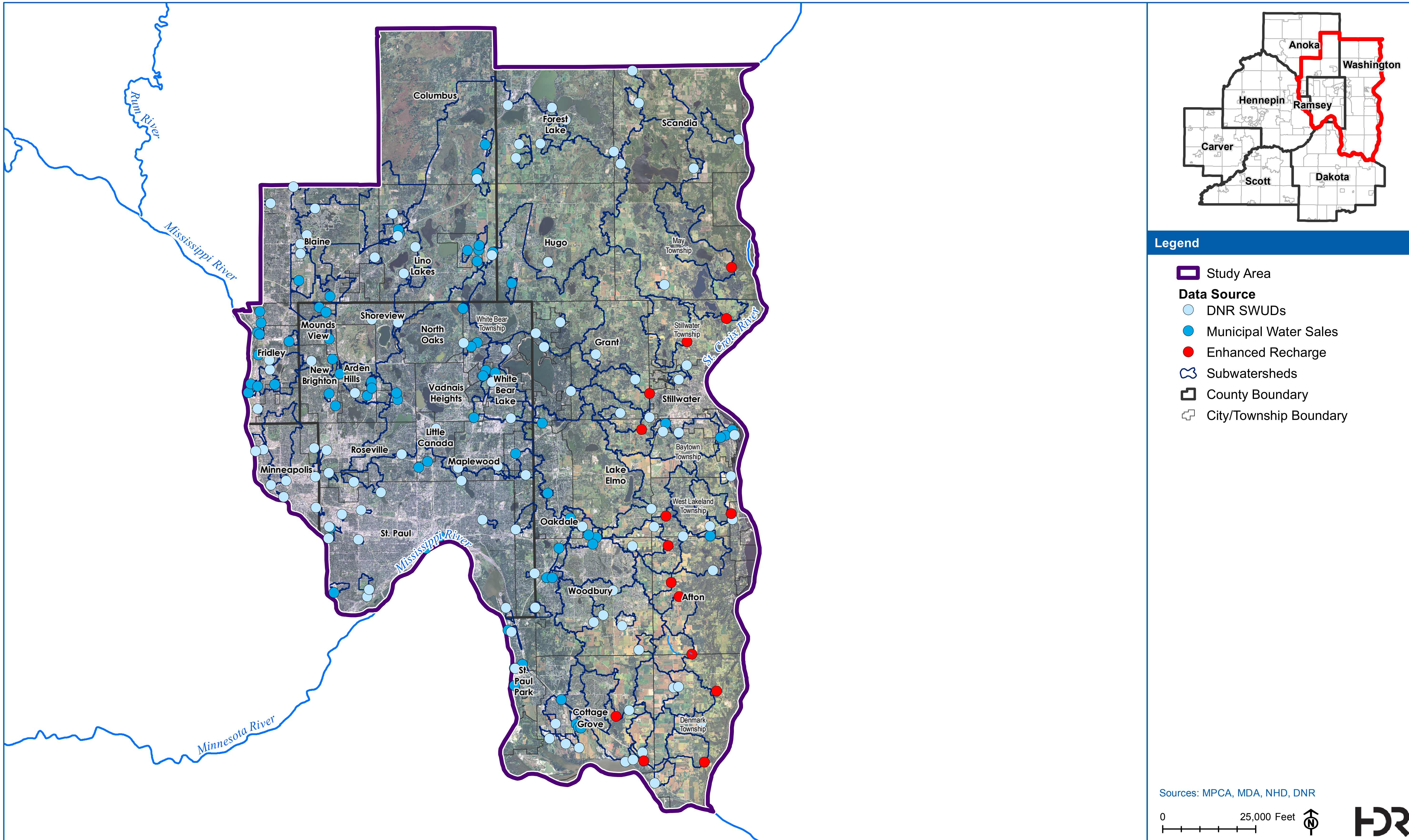
Figure A3-1
Modeled Sites and Drainage Areas for Stormwater Reuse & Recharge
North and East Metro Study Area



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