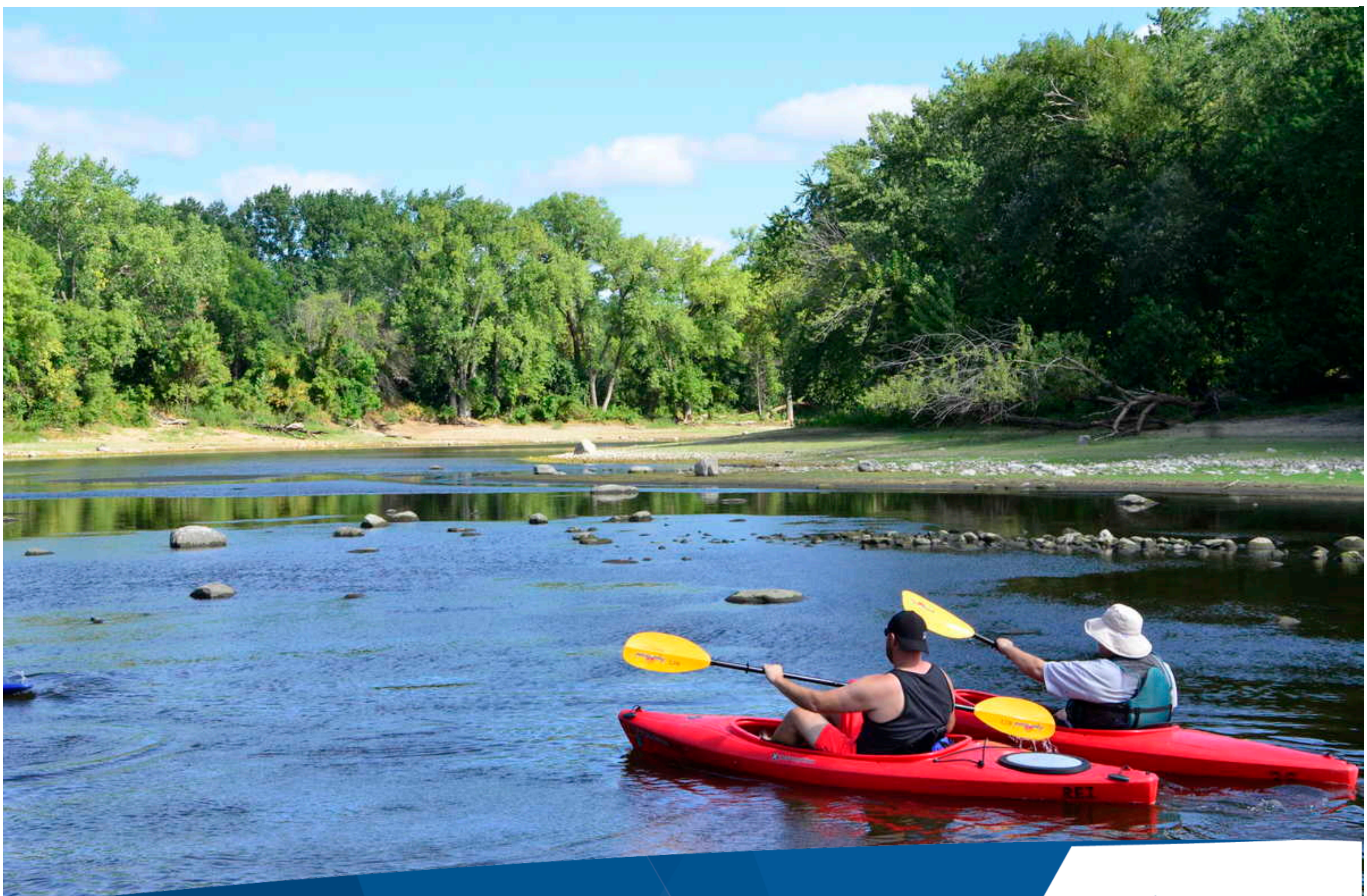
Regional Water Supply, Enhanced Groundwater Recharge, and Stormwater Capture and Reuse Study

Northwest Metro Study Area

December 2016



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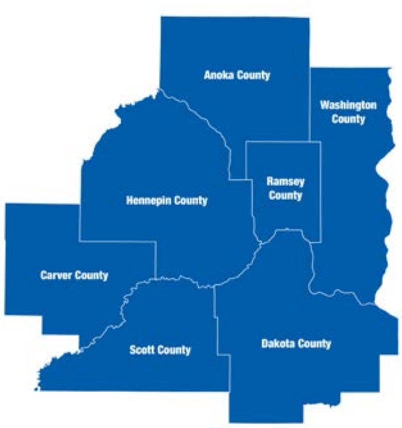

The Metropolitan Council is the regional planning organization for the seven-county Twin Cities area. The Council operates the regional bus and rail system, collects and treats wastewater, coordinates regional water resources, plans and helps fund regional parks, and administers federal funds that provide housing opportunities for low- and moderate-income individuals and families. The 17-member Council board is appointed by and serves at the pleasure of the governor.

Cover Photo: Kayakers on channel of Mississippi River below Coon Rapids Dam in Coon Rapids Dam Regional Park.

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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 three broad approaches to the regional sustainability of water resources in the northwest 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

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CLEAN WATER LAND & LEGACY AMENDMENT

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Executive Summary

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

Background

Groundwater is the principal source for water supply for municipalities in the Twin Cities 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 such as surface water or 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 resiliency of its water supply.

Scope of the Regional Study

This report summarizes the study of alternative water supplies for municipal use, enhanced aquifer recharge, and stormwater capture and reuse for the Northwest Metro Study Area. The study area (shown in the attached figure) covers portions of Anoka and Hennepin Counties, including the communities of Anoka, Andover, Brooklyn Center, Brooklyn Park, Champlin, Coon Rapids, Corcoran, Dayton, Fridley, Maple Grove, Osseo, Ramsey and Rogers.

The scope of the regional study includes three components: alternative water supply, enhanced recharge, and stormwater capture and reuse. Similar studies, including those that evaluate alternative drinking water sources, were conducted for other regions in the Twin Cities Metropolitan Area and are summarized in separate reports. The study incorporates many of the approaches to meet current and future municipal water demand identified in the 2015 Master Water Supply Plan (Metropolitan Council, 2015b), including surface water sources, groundwater sources, conservation, enhanced recharge, and stormwater reuse. Reclaimed wastewater was not a component of the study.

This study is a first look at diversifying water sources and enhancing bedrock aquifer recharge on a regional scale in this part of the Twin Cities Metropolitan Area. It is a desktop study, intended only to assess the potential of certain water supply alternatives, 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.

Water Supply

This study includes evaluation of available sources to meet future municipal drinking water demands. The analysis summarizes the potential effects of continued development of groundwater sources and water conservation on regional aquifer levels, as well as the availability of surface water sources to meet demands through 2040.

Two municipal groundwater use scenarios were analyzed, including the continued development of groundwater sources to meet demands, and a scenario that incorporates a 20 percent demand reduction in every community in the study area by 2040. Figures showing the projected effect on water levels in the Tunnel City-Wonewoc aquifer, the most widely used aquifer in the study area, and the Quaternary aquifer, which yields the most volume on an annual basis, were generated for each groundwater use scenario.

As the primary surface water source in the area, the Mississippi River was analyzed for its capacity to serve municipal water demands through the year 2040. In addition, the local geology was also evaluated to determine the potential for horizontal collector wells as an alternative surface water source.

Many factors will influence the development of water sources in the future, including the effect of projected water use on regional groundwater levels, source water quality, public acceptance and implementation challenges, and the degree to which any of the alternatives may have limited availability in the long-term.

Findings

- Population is expected to continue to grow, especially in the outer portions of the study area. Cities like Andover, Brooklyn Park, Corcoran, Dayton, Maple Grove, Ramsey and Rogers are projected to experience significant increases in population. More modest growth is expected in the more developed, inner-ring suburbs.
- Total municipal water demand in the study area is expected to increase by 50 percent by 2040.
- Municipal systems in the study area are served by groundwater. Wells draw from four main groundwater aquifers including the Mount Simon-Hinckley, the Tunnel City-Wonewoc, the Prairie du Chien-Jordan and the Quaternary, or water table aquifer. The water table aquifers typically provide the most volume, more than 40 percent in recent years.
- Groundwater modeling suggests that continued development of groundwater sources to meet projected demands is likely to cause declines in aquifer levels. Specifically, some concentrated areas in the study area could see greater than 30 feet of decline in the Tunnel City-Wonewoc aquifer by 2040. These trends, in addition to the existing restriction on the Mount Simon-Hinckley aquifer, may limit local groundwater resource availability in the future.
- Conserving water through reduced water losses and use efficiency can have a positive impact on existing resources. Under a scenario where future demands are reduced by 20 percent through conservation, modeling predicts less pronounced areas of decline in the Quaternary and Tunnel City-Wonewoc aquifers by 2040.
- The evaluation of the Mississippi River at two locations in the study area indicates viability of surface water supply to meet municipal demands through 2040, although low flow conditions during drought years could present supply challenges. The potential for collector wells near the Mississippi River is low based on a review of existing data. Ten

locations were identified where the geology might be suitable for a collector well; however further study and exploration of the geology at those sites would be needed to confirm these assessments.

Recommendations

- Municipalities should continue to monitor local groundwater levels and collaborate with neighboring communities and local and state agencies.
- Municipalities and agencies should identify and monitor areas where groundwater pumping may impact surface water features.
- Water conservation could reduce demands, lessening impact on existing sources.
- Should surface water be pursued as an alternative water source, daily fluctuations of the Mississippi River during peak demand periods should be studied further.
- If the Mississippi River is pursued as a potential municipal water supply source, the needs of other water uses and diversions, along with minimum flows needed to maintain water quality, navigation, and riparian habitat should be considered.
- If surface water sources are considered in the future, additional consideration should be given to environmental, regulatory and water quality requirements for diversions or intakes. Maintaining secondary supplies to accommodate daily fluctuations in flow and to meet certain demands during critical drought years is an important surface water supply consideration. However, water quality issues associated with blending surface water and groundwater in conjunctive use systems is an important implementation consideration. Establishing coordination with river stakeholders would be an advisable component in pursuing a surface water supply, as would a refined analysis incorporating water uses in the larger watershed and examination of specific location and nature of a potential water supply diversion.
- Viability of a collector well should be determined through site-specific test drilling and aquifer testing.

Enhanced Recharge

This study included a regional assessment of enhanced groundwater recharge in the Northwest Metro Study 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 could potentially recharge drinking water aquifers based on specific hydrogeologic, land use, drinking water protection, and other specific criteria. Both unconsolidated formations and permeable bedrock formations were evaluated since the groundwater used in the Northwest Metro Study Area for municipal supply comes from each of 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. Evaluation 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 specific 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.

The results of the initial planning-level screening are presented below. The potential for an area to be well suited for groundwater recharge (good, limited or poor) was based on combining all of the specific study criteria.

Findings

- Only 65 acres of the study area were classified as having good potential for enhanced groundwater recharge.
- An additional 27,000 acres were classified as having limited potential for groundwater recharge. A more detailed study of local conditions may result in a more favorable assessment.
- Most areas classified as having either good or limited potential are in the less developed communities of Corcoran, Dayton, and Rogers.
- Additional opportunities for enhanced recharge, though of lesser total area, may also exist in Andover, Brooklyn Park, Maple Grove, and Ramsey.
- Much of the eastern and southeastern portions of the study area are classified as having poor potential for enhanced groundwater recharge, primarily due to existing developed land.
- Low hydraulic conductivity limits enhanced recharge potential in the southwestern area.
- The potential for enhanced recharge in areas that are projected to experience significant aquifer decline with continued groundwater pumping is limited. There are only a few areas in Anoka, Brooklyn Park, and Rogers classified as having good or limited potential for enhanced recharge that overlap the areas of greatest projected aquifer decline. This is primarily due to a lack of undeveloped land in the decline areas.
- 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, municipalities and local watershed management districts should be consulted for the latest regulations or 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 Northwest 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.

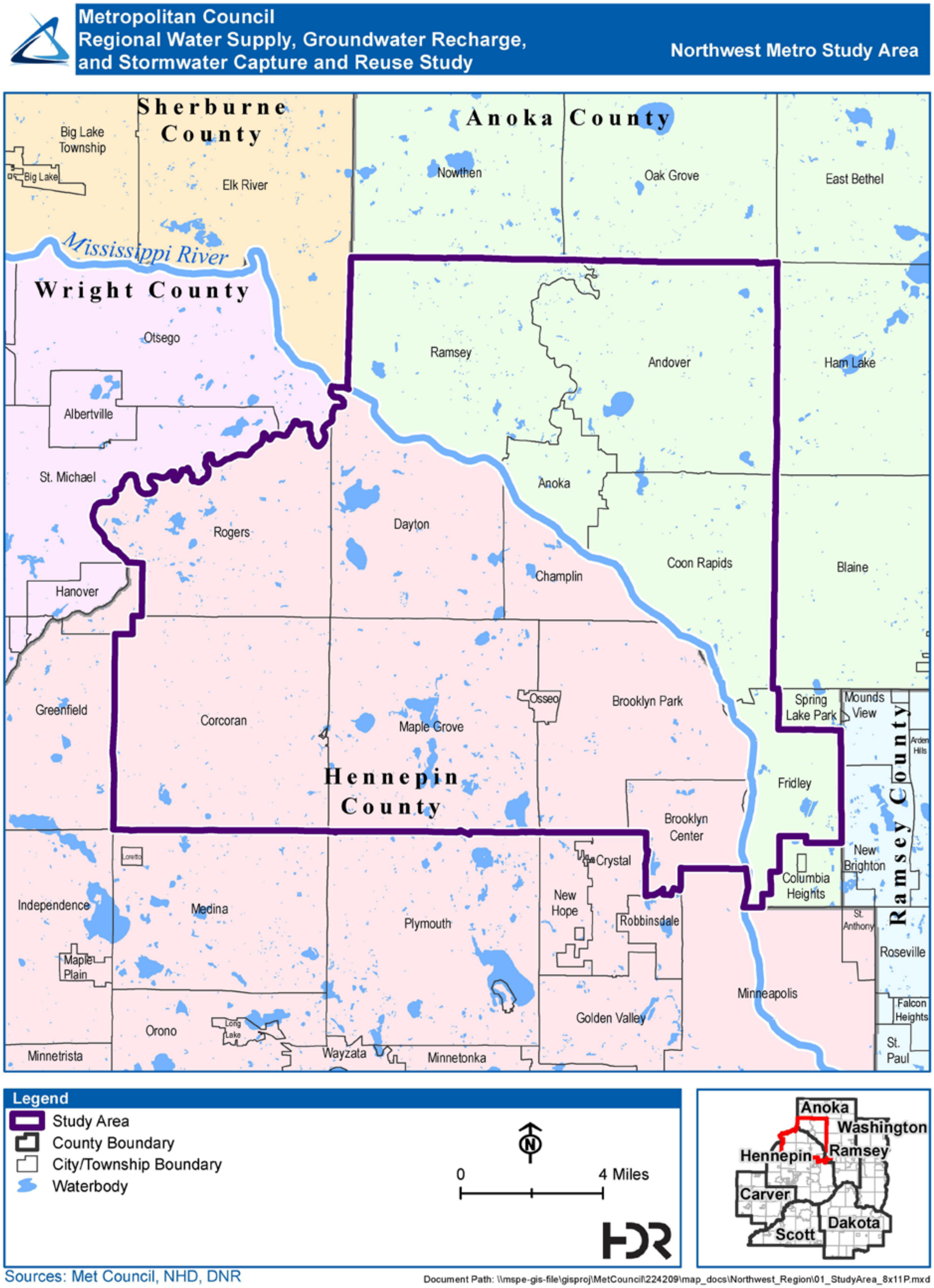
Findings

- The average annual non-winter runoff for the entire study area was calculated to be 35,800 million gallons (MG). Total groundwater use for 62 high-volume, non-potable uses identified in the study area totaled 745 MG, or 2.1% of non-winter runoff in 2010.
- Of the 62 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 23 of the sites classified as having good or limited potential for enhanced groundwater recharge based on study criteria amounts to approximately 3,900 MG per year, or 10.4 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.


Metropolitan Council
Regional Water Supply, Groundwater Recharge, and Stormwater Capture and Reuse Study
Northwest Metro Study Area
Sherburne County
Anoka County
Wright County
Hennepin County
Ramsey County
Mississippi River
Big Lake Township
Big Lake
Elk River
Nowthen
Oak Grove
East Bethel
Otsego
Ramsey
Andover
Ham Lake
Albertville
St. Michael
Anoka
Rogers
Dayton
Champlin
Coon Rapids
Blaine
Hanover
Greenfield
Corcoran
Maple Grove
Osseo
Brooklyn Park
Spring Lake Park
Mounds View
Arden Hills
Fridley
Brooklyn Center
New Brighton
Columbia Heights
Crystal
New Hope
Robbinsdale
St. Anthony
Roseville
Loretto
Independence
Medina
Plymouth
Maple Plain
Golden Valley
Minneapolis
Falcon Heights
Orono
Long Lake
Wayzata
Minnetonka
Minnetrista
St. Paul
Legend
Study Area
County Boundary
City/Township Boundary
Waterbody
0
4 Miles
N
HDR
Anoka
Washington
Hennepin
Ramsey
Carver
Scott
Dakota
Sources: Met Council, NHD, DNR
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Introduction

The Metropolitan Council (Council) contracted with HDR to study water supply and source alternatives in various regions of the seven-county Twin Cities Metropolitan Area. This Regional Water Supply, Groundwater Recharge, and Stormwater Reuse Study report summarizes the study of the Northwest Study Area (study area). The scope of the study includes a desktop-level assessment of municipal water supply sources, 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 (Figure 1) covers portions of Anoka and Hennepin Counties, and includes the communities of Anoka, Andover, Brooklyn Center, Brooklyn Park, Champlin, Coon Rapids, Corcoran, Dayton, Fridley, Maple Grove, Osseo, Ramsey and Rogers.

This approach to water supply evaluation is being applied to other sub-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 is being applied to other parts of the region. Detailed results of the analyses for other sub-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).

The focus on the Northwest Metro Study Area resulted from the Council's work with sub-regional groundwater work groups. Several of these ad-hoc workgroups have been formed around the Metro area to address local water supply challenges and ensure sustainability of water supplies. The Council conducted this study to better understand projected water supply challenges, and explore potential to diversify water sources, incorporate enhanced recharge, or implement stormwater reuse alternatives in this part of the Metropolitan area. The results of the study can help the Council and the participating communities in the sub-region better understand the potential to either augment or reduce demands on existing groundwater sources in the future.

Water Supply

This study of the Northwest Metro sub-region includes evaluation of available sources to meet future municipal drinking water demands. The analysis summarizes the potential effects of continued development of groundwater sources and water conservation on regional aquifer levels, as well as the availability of surface water sources to meet demands through 2040.

Two municipal groundwater use scenarios were analyzed, including the continued development of groundwater sources to meet demands and a scenario that incorporates a 20 percent demand reduction in every community in the study area by 2040. Figures showing the projected effect on water levels in the Tunnel City-Wonewoc aquifer, the most widely used aquifer in the study area, and the Quaternary aquifer, which yields the most volume on an annual basis, were generated for each groundwater use scenario.

As the primary surface water source in the area, the Mississippi River was analyzed for its capacity to serve municipal water demands through the year 2040. A review of the geology for siting potential horizontal collector wells (also referred to as Ranney™ wells, radial collector wells, and riverbank filtration wells) near the Mississippi River was also included in the analysis. Collector wells draw from both groundwater and surface water sources and are often used as an alternative to direct surface water intake.

Demand Projections

Average day and maximum day water demand projections for 2040 for the study area were developed for the analysis. Table 1 shows population, average day demands, and peak day demands for 2010 (the base year for both data at the time the study was initiated) and projections for 2040. The 2040 water demand projections are used in the analysis of available surface water, and in the analysis of the groundwater use scenarios.

Met Council provided average day demand projections for 2040 that were developed as part of the regional 2015 Master Water Supply Plan (Metropolitan Council, 2015b). Average day demand projections were based on historical per capita water use factors for each community in the study area multiplied by 2040 population forecasts from Thrive MSP 2040 (published September 11, 2013). Two alternate 2040 demand scenarios which increased or decreased the average projection by 20 percent were also presented in the Master Water Supply Plan. Table 1 lists the reduced demand scenario which was calculated by multiplying a reduced average day demand projection by the historic peaking factor.

Peak day demand projections for 2040 were based on average day projections, and applied maximum day to average day peaking factors. Peaking factors were obtained from data published in the 2010 Master Water Supply Plan (Metropolitan Council, 2010) for each community in the study area. Peaking factors in the study area range from 2.5 to 3.8. A composite peaking factor of 2.9 was calculated for the study area.

Population in the study area is expected to increase to more than 466,000 by 2040, or an increase of nearly 40 percent over 2010. Average demands are projected to increase by approximately 52 percent in the same period, from 43.4 MGD to more than 66 MGD. Peak day demands are also projected to increase from 122 MGD to more than 183 MGD by 2040.

Table 1. Northwest Metro Study Area Population and Water Demand Projections Summary

City	2010 Pop. Served [1]	2010 Average Day Demand (MGD) [2]	2010 Peak Day Demand (MGD) [3]	2040 Pop. Served [4]	2040 Average Day Demand (MGD) [4]	2040 Peak Day Demand (MGD) [3]	2040 Average Day Demand [-20%] [5] (MGD)	2040 Peak Day Demand [-20%] [5] (MGD)
Andover	18,463	2.52	9.5	29,765	4.57	17.32	3.7	13.9
Anoka	17,142	2.38	6.9	21,200	3.14	9.04	2.5	7.2
Brooklyn Center	30,104	3.19	7.5	35,400	4.07	9.52	3.3	7.6
Brooklyn Park	75,281	8.60	23.0	97,400	12.42	33.16	9.9	26.5
Champlin	23,089	2.48	7.0	24,000	2.86	8.01	2.3	6.4
Coon Rapids	61,476	7.88	26.8	72,100	9.65	32.81	7.7	26.2
Corcoran[6]								
Dayton	841	0.07	0.2	6,570	0.53	1.34	0.4	1.1
Fridley	26,882	4.43	11.3	30,474	4.92	12.50	3.9	10.0
Maple Grove	60,299	8.76	21.7	104,170	16.90	41.91	13.5	33.5
Osseo[6]								
Ramsey	11,190	1.72	4.3	22,222	3.63	9.08	2.9	7.3
Rogers	8,524	1.40	3.6	22,727	3.52	9.15	2.8	7.3
Total Study Area	333,291	43.4	121.7	466,028	66.21	183.8	53.0	147.1

1 *Population served derived from 2010 US Census data, Metropolitan Council, and data provided by cities in the study area.*
2 *From MnDNR State Water Use Database System (SWUDS) for the year 2010, as published on MnDNR website.*
3 *Peaking factors were derived from data in the 2010 Master Water Supply Plan: Andover (3.79), Anoka (2.88), Brooklyn Center (2.34), Brooklyn Park (2.67), Champlin (2.8), Coon Rapids (3.4), Corcoran (served by Maple Grove), Dayton (2.53), Fridley (2.54), Maple Grove (2.48), Osseo (served by Maple Grove), Ramsey (2.5), Rogers (2.6).*
4 *2040 population served and average day demand data were taken from the 2015 Master Water Supply Plan. 2040 average day demand calculated by multiplying average total per capita demand between 2003 and 2012 times 2040 population served.*
5 *[-20%] represents a water conservation scenario Peak demands were calculated using a reduced average day demand multiplied by the historic peaking factor.*
6 *Corcoran and Osseo are served by Maple Grove.*

Existing Municipal Water Supply Systems

Drinking water demands in the study area are currently served by groundwater. Wells serving municipal systems are completed in the region's bedrock aquifers, including the Tunnel City-Wonewoc (formerly Franconia-Ironton-Galesville), the Prairie du Chien-Jordan, and the Mt. Simon-Hinckley aquifers. The Quaternary sediments, or water table aquifers, also provides significant supply to the drinking water systems in the study area. There are also several multi-aquifer wells in the study area which are open to more than one of the formations. While the area has a number of wells in the Mt. Simon/Hinckley formation, use from this aquifer is restricted by law in Minnesota (Minnesota Statutes 103G.271). Chart 1 shows the number of wells by aquifer in the study area. Chart 2 shows the average pumping share from each aquifer based on recent pumping records.

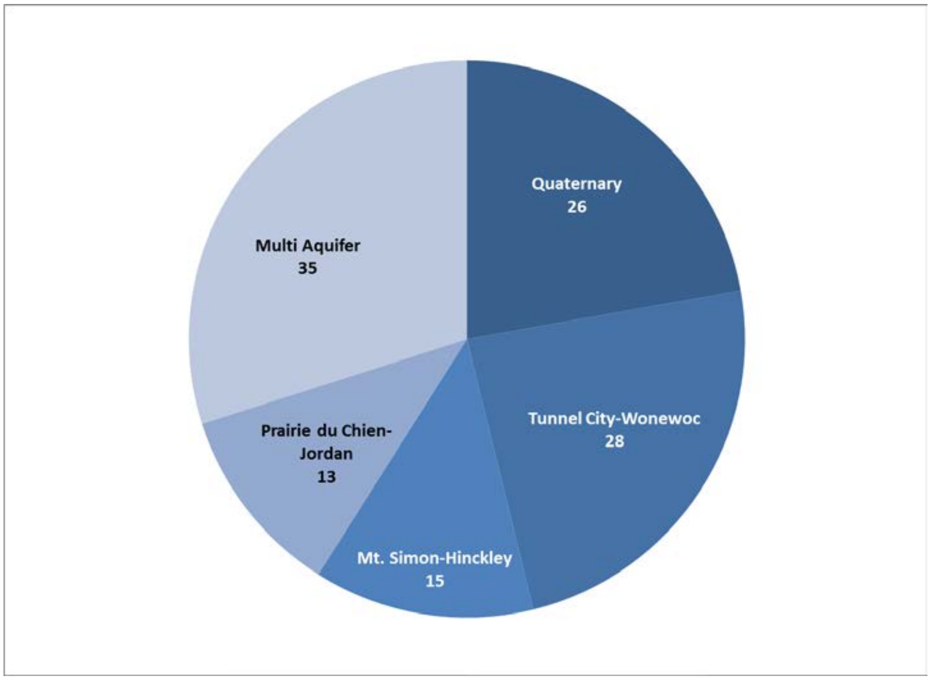


Chart 1. Number of Municipal Wells in Northwest Metro Study Area by Aquifer

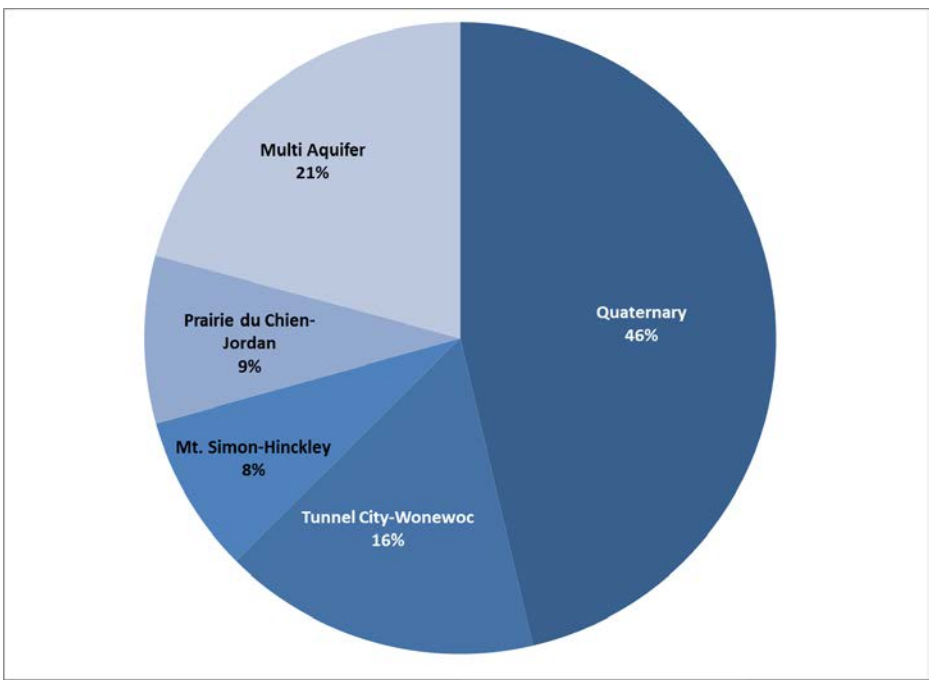


Chart 2. Average Supply in the Northwest Metro Study Area by Aquifer

While the Tunnel City-Wonewoc formation is the source for the highest number of municipal wells, the water table aquifers typically provide the most volume, more than 40 percent of total water supplied based on recent pumping records. Table 2 provides information on the water sources for each municipality, and if water treatment is done at centralized treatment plant or plants.

Table 2. Northwest Metro Study Area Water System Summary

City	No. of Wells [1]	Source Aquifer(s) [2, 3]	Centralized Treatment
Andover	8	QUAT, MTSH, TCW	Yes
Anoka	8	MTSH, TCW, MULTI	Yes
Brooklyn Center	8	PDCJ	Yes
Brooklyn Park	19	MTSH, PDCJ, QUAT, TCW, MULTI	Yes
Champlin	7	MTSH, TCW, MULTI	Yes
Coon Rapids	24	MTSH, TCW, QUAT, MULTI	Yes
Corcoran [4]	-	-	-
Dayton	2	TCW	No
Fridley	13	MTSH, PDCJ, QUAT, MULTI	Yes
Maple Grove	12	QUAT, MTSH, MULTI	Yes
Osseo [4]	-	-	-
Ramsey	8	TCW	No
Rogers	6	TCW	No

Notes:

1 *The number of wells was taken from the 2015 Master Water Supply Plan*

2 *QUAT= Quaternary, TCW = Tunnel City-Wonewoc, MTSH = Mt. Simon-Hinckley, PDCJ = Prairie du Chien-Jordan, MULTI = multi-aquifer (indicating that the well is open to more than one formation)*

3 *The number of multi aquifer wells by City: Anoka = 2, Brooklyn Park = 2, Champlin = 2, Coon Rapids = 12, Fridley = 2, Maple Grove = 1.*

4 *The cities of Corcoran and Osseo are served by the City of Maple Grove.*

Groundwater Source Projections

Two drinking water supply scenarios were developed to assess the continued development of groundwater sources to meet projected demands. The first scenario assessed the impact to regional aquifers assuming that water demands in the study area through 2040 would be met by increasing pumping from existing groundwater sources. This scenario assumes that the same mix of groundwater sources would be used to meet future demands in each community. The second scenario assessed the impact to the regional aquifers assuming that 2040 groundwater demands could be reduced by 20 percent as a result of conservation efforts. Groundwater use scenarios are summarized in Table 3.

Table 3. Groundwater Use Scenarios

Scenario	Description
Continue 100% Water Supply from Groundwater Sources at Current Total Per Capita Demand	All 13 communities would continue to rely upon groundwater as their source. 2040 Average Day Demand = 66.2 MGD
Continue 100% Water Supply from Groundwater Sources with Current Total per Capita Demand reduced by 20% through Conservation	All 13 communities would continue to rely upon groundwater as their source, but reduce total groundwater demand by 20% by 2040. 2040 Average Day Demand = 53.0 MGD

The continued development of groundwater sources to meet future water demands in the study area is projected to affect aquifer levels. The effects of each scenario's modified pumping conditions on aquifer levels were modeled by Met Council using the Metro Model 3 regional groundwater model (Metropolitan Council, 2015b). Figure 2, Figure 3, and Figure 4 show the model-projected decline and rebound from 2010 pumping conditions in the regional aquifers assuming that groundwater sources would continue to serve 100 percent of the municipal demands in the study area through 2040. Figure 2 shows the decline and rebound in the Quaternary aquifer; Figure 3 shows the decline and rebound in the Prairie du Chien aquifer; and Figure 4 shows the decline and rebound in the Tunnel City-Wonewoc aquifer. Figure 5, Figure 6 and Figure 7 show the model-projected decline and rebound in the aquifers from 2010 pumping conditions under the conservation scenario, where it is assumed that municipal demands could be reduced by 20 percent from the 2040 projection. This assessment illustrates the potential effect that conservation could have in terms of water supply management. Conserving groundwater would lessen the impact on the regional aquifers and could, for example, free up supply to serve growing populations and offset the capital expenses associated with additional wells and treatment capacity, while ensuring the long-term viability of the aquifer for future use.

An analysis of hydrogeologic conditions conducted by Met Council in 2010 found that approximately half of the surface water features in the Metropolitan Area are connected to the regional groundwater flow systems (Metropolitan Council, 2010). These surface water features, which include rivers, lakes, streams and wetlands that are within the study area are shown in Figure 8. While the nature of these interactions varies throughout the region, there is a potential that excessive groundwater pumping may impact surface water features. In addition, appropriation of groundwater may be limited if adverse impacts to surface water features would occur. For planning purposes, groundwater users should be aware of potential groundwater – surface water interactions, and anticipate that further monitoring and assessment may be needed to assess local conditions.

Alternative Water Source Evaluation

The analysis of water supplies for the study area included assessment of other water sources to better understand their viability as alternatives to groundwater. An analysis of the Mississippi River as a surface water source and a preliminary assessment of the potential for collector wells installed near the Mississippi River to partially satisfy water demands in the study area were conducted.

Surface Water Source Evaluation

The Mississippi River was analyzed for its capacity to serve recent (2010) and projected (2040) study area demands. Two locations were reviewed (Figure 9). The first location (*Location A - Mississippi River near Ramsey*) is at the Mississippi River below the confluence of the Crow River, in the upstream part of the study area. The second location (*Location B - Mississippi River near Anoka*) is further downstream near the confluence of the Rum River and the Mississippi River. These locations were selected because these are USGS stream gaging stations, and would provide a representative assessment of flow just upstream and just downstream of the study area. They are not recommendations for diversion points. Proper assessment of surface water diversion or intake location would require an in-depth study of water quality. The availability of surface water supply was evaluated by comparing historic river flows (or estimated flows, where historical data were unavailable) to projected 2040 water demands to identify periods when surface water sources could have limited capacity to meet demands in periods of low flows. Minimum stream flow requirements at each location were also considered.

Annual and Monthly Water Demand Evaluation

To be able to compare seasonal surface water availability with water demands, annual water demands for the study area were converted into averages for each month of the year. Monthly historical groundwater pumping data for the communities of the Northwest Metro study area (with the exception of Corcoran and Osseo, which are supplied by Maple Grove) were compiled for calendar years 2005 to 2013 to create a composite representation of typical monthly demand patterns for the study area. The average pumping volume for each month was converted into a percentage of the average annual total volume. A typical winter month represents approximately 5% to 6% of the total annual demands. The peak pumping month is July, when about 16% of the annual total is withdrawn. The typical monthly demand pattern is shown in Chart 3.

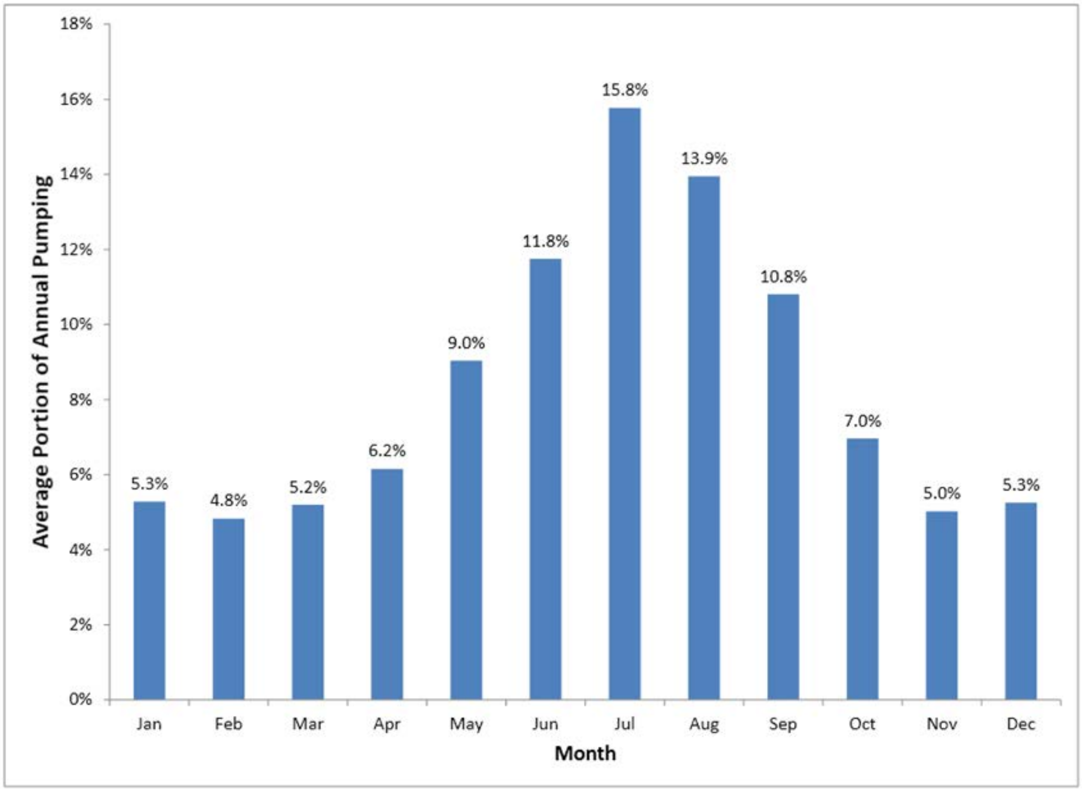


Chart 3. Monthly Water Demand Pattern

The derived demand pattern was used to estimate monthly demands for 2010 and project monthly demands for 2040. Table 4 provides the monthly distribution of demands as a percentage of annual demand, and estimates monthly demands for the study area for 2010 and 2040. Winter demands averaged 828 million gallons per month (42 cubic feet per second (cfs)) in 2010. Peak demands of 2.5 billion gallons per month (123 cfs) were estimated for July. For 2040, winter demands increased to about 1.1 billion gallons per month (57 cfs) and peak summertime use increased to 3.4 billion gallons per month (171 cfs) in July.

Table 4. Average Monthly and Total Annual Demands for the Northwest Metro Study Area

Time	Demand [Percent of Annual Total]	Year 2010 Demand [Million gallons/month] (cfs)	Year 2040 Demand [Million gallons/month] (cfs)
January	5.3%	855 (43 cfs)	1,145 (57 cfs)
February	4.8%	781 (43 cfs)	1,046 (58 cfs)
March	5.2%	842 (42 cfs)	1,127 (56 cfs)
April	6.2%	996 (51 cfs)	1,334 (69 cfs)
May	9.0%	1,462 (73 cfs)	1,959 (98 cfs)
June	11.8%	1,902 (98 cfs)	2,548 (131 cfs)
July	15.8%	2,552 (127 cfs)	3,418 (171 cfs)
August	13.9%	2,258 (113 cfs)	3,024 (151 cfs)
September	10.8%	1,749 (90 cfs)	2,342 (121 cfs)
October	7.0%	1,127 (56 cfs)	1,510 (75 cfs)
November	5.0%	813 (42 cfs)	1,089 (56 cfs)
December	5.3%	850 (42 cfs)	1,139 (57 cfs)
Annual	**100%**	**16,187 MG** (44.3 MGD ave.)	**21,680 MG** (59.3 MGD ave.)

Notes:

Amounts may not sum to 100% due to rounding.

The Minneapolis and St. Paul municipal water supply diversions are located near Fridley downstream of the study area. The current and projected demands for these two existing diversions were subtracted from the total available surface water for the northwest study area. Table 5 provides the demands for the combined Minneapolis and St. Paul diversions. The annual diversions assume surface water supply for both systems, and were expressed as monthly demands using the same demand pattern derived for the northwest study area.

Table 5. Average Monthly and Total Annual Demands for the Minneapolis and St. Paul Diversions near Fridley

Time	Demand [Percent of Annual Total]	Year 2010 Demand [Million gallons] (cfs)	Year 2040 Demand [Million gallons] (cfs)
January	5.3%	1,828 (91 cfs)	2,298 (115 cfs)
February	4.8%	1,671 (92 cfs)	2,101 (116 cfs)
March	5.2%	1,800 (90 cfs)	2,264 (113 cfs)
April	6.2%	2,130 (110 cfs)	2,678 (138 cfs)
May	9.0%	3,127 (156 cfs)	3,933 (196 cfs)
June	11.8%	4,068 (210 cfs)	5,116 (264 cfs)
July	15.8%	5,458 (272 cfs)	6,864 (343 cfs)
August	13.9%	4,829 (241 cfs)	6,072 (303 cfs)
September	10.8%	3,740 (193 cfs)	4,703 (243 cfs)
October	7.0%	2,410 (120 cfs)	3,031 (151 cfs)
November	5.0%	1,738 (90 cfs)	2,186 (113 cfs)
December	5.3%	1,818 (91 cfs)	2,287 (114 cfs)
Annual	**100%**	**34,616 MG** (= 94.8 MGD)	**43,532 MG** (= 119.2 MGD)

Notes:

Amounts may not sum to 100% due to rounding.

Mississippi River near Ramsey Surface Water Supply Analysis

An analysis of a surface water supply from the Mississippi River near Ramsey was completed by taking the estimated monthly average historic flows at the Mississippi River near the Elk River gage, adding the flows from the Crow River at Rockford gage and comparing the total flow to the recent 2010 and projected 2040 average monthly demands for the study area. The evaluation considered the potential for surface water sources to meet demands on an average monthly basis.

Two minimum flow scenarios were considered. The first scenario assumed that the full river flow less the volume required to meet the downstream demands for the Minneapolis and St. Paul systems would be available to meet northwest study area demands. The second scenario assumed Q_{90}[1] flow conditions less the volume required to meet the Minneapolis and St. Paul demands would be available. The second scenario would maintain a minimum amount of flow in the river. Under the first scenario, where full river flow would be available for use, there were no calculated shortages. For the second scenario, more than 50 out of the 112 years in the historic period of record show at least one month when either 2010 or 2040 demands exceed the available supply. Table 6 (2010 demands) and Table 7 (2040 demands) show annual and maximum monthly shortages in meeting 2010 and 2040 demands for the study area that would have occurred in select drought years. In most cases, the month of the maximum shortage occurs in the summer.

Table 6. Select Drought Shortage Statistics at Mississippi River near Ramsey (2010 Demands, Q90 Minimum Flows plus Minneapolis/St. Paul Diversion Flows)

Select Drought Year	Annual Shortage [Million Gallons]	Maximum Monthly Shortage [Million Gallons]	Month of Maximum Shortage
1934	13,729	2,552	July
1988	6,712	2,552	July
1959	4,735	2,258	August
1923	2,486	855	January
1911	1,636	855	January

Note: Selection of drought years based on the Palmer Modified Drought Index which classifies drought severity from mild to extreme. Select years were classified as severe.

Table 7. Select Drought Shortage Statistics at Mississippi River near Ramsey (Year 2040 Demands, Q90 Minimum Flows plus Minneapolis/St. Paul Diversion Flows)

Select Drought Year	Annual Shortage [Million Gallons]	Maximum Monthly Shortage [Million Gallons]	Month of Maximum Shortage
1934	18,388	3,418	July
1988	9,772	3,418	July
1959	6,342	3,024	August
1923	3,330	1,145	January
1911	2,191	1,145	January

[1] Minnesota water law will limit or prevent consumptive water uses from surface water sources based on a set minimum in-stream flow. The minimum in-stream flow is intended to protect river and habitat uses including fisheries, riparian habitat, navigation, and recreation. The minimum flows may be determined from a detailed study, but most often are based on a statistic of flows passing a gage site 90% of the time (also known as Q_{90}). By definition, the Q_{90} minimum flow target means at least 10% of the time there will be potential restrictions on water allocations.

Mississippi River near Anoka Surface Water Supply Shortage Analysis

An analysis of the Mississippi River near Anoka as a potential surface water source for the study area was completed by comparing the estimated monthly average historic flows at the Mississippi River near the Anoka gage site with 2010 and 2040 monthly average demands for the study area, taking into account the Minneapolis and St. Paul municipal supply diversions. The same full flow and Q_{90} minimum flow scenarios were evaluated. Under the minimum flow scenario there are no calculated shortages. When the Q_{90} flow plus the Minneapolis/St. Paul diversions are used as the minimum flow scenario, 30 years (2010 demands) and 33 years (2040 demands) out of the 112 years in the historic period of record show at least one month when demands exceed the available supply. Table 8 and Table 9 show annual and maximum monthly shortages for select drought years for 2010 and 2040, respectively. The critical drought year of 1934 has an 85% annual shortage of the study area demands under either 2010 or 2040 demands. The 1988 drought year shows an annual shortage of 28% to 35% for the 2010 and 2040 demands, respectively. Other representative years for other drought events have smaller annual shortages. In three out of the five drought years,, the month of the maximum shortage occurs in summer.

Table 8. Select Drought Shortage Statistics at Mississippi River near Anoka (Current Demands, Q90 Minimum Flows plus Minneapolis/St. Paul diversions)

Select Drought Year	Annual Shortage [Million Gallons]	Maximum Monthly Shortage [Million Gallons]	Month of Maximum Shortage
1934	13,729	2,552	July
1988	4,454	2,552	July
1959	2,946	855	August
1923	1,636	855	January
1911	0	0	n/a

Table 9. Select Drought Shortage Statistics at Mississippi River near Anoka (Year 2040 Demands, Q90 Minimum Flows plus Minneapolis/St. Paul diversions)

Select Drought Year	Annual Shortage [Million Gallons]	Maximum Monthly Shortage [Million Gallons]	Month of Maximum Shortage
1934	18,388	3,418	July
1988	7,565	3,418	July
1959	5,796	2,478	August
1923	2,191	1,145	January
1911	0	0	n/a

Collector Well Source Evaluation

The study for the Northwest Metro Study Area includes a preliminary evaluation of the potential for collector wells near the Mississippi River. The evaluation assumed that the collector wells, if feasible, could be used as an alternative to a direct river intake on the Mississippi River as part of a groundwater under the influence of surface water source scenario.

The collector well source evaluation included an assessment of local geology to identify areas that could have suitable aquifer permeability and thickness for collector wells. A comparison of the advantages and disadvantages of collector wells versus traditional vertical wells and direct surface intakes is provided. Considerations for the implementation of collector wells and estimated costs were also developed.

Collector Well Overview

Collector wells, also called horizontal collector wells, function similarly to vertical wells but have the potential to yield greater quantities of water. A collector well generally consists of a central concrete caisson constructed from the ground surface to a suitable depth in the aquifer, with horizontal well screens that project radially from the caisson into the aquifer. Water is drawn through the horizontal well screens and pumped from the central caisson. A schematic of a typical collector well configuration is shown in Figure 10.

Collector wells are designed to infiltrate water from the nearby surface water source and use the streambed and riverbank deposits to filter constituents such as microorganisms and suspended solids from the source water. Therefore, proximity to a surface water source that can recharge the aquifer, such as a major river, is a primary requirement for collector wells. Yield from a collector well will typically be derived from surface water and groundwater sources. Factors that influence the yield of a collector well include the permeability of the riverbed, the hydraulic conductivity of the aquifer, and the amount of available drawdown in the well (i.e., distance from static water level to top of well screens). Contributions from surface water and groundwater sources will vary depending on a number of factors, but can typically range from 50 to 90 percent surface water and 10 to 50 percent groundwater. Supply from collector wells is likely to be considered groundwater under the direct influence of surface water, which requires filtration and disinfection treatment processes to address potential microbial contamination.

Geology Review

Existing geologic data was reviewed to assess the potential development of collector wells in the study area. Areas along both sides of the Mississippi River were included in the review. Background data and a detailed summary of the review are included in Appendix A1.

Available boring logs indicate that the areas adjacent to the Mississippi River in the study area are underlain by a variety of materials ranging from clayey till to coarse sand and gravel. Depth to bedrock is typically greater than 50 feet. The locations of well logs reviewed for this review are shown on Figure 11.

Typically, sites that are suitable for collector wells will contain significant thicknesses of sand or gravel material with limited clay or silt content. Bedrock valleys containing deep sequences of unconsolidated sediments were targeted for review, followed by a review of the entire length of the Mississippi River within the study area. Areas shown to have 80 feet or more of unconsolidated material (primarily sand and gravel), with clay and silt thickness totaling no more than ten feet, were considered to be potentially suitable for collector wells.

The geology review revealed that, in general, few areas along the Mississippi River in the study area have suitable geology for collector wells. Well logs that show potentially suitable geology are listed in Table 10 below.

Table 10. Potentially Suitable Locations for Collector Wells

Unique Well No.	County	City	Depth Drilled (ft)	Depth to Bedrock (ft)	Sand and Gravel Bottom Depth (ft)
155281	Anoka	Ramsey	248	150	130
162868	Anoka	Ramsey	98	>98	>98
169236	Anoka	Ramsey	82	>82	>82
480414	Anoka	Ramsey	220	135	135
676424	Anoka	Ramsey	170	119	119
740949	Anoka	Ramsey	151	151	151
126482	Hennepin	Dayton	156	145	95
148118	Hennepin	Dayton	137	125	95
520054	Hennepin	Dayton	111	>111	>111
533918	Hennepin	Dayton	164	140	140

Notes:

All locations listed have less than ten feet of clay or silt noted as the primary or secondary lithology, and depth to bedrock is at least 80 feet.

The ten locations listed in Table 10 show an appreciable thickness of sand and gravel with limited amounts of clay and silt. The sand and gravel represents a potential target formation for a collector well, however the study area has a significant degree of geologic heterogeneity that could negatively impact well yield. Horizontally, many of the potentially suitable locations are adjacent to borings that are dominated by fine-grained material, resulting in apparent “pockets” of sand and gravel with uncertain extent. These pockets could limit the constructed length of horizontal well screens, and introduce uncertainty in the degree of hydraulic connection to the river. Vertically, the clay lenses noted within the sand and gravel at some locations also could potentially limit the rate of recharge to the collector well screens from the river. These horizontal and vertical limitations in the geology would result in an increased ratio of groundwater-to-surface water withdrawal, and the well yield would not be as high as it would be in a situation with a more direct connection to the river. While the presence of fine-grained material is not ideal for collector well yield, some fine material is beneficial for natural filtration, and significant amounts of water could still be withdrawn from a properly designed and constructed well. Viability of a collector well would need to be determined through site-specific test drilling and aquifer testing.

Costs

Concept-level costs were developed to cover a range of collector well sizes. Costs for construction will vary depending on the local geology, expected well yield, and distance from the water treatment plant. Costs shown in Table 11 represent estimated costs for collector well construction. Water treatment costs were not included. More detailed information on cost development is included in the Appendix.

Table 11. Concept-Level Costs for Various Collector Wells Sizes

Well Yield	Estimated Cost
5 MGD	$11,400,000
10 MGD	$13,100,000
15 MGD	$15,200,000
20 MGD	$17,000,000

Notes:

Costs include collector well and pumphouse, construction and construction of an estimated 5 miles of transmission main to convey water supply; Costs also include construction contingency (30%), and engineering, permitting, and administrative costs (20%). Costs do not include water treatment, land acquisition or landscaping improvements other than site restoration.

Water Supply Study Summary

The purpose and findings of this regional study are summarized in this section along with recommendations to monitor and plan for reliable water supplies in the region.

Study Purpose

The purpose of the water supply study was to perform a broad assessment of available water sources to meet projected demands in the study area. The sources include the continued use of groundwater, the Mississippi River as a surface water source, and the potential to locate collector wells along the Mississippi River. Detailed evaluation of infrastructure needed to meet future water demands scenarios was not included in the evaluation. While there is no immediate need to develop alternate water sources, an understanding of the limitations of existing sources and the potential capacity of alternative sources can help cities plan for and adapt to changing conditions in the future.

Findings

- Population is expected to continue to grow, especially in the outer portions of the study area. Cities like Andover, Brooklyn Park, Corcoran, Dayton Maple, Grove, Ramsey and Rogers are projected to experience significant increases in population. More modest growth is expected in the more developed, inner-ring suburbs.
- Total municipal water demand in the study area is expected to increase by 50 percent by 2040.
- Municipal systems in the study area are served by groundwater. Wells draw from four main groundwater aquifers including the Mount Simon-Hinckley, the Tunnel City-Wonewoc, the Prairie du Chien-Jordan and the Quaternary, or water table aquifer. The water table aquifers typically provide the most volume, more than 40 percent in recent years.
- Groundwater modeling suggests that continued development of groundwater sources to meet projected demands is likely to cause declines in aquifer levels. Specifically, some

concentrated areas in the study area could see greater than 30 feet of decline in the Tunnel City-Wonewoc aquifer by 2040. These trends, in addition to the existing restriction on the Mount Simon-Hinckley aquifer, may limit local groundwater resource availability in the future.

- Conserving water through reduced water losses and use efficiency can have a positive impact on existing resources. Under a scenario where future demands are reduced by 20 percent through conservation, modeling predicts less pronounced areas of decline in the Quaternary and Tunnel City-Wonewoc aquifers by 2040.
- The evaluation of the Mississippi River at two locations in the study area indicate viability of surface water supply to meet total municipal demands in the study area through 2040, although low flow conditions during drought years could present supply challenges. This underscores the importance of supply diversification.
- The potential for collector wells near the Mississippi River is low based on a review of existing data. Ten locations were identified where the geology might be suitable for a collector well; however further study and exploration of the geology at those sites would be needed to confirm these assessments.

Recommendations

- Municipalities should continue to monitor local groundwater levels and collaborate with neighboring communities and local and state agencies.
- Municipalities and agencies should identify and monitor areas where groundwater pumping may impact surface water features.
- Water conservation could reduce demands, lessening impact on existing sources.
- Should surface water be pursued as an alternative water source, daily fluctuations of the Mississippi River during peak demand periods should be studied further.
- If the Mississippi River is pursued as a potential municipal water supply source, the needs of other water uses and diversions, along with minimum flows needed to maintain water quality, navigation, and riparian habitat should be considered.
- If surface water sources are considered in the future, additional consideration should be given to environmental, regulatory and water quality requirements for diversions or intakes.
- Maintaining secondary supplies to accommodate daily fluctuations in flow and to meet certain demands during critical drought years is an important surface water supply consideration. However, water quality issues associated with blending surface water and groundwater in conjunctive use systems is an important implementation consideration. Establishing coordination with river stakeholders would be an advisable component in pursuing a surface water supply, as would a refined analysis incorporating water uses in the larger watershed and examination of specific location and nature of a potential water supply diversion.
- Viability of a collector well should be determined through site-specific test drilling and aquifer testing.

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 could potentially recharge either water table or bedrock drinking water aquifers. The analysis was completed by compiling and analyzing existing surface and subsurface data and comparing it to a set of criteria. Equal emphasis was given to recharge of unconsolidated formations and permeable bedrock formations as the groundwater used in the Northwest Metro study area for municipal supply comes from each of 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.

General concepts related to enhanced recharge, study methodology and results, and implementation of groundwater recharge projects are discussed in the following sections. Suggestions for data refinements that would facilitate more detailed analysis of location-specific recharge opportunities within the study area are provided. Although the enhanced recharge study 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 unconsolidated and bedrock aquifers, but also to 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.

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 12 shows the datasets that were collected and used in the study.

Table 12. 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 upper 60 feet of 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 average of the values in the upper 60 feet along the vertical column for each grid point was computed. This value was then applied to a 250-meter square area around each grid point. If the upper 60 feet 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.

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 13.

Contamination Sites: Although this study did not incorporate presence of soil and groundwater contamination into the criteria for the enhanced recharge assessment, it is important to identify and carefully consider contaminated and potentially contaminated areas when considering locations for enhanced recharge facilities. This is discussed further in the following section, Enhanced Groundwater Recharge Implementation.

Table 13. Processing of Datasets for Enhanced Recharge Study

Data Source	Processed Dataset(s)	Processing Required
Geology/Hydrogeology		
NRCS	Average 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	An average hydraulic conductivity value was generated for the upper 60 feet. This was done by calculating the average of the hydraulic conductivity for each of upper three 20-ft elevation “slices” 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 14. Rationale for the criteria is presented in Table 15. Individual datasets used in the evaluation are depicted on Figures A2-1 through A2-9 in Appendix A2. 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).[2]

[2] 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.

Table 14. Criteria for Evaluation of Enhanced Recharge Areas

Criteria	Tier 1	Tier 2	Tier 3	Figure Reference (see Appendix A2)
Geology/ Hydrogeology				
Average Vertical Infiltration Rate (k_{satr}) (Top 5 feet) (NRCS)	>5in/hr	0.5 - 5 in/hr	<0.5 in/hr	Figure A2-1
Soil Parent Material (NRCS)	N/A	(see Composite Hydraulic Conductivity, below)	N/A	Figure A2-2
Average Hydraulic Conductivity – Upper 60 feet (MGS)	>10 ft/day	1 - 10 ft/day, or Insufficient data but permeable parent material (glaciofluvial sediments, outwash)	<1 ft/day	Figure A2-3
Depth to Regional Water Table (MCES)	>50 feet	≥15 feet	<15 feet	Figure A2-4
Uppermost Bedrock (MGS)	(Uppermost bedrock was not used since the analysis considers recharge beneficial to all aquifers, including unconsolidated. A figure was generated for informational purposes.)			Figure A2-5
Land Use/ Natural Resources				
2010 Land Use (MCES)	Agricultural, parks, undeveloped areas	Agricultural, parks, undeveloped areas	All types other than agricultural, parks, undeveloped areas	Figure A2-6
Future Land Use – 2030 (MCES)	(2030 land use was not used for the analysis; a figure was generated for discussion purposes)			Figure A2-7

Criteria	Tier 1	Tier 2	Tier 3	Figure Reference (see Appendix A2)
Sensitive Natural Resources (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 A2-8
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 ft to the Prairie du Chien	Figure A2-9

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 15. Rationale for Enhanced Recharge Criteria

Criteria	Rationale
Geology/Hydrogeology	
Vertical Infiltration Rate - Top 5 feet (NRCS)	• 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.
Soil 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.
Average Hydraulic Conductivity – Upper 60 feet (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 Regional 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 aquifer transmissivity to accommodate mounding.
Land Use/Natural Resources	
2010 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.

Criteria	Rationale
Sensitive Natural Resources (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 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. 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 (included areas where all of Tier 2 and some, but not all, of Tier 1 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 specific criteria favor the potential for water to infiltrate and potentially reach a 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 12 shows the results using only the hydrogeological criteria, and Figure 13 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 16, with breakdowns of the Tier 1 and Tier 2 areas by municipality shown in Table 17. There is little Tier

1 recharge area in the study area, but appreciable amounts of Tier 2 areas do exist. The Tier 2 recharge areas are concentrated in Corcoran, Dayton, and Rogers, which have considerable amounts of agricultural and undeveloped land that may be available for construction of infiltration basins. Reasonable opportunities for enhanced recharge also exist in Andover, the northwest corners of Brooklyn Park and Maple Grove, and Ramsey. Andover's recharge opportunities are mostly in the west and north where the depth to the water table tends to be greater. Recharge opportunities appear limited in Anoka, Brooklyn Center, Champlin, Coon Rapids, Fridley, and Osseo, primarily due to development and a shallow water table in many areas. MCES has selected 20 acres as a reasonable minimum size for an infiltration basin.

Table 16. 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	65	<1%
Tier 2 Area	26,787	15%

Table 17. 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)
Andover	37	3,393
Anoka	0	473
Brooklyn Center	0	78
Brooklyn Park	1	2,448
Champlin	0	629
Coon Rapids	4	488
Corcoran	3	4,807
Dayton	0	4,267
Fridley	0	342
Maple Grove	8	2,251
Osseo	0	11
Ramsey	1	3,284
Rogers	11	4,316

Table 18 lists the Tier 1 and Tier 2 areas by watershed jurisdiction. The Tier 1 and Tier 2 recharge areas in the study area occur primarily in the Elm Creek Watershed Management Commission, Lower Rum River Watershed Management Organization, and West Mississippi River Watershed Management Commission. The boundaries of the watershed jurisdictions are shown on Figure 14 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 18. 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)
Coon Creek Watershed District	0	751
Elm Creek Watershed Management Commission	17	15,582
Lower Rum River Watershed Management Organization	38	6,589
Pioneer-Sarah Creek Watershed Management Organization	0	30
Rice Creek Watershed District	0	112
Shingle Creek Watershed Management Commission	3	465
Six Cities Watershed Management Organization	4	522
West Mississippi River Watershed Management Commission	3	2,720

Contamination datasets were gathered from public sources and are summarized in Table 19. The provided datasets consist of either point locations (e.g., pollution containment wells) or polygons (e.g., contaminant plumes), and are shown on Figure 15 with the Tier 1, Tier 2, and Tier 3 areas for enhanced recharge using all criteria. Little Tier 1 and Tier 2 area is in areas where known contamination exists.

Table 19. 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, 2015)
US Army c/o Wenck and Associates	Large, known contaminant plumes, including Twin Cities Army Ammunition Plant (TCAAP) (2013 mapping). Plumes are provided as polygons.	(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 Agency (MPCA)	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 decline in a drinking water aquifer. Aquifer decline 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. Notable declines are projected in the Tunnel City – Wonewoc aquifer under average pumping conditions through 2040.. Figure 16 shows the Tier 1, Tier 2, and Tier 3 areas for enhanced recharge (using all criteria) overlain with projected 2040 groundwater decline and rebound in the Tunnel City-Wonewoc 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 decline, primarily because pumping demands and corresponding groundwater decline tends to be more pronounced in highly developed areas which are generally classified as Tier 3 because of existing land use. Few opportunities exist for enhanced recharge in areas projected to see over ten feet of additional decline in 2040. Some areas that are projected to see between two and ten feet of additional decline in 2040 may have limited opportunities for enhanced recharge, such as Anoka, northwestern Brooklyn Park, and Rogers. As Figure 16 indicates, most Tier 1 and Tier 2 recharge areas are in locations where the Tunnel City-Wonewoc aquifer is projected to see between zero and four feet of additional decline in 2040.

Enhanced Groundwater Recharge Implementation

Enhanced Recharge Methods

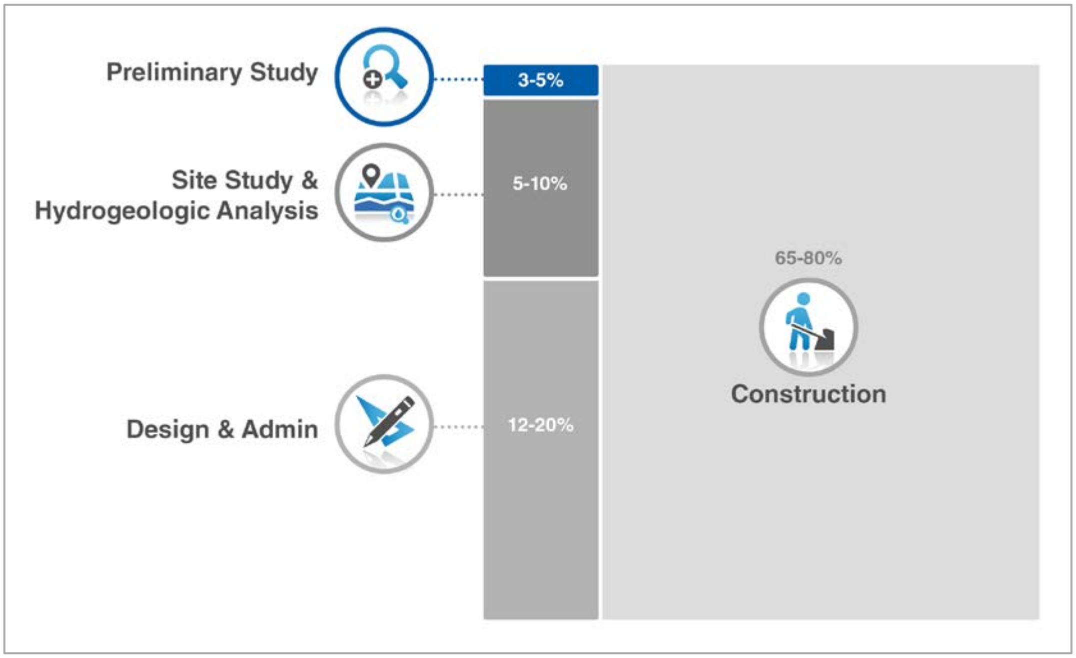
Enhanced recharge is the focused infiltration of water from the surface into the zone of saturation with the express purpose of recharging an aquifer(s) using an engineered system. There are three basic methods of enhanced recharge including surface infiltration basins, sub-surface infiltration systems,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

Surface infiltration systems, which are also called recharge basins, infiltration basins, and rapid infiltration basins, 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 because the Minnesota Well Code (Minnesota Administrative Rules Chapter 4725.2050) prohibits groundwater injection.

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 4 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.



Note: Project cost share percentages are based on HDR historic project cost information.

Chart 4. 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 in this analysis, 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 , 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 A3.

Table 20. 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 Northwest Metro Study Area to identify areas where water applied at the surface would have the highest potential to recharge a drinking water aquifer based on specific hydrogeologic, land use, drinking water protection, and other specific criteria. Equal emphasis was given to recharge of unconsolidated formations and permeable bedrock formations as the groundwater used in the Northwest Metro study area for municipal supply comes from each of 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

- Only 65 acres were classified as having good potential for groundwater recharge based on study criteria.
- Nearly 27,000 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 Corcoran, Dayton, and Rogers.
- Reasonable opportunities for enhanced recharge may also exist in Andover, Brooklyn Park, Maple Grove, and Ramsey.
- Much of the eastern and southeastern portions of the study area are classified as having poor potential for enhanced groundwater recharge, primarily due to land development. Low hydraulic conductivity limits enhanced recharge potential in the southwestern area.

- There are only a few areas, such as in Anoka, Brooklyn Park, and Rogers classified as having good or limited potential for enhanced recharge that intersect areas that are projected to experience significant aquifer decline 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 A4.

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[3] 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[4] 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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[3] The annual non-winter runoff period is defined as the period from March 15 to November 31.

[4] 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, 2014).

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 (non-crop) irrigation, including golf courses, landscaping, and athletic fields. 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. A total of 23 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 A4.

Results

Comparison of Stormwater Runoff and Groundwater Use 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 A2-6) 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 35,800 million gallons (MG)[5].

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

The reported 2010[6] groundwater use for the study area, as tabulated from permit records in the MnDNR SWUDS database, was approximately 16,900 MG. This represents all permitted water withdrawals[7] (both potable and non-potable) within the study area.

Non-potable water users that use groundwater for non-crop irrigation were the focus of this study. Non-crop irrigation uses include golf courses, landscaping, and athletic fields. A total of 61 such users were identified from the MnDNR SWUDS database. In addition to the MnDNR

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[5] Assumptions and parameters used in the rational method calculation are included in Appendix A4.

[6] 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.

[7] 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.

appropriations permit holders, one high-volume municipal customer who uses water for non-crop irrigation use was identified. Groundwater withdrawals for each of the 62 non-crop irrigation users totaled approximately 745 MG in 2010. Chart 5 shows a breakdown of high-volume, non-potable water uses in the non-crop irrigation category in the study area.

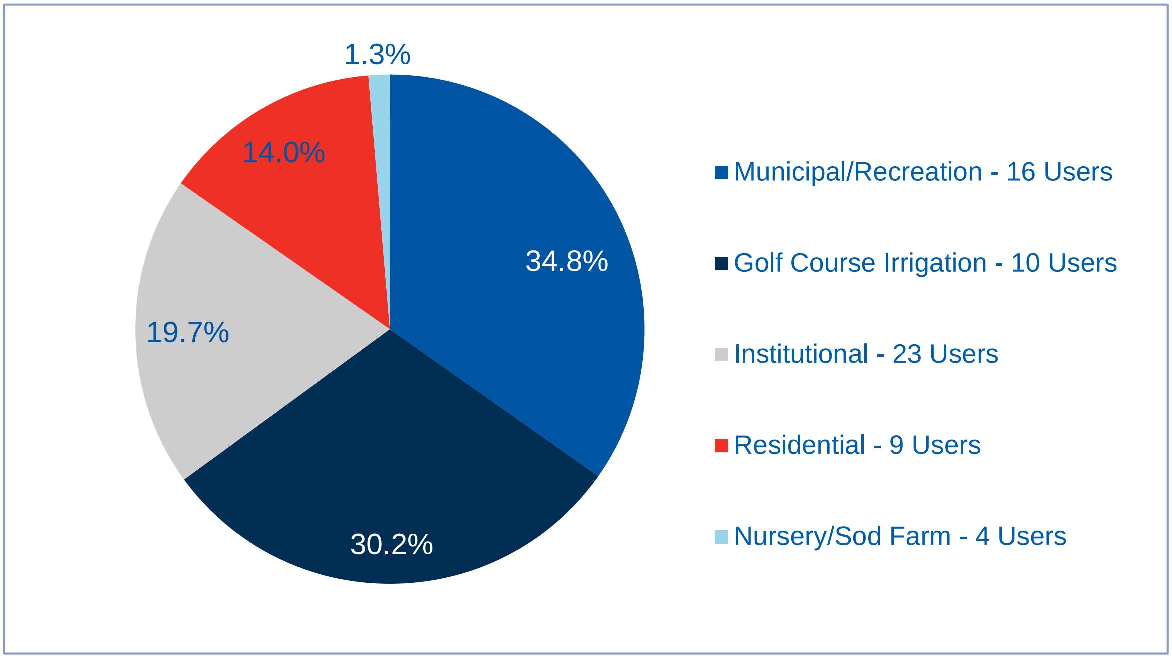

Chart 5. 2010 Non-Potable High-Volume Water Users within the Northwest Metro Study Area

Comparison of Stormwater Runoff and Groundwater Use in the Study Area

Chart 6 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 2010 groundwater use in the study area (16,900 MG) amounted to 47 percent of average annual non-winter runoff. The reported volume for the 62 high-volume non-potable urban irrigation users (745 MG) amounted to 2.1 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.

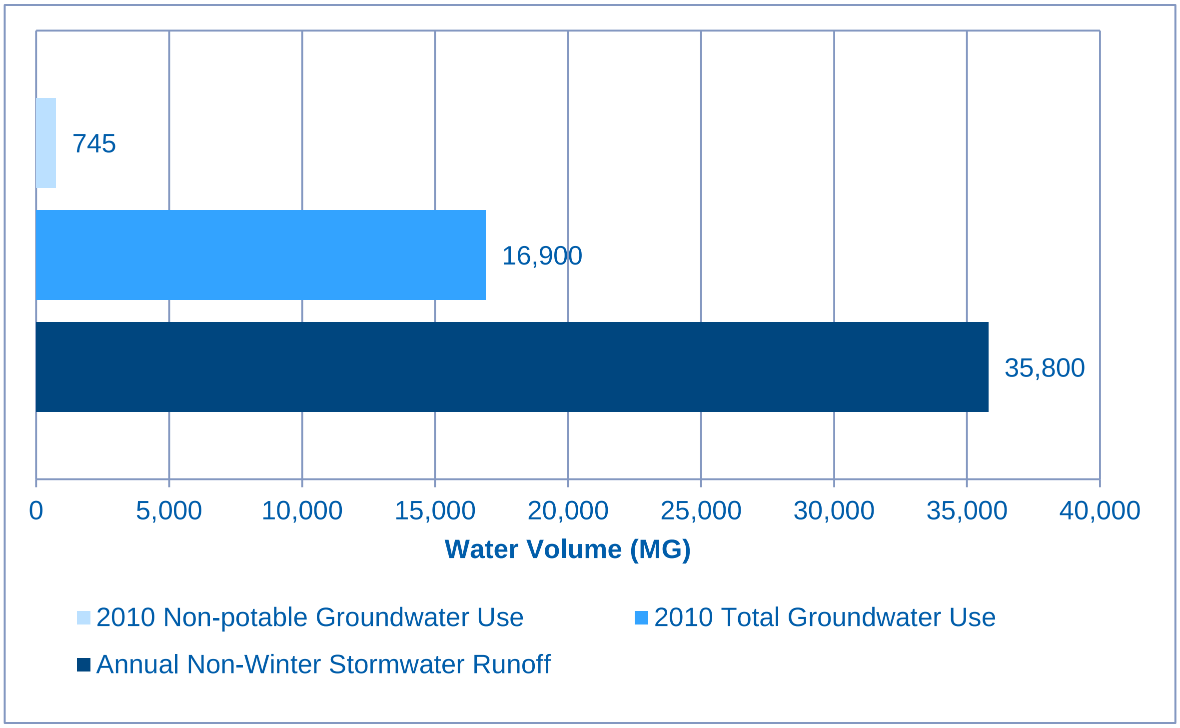

Chart 6. Comparison of Annual Groundwater Use by Identified High-Volume Non-Potable Water Users with Average Annual Stormwater Runoff and 2010 Groundwater Use within the Northwest Metro Study Area

Stormwater and Enhanced Groundwater Recharge in the Study Area

In addition to the 62 high-volume, non-potable water users identified from SWUDS and municipal water use data, 23 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 23 sites were selected for meeting various hydrogeological, land use, and other criteria.

Estimating Stormwater Run-on to Potential Use Sites

In total, 85 potential stormwater capture and reuse sites were identified. These sites are mapped in Figure 17. Table 21 summarizes the sites by identification source category.

Table 21. Potential Sites for Stormwater Capture and Reuse in the Northwest Metro Study Area

Site Identification Source	Number of Sites
MnDNR SWUDS	61
WECP/City Water Sales	1
Enhanced Groundwater Recharge Sites	23
Total	**85**

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 85 sites described above. Potential water use sites and modeled drainage areas are shown in Figure 17.

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 62 high-volume, non-potable use sites was modeled to be over 10,000 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 62 sites. At 52 of the 62 sites (84%), total run-on volume exceeded water use. At 45 of the 62 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 22.

Table 22. 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	52 (84%)	501
Water Users with Annual Run-on > 2x Annual Water Use	45 (73%)	378

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 45 sites identified), then approximately 189 MG per year in groundwater use could be offset with stormwater reuse.

Stormwater run-on volumes were also calculated for 23 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 23 sites averages over 5,900 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 3,900 MG per year, or 10.4 MG per day, on average, that could be applied for groundwater recharge. The recharge analysis determined that these sites had good or limited 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 23.

Table 23. 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	62	10,306	189 [2]
Enhanced Recharge Sites	23	5,939	3,860 [3]
Total	**85**	**16,245**	**4,049**

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 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, 2014). 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 A4.

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 24. The concentration of specific contaminants will vary with storm event, land use, and location, and data collection and monitoring should be performed to determine the actual concentration of any constituent in a given watershed (Gulliver, et al, 2013).

Table 24. 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 Suspended 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 (NO_3-N) (mg/L)	0.53	0.68
Ammonium (NH_4) (mg/L)	N/A	N/A
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: (EPA, 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 25.

Table 25. 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, in 2007 the Minnesota Department of Health published guidance (MDH, 2007) related to infiltration of stormwater, 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 26.

Table 26. 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 it is 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).

Agency/Regulatory Authority	Summary of Requirements
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.
MnDNR 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 27. 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 A4.

Table 27. Conceptual Cost for Stormwater Capture and Reuse Systems

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

Notes:
[1] *Costs include construction costs, contingency (30%), and engineering, permitting, and administration costs (20%). Costs do not include treatment, 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 be 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 for biofilm and accumulation of sediment in filters;
- Annual 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 (Mississippi Watershed Management Organization, 2016).

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, 2014).

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 Northwest 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 35,800 million gallons (MG). Total groundwater use for 62 high-volume, non-potable uses identified in the study area totaled 745 MG, or 2.1% of non-winter runoff in 2010.
- Of the 62 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 23 of the sites classified as having good or limited potential for enhanced groundwater recharge based on study criteria amounts to approximately 3,900 MG per year, or 10.4 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

Term	Definition
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.

Term	Definition
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 used 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.

Term	Definition
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 used 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

Acronym	Phrase
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 U.S. 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
MWI	Minnesota Well Index
NCEI	National Centers for Environmental Information
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
RNRA	Regional Natural Resource Area
SDS	State Disposal System

Acronym	Phrase
SNA	Scientific and Natural Area
SWBCA	Special Well and Boring Construction Area
SWUDS	State Water Use Database System
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
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

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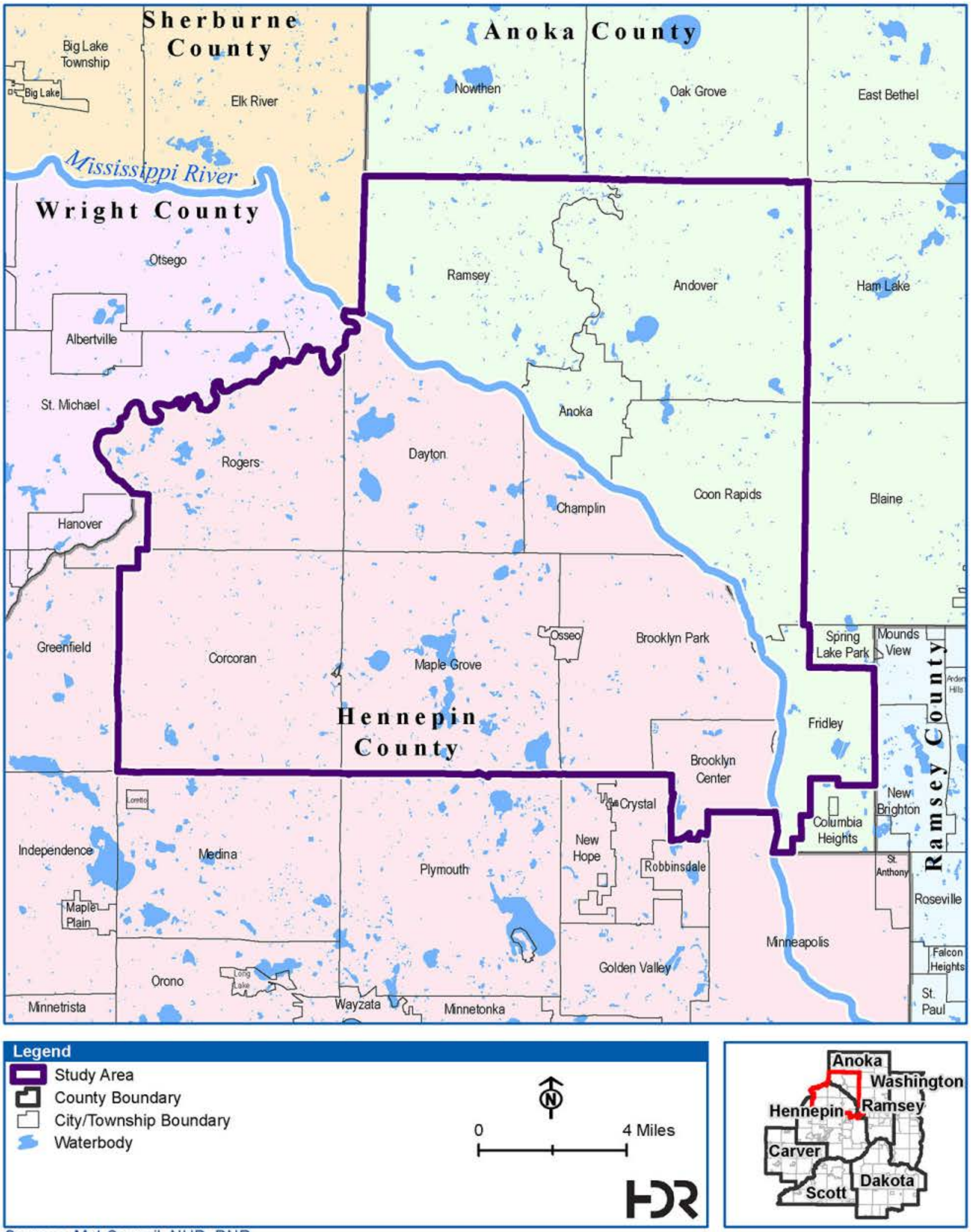
Figures

Metropolitan Council
Regional Water Supply, Groundwater Recharge, and Stormwater Capture and Reuse Study

Figure 1
Northwest Metro Study Area



Sources: Met Council, NHD, DNR

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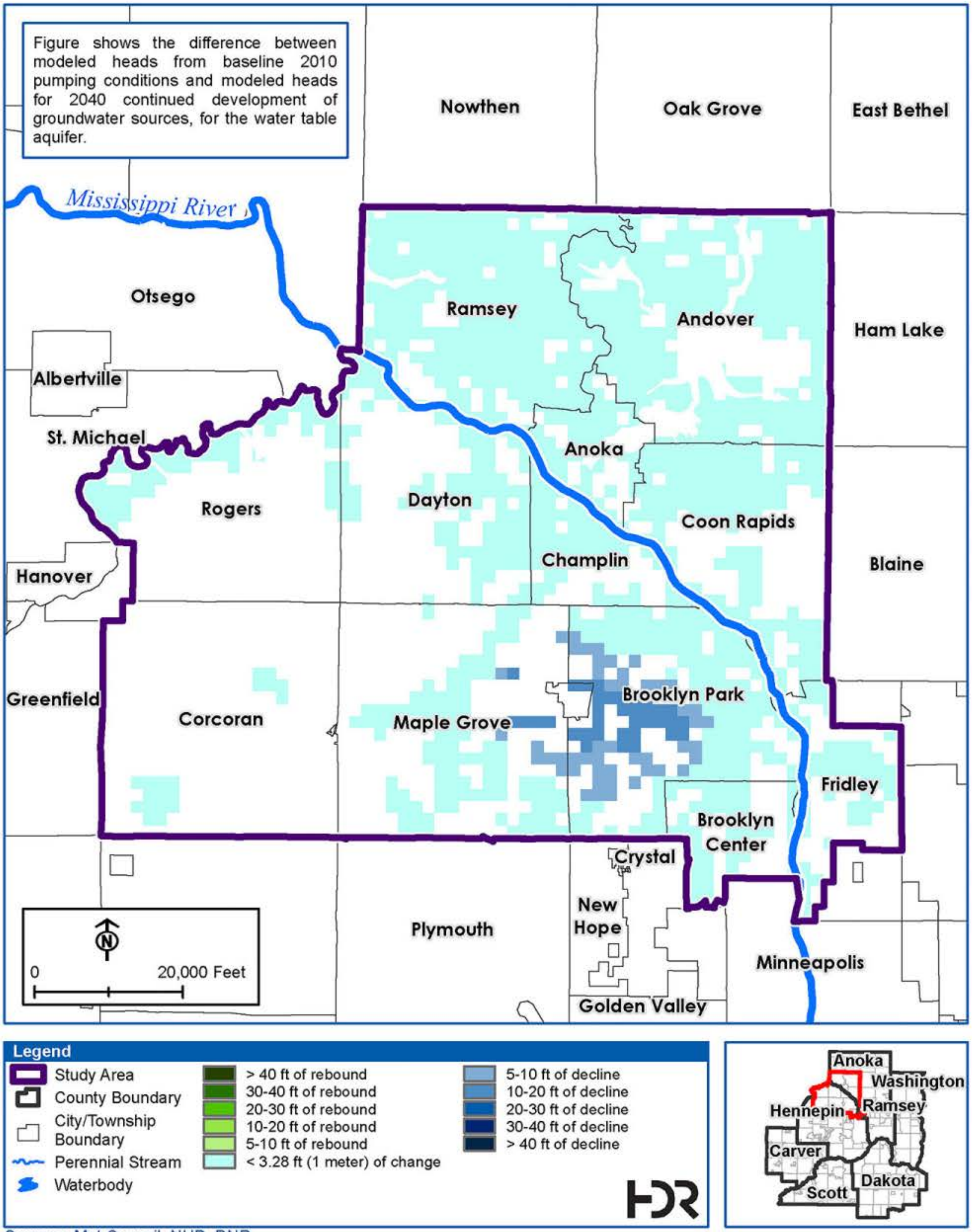
Metropolitan Council
Regional Water Supply, Groundwater Recharge, and Stormwater Capture and Reuse Study

Figure 2
Water Table Aquifer 2040 Decline/Rebound
Northwest Metro Study Area



Sources: Met Council, NHD, DNR

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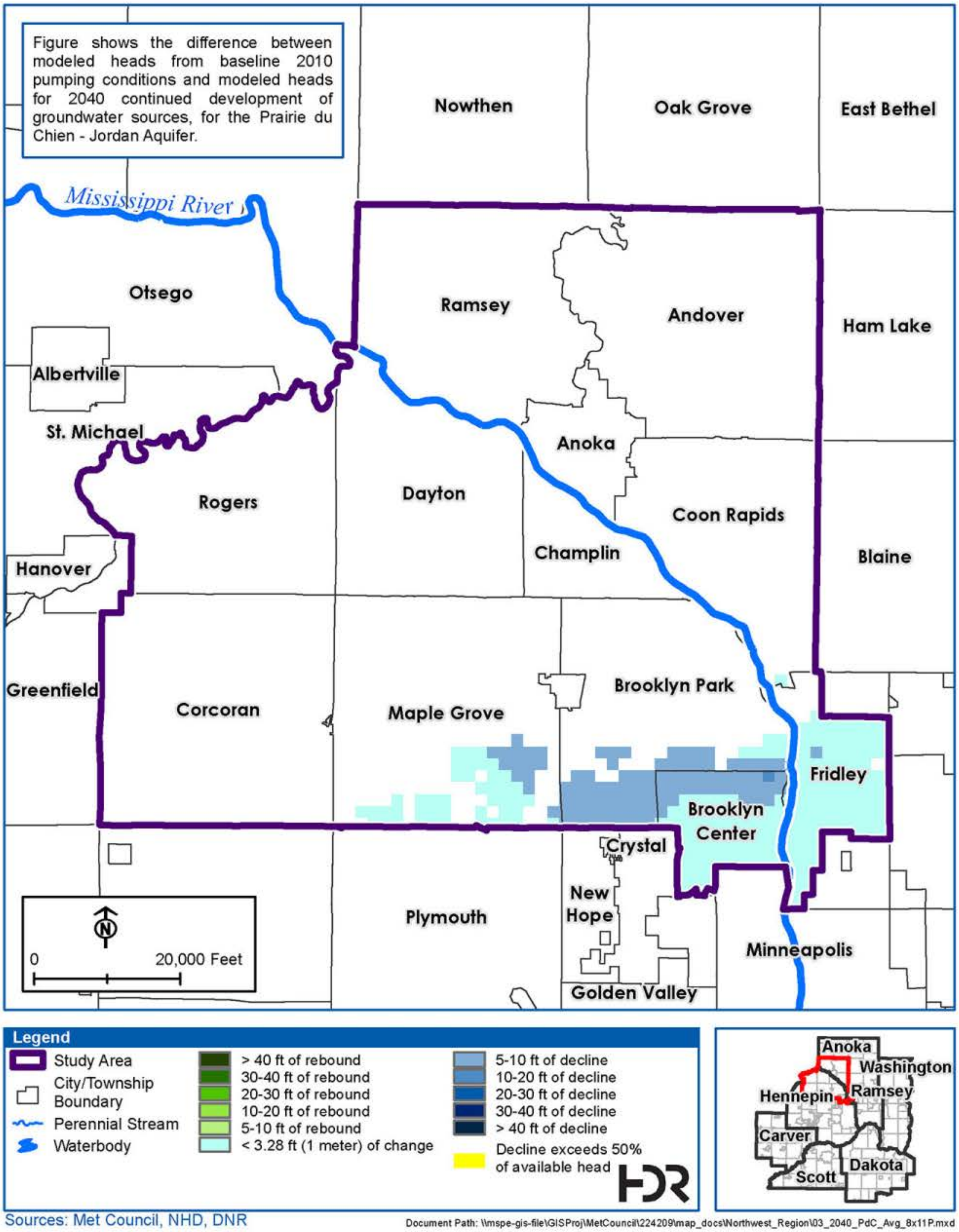
Metropolitan Council
Regional Water Supply, Groundwater Recharge, and Stormwater Capture and Reuse Study

Figure 3
PDCJ Aquifer 2040 Decline/Rebound
Northwest Metro Study Area



Sources: Met Council, NHD, DNR

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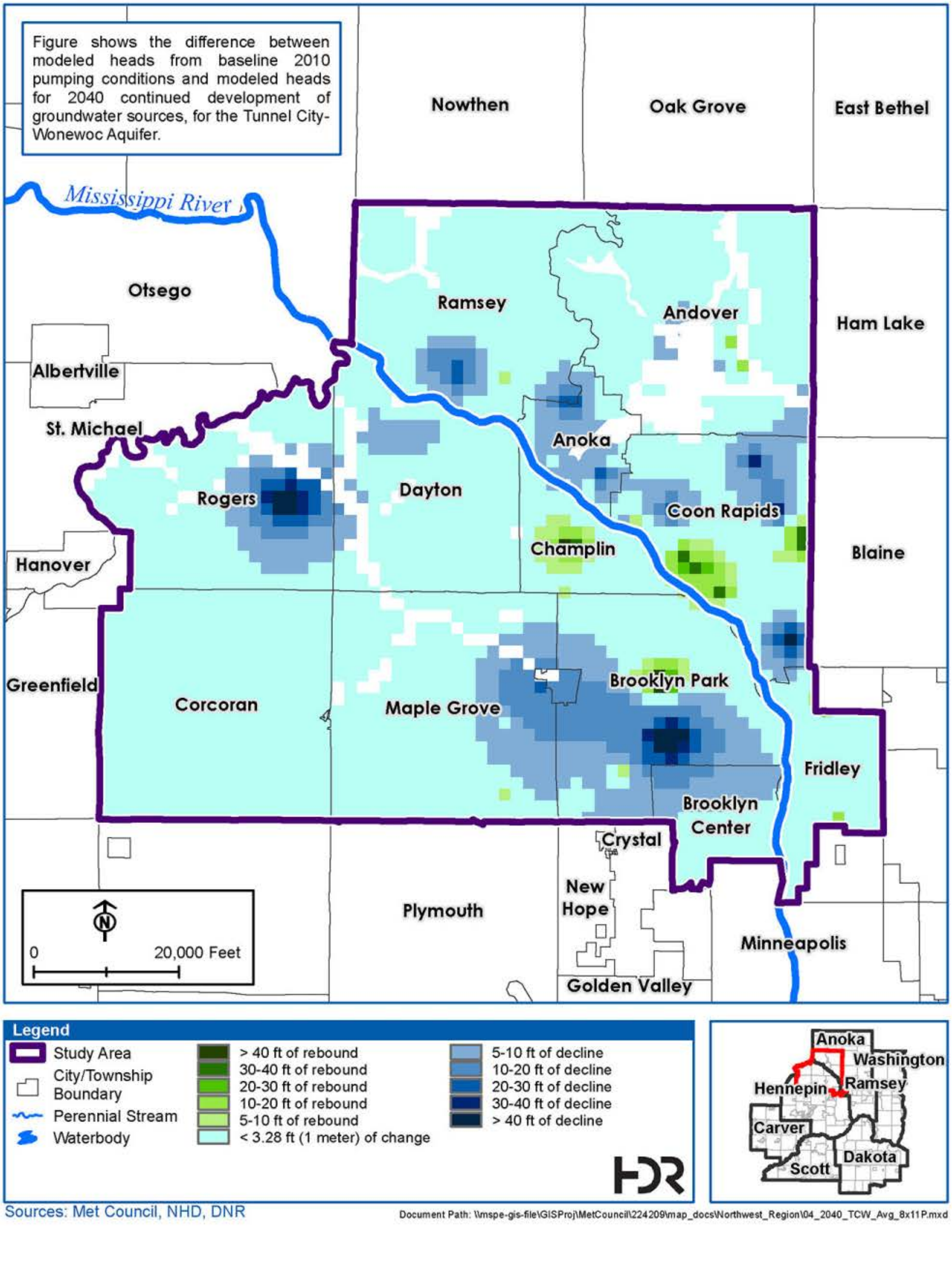
Figure 4
TCW Aquifer 2040 Decline/Rebound
Northwest Metro Study Area



Sources: Met Council, NHD, DNR

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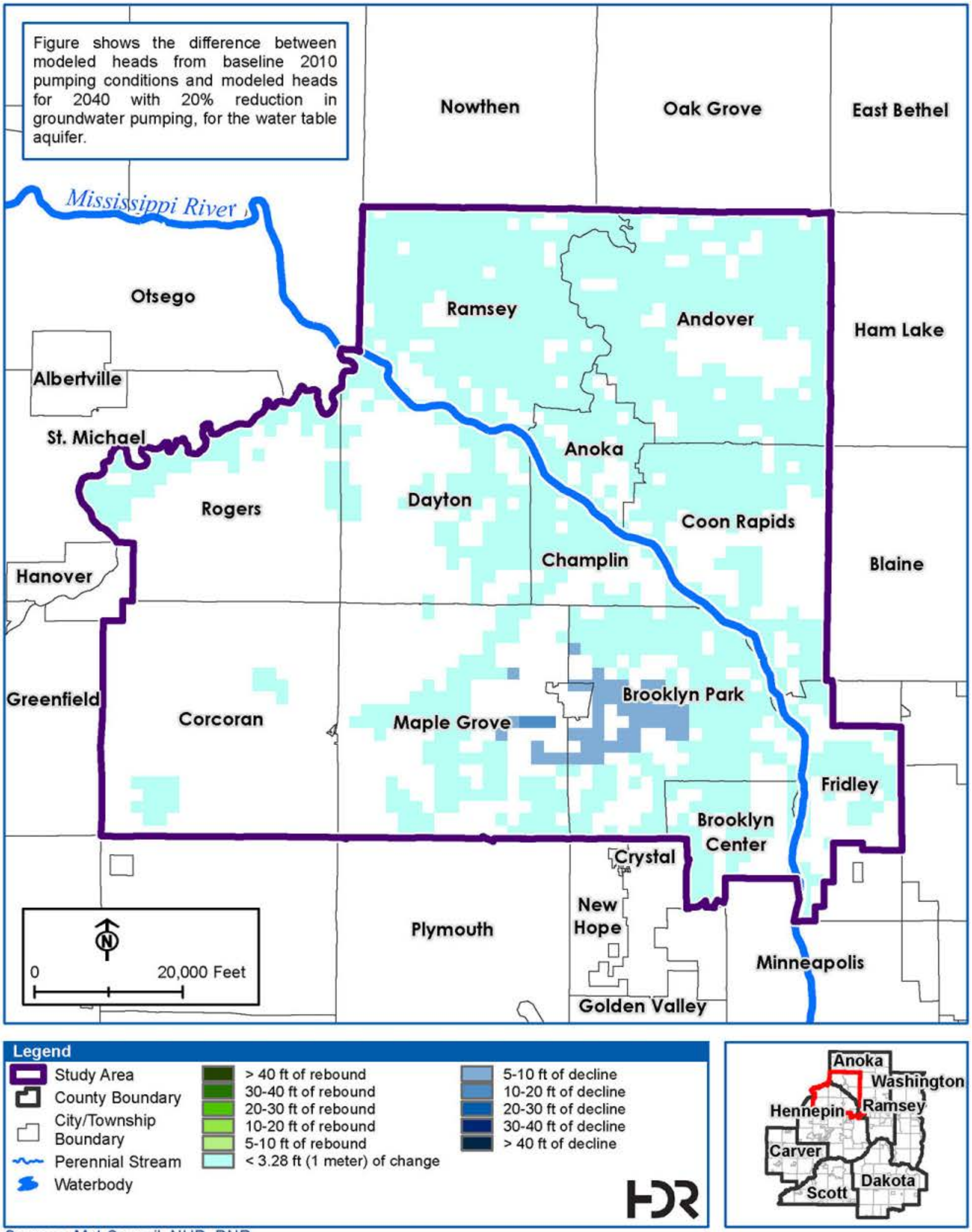
Metropolitan Council
Regional Water Supply, Groundwater Recharge, and Stormwater Capture and Reuse Study

Figure 5 - Water Table Aquifer 2040 Decline/Rebound: 20% Reduction Northwest Metro Study Area



Sources: Met Council, NHD, DNR

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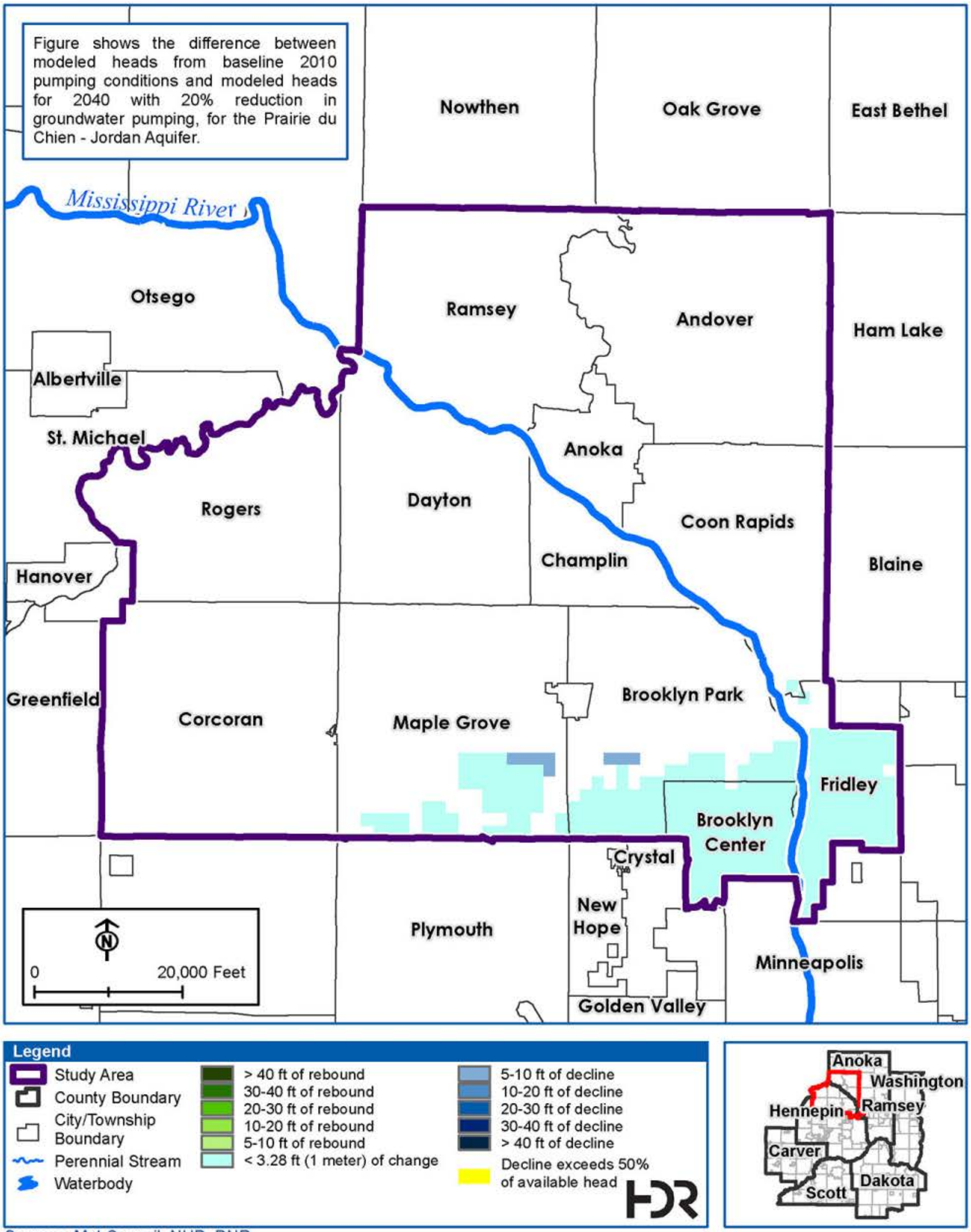
Figure 6 - PDCJ Aquifer 2040 Decline/Rebound: 20% Reduction Northwest Metro Study Area



Sources: Met Council, NHD, DNR

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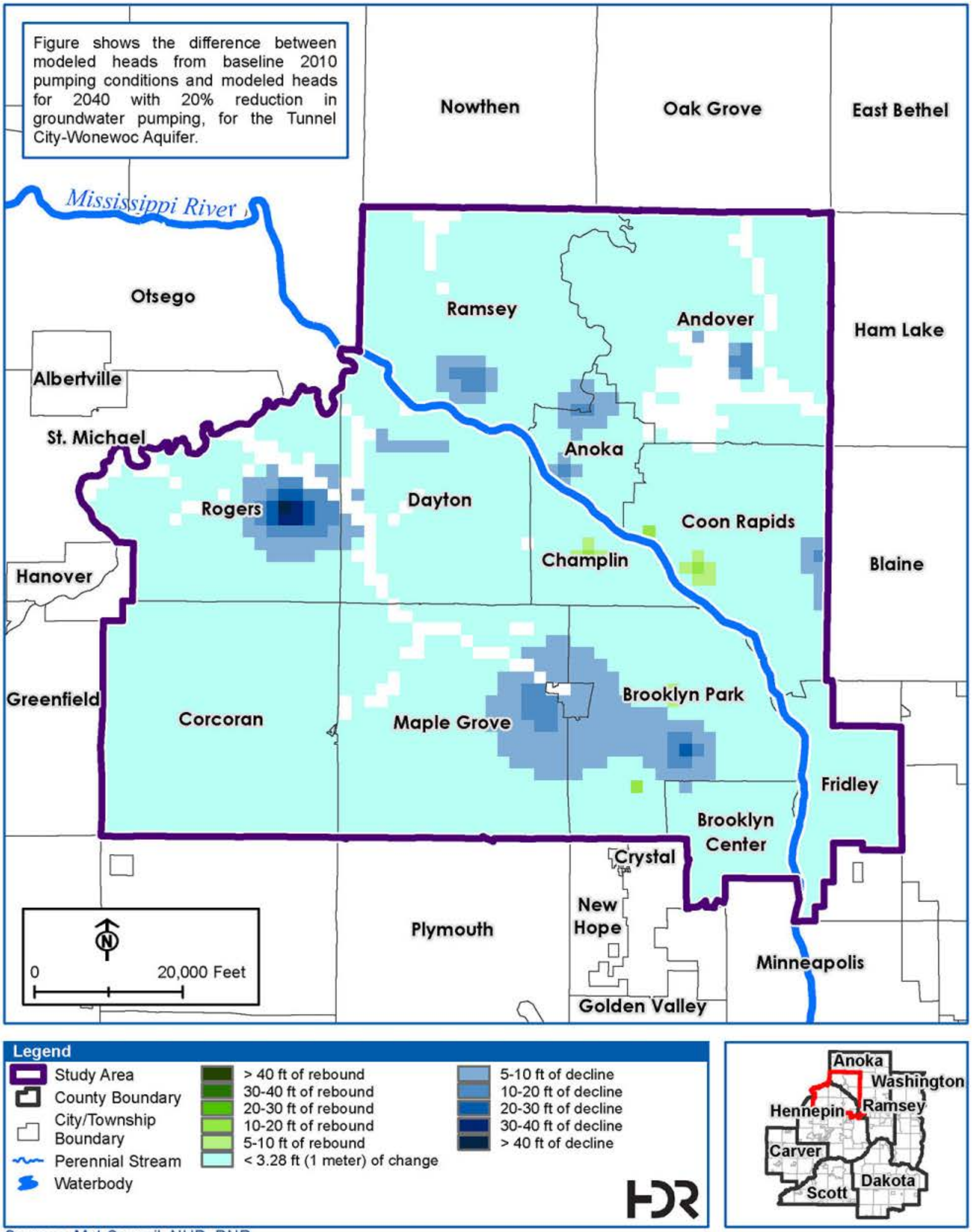
Metropolitan Council
Regional Water Supply, Groundwater Recharge, and Stormwater Capture and Reuse Study

Figure 7 - TCW Aquifer
2040 Decline/Rebound: 20% Reduction
Northwest Metro Study Area



Sources: Met Council, NHD, DNR

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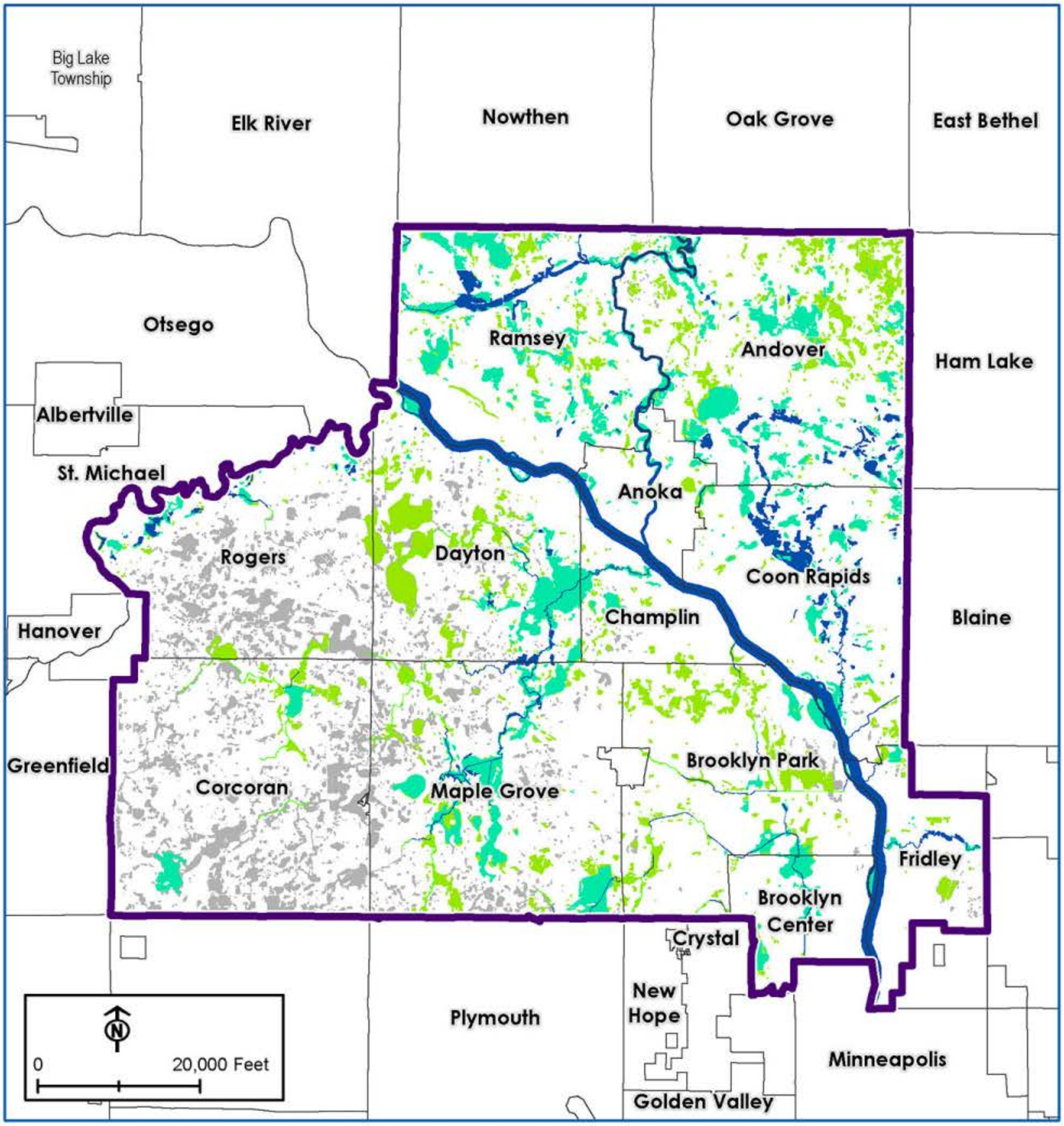
Metropolitan Council
Regional Water Supply, Groundwater Recharge, and Stormwater Capture and Reuse Study

Figure 8
Surface Water - Groundwater Interactions
Northwest Metro Study Area



Legend

Study Area

City/Township Boundary

Surface Water Type

- Disconnected from the regional groundwater system
- Recharges aquifers
- Receives and discharges groundwater
- Supported by upwelling groundwater

Sources: Met Council, NHD, DNR

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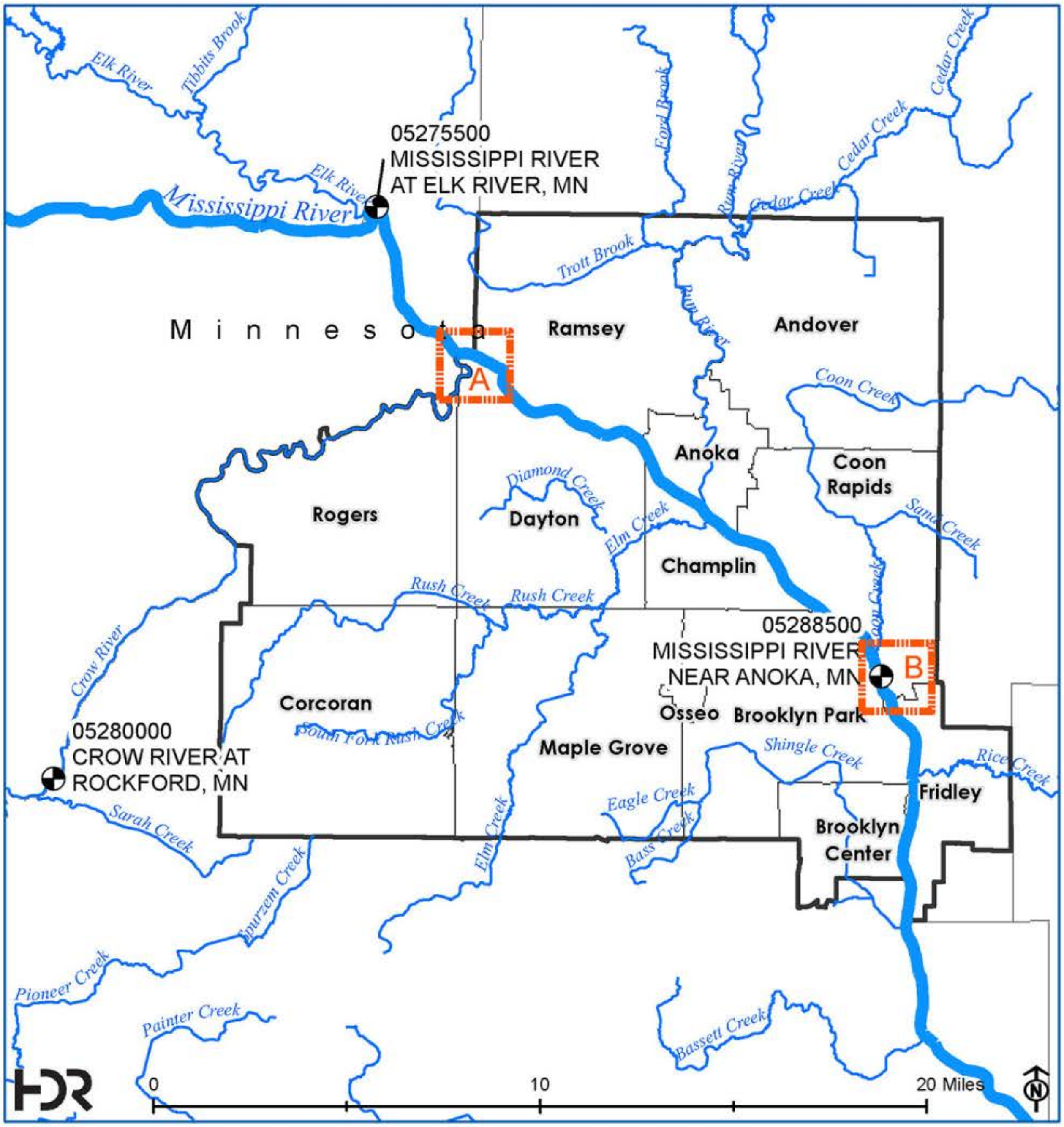
Metropolitan Council
Regional Water Supply, Groundwater Recharge, and Stormwater Capture and Reuse Study

Figure 9
Mississippi River Potential Diversion Locations
Northwest Metro Study Area



Legend
- Study Area
- Perennial Stream
- Waterbody
- USGS Stream Gage
- Potential Diversion Location:
  - A) Mississippi River near Ramsey
  - B) Mississippi River near Anoka

Sources: USGS NED, NHD, NWIS

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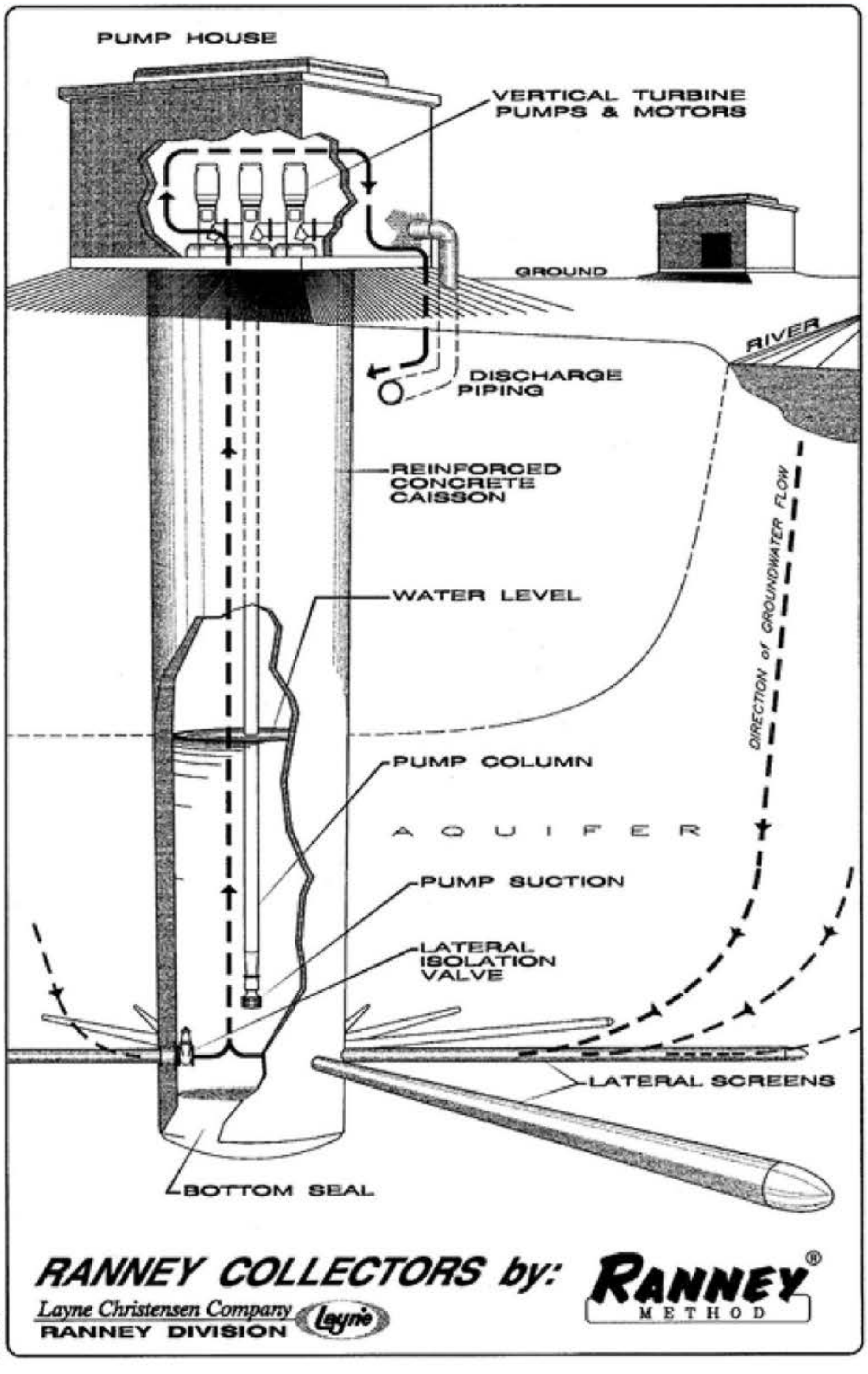
Metropolitan Council
Regional Water Supply, Groundwater Recharge, and Stormwater Capture and Reuse Study

Figure 10
Collector Well Schematic
Northwest Metro Study Area



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Metropolitan Council
Regional Water Supply, Groundwater Recharge, and Stormwater Capture and Reuse Study

Figure 11
Collector Well Analysis Locations
Northwest Metro Study Area

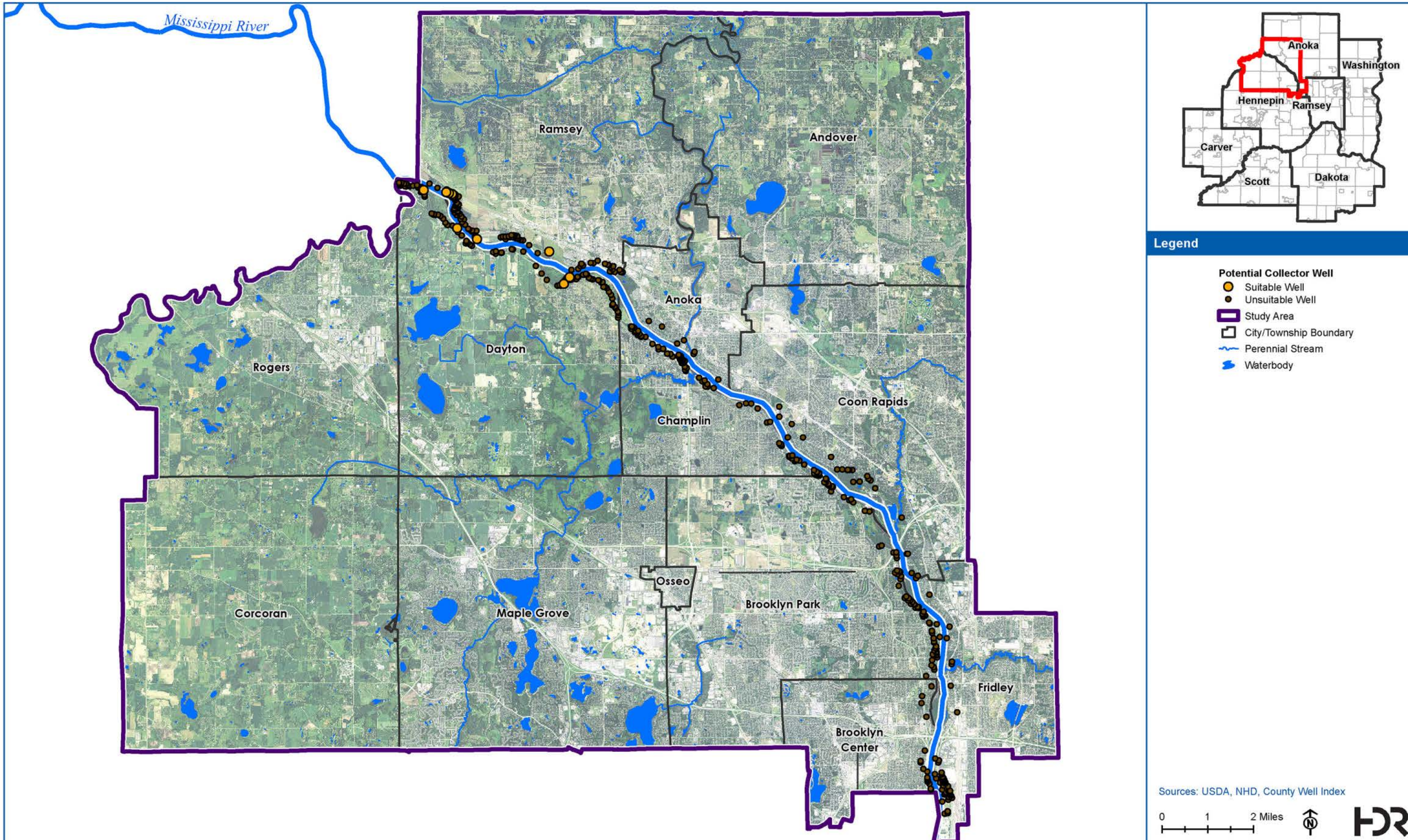

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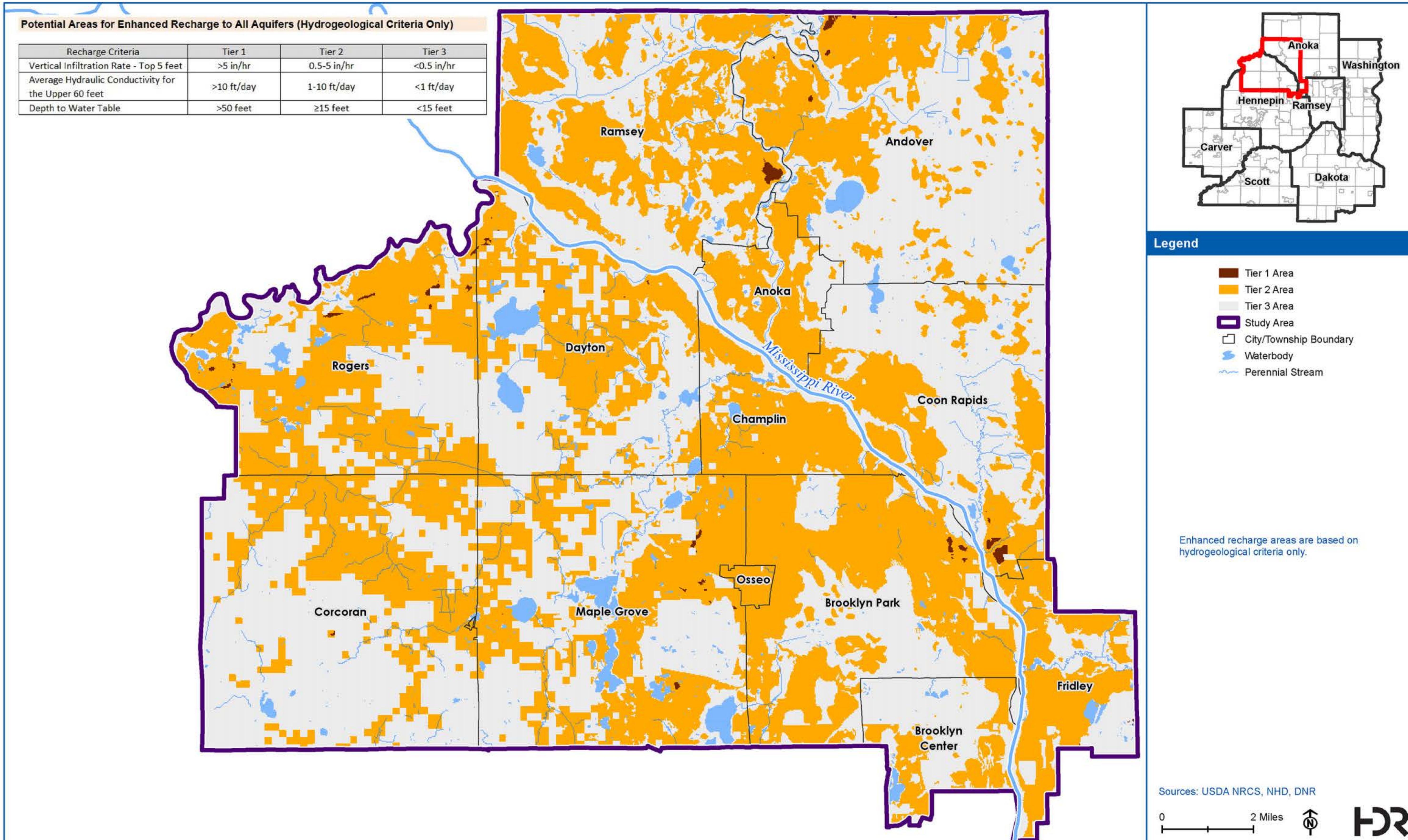
Figure 12
Potential Areas for Enhanced Recharge to All Aquifers (Hydrogeological Criteria)
Northwest Metro Study Area

Potential Areas for Enhanced Recharge to All 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
Average Hydraulic Conductivity for the Upper 60 feet	>10 ft/day	1-10 ft/day	<1 ft/day
Depth to Water Table	>50 feet	≥15 feet	<15 feet



Enhanced recharge areas are based on hydrogeological criteria only.

Sources: USDA NRCS, NHD, DNR

HDR

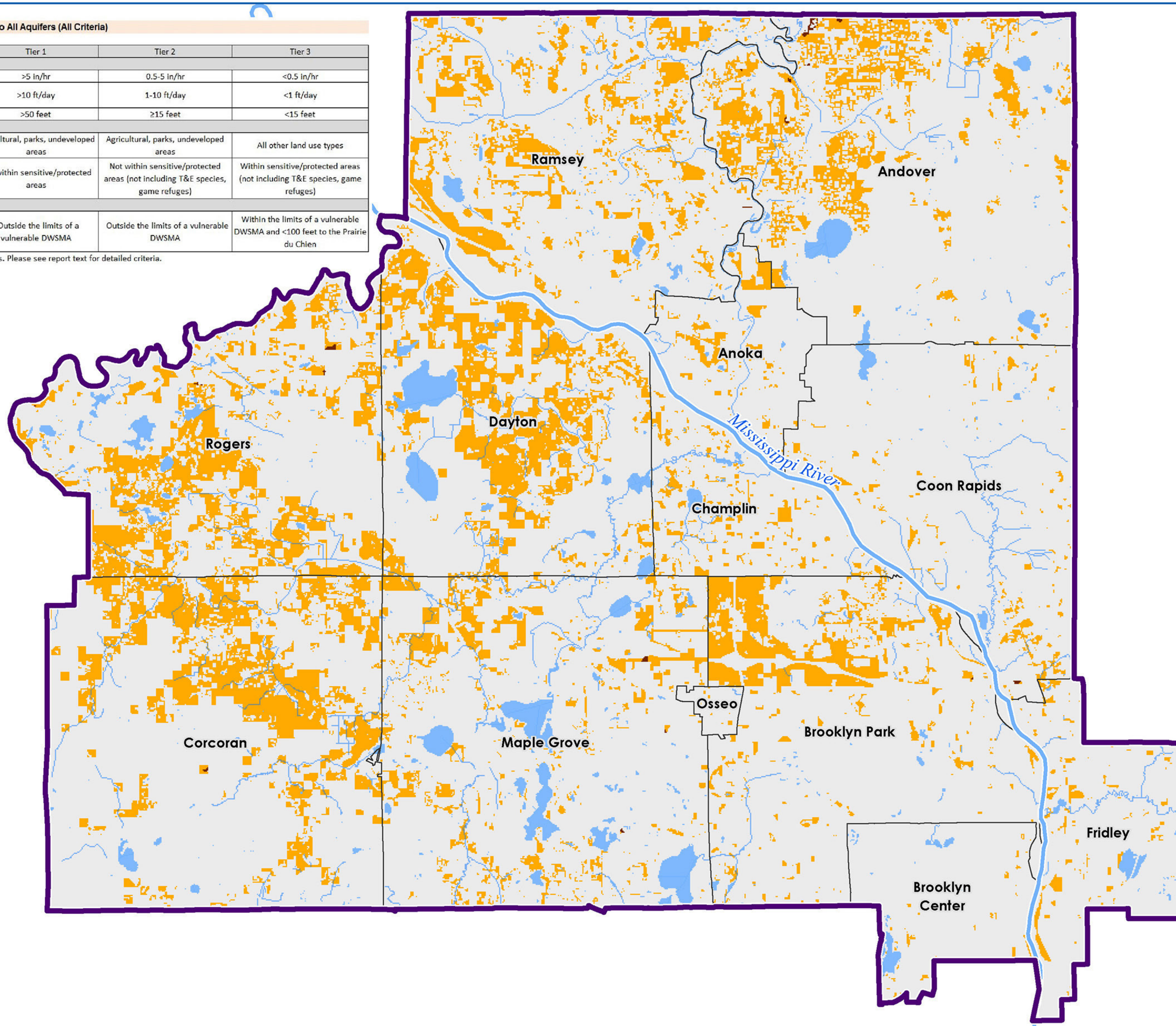
Metropolitan Council
Regional Water Supply, Groundwater Recharge, and Stormwater Capture and Reuse Study

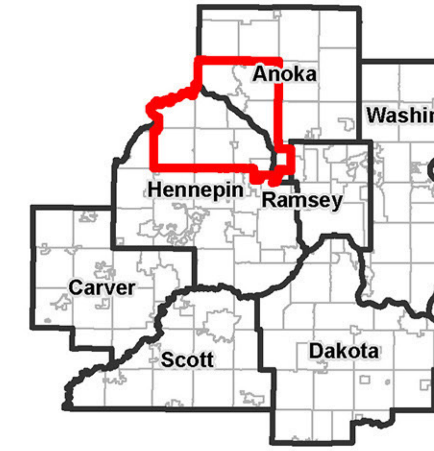
Figure 13
Potential Areas for Enhanced Recharge to All Aquifers (All Criteria)
Northwest Metro Study Area

Potential Areas for Enhanced Recharge to All 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
Average Hydraulic Conductivity for the Upper 60 feet	>10 ft/day	1-10 ft/day	<1 ft/day
Depth to Water Table	>50 feet	≥15 feet	<15 feet
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.





Legend

- Tier 1 Area
- Tier 2 Area
- Tier 3 Area
- Study Area
- City/Township Boundary
- Waterbody
- Perennial Stream

Sources: USDA NRCS, NHD, DNR

0 2 Miles

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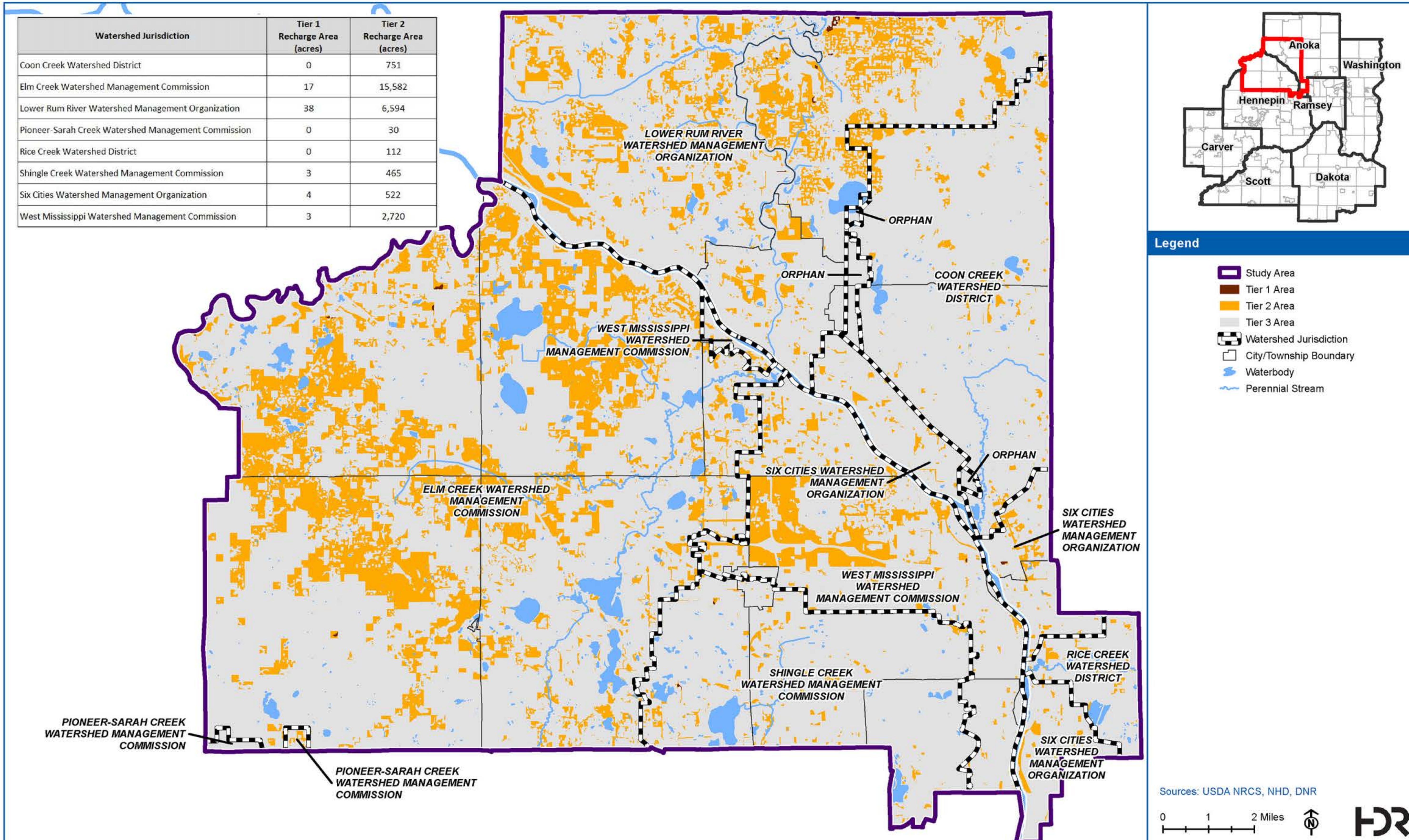
Metropolitan Council
Regional Water Supply, Groundwater Recharge, and Stormwater Capture and Reuse Study

Figure 14
Enhanced Recharge Areas within Watershed Jurisdictions
Northwest Metro Study Area

Watershed Jurisdiction	Tier 1 Recharge Area (acres)	Tier 2 Recharge Area (acres)
Coon Creek Watershed District	0	751
Elm Creek Watershed Management Commission	17	15,582
Lower Rum River Watershed Management Organization	38	6,594
Pioneer-Sarah Creek Watershed Management Commission	0	30
Rice Creek Watershed District	0	112
Shingle Creek Watershed Management Commission	3	465
Six Cities Watershed Management Organization	4	522
West Mississippi Watershed Management Commission	3	2,720



Metropolitan Council
Regional Water Supply, Groundwater Recharge, and Stormwater Capture and Reuse Study

Figure 15
Potential Contamination and Enhanced Recharge Areas
Northwest Metro Study Area

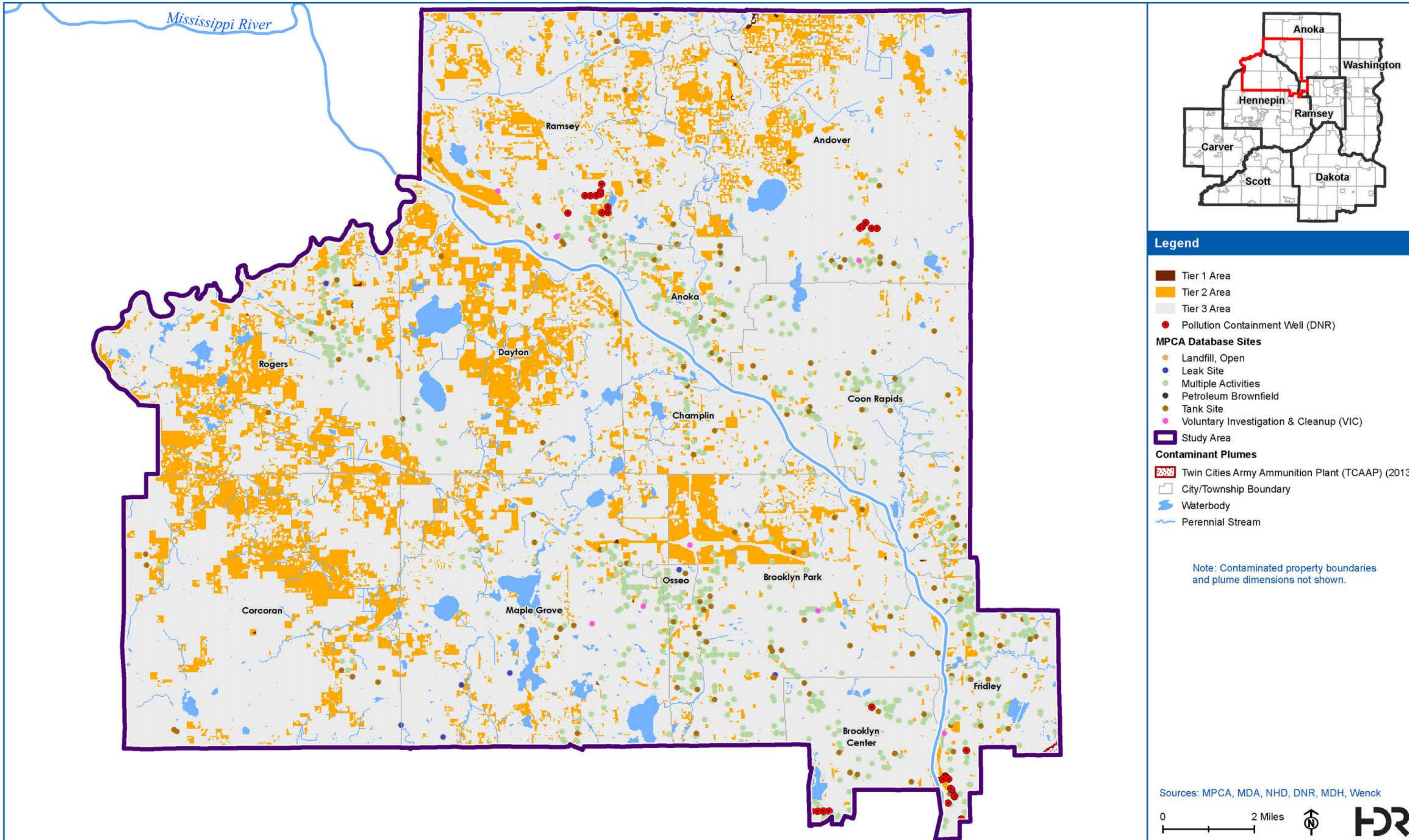


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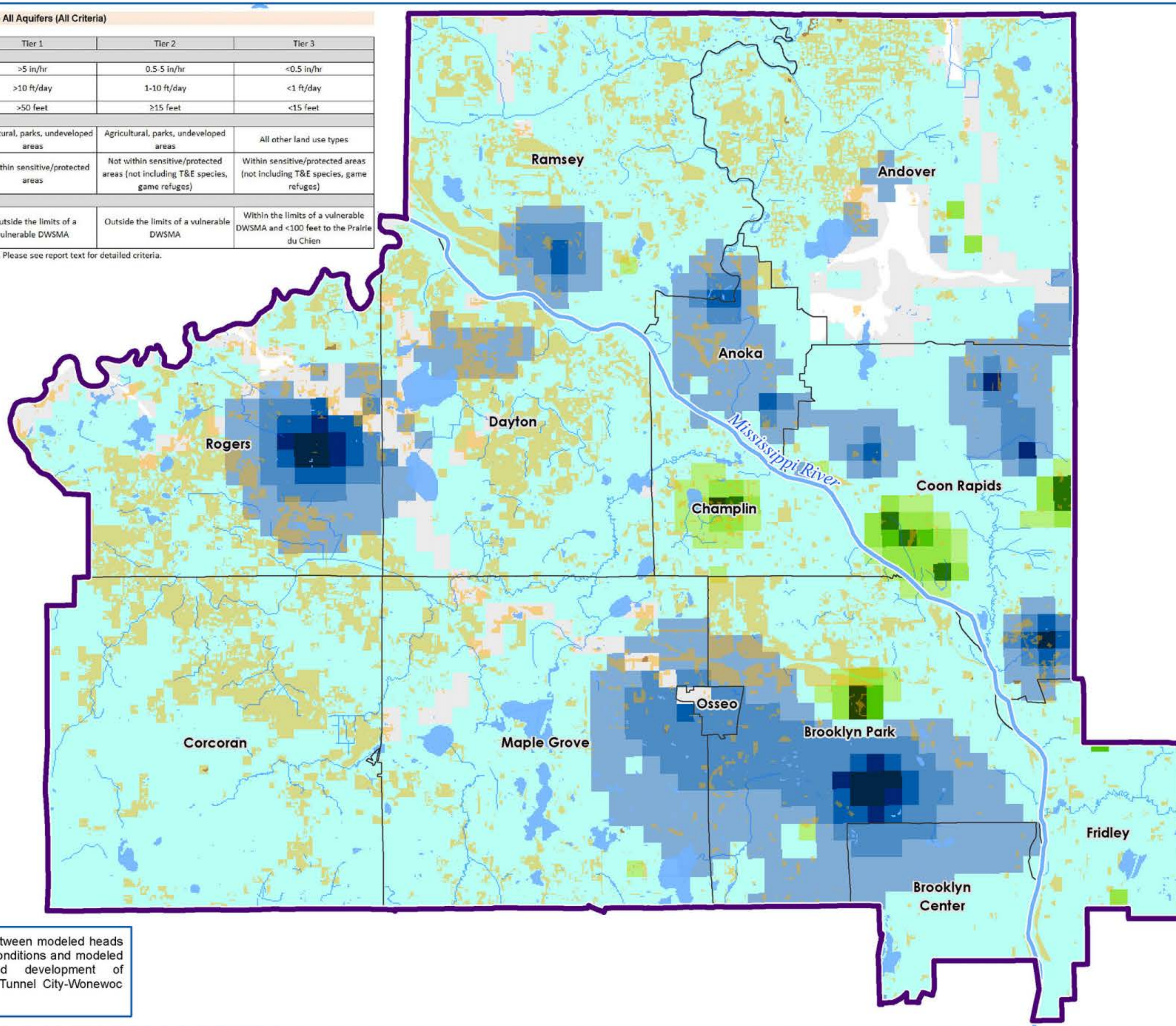
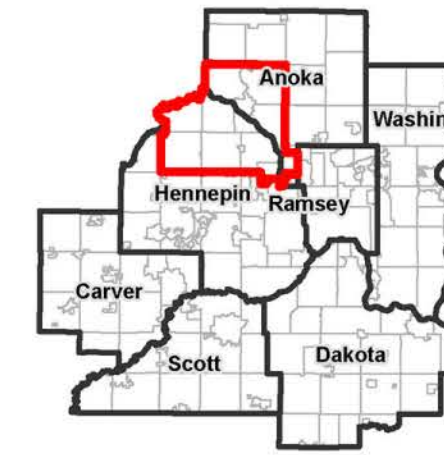
Figure 16
Potential Enhanced Recharge Areas and 2040 Model-projected Decline/Rebound
Northwest Metro Study Area

Potential Areas for Enhanced Recharge to All 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
Average Hydraulic Conductivity for the Upper 60 feet	>10 ft/day	1-10 ft/day	<1 ft/day
Depth to Water Table	>50 feet	≥15 feet	<15 feet
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.





Legend

- Tier 1 Area
- Tier 2 Area
- Tier 3 Area
- Study Area
- City/Township Boundary
- Waterbody
- Perennial Stream
- > 40 ft of rebound
- 30-40 ft of rebound
- 20-30 ft of rebound
- 10-20 ft of rebound
- 5-10 ft of rebound
- < 3.28 ft (1 meter) of change
- 5-10 ft of decline
- 10-20 ft of decline
- 20-30 ft of decline
- 30-40 ft of decline
- > 40 ft of decline

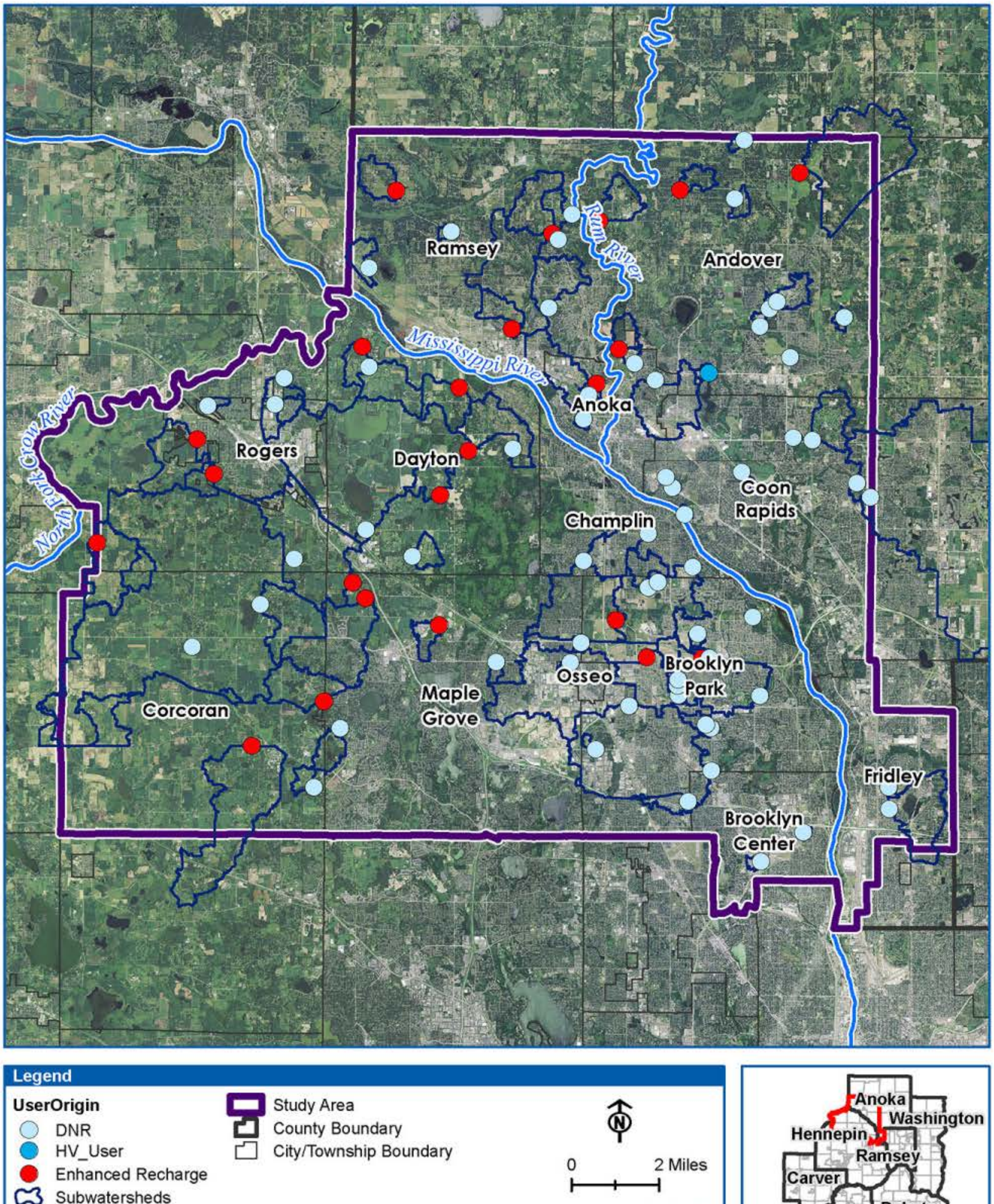
Sources: USDA NRCS, NHD, DNR

0 2 Miles

Figure shows the difference between modeled heads from baseline 2010 pumping conditions and modeled heads for 2040 continued development of groundwater sources, for the Tunnel City-Wonewoc Aquifer.

Metropolitan Council
Regional Water Supply, Groundwater Recharge, and Stormwater Capture and Reuse Study

Figure 17
Modeled Sites for Stormwater Reuse & Recharge
Northwest Metro Study Area



Sources: Met Council, DNR

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Appendix A1: Collector Well Analysis

Methodology

A review of existing geology data was performed to assess the potential development of collector wells in the Northwest Metro study area. Areas along both sides of the Mississippi River were included in the review. Well logs in the Minnesota Well Index (MWI) and logs of geotechnical borings in the Minnesota Department of Transportation (MnDOT) database were reviewed. The City of Ramsey Water Supply and Treatment Evaluation Report (Bolton & Menk, 2008) was also reviewed. Borings and wells that were drilled within approximately 500 feet of the Mississippi River were taken into consideration, representing a reasonable zone where a collector well might be proposed. Bedrock valleys containing deep sequences of unconsolidated sediments were targeted for review, followed by review of all areas along the Mississippi River. Areas shown to have 80 or more feet of unconsolidated material (primarily sand and gravel), with clay and silt thickness totaling no more than ten feet, were considered to be potentially suitable for collector wells. Bedrock formations were not evaluated. If unsuitable materials (e.g., clay or silt) were discovered laterally between the river and a suitable location, then the suitable location was removed from consideration since recharge from the river might be limited.

Geology Review

The study area adjacent to the Mississippi River is underlain by a variety of materials ranging from clayey till to coarse sand and gravel. Depth to bedrock is typically greater than 50 feet. In general, few areas along the Mississippi River have suitable geology for collector wells. MWI well logs indicate the bedrock valleys in the study area, such as in north Fridley, are filled mostly with clayey till. MnDOT borings at the US Highway 169 bridge crossing encountered bedrock at a depth of 80 feet or less, and the logs indicate significant loamy material and fine sand. MnDOT borings at the State Highway 610 bridge crossing indicated clay and silt throughout the borings. The collector well study performed by the City of Ramsey involved drilling eight borings (four of which were found in the MWI), and all locations were considered unsuitable for collector wells due to the presence of fine-grained materials (Bolton & Menk, 2008). Overall, 491 boring logs were reviewed, and ten of these locations appeared to have geologic materials suitable for collector wells. The reviewed locations are shown on Figure 8 in the main body of the report. A summary of the potentially suitable collector locations is provided in Table A1-1. Copies of the corresponding boring logs are included in Attachment A1-1.

Some of the well logs showing suitable material describe the entire unconsolidated zone as sand and gravel, whereas other logs indicate the presence of clay lenses within the coarser sediments. Well logs for Unique Nos. 480414, 520054, 533918, and 740949 indicate one or more clay lenses above a depth of 80 feet, although the clay lenses do not exceed ten feet in total thickness. Unique Nos. 126482, 148118, 155281, 162868, 169236, and 676424 indicate continuous sand and/or gravel to depths greater than 80 feet. A few locations (Unique Nos. 162868, 169236, and 520054) indicated sand and gravel at the termination depth, meaning the sand and gravel could continue deeper than the depth that was drilled (see Table A1-1). One potentially suitable location, corresponding with Unique No. 740949, is within the City of Ramsey collector well study area that was found to contain fine-grained material, which indicates the unconsolidated materials may be laterally heterogeneous. Geologic heterogeneity is also evidenced near well locations that have sufficient sand and gravel, such as Unique No. 148118, 480414, 533918, and 676424, which are only 100 feet from wells that have unsuitable geology. One area in the City of Ramsey has a group of four potentially suitable locations (Unique Nos. 162868, 169236, 480414, and 676424) that could indicate more widespread sand and gravel in that area, although it should be pointed out that two of the four locations are within

100 feet of unsuitable locations. Potentially suitable collector well locations are shown on Figure 8 in the main body of the report.

Table A1-1: Potentially Suitable Collector Locations

Unique Well No.	County	City	Depth Drilled (ft)	Depth to Bedrock (ft)	Sand and Gravel Bottom Depth (ft)
155281	Anoka	Ramsey	248	150	130
162868	Anoka	Ramsey	98	>98	>98
169236	Anoka	Ramsey	82	>82	>82
480414	Anoka	Ramsey	220	135	135
676424	Anoka	Ramsey	170	119	119
740949	Anoka	Ramsey	151	151	151
126482	Hennepin	Dayton	156	145	95
148118	Hennepin	Dayton	137	125	95
520054	Hennepin	Dayton	111	>111	>111
533918	Hennepin	Dayton	164	140	140

Notes:

All locations listed have less than ten feet of clay or silt noted as the primary or secondary lithology, and depth to bedrock is at least 80 feet.

Conclusion

The available boring logs within 500 feet of the Mississippi River in the Northwest Metro study area indicate ten individual locations where an appreciable thickness of sand and gravel may exist with limited amounts of clay and silt. The sand and gravel represents a potential target formation for a collector well, however the study area has a significant degree of geologic heterogeneity that could negatively impact well yield. Horizontally, many of the potentially suitable locations are adjacent to borings that are dominated by fine-grained material, resulting in apparent “pockets” of sand and gravel with uncertain extent. These pockets could limit the constructed length of horizontal well screens, and the degree of hydraulic connection to the river becomes questionable. Vertically, the clay lenses noted within the sand and gravel at some locations also could potentially limit the rate of recharge to the collector well screens from the river. These horizontal and vertical geologic limitations would result in an increased ratio of groundwater-to-surface water withdrawal, and the well yield would not be as high as in a situation with a more direct connection to the river. While the presence of fine-grained material is not ideal for collector well yield, some fine material is beneficial for natural filtration, and significant amounts of water could still be withdrawn from a properly designed and constructed well. Viability of a collector well would need to be determined through site-specific test drilling and aquifer testing.

Comparison of Collector Wells to Other Sources

There are advantages and disadvantages to consider when comparing collector wells with vertical wells and surface water intakes. Due to the ability to install long sections of well screen at the base of the most hydraulically efficient portion of the aquifer, collector well yields can be many times that of vertical wells. Compared to surface intakes, however, the yield of a collector is generally lower. Benefits of collector wells include a higher degree of reliability during drought conditions compared to direct surface water intake systems since the well yield is drawn from below the surface and is derived from a blend of groundwater and surface water sources.

The quality of the water obtained from collector wells will depend on the quality of the groundwater and surface water sources. Water drawn from a collector well with laterals underneath or in the vicinity of a river will typically provide a blend of water, drawing 50 to 90 percent of the water from the surface water source, and drawing 10 to 50 percent from groundwater. Upon startup a collector well would draw mostly groundwater, followed by an increasing percentage from surface water recharge as the well is pumped. Groundwater typically contains relatively high concentrations of hardness and metals compared to surface water. Blending groundwater with surface water in a collector well would reduce, through dilution, the concentrations of these constituents compared to vertical wells. To optimize yield and water quality, collector wells should be located as close to the river as possible.

In general, the water quality in collector wells will benefit from natural filtration through the riverbed materials and aquifer, and result in improved water quality over direct surface water intakes. The natural filtration will reduce suspended particulates, turbidity, natural organic matter, total organic carbon, and microbials from the source water. Natural filtration of surface water also eliminates the possibility of intake of fish and other aquatic organisms (e.g. zebra mussels). Collector wells can provide some protection and dampening of potential shock loads from contaminant spills.

As with vertical wells, temperature and water quality from collector wells is generally more consistent than that from direct surface water sources. The blending of the surface water with some component of groundwater will temper the seasonal variations in raw water temperature, as the temperature of groundwater is more consistent throughout the year. From a water treatment perspective, this can have an impact on the effectiveness of certain chemical processes and chemical feed quantities, including disinfection. When treated with a lime softening process, the water from a collector well would produce a lower quantity of solids (sludge) than water from a direct surface intake due to lower suspended solids in the influent water.

Land acquisition and easement requirements for collectors can be less intensive than well fields and surface water intakes. A typical collector well might require one parcel of land for the caisson building and a limited number of easements for the transmission pipeline, assuming the collector well is in close proximity to the treatment plant. A field of vertical wells could require multiple parcels and pipeline easements. Effects of collector well construction on natural resources can be minimal compared to a surface water intake since the well screens are drilled below the surface and trenching through potentially sensitive areas near rivers can usually be avoided. The environmental advantages of collector wells over surface water intakes could reduce permitting process time and expedite project implementation. Collector well construction costs are typically much higher than vertical well costs, and in some cases can cost more than surface water intakes.

Collector Well Planning and Design Considerations

Many of the steps taken to construct a collector well are similar to a vertical well. Prior to construction, land should be acquired for construction of the concrete caisson, pump house, and raw water delivery pipeline. Electrical service is required at the pump house, potentially requiring additional land easement. Wells are regulated by the Minnesota Department of Health (MDH), who must approve the well design and location prior to construction. The Minnesota Department of Natural Resources (MnDNR) requires a preliminary well construction approval and a water use (appropriation) permit for any well that withdraws greater than 10,000 gallons of water per day or 1 million gallons per year. To protect any private wells used for domestic water supply that might be in the vicinity of a collector well, the MnDNR may request that the applicant estimate the well interference the new well might cause with nearby wells. Since a collector well would likely draw water from both groundwater and surface water sources, the MnDNR might also require a study of potential impacts to the river (e.g., streamflow depletion).

Collector Well Construction Costs

Concept-level costs were developed to cover a range of collector well sizes. Costs for construction will vary depending on the local geology, expected well yield, and distance from the water treatment plant. Costs shown in Table A1-2 represent estimated costs for collector well construction. Water treatment costs were not included.

The following assumptions were used in the development of collector well costs:

- Raw water transmission distance: 5 miles;
- Static groundwater level: 20 feet below ground surface;
- Drawdown in well: 70 feet below static water level;
- Elevation rise from well to treatment plant: 50 feet; and
- Well maintenance interval: every 7 years.

Table A1-2: Estimated Costs for Collector Well Construction

Item	Estimated Costs for Facilities			
Well Yield	5 MGD	10 MGD	15 MGD	20 MGD
CAPITAL COSTS				
Well Construction	$1,500,000	$2,200,000	$3,000,000	$3,800,000
Pumps, Well House	$750,000	$1,000,000	$1,400,000	$1,700,000
Transmission Pipeline (5 miles)	$5,000,000	$7,500,000	$10,500,000	$13,000,000
TOTAL COST OF FACILITIES (includes 5 miles of pipeline)	**$7,250,000**	**$10,700,000**	**$14,900,000**	**$18,500,000**
PROJECT COSTS				
Design Contingencies (30%)	$2,175,000	$3,210,000	$4,470,000	$5,550,000
Engineering, Administration, Legal (20%)	$1,450,000	$2,140,000	$2,980,000	$3,700,000
Environmental & Archaeology Studies and Mitigation	$1,988,000	$1,988,000	$1,988,000	$1,988,000
Land Acquisition and Surveying (18 acres)	$5,793,000	$5,793,000	$5,793,000	$5,793,000
TOTAL PROJECT COSTS	**$11,406,000**	**$13,131,000**	**$15,231,000**	**$17,031,000**
OPERATION AND MAINTENANCE COSTS				
Pipelines (1% of Cost of Facilities)	$50,000	$75,000	$105,000	$130,000
Pumps, Well House (2.5% Cost of Facilities)	$56,000	$80,000	$110,000	$138,000
Pumping Energy Costs (includes 5-mile delivery) , $0.072/kW-hr	$64,000	$108,000	$145,000	$175,000
Well Screen Maintenance (annualized)	$19,000	$22,000	$25,000	$28,000
ANNUAL O&M COSTS	**$189,000**	**$285,000**	**$385,000**	**$471,000**

Attachment A1-1: Collector Well Geology Evaluation – Well Logs

Minnesota Unique Well No.

126482

County Hennepin
Quad Anoka
Quad ID 120B

MINNESOTA DEPARTMENT OF HEALTH

WELL AND BORING RECORD

Minnesota Statutes Chapter 1031

Entry Date 08/24/1991
Update Date 02/14/2014
Received Date

Well Name	Township	Range	Dir	Section	Subsections	Use	Depth Drilled	Depth Completed	Date Completed	Lic/Reg. No.
	120	22	W	10	DDBBBD	Domestic	156 ft.	156 ft.	10/11/1976	27056

Elevation 872 ft. **Method** 7.5 minute topographic map (+/- 5 feet) **Aquifer** Jordan **Depth to Bedrock** 145 ft. **Open Hole** - ft. **Static Water Level** 35 ft.

Field Located Minnesota Geological Survey
Unique No. Verified Address verification
Geologic Interpetation John Mossler

Location Method Digitized - scale 1:24,000 or larger (Digitizing Table)
Input Source Minnesota Geological Survey
Input Date 01/01/1990
Agency (interpetation) Minnesota Geological Survey

Universial Transverse Mercator (UTM) - NAD83 - Zone 15 - Meters
UTM Easting (X) 464888
UTM Northing (Y) 5006727
Interpetation Method Geologic study 1:24k to 1:100k

Geological Material	Color	Hardness	DEPTH (ft.) From	To	Thickness	ELEVATION From	To	Stratigraphy	Primary Lithology	Secondary Lithology	Minor Lithology
SAND			0	55	55	872	817	sand	Sand		
GRAVEL			55	95	40	817	777	gravel (+larger)	Gravel		
CLAY			95	145	50	777	727	clay	Clay		
SOFT SANDROCK			145	156	11	727	716	Jordan Sandstone	Sandstone		

County Well Index Online Well Stratigraphy Report

126482

Printed 7/18/2014

Minnesota Unique Well No.

148118

County Hennepin
Quad Anoka
Quad ID 120B

MINNESOTA DEPARTMENT OF HEALTH

WELL AND BORING RECORD

Minnesota Statutes Chapter 103I

Entry Date 08/24/1991
Update Date 02/14/2014
Received Date

Well Name ODIN INC.

Township Range Dir Section Subsections Elevation 873 ft.

120 22 W 10 DADBAB Elevation Method 7.5 minute topographic map (+/- 5 feet)

Well Depth	Depth Completed	Date Well Completed
137 ft.	137 ft.	10/14/1976

Drilling Method Non-specified Rotary

Well Address
12801 OVERLOOK RD
DAYTON MN 55327

Geological Material	Color	Hardness	From	To
SAND			0	95
CLAY			95	125
SANDROCK		SOFT	125	137

Drilling Fluid
--

Well Hydrofractured? ☐ Yes ☐ No
From Ft. to Ft.

Use Domestic

Casing Type Steel (black or low carbon) Joint No Information Drive Shoe? ☐ Yes ☐ No Above/Below 0 ft.

Casing Diameter	Weight	Hole Diameter
4 in. to 132 ft.	lbs./ft.	

Open Hole from ft. to ft.

Screen YES Make JOHNSON Type stainless steel

Diameter	Slot/Gauze	Length	Set Between
		4	ft. and ft.

Static Water Level
40 ft. from Land surface Date Measured 10/14/1976

PUMPING LEVEL (below land surface)
50 ft. after 3 hrs. pumping 20 g.p.m.

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

REMARKS
SOUTH 0.5 SECT.

Located by: Minnesota Geological Survey
Method: Digitized - scale 1:24,000 or larger (Digitizing Table)
Unique Number Verification: Address verification
Input Date: 01/01/1990
System: UTM - Nad83, Zone15, Meters
X: 465095 Y: 5006954

Grouting Information Well Grouted? ☑ Yes ☐ No

Nearest Known Source of Contamination
__feet __direction __type

Well disinfected upon completion? ☑ Yes ☐ No

Pump ☑ Not Installed Date Installed 10/20/1976
Manufacturer's name AERMOTOR Model number __ HP 0.5 Volts
Length of drop Pipe 63 ft. Capacity _g.p.m Type Submersible Material Galvanized

Abandoned Wells Does property have any not in use and not sealed well(s)? ☐ Yes ☐ No

Variance Was a variance granted from the MDH for this well? ☐ Yes ☐ No

First Bedrock Jordan Sandstone
Last Strat Jordan Sandstone
Aquifer Jordan
Depth to Bedrock 125 ft.

Well Contractor Certification

License Business Name	Lic. Or Reg. No.	Name of Driller
Torgerson Well Co.	27056	TORGERSON, S.

County Well Index Online Report 148118 Printed 7/17/2014
HE-01205-07

Minnesota Unique Well No.

155281

County Anoka
Quad Anoka
Quad ID 120B

MINNESOTA DEPARTMENT OF HEALTH

WELL AND BORING RECORD

Minnesota Statutes Chapter 103I

Entry Date 04/15/1991
Update Date 02/14/2014
Received Date

Well Name LUKE, TERRY

Township	Range	Dir	Section	Subsections	Elevation	866 ft.
32	25	W	29	CCCDDD	Elevation Method	7.5 minute topographic map (+/- 5 feet)

Well Depth	Depth Completed	Date Well Completed
248 ft.	248 ft.	10/24/1978

Drilling Method Non-specified Rotary

Well Address
14200 BOWERS DR NW
RAMSEY MN 55303

Geological Material	Color	Hardness	From	To
SAND			0	80
GRAVEL			80	130
CLAY			130	150
SANDROCK			150	186
ROCK			186	248

Drilling Fluid
--

Well Hydrofractured? ☐ Yes ☐ No
From Ft. to Ft.

Use Domestic

Casing Type Steel (black or low carbon) Joint Threaded Drive Shoe? ☐ Yes ☐ No Above/Below ft.

Casing Diameter	Weight	Hole Diameter
4 in. to 186 ft.	lbs./ft.	4 in. to 248 ft.

Open Hole from 186 ft. to 248 ft.

Screen NO Make Type

Diameter	Slot/Gauze	Length	Set Between

Static Water Level
30 ft. from Land surface Date Measured 10/24/1978

PUMPING LEVEL (below land surface)
40 ft. after 3 hrs. pumping 30 g.p.m.

Well log showing the geology at Minnesota Unique Well No. 155281.

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

REMARKS
BOWERS MISS. ACRES BLK 1 LOT 8. SOUTH 0.5 SECT.

Located by: Minnesota Geological Survey
Method: Digitization (Screen) - Map (1:24,000)
Unique Number Verification: Address verification
Input Date: 07/13/2004
System: UTM - Nad83, Zone15, Meters
X: 461846 Y: 5008333

Grouting Information Well Grouted? ☑ Yes ☐ No

Nearest Known Source of Contamination
__feet __direction __type

Well disinfected upon completion? ☑ Yes ☐ No

Pump ☑ Not Installed Date Installed 10/27/1978
Manufacturer's name AERMOTOR Model number __ HP 0.5 Volts
Length of drop Pipe 54 ft. Capacity _g.p.m Type Submersible Material Galvanized

Abandoned Wells Does property have any not in use and not sealed well(s)? ☐ Yes ☐ No

Variance Was a variance granted from the MDH for this well? ☐ Yes ☐ No

First Bedrock Franconia
Last Strat Franconia
Aquifer Franconia
Depth to Bedrock 150 ft.

Well Contractor Certification

Torgerson Well Co.	27056	OTTEN, D.
License Business Name	Lic. Or Reg. No.	Name of Driller

County Well Index Online Report

155281

Printed 7/17/2014
HE-01205-07

Minnesota Unique Well No.

162868

County	Anoka
Quad	Anoka
Quad ID	120B

MINNESOTA DEPARTMENT OF HEALTH

WELL AND BORING RECORD

Minnesota Statutes Chapter 1031

Entry Date	04/15/1991
Update Date	02/14/2014
Received Date	

Well Name	Township	Range	Dir	Section	Subsections	Use	Depth Drilled	Depth Completed	Date Completed	Lic/Reg. No.
GORHAM, GARY	32	25	W	19	DCDDBC	Domestic	98 ft.	98 ft.	09/25/1979	02164

Elevation 870 ft. **Method** 7.5 minute topographic map (+/- 5 feet) **Aquifer** Quat. Water Table Aquifer **Depth to Bedrock** ft. **Open Hole** - ft. **Static Water Level** 28 ft.

Field Located Minnesota Geological Survey
Unique No. Verified Address verification
Geologic Interpetation Emily Bauer

Location Method Digitized - scale 1:24,000 or larger (Digitizing Table)
Input Source Minnesota Geological Survey
Input Date 01/01/1990
Agency (interpetation) Minnesota Geological Survey

Universial Transverse Mercator (UTM) - NAD83 - Zone 15 - Meters
UTM Easting (X) 460984
UTM Northing (Y) 5009928
Interpetation Method Geologic study 1:24k to 1:100k

Geological Material	Color	Hardness	DEPTH (ft.) From	To	Thickness	ELEVATION From	To	Stratigraphy	Primary Lithology	Secondary Lithology	Minor Lithology
SAND & GRAVEL	BROWN	HARD	0	88	88	870	782	sand +larger-brown	Sand	Gravel	
UNIFORM WATERSAND	BROWN	MEDIUM	88	98	10	782	772	sand-brown	Sand		

County Well Index Online Well Stratigraphy Report | **162868** | Printed 7/17/2014

Minnesota Unique Well No.

169236

County	Anoka
Quad	Anoka
Quad ID	120B

MINNESOTA DEPARTMENT OF HEALTH

WELL AND BORING RECORD

Minnesota Statutes Chapter 1031

Entry Date	04/15/1991
Update Date	02/14/2014
Received Date	

Well Name	Township	Range	Dir	Section	Subsections	Use	Depth Drilled	Depth Completed	Date Completed	Lic/Reg. No.
PETERSON, PETE	32	25	W	19	DCDDDC	Domestic	82 ft.	82 ft.	12/29/1980	27086

Elevation 870 ft. **Method** 7.5 minute topographic map (+/- 5 feet) **Aquifer** Quat. Water Table Aquifer **Depth to Bedrock** ft. **Open Hole** - ft. **Static Water Level** 40 ft.

Field Located Minnesota Geological Survey
Unique No. Verified Information from owner
Geologic Interpetation Bruce Bloomgren

Location Method Digitization (Screen) - Map (1:24,000)
Input Source Minnesota Geological Survey
Input Date 08/19/2008
Agency (interpetation) Minnesota Geological Survey

Universial Transverse Mercator (UTM) - NAD83 - Zone 15 - Meters
UTM Easting (X) 461023
UTM Northing (Y) 5009874
Interpetation Method Geologic study 1:24k to 1:100k

Geological Material	Color	Hardness	DEPTH (ft.) From	To	Thickness	ELEVATION From	To	Stratigraphy	Primary Lithology	Secondary Lithology	Minor Lithology
SAND	BROWN	SOFT	0	82	82	870	788	sand-brown	Sand		

County Well Index Online Well Stratigraphy Report | **169236** | Printed 7/17/2014

Minnesota Unique Well No.

480414

County	Anoka
Quad	Anoka
Quad ID	120B

MINNESOTA DEPARTMENT OF HEALTH

WELL AND BORING RECORD

Minnesota Statutes Chapter 1031

Entry Date	03/02/1993
Update Date	02/14/2014
Received Date	10/30/1992

Well Name	Township	Range	Dir	Section	Subsections	Use	Depth Drilled	Depth Completed	Date Completed	Lic/Reg. No.
	32	25	W	19	DCDCBD	Domestic	220 ft.	220 ft.	06/26/1992	02203

Elevation 873 ft. **Method** 7.5 minute topographic map (+/- 5 feet) **Aquifer** Franconia-Ironton-Galesvill **Depth to Bedrock** 135 ft. **Open Hole** 153 - 220 ft. **Static Water Level** 30 ft.

Field Located Minnesota Geological Survey
Unique No. Verified Address verification

Geologic Interpetation John Mossler

Location Method Digitization (Screen) - Map (1:24,000)
Input Source Minnesota Geological Survey
Input Date 07/03/2008
Agency (interpetation) Minnesota Geological Survey

Universial Transverse Mercator (UTM) - NAD83 - Zone 15 - Meters
UTM Easting (X) 460881
UTM Northing (Y) 5009960
Interpetation Method Geologic study 1:24k to 1:100k

Geological Material	Color	Hardness	DEPTH (ft.) From	To	Thickness	ELEVATION From	To	Stratigraphy	Primary Lithology	Secondary Lithology	Minor Lithology
SAND	BROWN	SOFT	0	30	30	873	843	sand-brown	Sand		
CLAY	BROWN	MEDIUM	30	40	10	843	833	clay-brown	Clay		
ROCKS, GRAVEL	BLACK	HARD	40	135	95	833	738	gravel (+larger)-black	Gravel	Cobble	
SHALE	BLUE	MEDIUM	135	145	10	738	728	Franconia	Shale	Sandstone	Dolomite
SHALE	GREEN	MEDIUM	145	153	8	728	720	Franconia	Shale	Sandstone	Dolomite
SANDROCK	WHITE	HARD	153	220	67	720	653	Franconia-Ironton-Galesvill	Sandstone	Shale	

County Well Index Online Well Stratigraphy Report **480414** Printed 7/17/2014

Minnesota Unique Well No.

520054

County	Hennepin
Quad	Rogers
Quad ID	121A

MINNESOTA DEPARTMENT OF HEALTH

WELL AND BORING RECORD

Minnesota Statutes Chapter 1031

Entry Date	06/11/1993
Update Date	02/14/2014
Received Date	04/09/1993

Well Name	Township	Range	Dir	Section	Subsections	Use	Depth Drilled	Depth Completed	Date Completed	Lic/Reg. No.
AKERMAN, JERRY	121	22	W	31	DBCBCB	Domestic	111 ft.	110 ft.	02/25/1993	71015

Elevation 870 ft. **Method** 7.5 minute topographic map (+/- 5 feet) **Aquifer** Quat. Buried Unconf. Aquife **Depth to Bedrock** ft. **Open Hole** - ft. **Static Water Level** 40 ft.

Field Located Minnesota Geological Survey
Unique No. Verified Address verification
Geologic Interpetation Bruce Bloomgren

Location Method Digitization (Screen) - Map (1:24,000)
Input Source Minnesota Geological Survey
Input Date 07/14/2008
Agency (interpetation) Minnesota Geological Survey

Universial Transverse Mercator (UTM) - NAD83 - Zone 15 - Meters
UTM Easting (X) 459985
UTM Northing (Y) 5010078
Interpetation Method Geologic study 1:24k to 1:100k

			DEPTH (ft.)			ELEVATION					
Geological Material	**Color**	**Hardness**	**From**	**To**	**Thickness**	**From**	**To**	**Stratigraphy**	**Primary Lithology**	**Secondary Lithology**	**Minor Lithology**
CLAY	BROWN	MEDIUM	0	10	10	870	860	clay-brown	Clay		
SAND	BROWN	SOFT	10	34	24	860	836	sand-brown	Sand		
SAND & GRAVEL	BROWN	SOFT	34	82	48	836	788	sand +larger-brown	Sand	Gravel	
SAND	BROWN	SOFT	82	111	29	788	759	sand-brown	Sand		

County Well Index Online Well Stratigraphy Report **520054** Printed 7/17/2014

Minnesota Unique Well No.

533918

County Hennepin
Quad Anoka
Quad ID 120B

MINNESOTA DEPARTMENT OF HEALTH

WELL AND BORING RECORD

Minnesota Statutes Chapter 1031

Entry Date 12/12/1996
Update Date 02/14/2014
Received Date 03/09/1994

Well Name	Township	Range	Dir	Section	Subsections	Use	Depth Drilled	Depth Completed	Date Completed	Lic/Reg. No.
	120	22	W	5	CAABDB	Domestic	164 ft.	164 ft.	02/22/1994	02164

Elevation 903 ft. **Method** 7.5 minute topographic map (+/- 5 feet) **Aquifer** Jordan **Depth to Bedrock** 140 ft. **Open Hole** - ft. **Static Water Level** 55 ft.

Field Located Minnesota Geological Survey
Unique No. Verified Address verification
Geologic Interpetation John Mossler

Location Method Digitization (Screen) - Map (1:24,000)
Input Source Minnesota Geological Survey
Input Date 07/10/2008
Agency (interpetation) Minnesota Geological Survey

Universial Transverse Mercator (UTM) - NAD83 - Zone 15 - Meters
UTM Easting (X) 461154
UTM Northing (Y) 5008725
Interpetation Method Geologic study 1:24k to 1:100k

			DEPTH (ft.)			ELEVATION					
Geological Material	**Color**	**Hardness**	**From**	**To**	**Thickness**	**From**	**To**	**Stratigraphy**	**Primary Lithology**	**Secondary Lithology**	**Minor Lithology**
SAND	TAN	SOFT	0	15	15	903	888	sand-brown	Sand		
CLAY	GRAY	MEDIUM	15	25	10	888	878	clay-gray	Clay		
SAND & GRAVEL	BROWN	MEDIUM	25	110	85	878	793	sand +larger-brown	Sand	Gravel	
GRAVEL	BROWN	HARD	110	140	30	793	763	gravel (+larger)-brown	Gravel		
SANDSTONE	GRAY	SOFT	140	164	24	763	739	Jordan Sandstone	Sandstone		

County Well Index Online Well Stratigraphy Report **533918** Printed 7/17/2014

Minnesota Unique Well No.

676424

County Anoka
Quad Anoka
Quad ID 120B

MINNESOTA DEPARTMENT OF HEALTH
WELL AND BORING RECORD
Minnesota Statutes Chapter 1031

Entry Date 12/30/2002
Update Date 12/11/2008
Received Date

Well Name	Township	Range	Dir	Section	Subsections	Use	Depth Drilled	Depth Completed	Date Completed	Lic/Reg. No.
DUMKE, JOSEPHINE	32	25	W	19	DCCACD	Domestic	170 ft.	170 ft.	09/09/2002	71015

Elevation 872 ft. **Method** 7.5 minute topographic map (+/- 5 feet) **Aquifer** Franconia **Depth to Bedrock** 119 ft. **Open Hole** 126 - 170 ft. **Static Water Level** 28 ft.

Field Located Minnesota Geological Survey
Unique No. Verified Address verification
Geologic Interpetation John Mossler

Location Method Digitization (Screen) - Map (1:24,000)
Input Source Minnesota Geological Survey
Input Date 06/26/2008
Agency (interpetation) Minnesota Geological Survey

Universial Transverse Mercator (UTM) - NAD83 - Zone 15 - Meters
UTM Easting (X) 460783
UTM Northing (Y) 5009996
Interpetation Method Geologic study 1:24k to 1:100k

Geological Material	Color	Hardness	DEPTH (ft.) From	To	Thickness	ELEVATION From	To	Stratigraphy	Primary Lithology	Secondary Lithology	Minor Lithology
SAND & GRAVEL	BROWN	MEDIUM	0	86	86	872	786	sand +larger-brown	Sand	Gravel	
CLAY & ROCKS	GRAY	HARD	86	111	25	786	761	pebbly sand/silt/clay-gray	Clay	Cobble	
GRAVEL	GRAY	MEDIUM	111	119	8	761	753	gravel (+larger)-gray	Gravel		
SANDSTONE W/SHALE	TAN	HARD	119	170	51	753	702	Franconia	Sandstone	Shale	Dolomite

County Well Index Online Well Stratigraphy Report | **676424** | Printed 7/17/2014

Minnesota Unique Well No.

740949

County Anoka
Quad Anoka
Quad ID 120B

MINNESOTA DEPARTMENT OF HEALTH

WELL AND BORING RECORD

Minnesota Statutes Chapter 103I

Entry Date 09/25/2006
Update Date 08/13/2010
Received Date 08/03/2008

Well Name CITY OF RAMSEY

Township Range Dir Section Subsections Elevation 856 ft.

32 25 W 33 AACCAD Elevation Method 7.5 minute topographic map (+/- 5 feet)

Well Depth 151 ft. Depth Completed 71 ft. Date Well Completed 06/08/2006

Drilling Method Multiple methods used

Well Address
XXXXX TRAPROCK ST
RAMSEY MN 55303

Drilling Fluid Water

Well Hydrofractured? ☐ Yes ☑ No
From Ft. to Ft.

Use Test well

Geological Material	Color	Hardness	From	To
SAND	BROWN	SOFT	0	10
SAND/MEDIUM GRAVEL	GRAY	SOFT	10	60
FINE SAND	GRAY	SOFT	60	65
SAND,GRAVEL,CLAY	BROWN	SOFT	65	70
SAND/GRAVEL	BROWN	SOFT	70	75
CLAY/GRAVEL	GRAY	SOFT	75	80
SAND/GRAVEL LAYERS	BROWN	SOFT	80	115
MEDIUM SAND/GRAVEL	BROWN	SOFT	115	120
SAND/GRAVEL/CLAY LENSES	BROWN	SOFT	120	125
SILTY FINE SAND	BROWN	SOFT	125	135
FN-CRS SAND/CLAY LENSES	BROWN	SOFT	135	140
FN-CRS SAND	BROWN	SOFT	140	145
CRS SAND & GRAVEL	BROWN	SOFT	145	151
PINK SANDSTONE	PINK	MED-HRD	151	151

Casing Type Steel (black or low carbon) Joint Welded Drive Shoe? ☑ Yes ☐ No Above/Below ft.

Casing Diameter 6 in. to 62 ft.
Weight 18.97 lbs./ft.
Hole Diameter 6.88 in. to 151 ft.

Open Hole from ft. to ft.

Screen YES Make JOHNSON Type stainless steel

Diameter	Slot/Gauze	Length	Set Between
6	30	5	62 ft. and 67 ft.
6	20	4	67 ft. and 71 ft.

Static Water Level
20.8 ft. from Land surface Date Measured 06/08/2006

PUMPING LEVEL (below land surface)
48.5 ft. after 1 hrs. pumping 62 g.p.m.

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

NO REMARKS

Grouting Information Well Grouted? ☐ Yes ☑ No

Located by:
Unique Number Verification: Address verification
System: UTM - Nad83, Zone15, Meters

Method: Digitization (Screen) - Map (1:12,000)
Input Date: 02/08/2010
X: 464386 Y: 5007860

Nearest Known Source of Contamination
150 feet N direction Septic tank/drain field type
Well disinfected upon completion? ☐ Yes ☐ No

Pump ☐ Not Installed Date Installed
Manufacturer's name Model number HP Volts
Length of drop Pipe ft. Capacity g.p.m Type Material

Abandoned Wells Does property have any not in use and not sealed well(s)? ☐ Yes ☑ No

Variance Was a variance granted from the MDH for this well? ☐ Yes ☑ No

Well Contractor Certification
Mark J Traut Wells, Inc. — License Business Name
1404 — Lic. Or Reg. No.
ED/TONY — Name of Driller

First Bedrock Franconia
Last Strat Franconia

Aquifer Quat. Water Table Aquifer
Depth to Bedrock 151 ft.

County Well Index Online Report

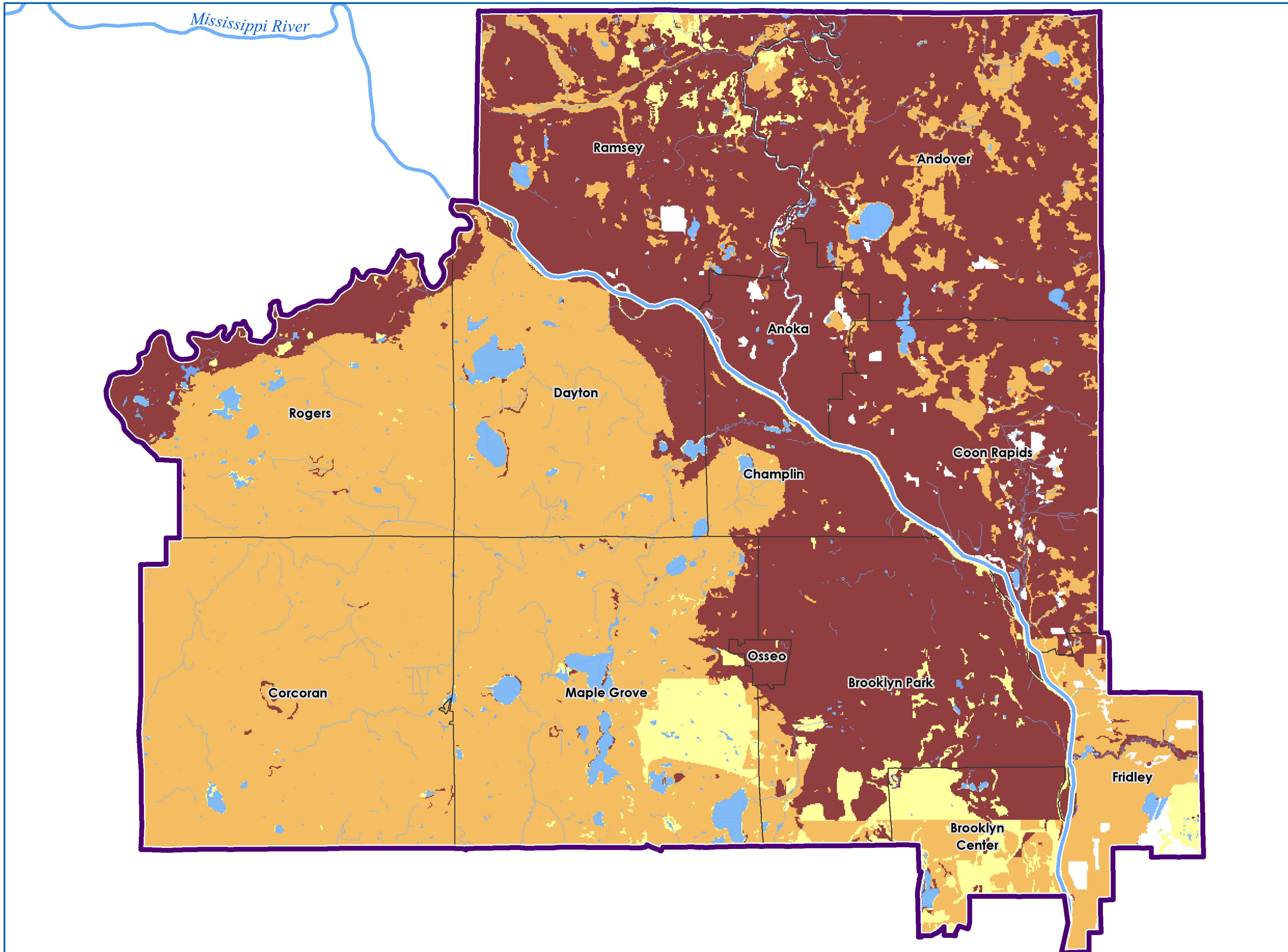
740949

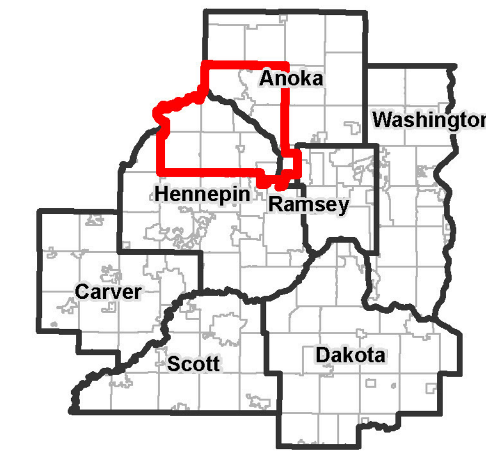
Printed 7/17/2014
HE-01205-07

Appendix A2: Enhanced Recharge Study Figures

Metropolitan Council
Regional Water Supply, Groundwater Recharge, and Stormwater Capture and Reuse Study

Figure A2-1
Average Vertical Infiltration Rate (Top 5 feet)
Norhwest Metro Study Area





Legend

Average Vertical Infiltration Rate (in/hr)

- > 5 in/hr (Tier 1)
- 0.5 - 5 in/hr (Tier 2)
- < 0.5 in/hr (Tier 3)
- Study Area
- City/Township Boundary
- Waterbody
- Perennial Stream

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

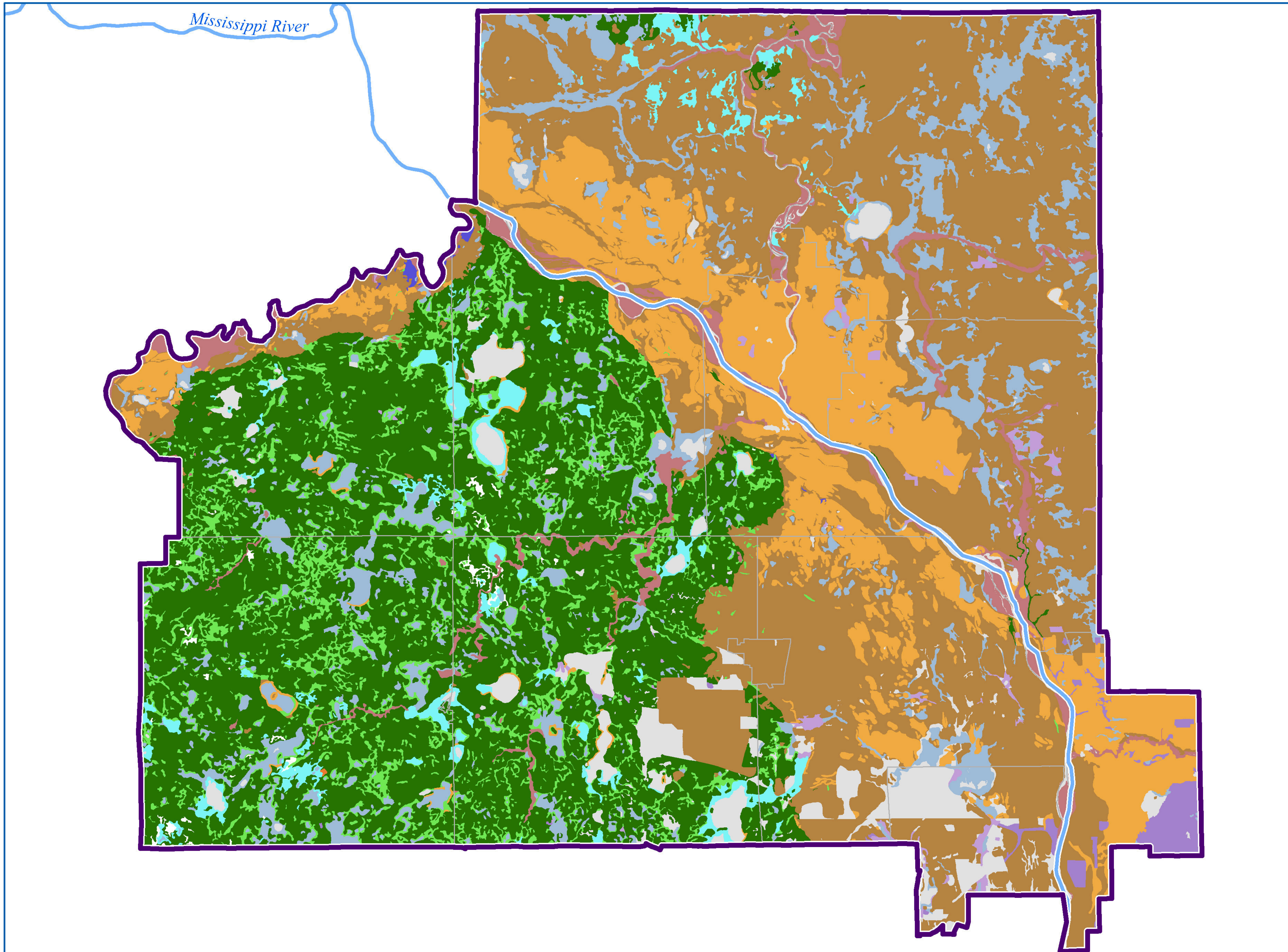
Sources: USDA NRCS, NHD, DNR

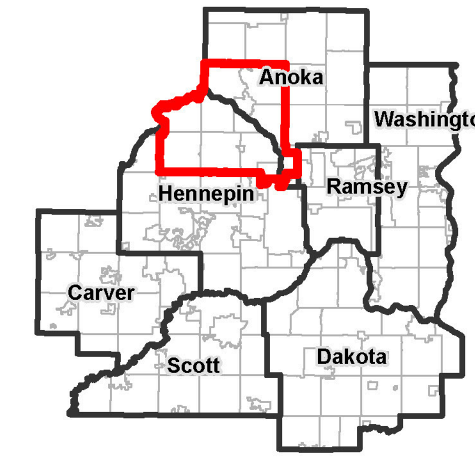
0 2 Miles

Document Path: \\mspe-gis-file\gisproj\MetCouncil\224209\map_docs\Northwest_Region\A2-01_Average_ksatR_11x17L.mxd

Metropolitan Council
Regional Water Supply, Groundwater Recharge, and Stormwater Capture and Reuse Study

Figure A2-2
Soil Parent Material
Northwest Metro 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
- Study Area
- County Boundary
- City/Township Boundary

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

Sources: USDA NRCS, NHD, DNR

0 2 Miles

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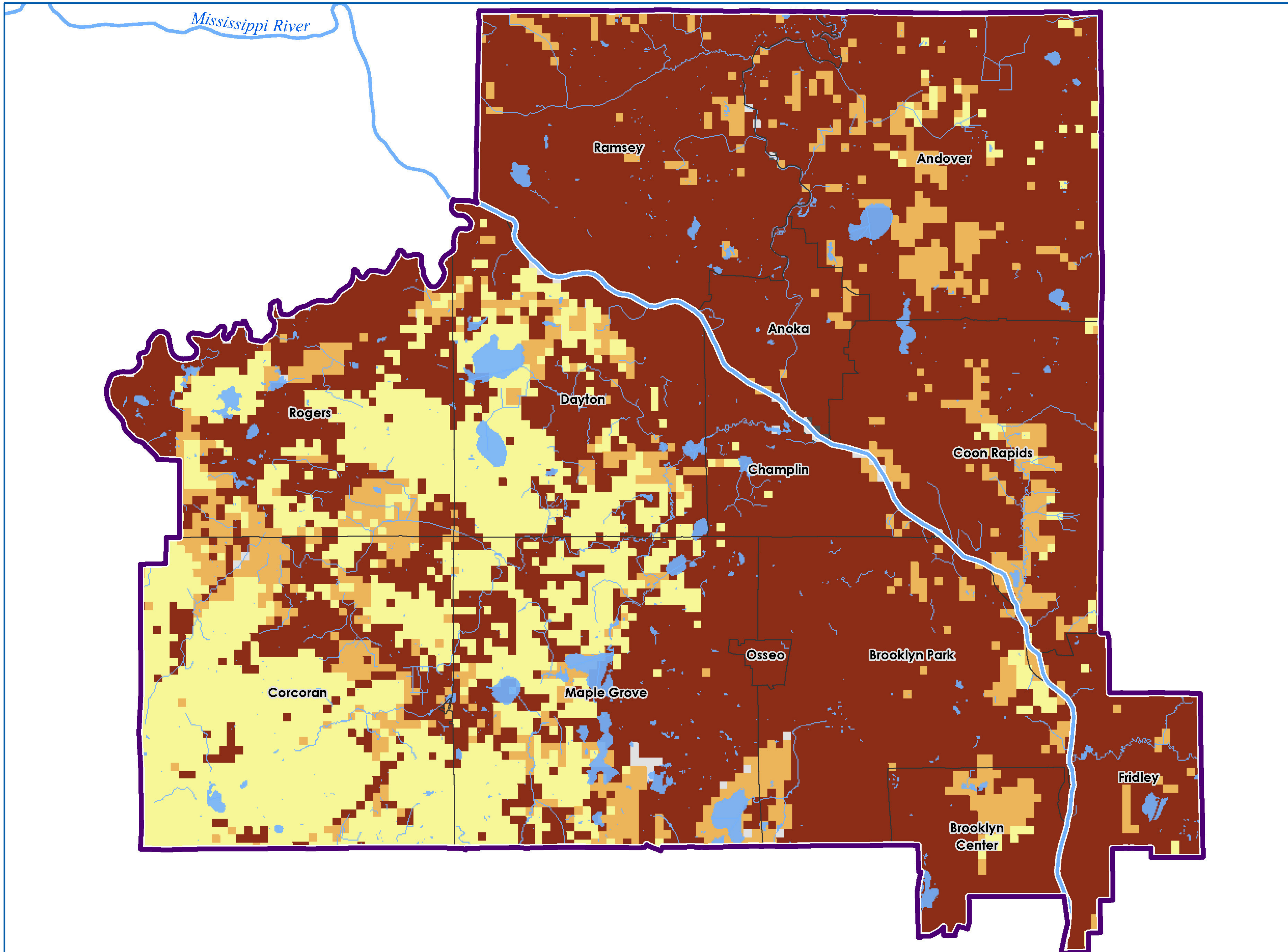
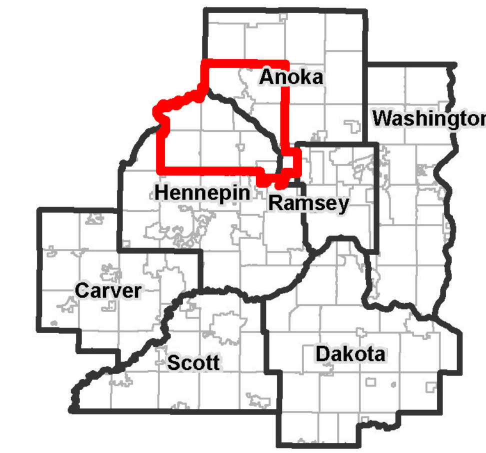
Metropolitan Council
Regional Water Supply, Groundwater Recharge, and Stormwater Capture and Reuse Study

Figure A2-3
Average Hydraulic Conductivity Upper 60 ft
Northwest Metro Study Area





Legend

Hydraulic Conductivity (ft/day)
- > 10 (Tier 1)
- 1-10 (Tier 2)
- < 1 (Tier 3)
- Insufficient Data (Permeable Parent Material)
- Insufficient Data
- Study Area
- City/Township Boundary
- Waterbody
- Perennial Stream

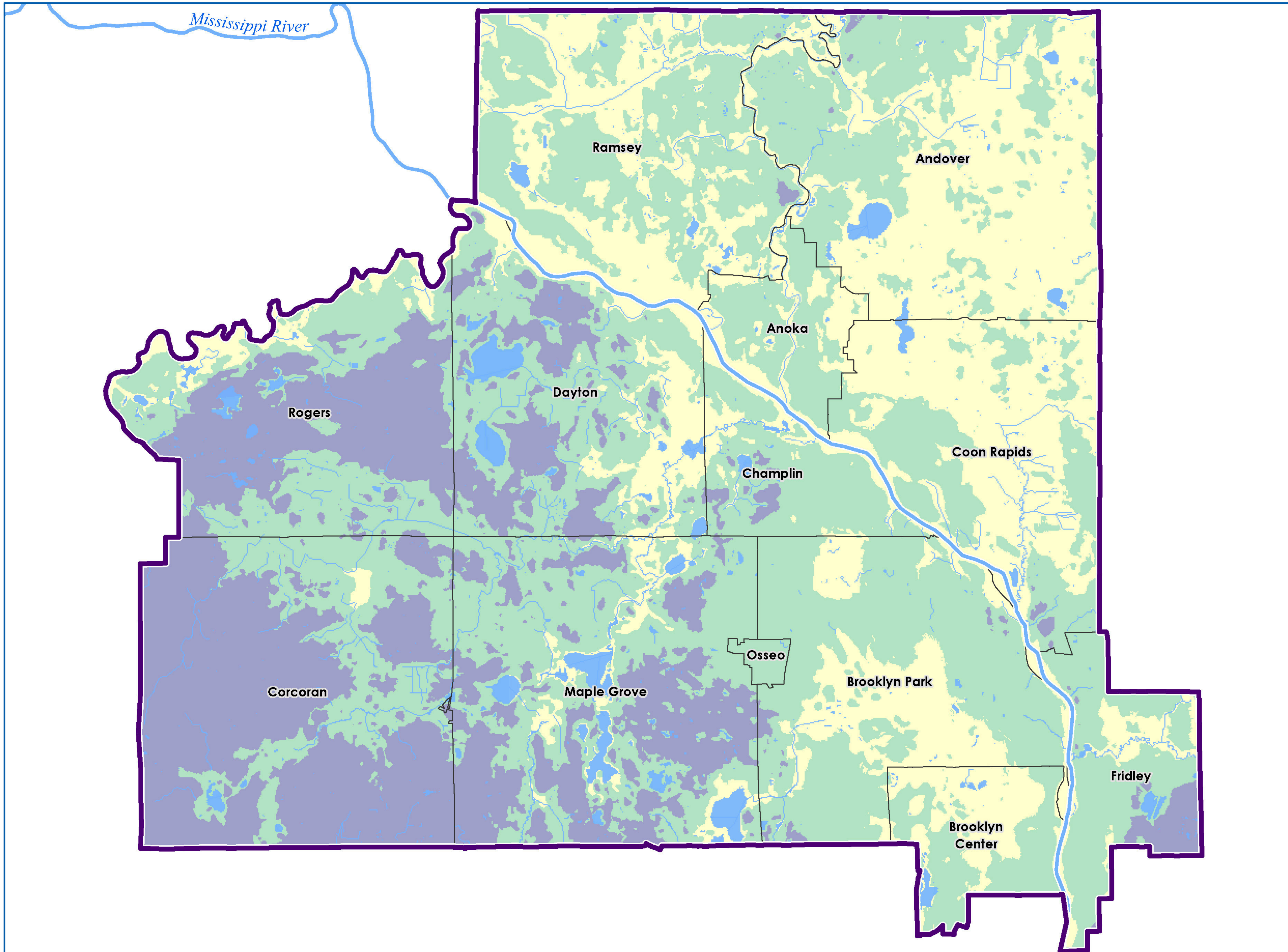
Note: Average hydraulic conductivity calculated from Tipping (2011).

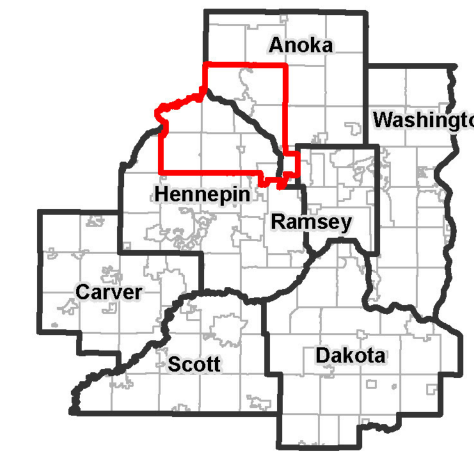
Sources: MGS Tipping, NHD, DNR

0 2 Miles

Metropolitan Council
Regional Water Supply, Groundwater Recharge, and Stormwater Capture and Reuse Study

Figure A2-4
Depth to Regional Water Table Northwest Metro Study Area





Legend

Depth to Water Table (ft)
- > 50 (Tier 1)
- 15-50 (Tier 2)
- < 15 (Tier 3)
- Study Area
- 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 2 Miles

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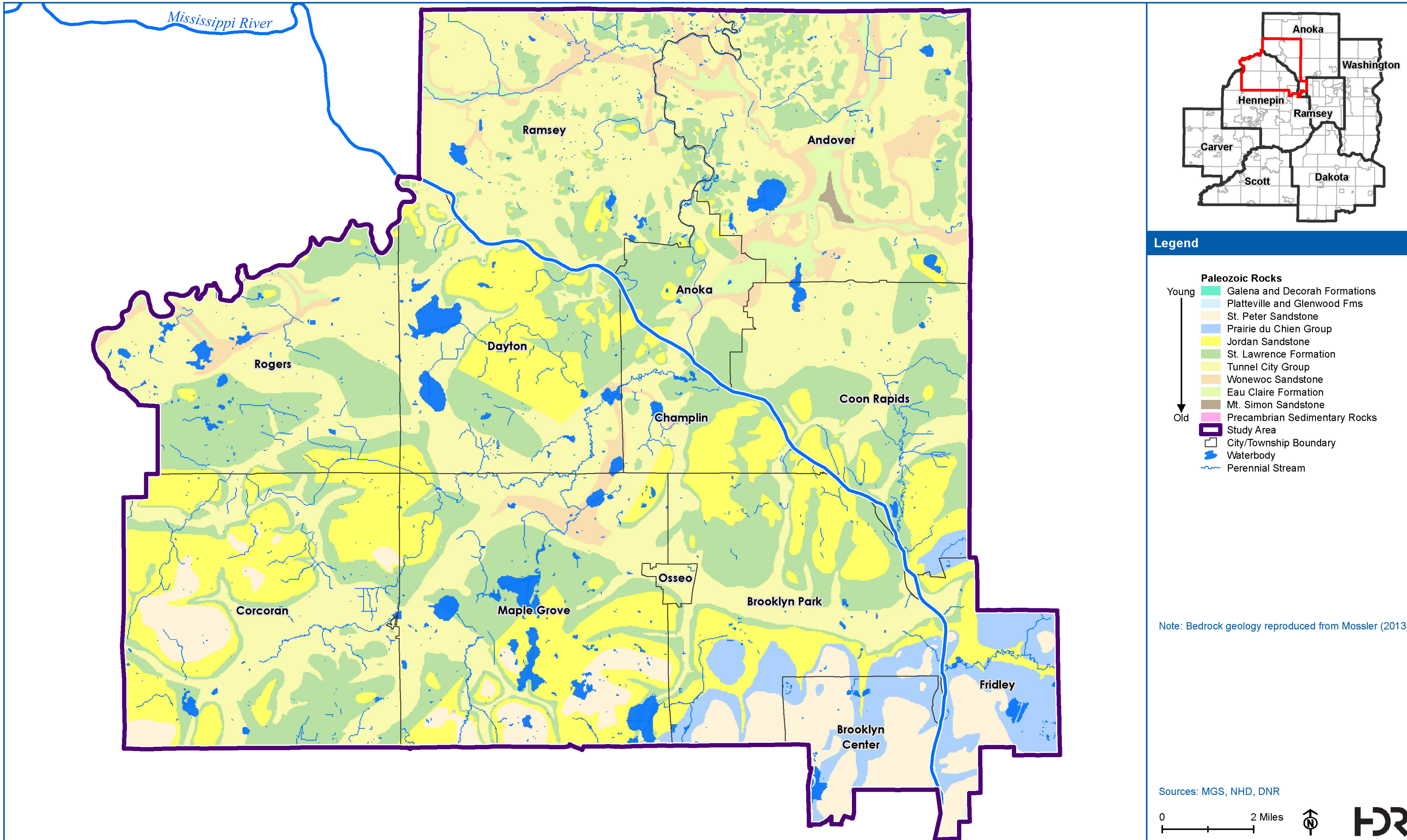
Metropolitan Council
Regional Water Supply, Groundwater Recharge, and Stormwater Capture and Reuse Study

Figure A2-5
Bedrock Geology
Northwest Metro Study Area



Legend

Paleozoic Rocks

Young → Old

- Galena and Decorah Formations
- Platteville and Glenwood Fms
- St. Peter Sandstone
- Prairie du Chien Group
- Jordan Sandstone
- St. Lawrence Formation
- Tunnel City Group
- Wonewoc Sandstone
- Eau Claire Formation
- Mt. Simon Sandstone
- Precambrian Sedimentary Rocks
- Study Area
- City/Township Boundary
- Waterbody
- Perennial Stream

Note: Bedrock geology reproduced from Mossler (2013).

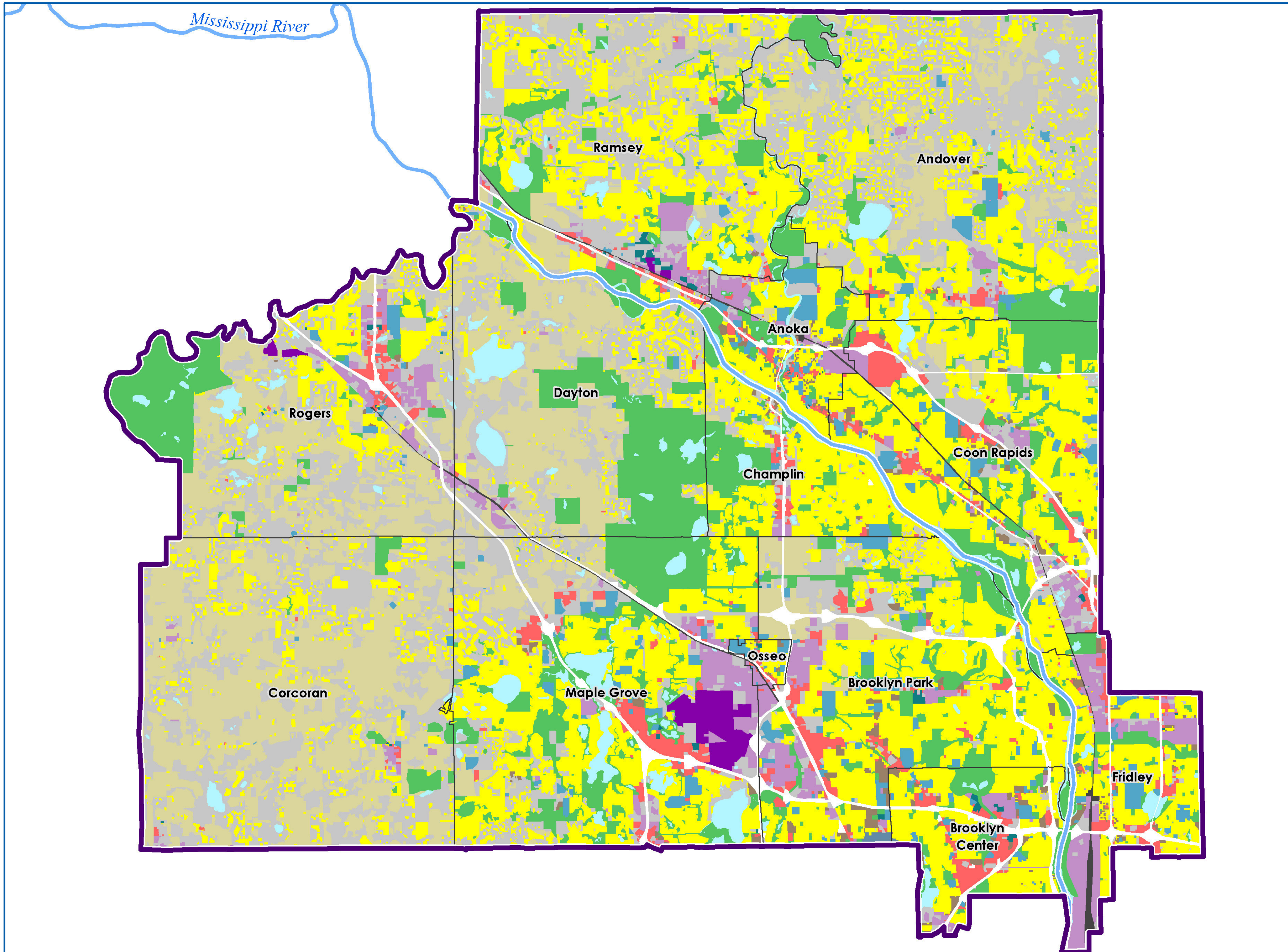
Sources: MGS, NHD, DNR

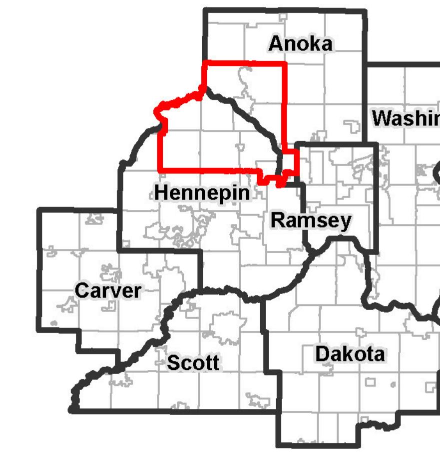
0 2 Miles

Document Path: \\mspe-gis-file\gisproj\MetCouncil\224209\map_docs\Northwest_Region\A2-05_Bedrock_Geology_11x17L.mxd

Metropolitan Council
Regional Water Supply, Groundwater Recharge, and
Stormwater Capture and Reuse Study

Figure A2-6
2010 Land Use
Northwest Metro 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
- Study Area
- City/Township Boundary

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

Sources: Met Council, NHD, DNR

0 2 Miles

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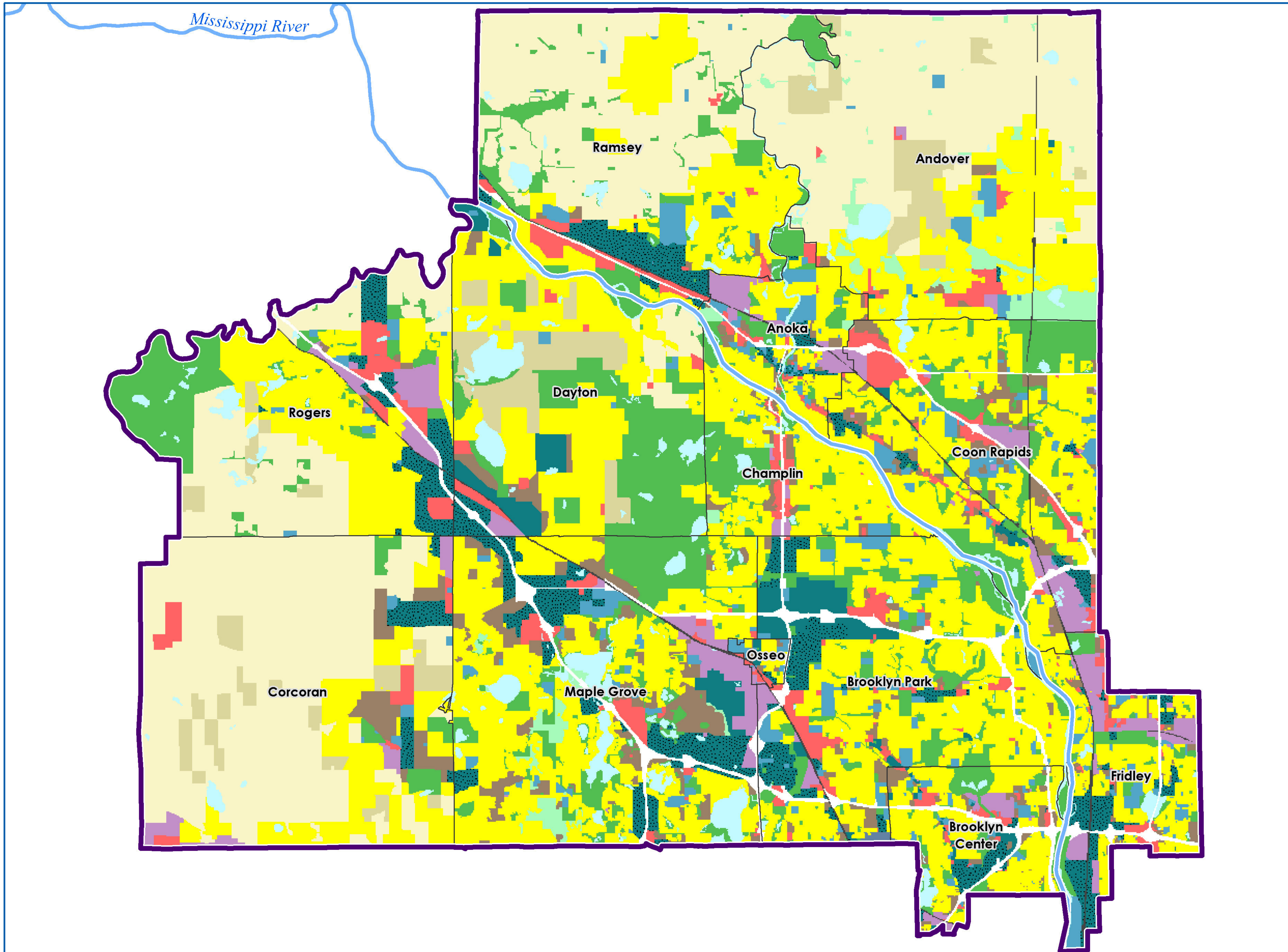
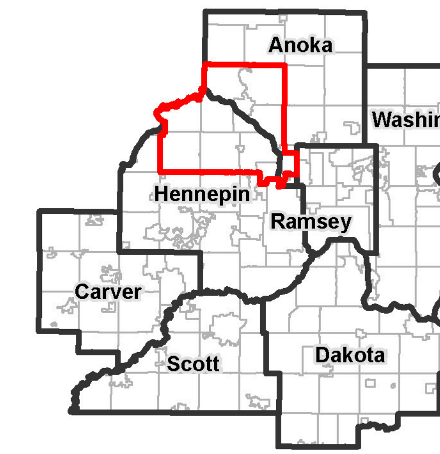
Metropolitan Council
Regional Water Supply, Groundwater Recharge, and
Stormwater Capture and Reuse Study

Figure A2-7
2030 Land Use
Northwest Metro Study Area





Legend

- Agricultural
- Rural or Large-Lot Residential
- Single Family Residential
- Multifamily Residential
- Commercial
- Industrial
- Institutional
- Mixed Use
- Multi-Optional Development
- Park and Recreation
- Open Space or Restrictive Use
- Rights-of-Way (i.e., Roads)
- Railway (inc. LRT)
- Airport
- Vacant or Unknown
- Open Water
- Study Area
- City/Township Boundary

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

Sources: Met Council, NHD, DNR

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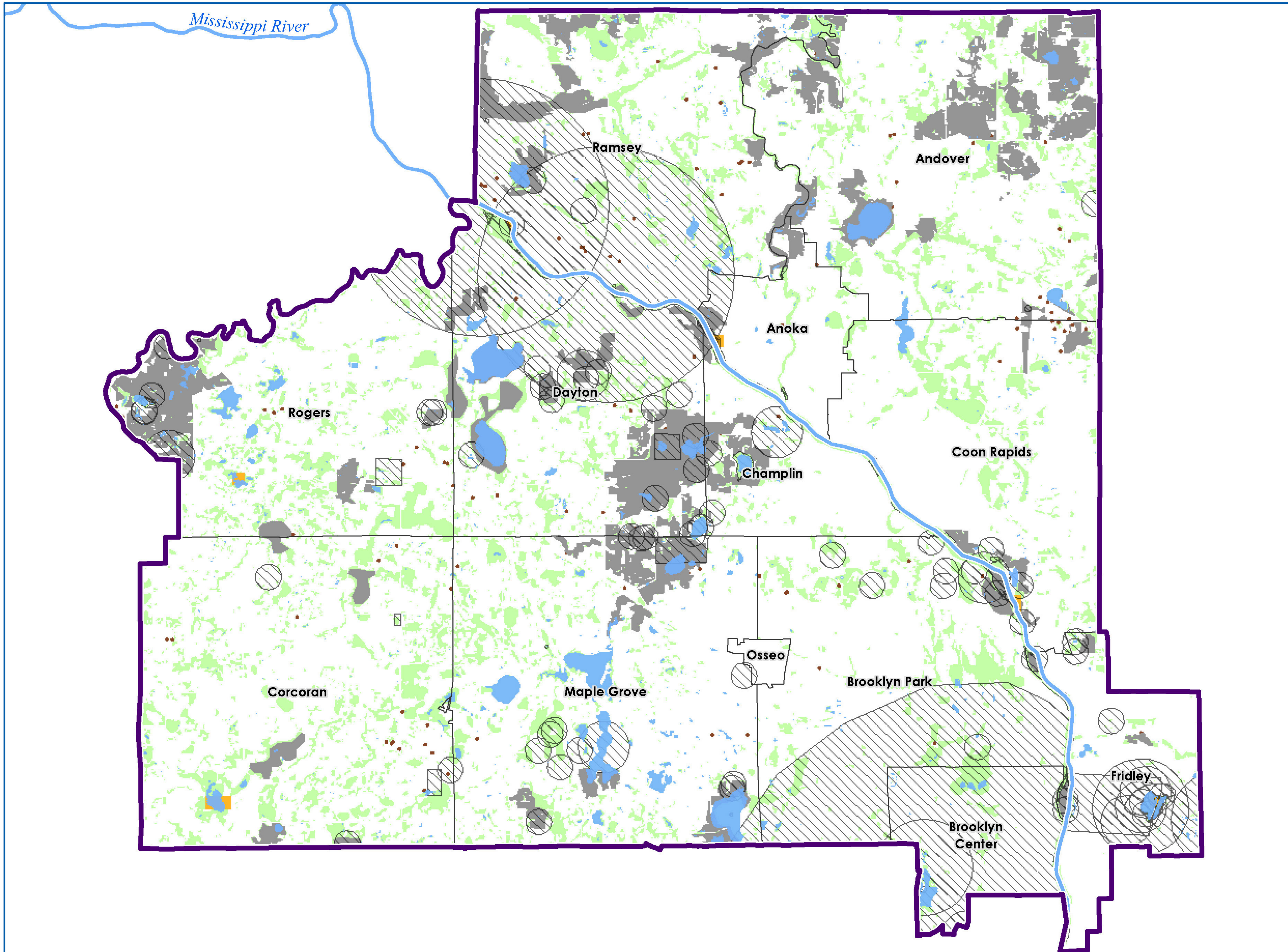
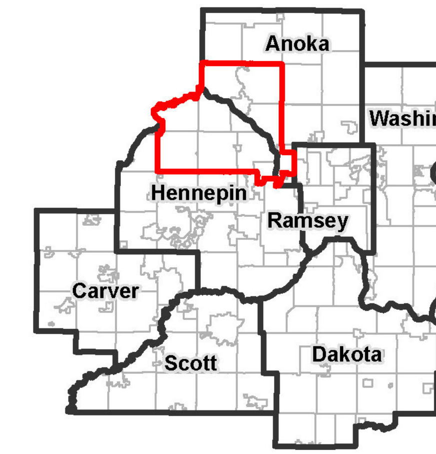
Metropolitan Council
Regional Water Supply, Groundwater Recharge, and
Stormwater Capture and Reuse Study

Figure A2-8
Sensitive Natural Resources
Northwest Metro Study Area





Legend

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

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
- Study Area
- City/Township Boundary
- Waterbody
- NWI Wetland

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

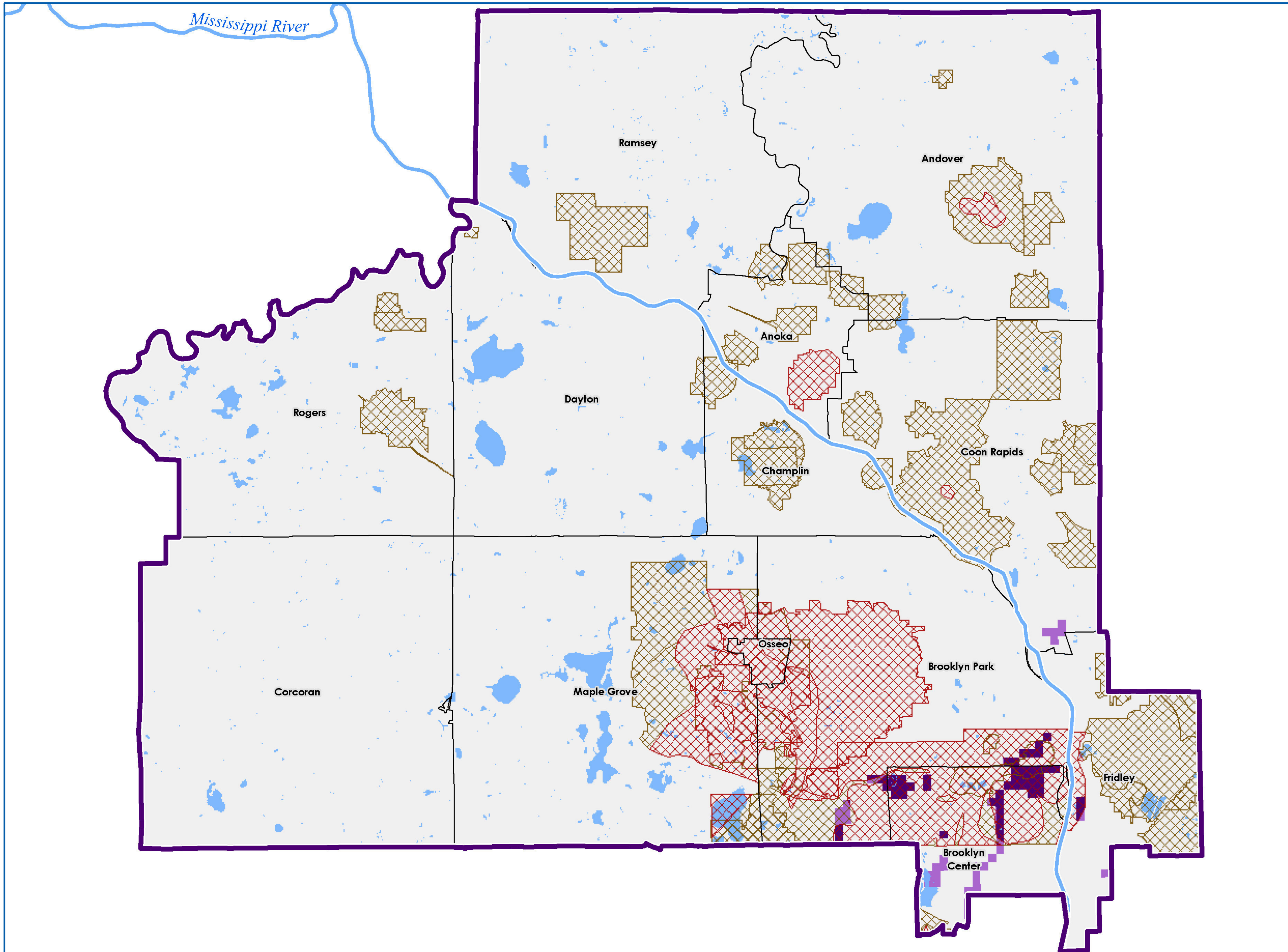
Note: Sensitive natural resources mapping provided by MnDNR (2014a).

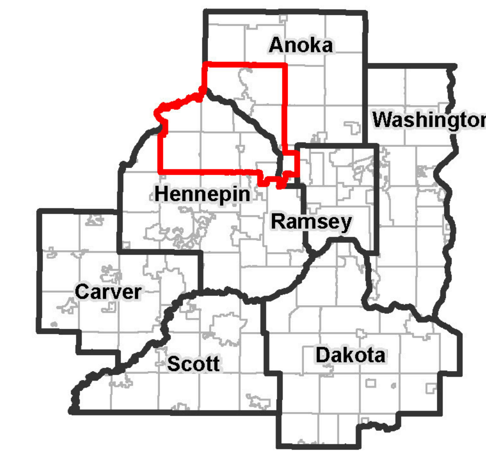
Sources: MPCA, NHD, DNR

0 2 Miles

Metropolitan Council
Regional Water Supply, Groundwater Recharge, and Stormwater Capture and Reuse Study

Figure A2-9
Drinking Water Protection
Northwest Metro 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'.*
- Study Area
- City/Township Boundary

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

Sources: MDH, NHD, DNR

0 2 Miles

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Appendix A3: 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 Table A3-1 and Table A3-2.

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 sub basin 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 A3-1. 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
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 A3-2. 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
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 A4: 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:

$$R_{annual} = \sum [(P*P_j*R_v)/12](A), \text{ where}$$

R_{annual} = Total annual non-winter runoff from the study area drainage area, acre-ft.
P = Depth of rainfall in inches per year (28.15 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 = **<u>0.493</u>**

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) = **28.15 inches**

[1] Depth of Rainfall is the 30-year average (1981-2010) of non-winter (March 15 to November 30) precipitation from three National Centers for Environmental Information (NCEI) rain gage stations within and near the study area (NCEI, 2014).

Thus, using the modified Rational Method equation,

Annual Runoff (R_{annual}) = [(28.15 inches*0.9*0.493)/(12 inch/foot)] * 1,000 acres = **1,040.85 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 non-potable, non-crop irrigation use, such as golf courses, landscaping, and athletic fields. 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 85 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 15 in the main body of this report), 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 15), 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 evaluated for the regional-scale systems considered in this report.

After collecting in the storm sewer network, stormwater usually passes through an in-line screen to remove leaves, twigs, and other debris before entering a storage component. At this stage, 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 A4-1.

- **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 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 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 A4-1. 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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