Final Report

Twin Cities Area Enhanced Groundwater Recharge Study

December 2016

METROPOLITAN COUNCIL

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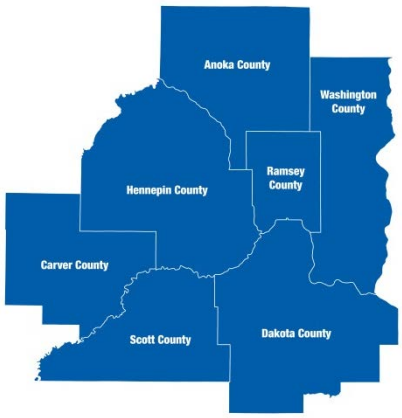

The Metropolitan Council is the regional planning organization for the seven-county Twin Cities area. The Council operates the regional bus and rail system, collects and treats wastewater, coordinates regional water resources, plans and helps fund regional parks, and administers federal funds that provide 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.

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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 enhanced groundwater recharge in the seven-county 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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Introduction

As part of the Regional Feasibility Assessments project, HDR completed a study of enhanced groundwater recharge in the seven-county metropolitan area. 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). 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 this enhanced groundwater recharge study was to perform an initial screening of the seven-county metropolitan area to identify areas where water applied at the surface would have the highest potential to infiltrate and recharge drinking water aquifers (both unconsolidated and bedrock aquifers). This recharge analysis was completed by compiling and analyzing existing surface and subsurface data and comparing it to a set of criteria. Other potential benefits of enhanced recharge, such as its impact on sensitive surface water features, were not specifically evaluated as part of the study.

This report describes the enhanced groundwater recharge study methodology and results for the Twin Cities metropolitan area. Results of similar studies completed by HDR for the Metropolitan Council for sub-regions of the Twin Cities including the Southeast Metro, North and East Metro, and Northwest Metro study areas are documented in separate reports.

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 recharge on a regional scale, and the evaluation of the data against the established criteria. These steps are described in more detail below.

Data Collection

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

Table 1. Data Sources and Datasets for Enhanced Recharge Study

Data Source	Dataset(s) Used	Reference
Geology/Hydrogeology		
United States Department of Agriculture Natural Resources Conservation Service (NRCS) Soil Survey Geographic Database	Vertical infiltration rate data for soils, top 5 feet	(NRCS, 2014)
	Parent material for soils	(NRCS, 2014)
Minnesota Geological Survey (MGS)	Hydraulic conductivity data 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, 2014a)
	Hastings Groundwater Capture Zone	(MDH, 2014b)
HDR	Calculation of Inver Grove Heights preliminary Wellhead Protection Areas (WHPAs)	

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 included the following:

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

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

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

The processing of the datasets is described in Table 2.

Table 2. Processing of Data Sources for Enhanced Recharge Study

Data Source	Processed Dataset(s)	Processing Required
Geology/Hydrogeology		
NRCS	Vertical infiltration rate (k_{satr})	The average vertical infiltration rate was calculated using a weighted average of all k_{satr} values in the top 5 feet of soil at a given location.
MGS	Hydraulic conductivity data for unconsolidated zone	For the analysis of recharge to **all aquifers**, an average hydraulic conductivity value was generated for the upper 60 feet of the unconsolidated zone. 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. For the analysis of recharge to **bedrock drinking water aquifers only**, a composite hydraulic conductivity value was calculated for the entire unconsolidated zone by taking the harmonic mean of the hydraulic conductivity of each 20-ft elevation "slice" created by Tipping (2011) at each grid cell. Note: If the entire vertical profile of a grid cell was given an intermediate value of 10.05 ft/day by Tipping (2011) due to insufficient lithologic data, HDR cross-checked these areas for permeable parent material to determine recharge feasibility.
MCES	Water table elevation	Depth to water table was calculated by subtracting the water table elevations given by Barr Engineering (2010) from national elevation dataset (NED) 30.
Drinking Water Protection		
MDH	DWSMA vulnerability	Hastings' DWSMA was removed from the dataset because it was developed based on susceptibility to contamination from surface water. MDH suggested using the Hastings groundwater capture zone instead.

Data Source	Processed Dataset(s)	Processing Required
HDR	Calculation of Inver Grove Heights preliminary WHPAs	New preliminary WHPAs were generated in accordance with MDH published guidance, in lieu of actual WHPAs which were being produced by the city as of May 7, 2014.

Criteria Development

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

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

Table 3. Criteria for Evaluation of Enhanced Recharge Areas

Criteria	Tier 1	Tier 2	Tier 3	Figure Reference
Geology/Hydrogeology				
Vertical Infiltration Rate - (k_{satr}) - Top 5 feet (NRCS)	>5 in/hr	0.5-5 in/hr	<0.5 in/hr	Figure 1
Parent Material (NRCS)	N/A	(see Average Hydraulic Conductivity – Upper 60 feet, and Composite Hydraulic Conductivity, below)	N/A	Figure 2
Average Hydraulic Conductivity – Upper 60 feet (MGS) **(for analysis of all drinking water aquifers, including unconsolidated)**	>10 ft/day	1-10 ft/day, or Insufficient data but permeable parent material (glaciofluvial sediments, outwash)	<1 ft/day	Figure 3a

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

Criteria	Tier 1	Tier 2	Tier 3	Figure Reference
Composite Hydraulic Conductivity (MGS) (for analysis of bedrock drinking water aquifers)	>10 ft/day	1-10 ft/day, or Insufficient data but permeable parent material (glaciofluvial sediments, outwash)	<1 ft/day	Figure 3b
Depth to Water Table (MCES)	>50 feet	≥15 feet	<15 feet	Figure 4
Uppermost Bedrock (MGS) (for analysis of bedrock drinking water aquifers)	Prairie du Chien and older	St. Peter and older	Galena, Decorah, Platteville, Glenwood	Figure 5
Land Use/Natural Resources				
Current Land Use - 2010 (MCES)	Agricultural, parks, undeveloped areas	Agricultural, parks, undeveloped areas	All types other than agricultural, parks, undeveloped areas	Figure 6
Future Land Use – 2030 (MCES)	(2030 land use was not used for the analysis; a figure was generated for discussion purposes)			Figure 7
Sensitive Natural Resource Areas (MnDNR)	Not within: Calcareous Fens, Trout Streams, NPC, AMA, WMA, Federal Land/Easement, SNA, State Parks, USDA NRCS Easement, Nature Conservancy, RNRA, T&E Species Areas, Game Refuge [1]	Not within: Calcareous Fens, Trout Streams, NPC, AMA, WMA, Federal Land/Easement, SNA, State Parks, USDA NRCS Easement, Nature Conservancy, RNRA	Within: Calcareous Fens, Trout Streams, NPC, AMA, WMA, Federal Land/ Easement, SNA, State Parks, USDA NRCS Easement, Nature Conservancy, RNRA	Figure 8
Drinking Water Protection				
High or Very High Vulnerability DWSMA and <100 ft to Prairie du Chien (MDH)	Outside the limits of a vulnerable DWSMA	Outside the limits of a vulnerable DWSMA	Within the limits of a vulnerable DWSMA and <100 feet to the Prairie du Chien	Figure 9
Hastings Groundwater Capture Zone and <100 ft to Prairie du Chien (MDH)	Outside the limits of the Groundwater Capture Zone	Outside the limits of the Groundwater Capture Zone	Within the limits of the Groundwater Capture Zone and <100 feet to Prairie du Chien	Figure 9
Inver Grove Heights Preliminary WHPAs (HDR) and <100 ft to Prairie du Chien	Outside the limits of the preliminary WHPAs	Outside the limits of the preliminary WHPAs	Within the limits of the preliminary WHPAs and <100 feet to Prairie du Chien	Figure 9

Notes:
Data sources are shown in parenthesis.
[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; T&E = Threatened and endangered; RNRA = Regional Natural Resource Area.

Table 4. Rationale for Enhanced Recharge Criteria

Criteria	Rationale
Geology/Hydrogeology	
Vertical Infiltration Rate - (k_{satr}) - Top 5 feet (NRCS)	• 5 in/hr (or greater) was chosen as the Tier 1 criterion for vertical infiltration; 5 in/hr is generally considered to be a lower threshold limit for rapid infiltration basins. • 0.5-5 in/hr was chosen as the Tier 2 criterion, representing a site with limited potential for a rapid infiltration basin. • 0.5 in/hr. the Tier 3 criterion, 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 value in the Minnesota Stormwater Manual (MPCA, 2015b) for infiltration basins.
Parent Material (NRCS)	• Parent material was used to cross-check for permeability the areas where hydraulic conductivity data (Tipping, 2011) is insufficient. If permeable parent material is indicated, the grid cell was deemed Tier 2 (generally feasible) for recharge. • Coarse-grained materials such as glaciofluvial sediments and outwash are deemed Tier 2 for transmitting water for recharge.
Average Hydraulic Conductivity-Upper 60 feet (MGS) (for analysis of all drinking water aquifers, including unconsolidated); **Composite Hydraulic Conductivity (MGS) (for analysis of bedrock drinking water aquifers)**	• 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 recharge. The hydraulic conductivity of the formation material is too low and the recharge from the infiltration basin would cause excessive mounding.
Depth to Water Table (MCES)	• 50 feet (or greater) unsaturated thickness was chosen as the Tier 1 criterion for infiltration. • 15 feet was chosen as the Tier 2 criterion, representing a reasonable minimum unsaturated thickness over which water from an infiltration basin can build a sufficient vertical gradient to effectively drive infiltration. Higher water tables will require higher transmissivity to accommodate mounding.
Uppermost Bedrock (MGS) (for analysis of bedrock drinking water aquifers)	• Subcropping Prairie du Chien and older bedrock aquifers are deemed Tier 1 (most feasible) for receiving recharge since they typically have sufficient permeability (i.e., could be effectively recharged) and are heavily pumped. • Subcropping St. Peter and older aquifers are deemed Tier 2 since the basal St. Peter may contain a lower confining layer that could hinder recharge to lower aquifers. • Subcropping Galena, Decorah, Platteville, and Glenwood formations are typically considered to be either 1) a confining unit, or 2) not typically used for water supply, and are deemed Tier 3 (unfeasible) for receiving recharge.
Land Use/Natural Resources	
Current Land Use (MCES)	• Agricultural, parks, and undeveloped areas may have land available and are considered Tier 1 and Tier 2 for locating large infiltration basins. • All other types of land use are considered Tier 3 since the land is already developed.
Natural Resource Areas (MnDNR)	• Calcareous Fens, Trout Streams, NPC, AMA, WMA, Federal Land/Easement, SNA, State Parks, USDA NRCS Easement, Nature Conservancy, and RNRA are Tier 3 for locating infiltration basins since they are sensitive and/or protected natural resources. • T&E Species Areas and Game Refuges are considered Tier 2 (generally feasible) for locating infiltration basins at this time based on low potential for impact to those areas.

Criteria	
Drinking Water Protection	
High or Very High Vulnerability DWSMA and <100 ft to fractured bedrock (MDH)	Considered to be Tier 3 (unfeasible). MDH guidance (MDH, 2007) specifies stormwater infiltration should not occur where less than 100 feet of unconsolidated sediments separate fractured bedrock (e.g., Prairie du Chien dolomite) from the ground surface within a vulnerable DWSMA. This guidance is in place to protect vulnerable public supply wells from potential pathogens.
Hastings Groundwater Capture Zone and <100 ft to Prairie du Chien (MDH)	Rationale is similar to DWSMAs, above. The Hastings Groundwater Capture Zones are considered vulnerable by MDH.
Inver Grove Heights Preliminary WHPAs (HDR) and <100 ft to Prairie du Chien	Rationale is similar to DWSMAs, above. The preliminary wellhead protection areas for Inver Grove Heights are considered vulnerable for this study.

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:

1. *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 are areas with good potential for enhanced recharge.
2. *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 with limited potential for enhanced recharge. However, it is possible that local conditions are more favorable than what is indicated in the regional datasets for the Tier 2 areas.
3. *Tier 3* areas are those not classified as Tier 1 or Tier 2, indicating that there is poor potential for enhanced recharge based on the specific criteria established for this analysis. For an area to be classified as Tier 3, any one of the criteria for a Tier 3 recharge location needed to be met.

Two approaches were taken to study enhanced recharge potential in the seven-county metropolitan area. The first approach focused on using only hydrogeological criteria to identify areas where water could infiltrate and potentially reach an unconsolidated or bedrock aquifer, without consideration for the current land use or other human- or environmental-influenced limitations. The second approach expanded upon the hydrogeological approach to incorporate land use, sensitive natural resource areas, and drinking water protection criteria into the data calculation. Each of these approaches was used to identify potential areas for enhanced recharge to two groups of aquifers: 1) all aquifers, including unconsolidated and bedrock aquifers, and 2) bedrock drinking water aquifers only. As a result, four enhanced recharge evaluation scenarios were developed, shown in Table 5. Criteria associated with each of the four scenarios are shown in Tables 6 through 9.

Table 5. Enhanced Recharge Evaluation Scenarios

	Hydrogeological Criteria	All Criteria
All Aquifers (including unconsolidated)	1. Enhanced recharge to all aquifers using only hydrogeological criteria	2. Enhanced recharge to all aquifers using all criteria
Bedrock Aquifers	3. Enhanced recharge to bedrock aquifers using only hydrogeological criteria	4. Enhanced recharge to bedrock aquifers using all criteria

Table 6. Criteria for Evaluation of Enhanced Recharge Areas (All Aquifers, Hydrogeological Criteria)

Criteria	Tier 1	Tier 2	Tier 3	Figure Reference
Geology/Hydrogeology				
Vertical Infiltration Rate - (k_{satr}) - Top 5 feet (NRCS)	>5 in/hr	0.5-5 in/hr	<0.5 in/hr	Figure 1
Parent Material (NRCS)	N/A	(see Average Hydraulic Conductivity-Upper 60 feet, below)	N/A	Figure 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 3a
Depth to Water Table (MCES)	>50 feet	≥15 feet	<15 feet	Figure 4

Table 7. Criteria for Evaluation of Enhanced Recharge Areas (All Aquifers, All Criteria)

Criteria	Tier 1	Tier 2	Tier 3	Figure Reference
Geology/Hydrogeology				
Vertical Infiltration Rate - (k_{satr}) - Top 5 feet (NRCS)	>5 in/hr	0.5-5 in/hr	<0.5 in/hr	Figure 1
Parent Material (NRCS)	N/A	(see Average Hydraulic Conductivity-Upper 60 feet, below)	N/A	Figure 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 3a
Depth to Water Table (MCES)	>50 feet	≥15 feet	<15 feet	Figure 4
Land Use/Natural Resources				
Current Land Use - 2010 (MCES)	Agricultural, parks, undeveloped areas	Agricultural, parks, undeveloped areas	All types other than agricultural, parks, undeveloped areas	Figure 6
Future Land Use – 2030 (MCES)	(2030 land use was not used for the study; a figure was generated for discussion purposes)			Figure 7

Criteria	Tier 1	Tier 2	Tier 3	Figure Reference
Sensitive Natural Resource Areas (MnDNR)	Not within: Calcareous Fens, Trout Streams, NPC, AMA, WMA, Federal Land/ Easement, SNA, State Parks, USDA NRCS Easement, Nature Conservancy, RNRA, T&E Species Areas, Game Refuge	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 8
Drinking Water Protection				
High or Very High Vulnerability DWSMA and <100 ft to Prairie du Chien (MDH)	Outside the limits of a vulnerable DWSMA	Outside the limits of a vulnerable DWSMA	Within the limits of a vulnerable DWSMA and <100 feet to the Prairie du Chien	Figure 9
Hastings Groundwater Capture Zone and <100 ft to Prairie du Chien (MDH)	Outside the limits of the Groundwater Capture Zone	Outside the limits of the Groundwater Capture Zone	Within the limits of the Groundwater Capture Zone and <100 feet to Prairie du Chien	Figure 9
Preliminary Inver Grove Heights WHPAs (HDR) and <100 ft to Prairie du Chien	Outside the limits of the preliminary WHPAs	Outside the limits of the preliminary WHPAs	Within the limits of the preliminary WHPAs and <100 feet to Prairie du Chien	Figure 9

Table 8. Criteria for Evaluation of Enhanced Recharge Areas (Bedrock Aquifers, Hydrogeological Criteria)

Criteria	Tier 1	Tier 2	Tier 3	Figure Reference
Geology/Hydrogeology				
Vertical Infiltration Rate - (k_{satr}) - Top 5 feet (NRCS)	>5 in/hr	0.5-5 in/hr	<0.5 in/hr	Figure 1
Parent Material (NRCS)	N/A	(see Composite Hydraulic Conductivity, below)	N/A	Figure 2
Composite Hydraulic Conductivity (MGS)	>10 ft/day	1-10 ft/day, or Insufficient data but permeable parent material (glaciofluvial sediments, outwash)	<1 ft/day	Figure 3b
Depth to Water Table (MCES)	>50 feet	≥15 feet	<15 feet	Figure 4

Uppermost Bedrock (MGS)	Prairie du Chien and older	St. Peter and older	Galena, Decorah, Platteville, Glenwood	Figure 5

Table 9. Criteria for Evaluation of Enhanced Recharge Areas (Bedrock Aquifers, All Criteria)

Criteria	Tier 1	Tier 2	Tier 3	Figure Reference
Geology/Hydrogeology				
Vertical Infiltration Rate - (k_{satr}) - Top 5 feet (NRCS)	>5 in/hr	0.5-5 in/hr	<0.5 in/hr	Figure 1
Parent Material (NRCS)	N/A	(see Composite Hydraulic Conductivity, below)	N/A	Figure 2
Composite Hydraulic Conductivity (MGS)	>10 ft/day	1-10 ft/day, or Insufficient data but permeable parent material (glaciofluvial sediments, outwash)	<1 ft/day	Figure 3b
Depth to Water Table (MCES)	>50 feet	≥15 feet	<15 feet	Figure 4
Uppermost Bedrock (MGS)	Prairie du Chien and older	St. Peter and older	Galena, Decorah, Platteville, Glenwood	Figure 5
Land Use/Natural Resources				
Current Land Use - 2010 (MCES)	Agricultural, parks, undeveloped areas	Agricultural, parks, undeveloped areas	All types other than agricultural, parks, undeveloped areas	Figure 6
Future Land Use – 2030 (MCES)	(2030 land use was not used for the study; a figure was generated for discussion purposes)			Figure 7
Sensitive Natural Resource Areas (MnDNR)	Not within: Calcareous Fens, Trout Streams, NPC, AMA, WMA, Federal Land/Easement, SNA, State Parks, USDA NRCS Easement, Nature Conservancy, RNRA, T&E Species Areas, Game Refuge	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 8
Drinking Water Protection				
High or Very High Vulnerability DWSMA and <100 ft to Prairie du Chien (MDH)	Outside the limits of a vulnerable DWSMA	Outside the limits of a vulnerable DWSMA	Within the limits of a vulnerable DWSMA and <100 feet to the Prairie du Chien	Figure 9

Criteria	Tier 1	Tier 2	Tier 3	Figure Reference
Hastings Groundwater Capture Zone and <100 ft to Prairie du Chien (MDH)	Outside the limits of the Groundwater Capture Zone	Outside the limits of the Groundwater Capture Zone	Within the limits of the Groundwater Capture Zone and <100 feet to Prairie du Chien	Figure 9
Preliminary Inver Grove Heights WHPAs (HDR) and <100 ft to Prairie du Chien	Outside the limits of the preliminary WHPAs	Outside the limits of the preliminary WHPAs	Within the limits of the preliminary WHPAs and <100 feet to Prairie du Chien	Figure 9

Results

A GIS-generated map was produced for each of the four enhanced recharge scenarios described above. Figure 10 shows the results for all aquifers using only the hydrogeological criteria, and Figure 11 shows the results for all aquifers using the expanded criteria. Figure 12 shows the results for recharge to bedrock aquifers using only the hydrogeological criteria, and Figure 13 shows the results for bedrock aquifers using the expanded criteria. Each figure includes a summary of the enhanced recharge criteria used to generate the figure.

The total Tier 1 or Tier 2 area using all (expanded) criteria is summarized for each of the seven metropolitan area counties in Table 10 and Table 11. Table 10 lists the Tier 1 and Tier 2 areas all aquifers (unconsolidated and bedrock), and Table 11 lists the results for bedrock aquifers. In general, areas that meet Tier 1 criteria are concentrated in Dakota and Washington Counties, with some additional areas along the Minnesota River in Scott, Carver, and Hennepin Counties.

Table 10. Tier 1 and Tier 2 Areas for Enhanced Recharge to All Aquifers (unconsolidated and bedrock) in metropolitan area Counties Using All Criteria

County	Area Meeting Tier 1 Criteria (acres)	Area Meeting Tier 2 Criteria (acres)
Anoka County	690	41,880
Carver County	5,680	18,490
Dakota County	42,350	133,530
Hennepin County	1,500	43,210
Ramsey County	1,000	8,430
Scott County	6,070	25,010
Washington County	31,180	88,040
Total	**88,470**	**358,590**

Table 11. Tier 1 and Tier 2 Areas for Enhanced Recharge to Bedrock Aquifers in metropolitan area Counties Using All Criteria

County	Area Meeting Tier 1 Criteria (acres)	Area Meeting Tier 2 Criteria (acres)
Anoka County	10	1,290
Carver County	270	460
Dakota County	32,730	98,440
Hennepin County	390	2,920
Ramsey County	70	2,050
Scott County	1,600	3,840
Washington County	12,800	46,460
Total	**47,870**	**155,460**

Although this study did not incorporate presence of soil and groundwater contamination into the criteria for enhanced recharge, it is important to note the location of contaminated and potentially contaminated areas when considering the feasibility and applicability of groundwater recharge. Contamination datasets were gathered from public sources and are summarized in Table 12. The datasets consist of either point locations (e.g., pollution containment wells) or polygons (e.g., contaminant plumes), and are shown on Figure 14 along with the Tier 1, Tier 2, and Tier 3 areas using the all criteria-all aquifers scenario.

Table 12. Contamination Datasets Mapped for Enhanced Recharge Study

Data Source	Dataset(s) Used	Reference
MDH	Special Well and Boring Construction Areas (SWBCAs) generally define the footprint of areas with relatively high concentrations of contaminants. SWBCAs are provided as polygons.	(MDH, 2015a)
MDH, US Army c/o Wenck and Associates	Large, known contaminant plumes, including 3M perfluorochemicals (PFCs), Baytown Township, Lakeland/Lakeland Shores, Twin Cities Army Ammunition Plant (TCAAP), and St. Louis Park. Plumes are provided as polygons.	(MDH, 2015b) (Wenck, 2015) (MPCA, 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)

Data Source	Dataset(s) Used	Reference
Minnesota Pollution Control Agency (MPCA)	*What's In My Neighborhood?* database indicates 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, 2014)
Minnesota Department of Agriculture (MDA)	Agricultural spill investigation boundaries indicate potentially contaminated areas. Provided as polygons.	(MDA, 2014)

Availability of Data Sets

GIS shapefiles and associated metadata were generated for all datasets produced during the enhanced recharge analysis for the metropolitan area. Specifically, the Tier 1 and Tier 2 subsets for the criteria, and the Tier 1 and Tier 2 subsets for each of the four scenarios were provided to Met Council, to be made available for public use.

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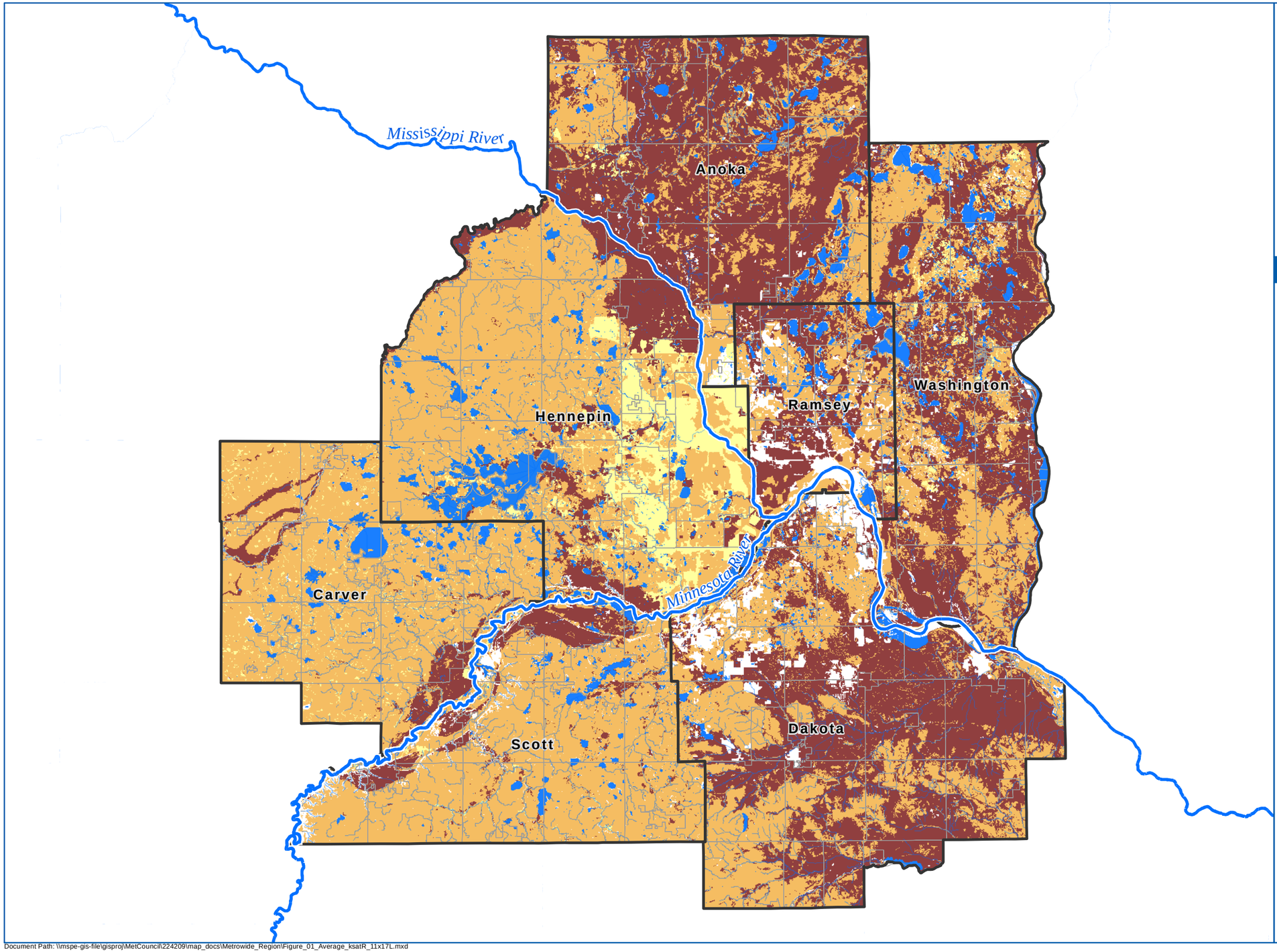
Figures

Note:

Information used to generate the figures in this report was current at the time the data was gathered, at the dates provided in the References section. Changes in land use and new information regarding the location and extent of contamination sites may not be reflected in this report.

Metropolitan Council
Regional Groundwater Recharge Study

Figure 1
Average Vertical Infiltration Rate (Top 5 feet)
Twin Cities Metro Study Area



Legend

Average Vertical Infiltration Rate (ft/day)

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

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

Sources: USDA NRCS, NHD, DNR

0 40,000 Feet

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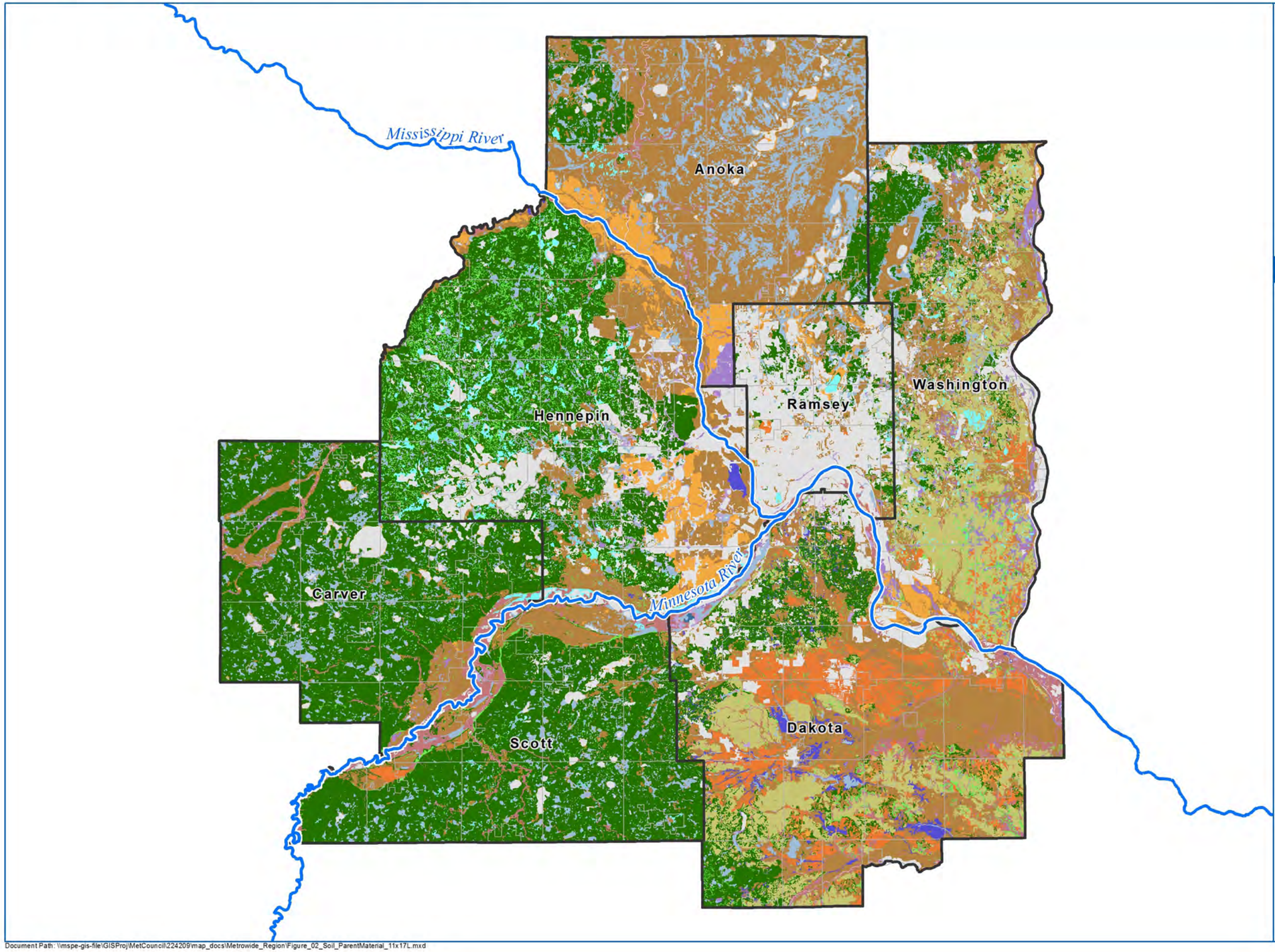
Metropolitan Council
Regional Groundwater Recharge Study

Figure 2
Soil Parent Material
Twin Cities 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
- County Boundary
- City/Township Boundary

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

Sources: USDA NRCS, NHD, DNR

0 40,000 Feet

N

HDR

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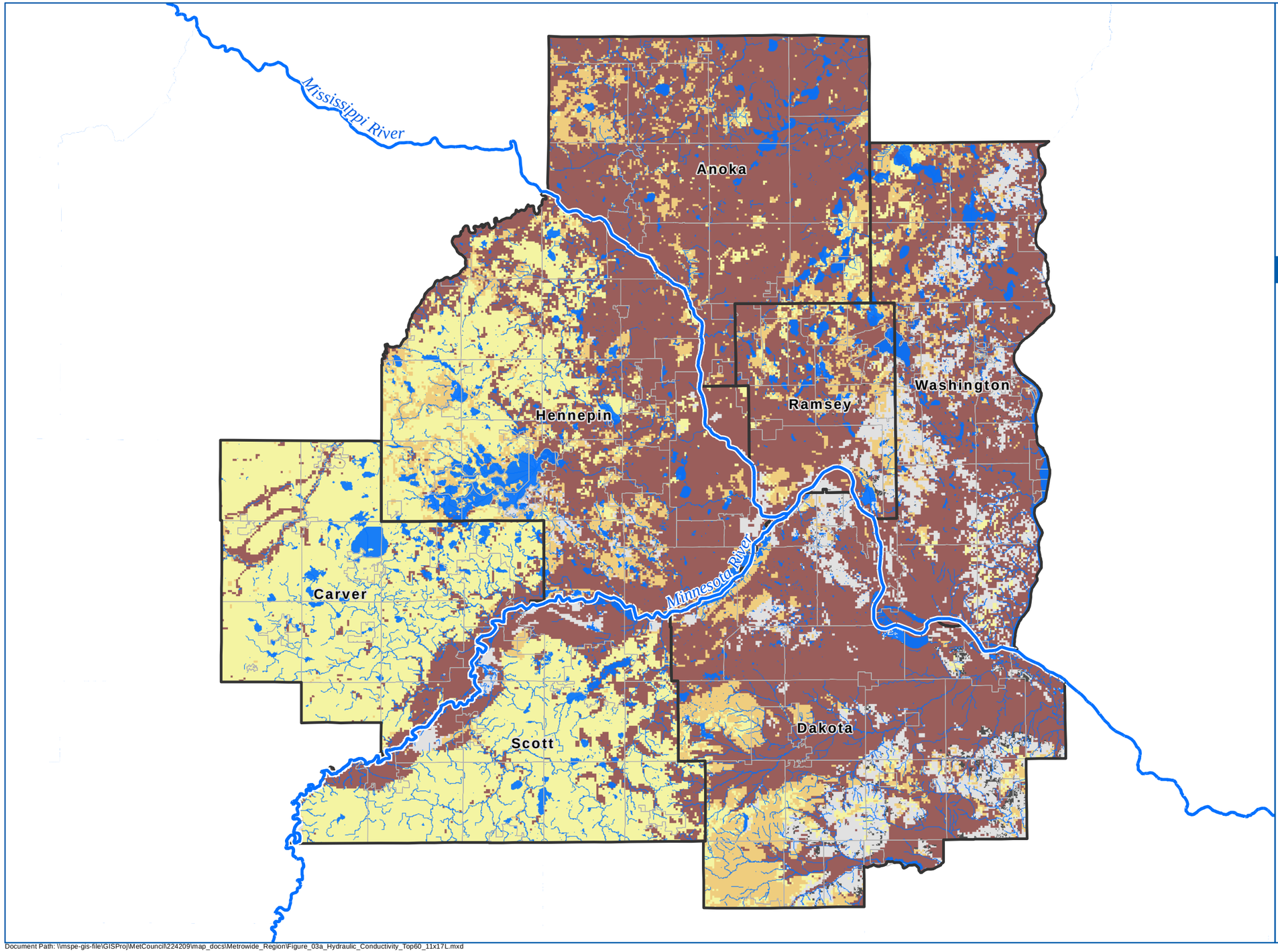
Metropolitan Council
Regional Groundwater Recharge Study

Figure 3a
Average Hydraulic Conductivity Upper 60 ft
Twin Cities 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
- County Boundary
- City/Township Boundary
- Waterbody
- Perennial Stream

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

Sources: MGS Tipping, NHD, DNR

0 40,000 Feet

N

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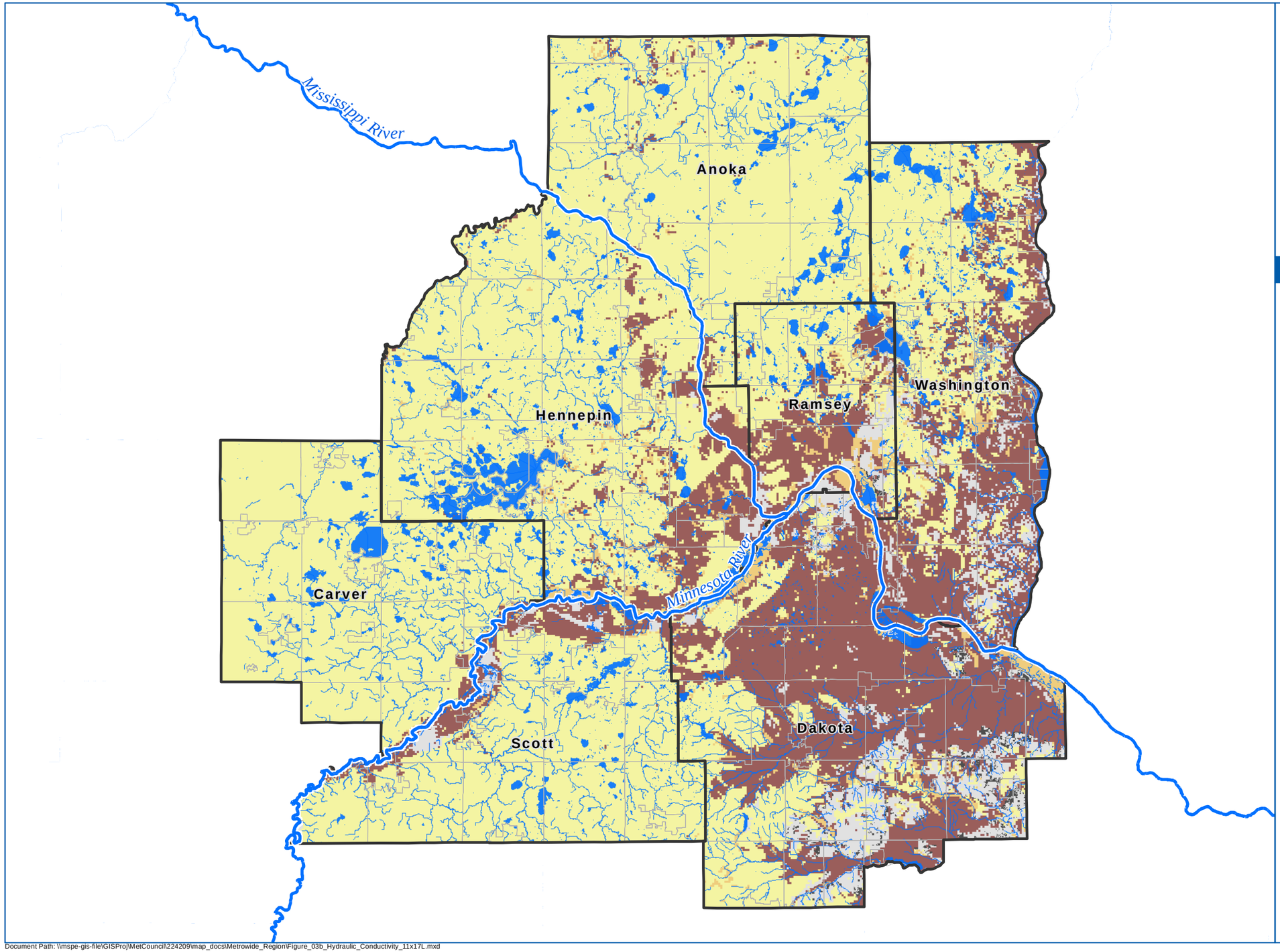
Metropolitan Council
Regional Groundwater Recharge Study

Figure 3b
Composite Hydraulic Conductivity - Unconsolidated Formation
Twin Cities 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
- County Boundary
- City/Township Boundary
- Waterbody
- Perennial Stream

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

Sources: MGS Tipping, NHD, DNR

0 40,000 Feet

N

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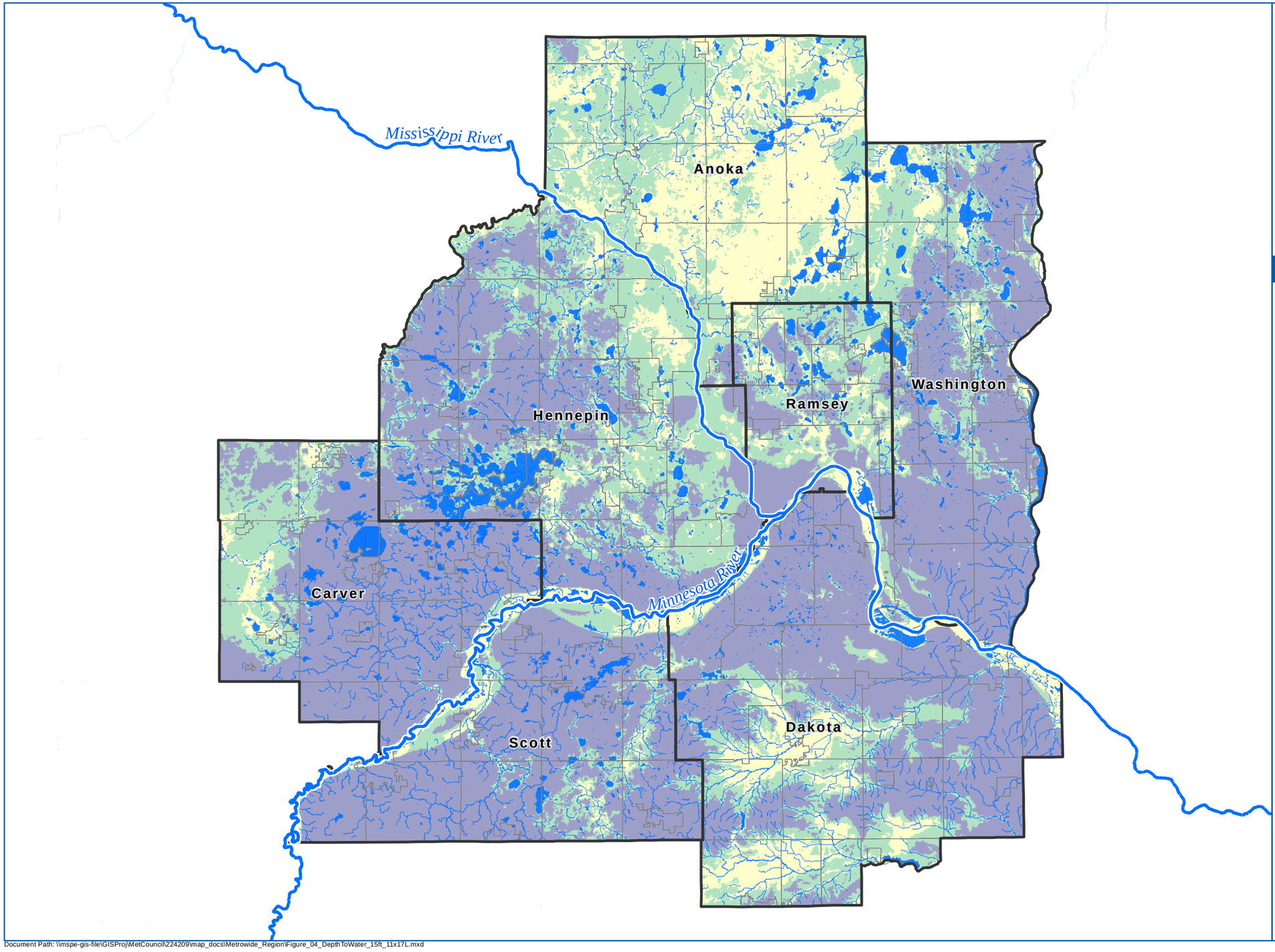
Metropolitan Council
Regional Groundwater Recharge Study

Figure 4
Depth to Regional Water Table
Twin Cities Metro Study Area



Legend

Depth to Water Table (ft)

- > 50 (Tier 1)
- 15-50 (Tier 2)
- < 15 (Tier 3)
- County Boundary
- City/Township Boundary
- Waterbody
- Perennial Stream

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

Sources: Barr, NHD, DNR

0 40,000 Feet

N

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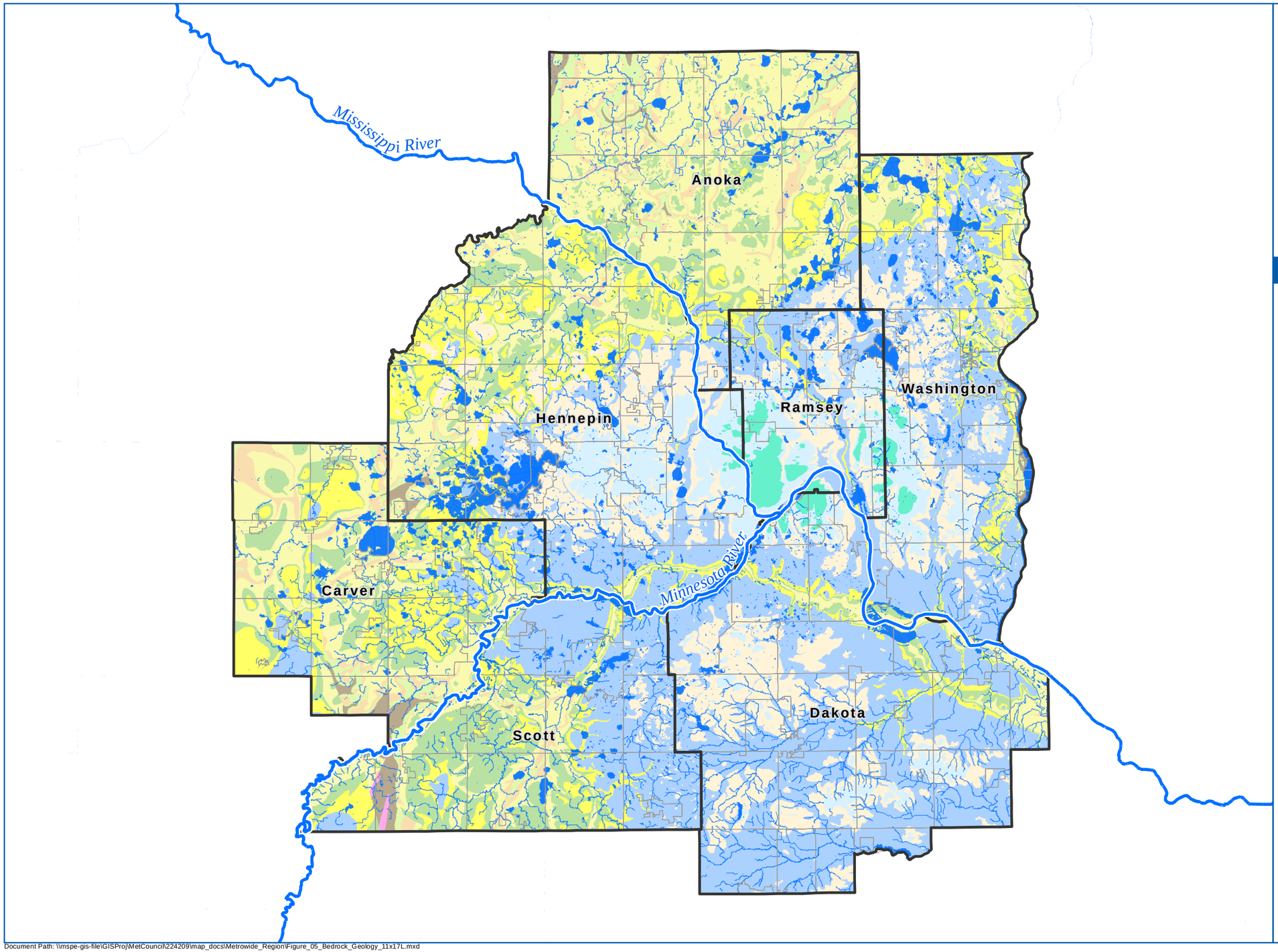
Metropolitan Council
Regional Groundwater Recharge Study

Figure 5
Bedrock Geology
Twin Cities Metro Study Area



Legend

Paleozoic Rocks

Young

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

Tier 2
- St. Peter Sandstone

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

Old

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

Note: Bedrock geology reproduced from Mossler (2013).

Sources: MGS, NHD, DNR

0 40,000 Feet

N

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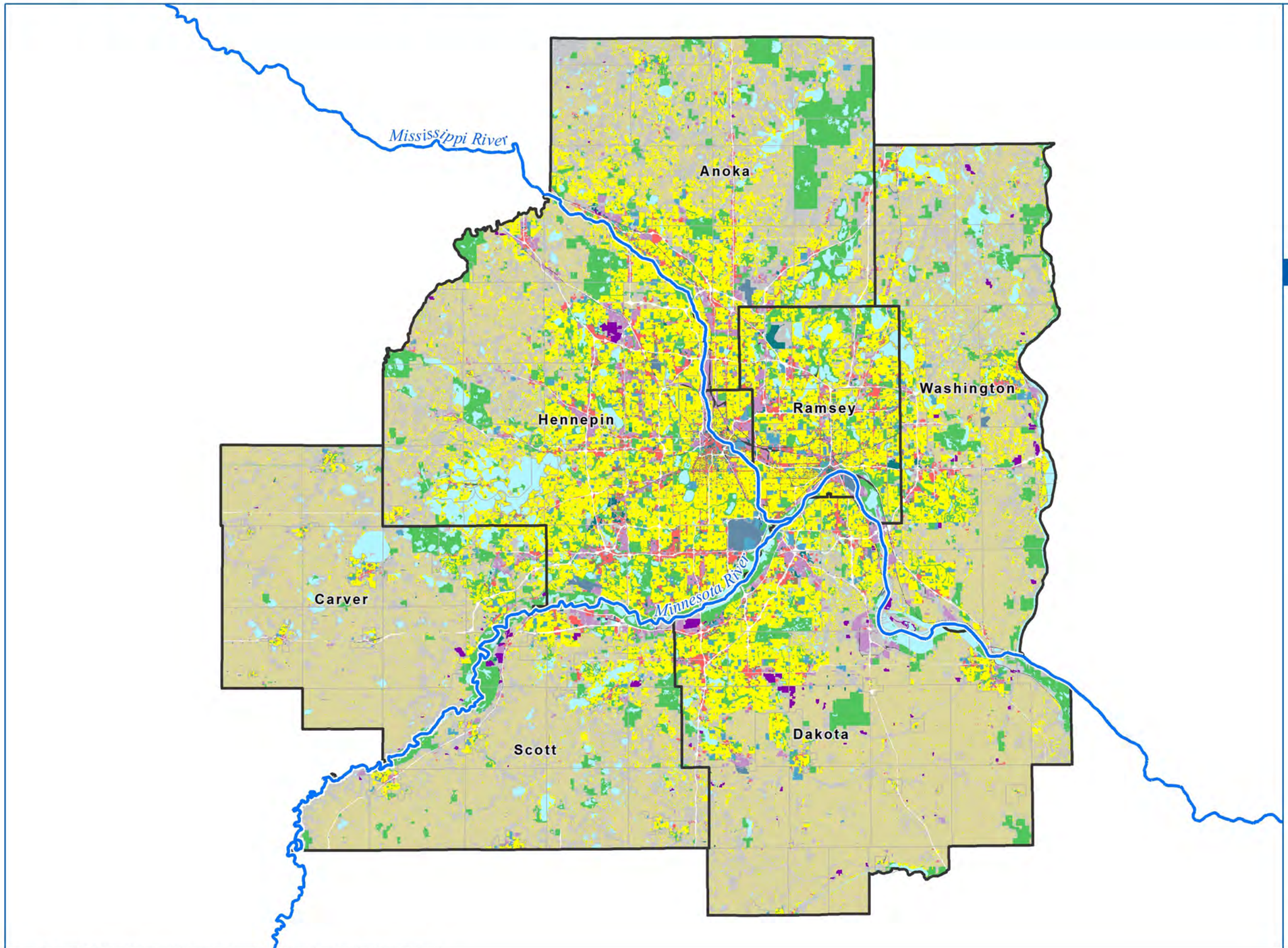
Metropolitan Council
Regional Groundwater Recharge Study

Figure 6
2010 Land Use
Twin Cities 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
- County Boundary
- City/Township Boundary

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

Sources: Met Council, NHD, DNR

0 40,000 Feet

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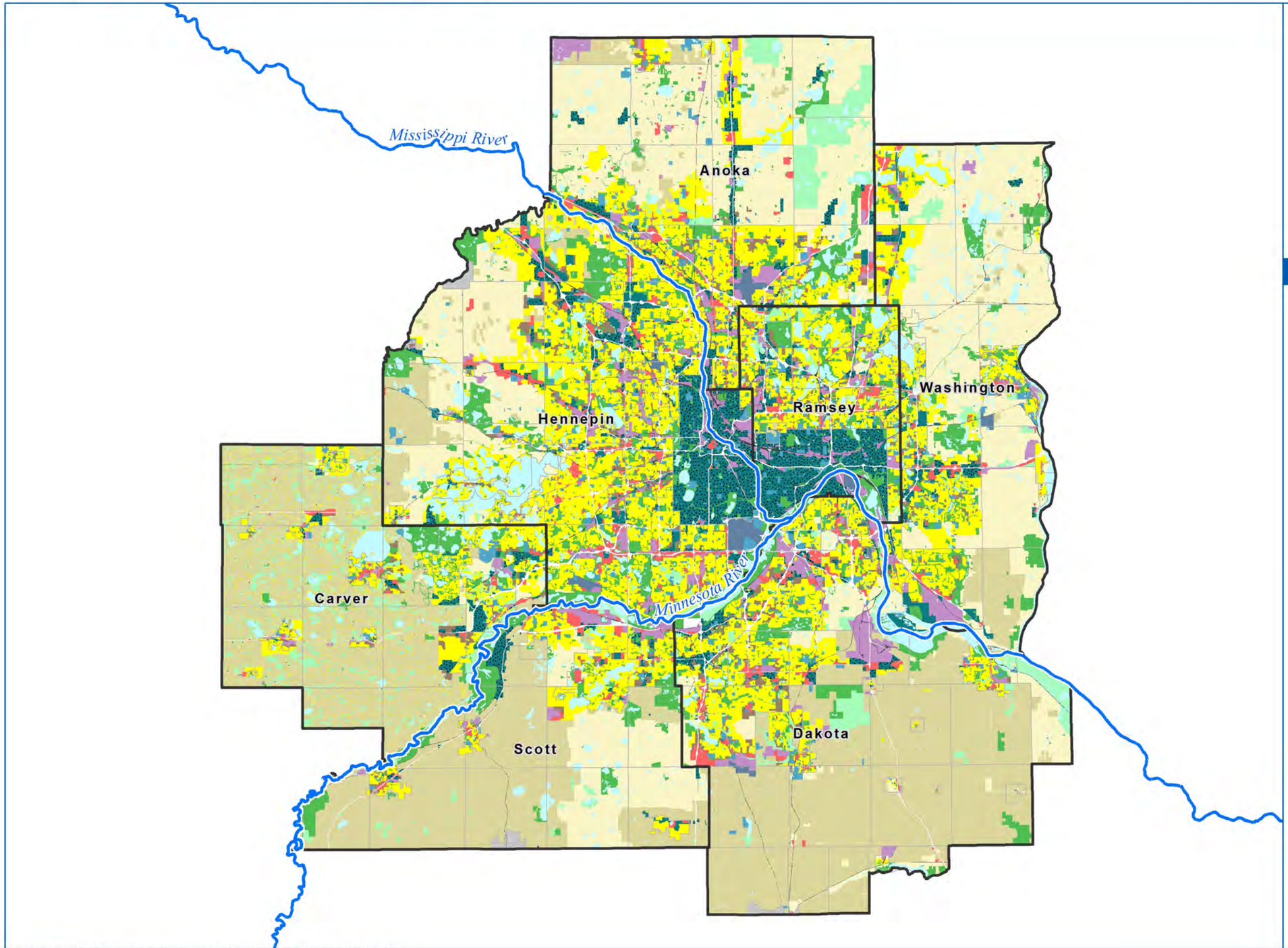
Metropolitan Council
Regional Groundwater Recharge Study

Figure 7
2030 Land Use
Twin Cities 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
- County Boundary
- City/Township Boundary

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

Sources: Met Council, NHD, DNR

0 40,000 Feet

N

HDR

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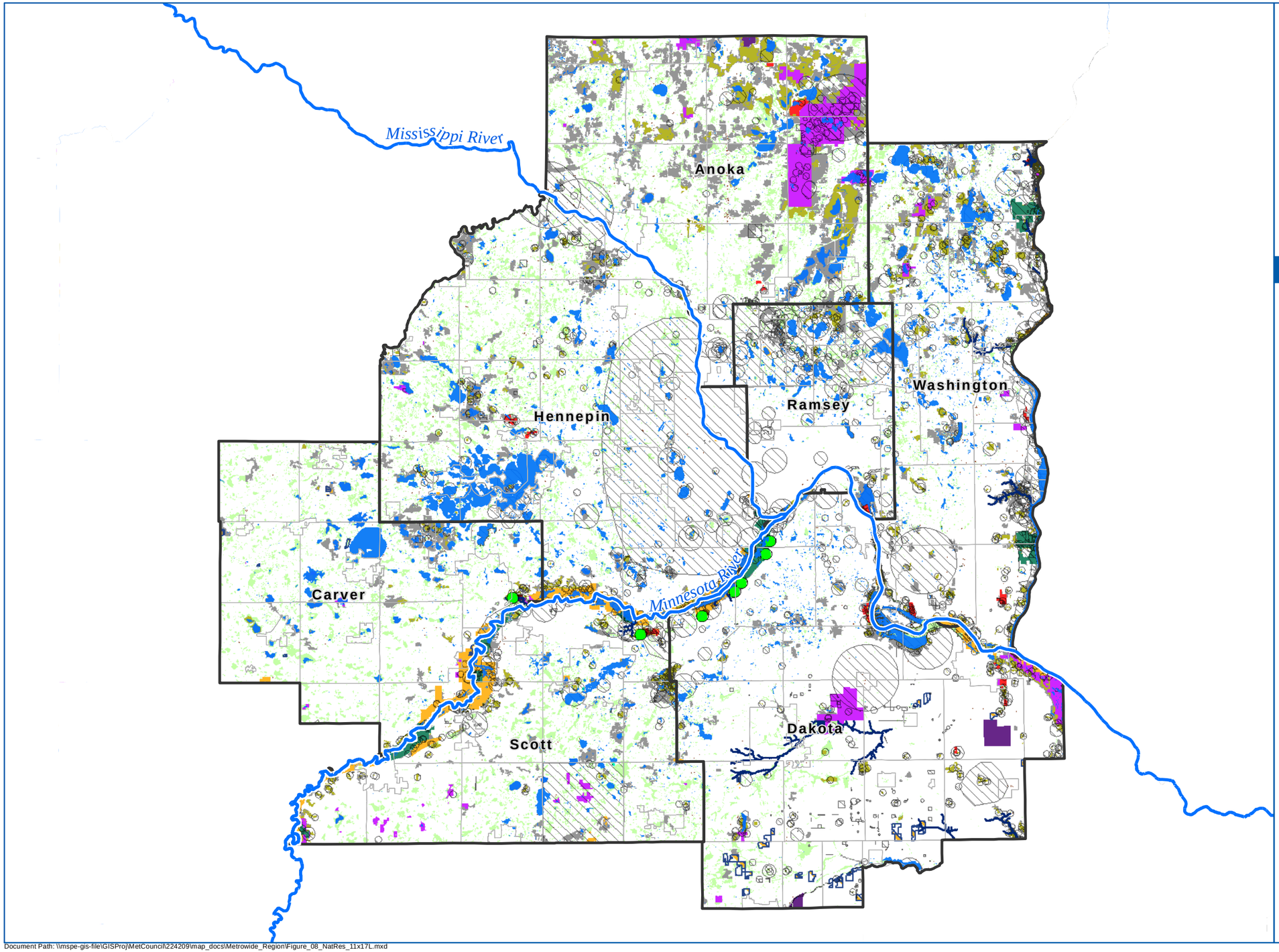
Metropolitan Council
Regional Groundwater Recharge Study

Figure 8
Sensitive Natural Resources
Twin Cities Metro Study Area



Legend

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

Tier 2
- Potential T&E Species Area
- Game Refuge
- County Boundary
- City/Township Boundary
- Waterbody
- NWI Wetland

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

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

Sources: MPCA, NHD, DNR

0 40,000 Feet

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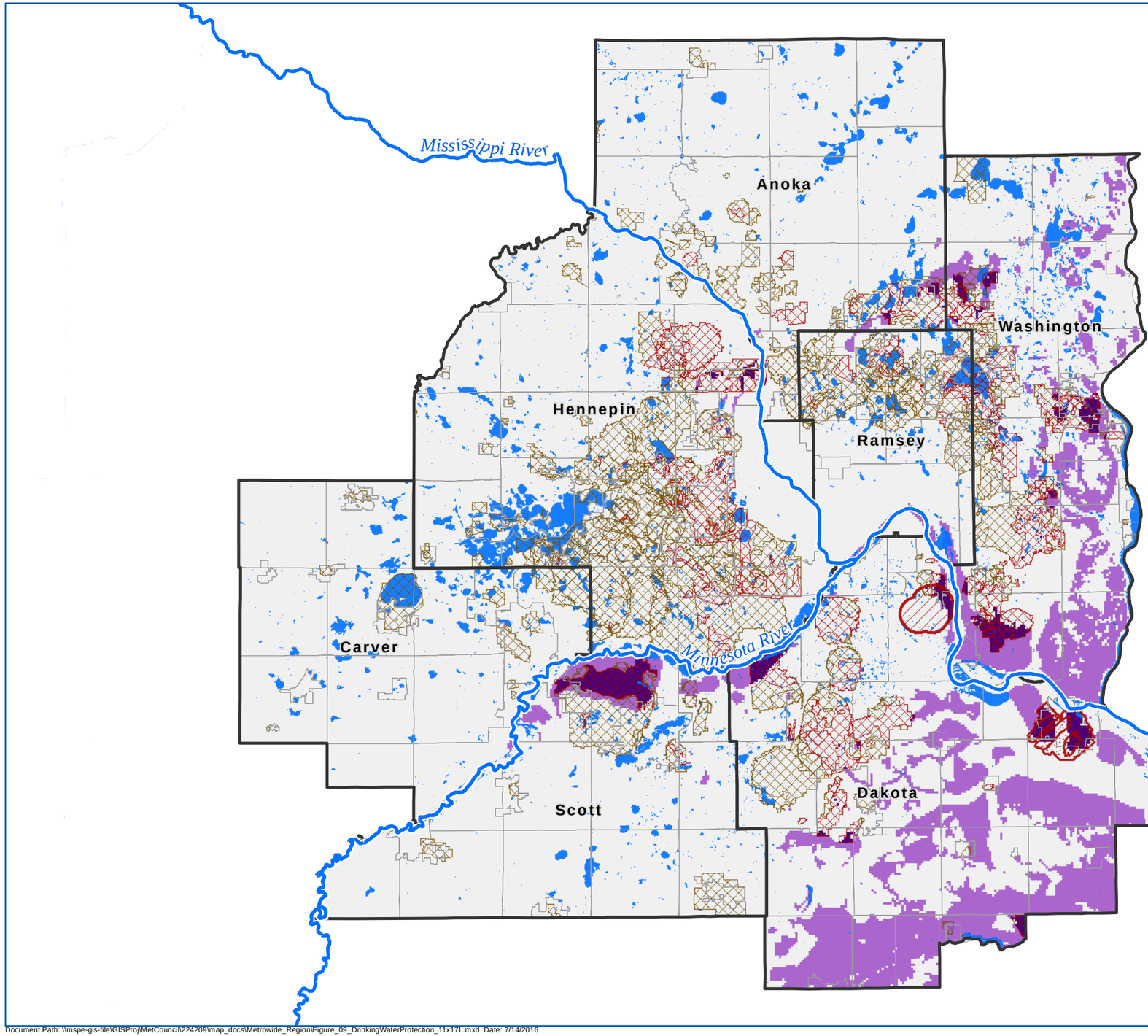
Metropolitan Council
Regional Groundwater Recharge Study

Figure 9
Drinking Water Protection
Twin Cities Metro Study Area



Legend

- DWSMA
- Vulnerable DWSMA
- Preliminary Inver Grove Heights WHPA (HDR)
- Hastings Groundwater Capture Zone
- Depth to Prairie du Chien < 100'
- Prairie du Chien not Subcropping
- Tier 3 — *Within a vulnerable DWSMA / Preliminary IGH WHPA / Hastings Groundwater Capture Zone AND Depth to Prairie du Chien < 100'.*
- County Boundary
- City/Township Boundary

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

Sources: MDH, NHD, DNR

0 — 40,000 Feet

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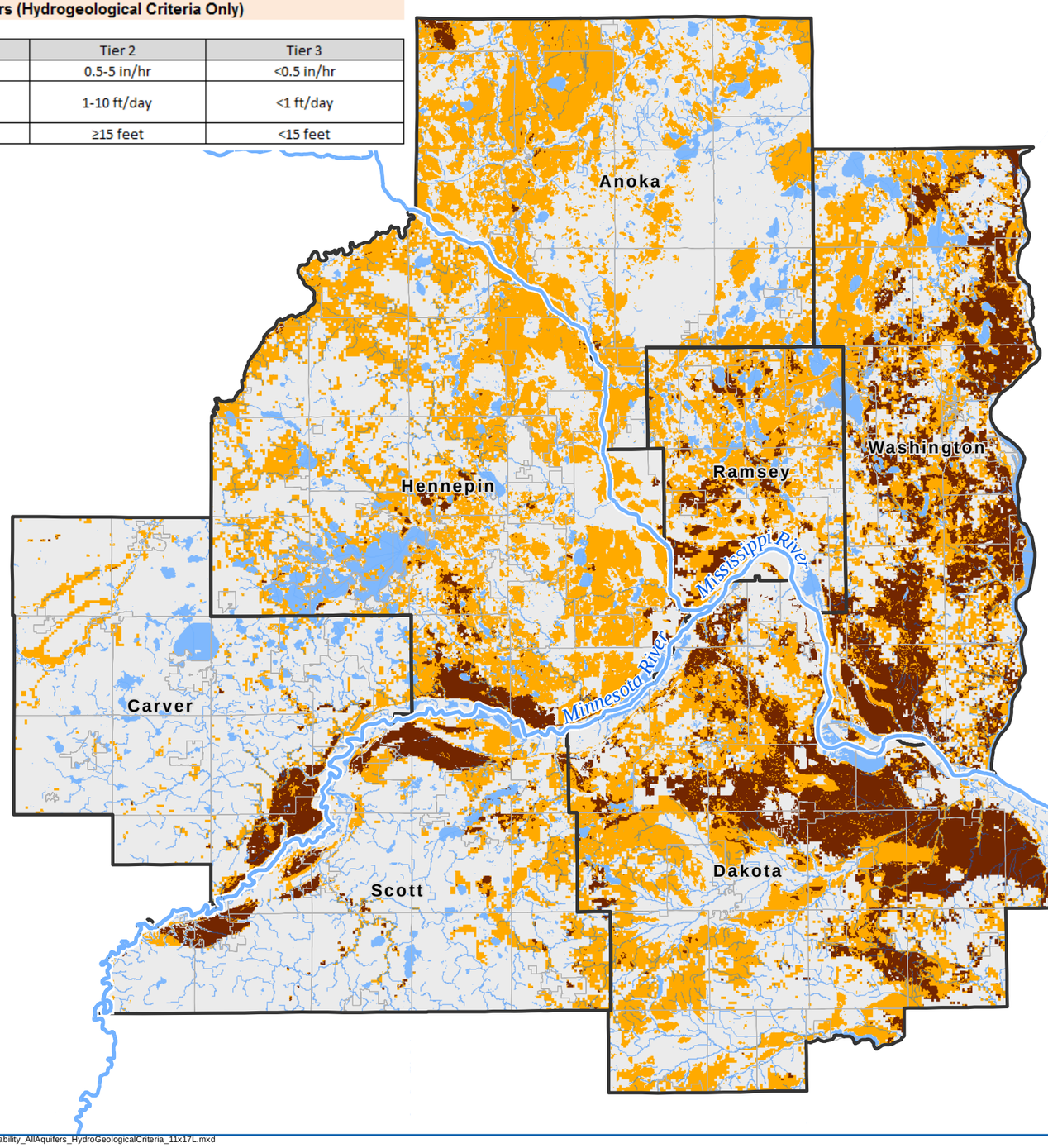
Metropolitan Council
Regional Groundwater Recharge Study

Figure 10
Potential Areas for Enhanced Recharge to All Aquifers (Hydrogeological Criteria)
Twin Cities Metropolitan 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



Legend

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

Enhanced recharge areas are based on hydrogeological criteria only.

Sources: USDA NRCS, NHD, DNR

0 40,000 Feet

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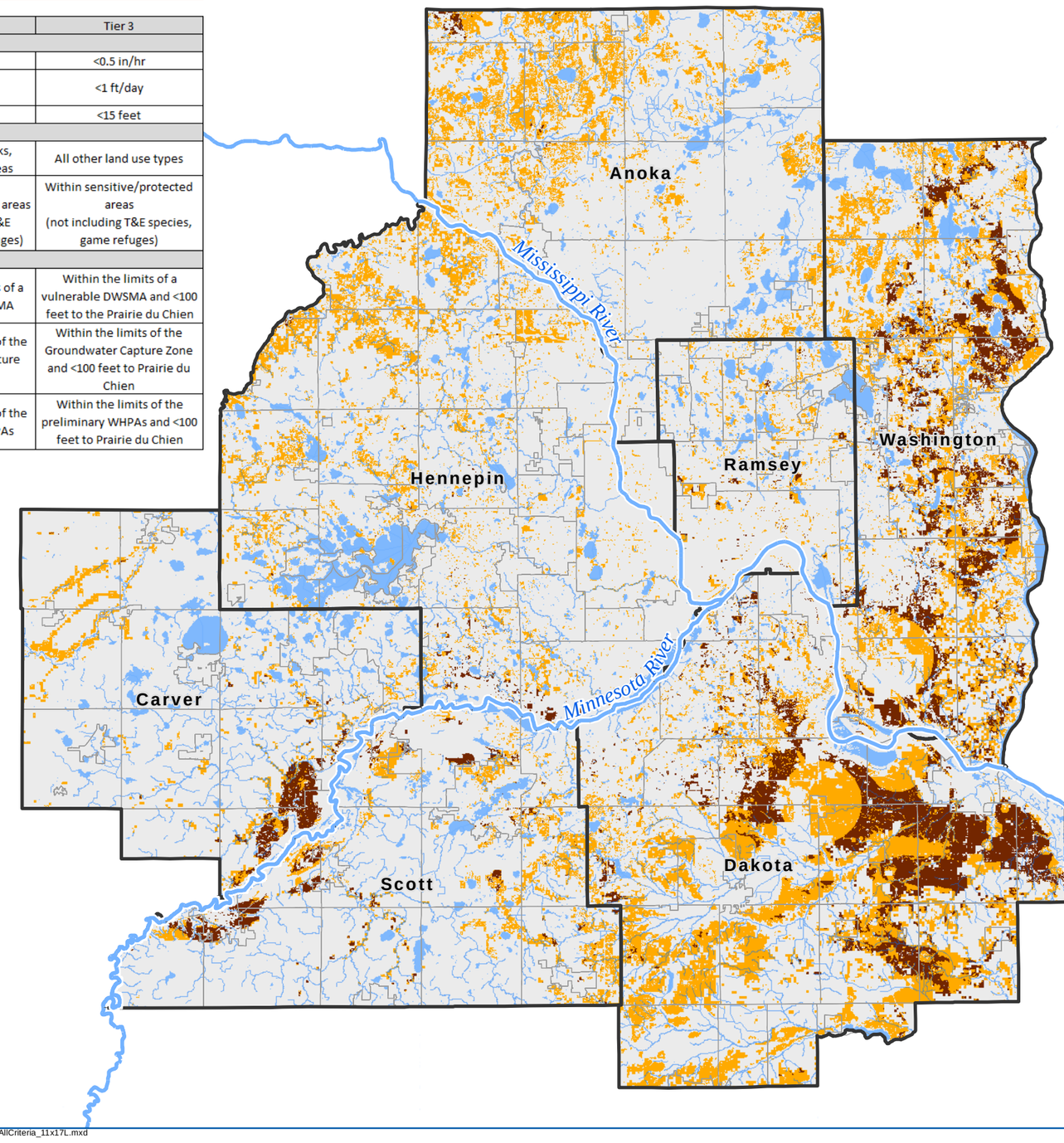
Metropolitan Council
Regional Groundwater Recharge Study

Figure 11
Potential Areas for Enhanced Recharge to All Aquifers (All Criteria)
Twin Cities Metropolitan 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
Hastings Groundwater Capture Zone and <100 ft to Prairie du Chien	Outside the limits of the Groundwater Capture Zone	Outside the limits of the Groundwater Capture Zone	Within the limits of the Groundwater Capture Zone and <100 feet to Prairie du Chien
Preliminary Inver Grove Heights WHPAs (HDR) and <100 ft to Prairie du Chien	Outside the limits of the preliminary WHPAs	Outside the limits of the preliminary WHPAs	Within the limits of the preliminary WHPAs and <100 feet to 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
- County Boundary
- City/Township Boundary

Sources: USDA NRCS, NHD, DNR, MDH

0 40,000 Feet

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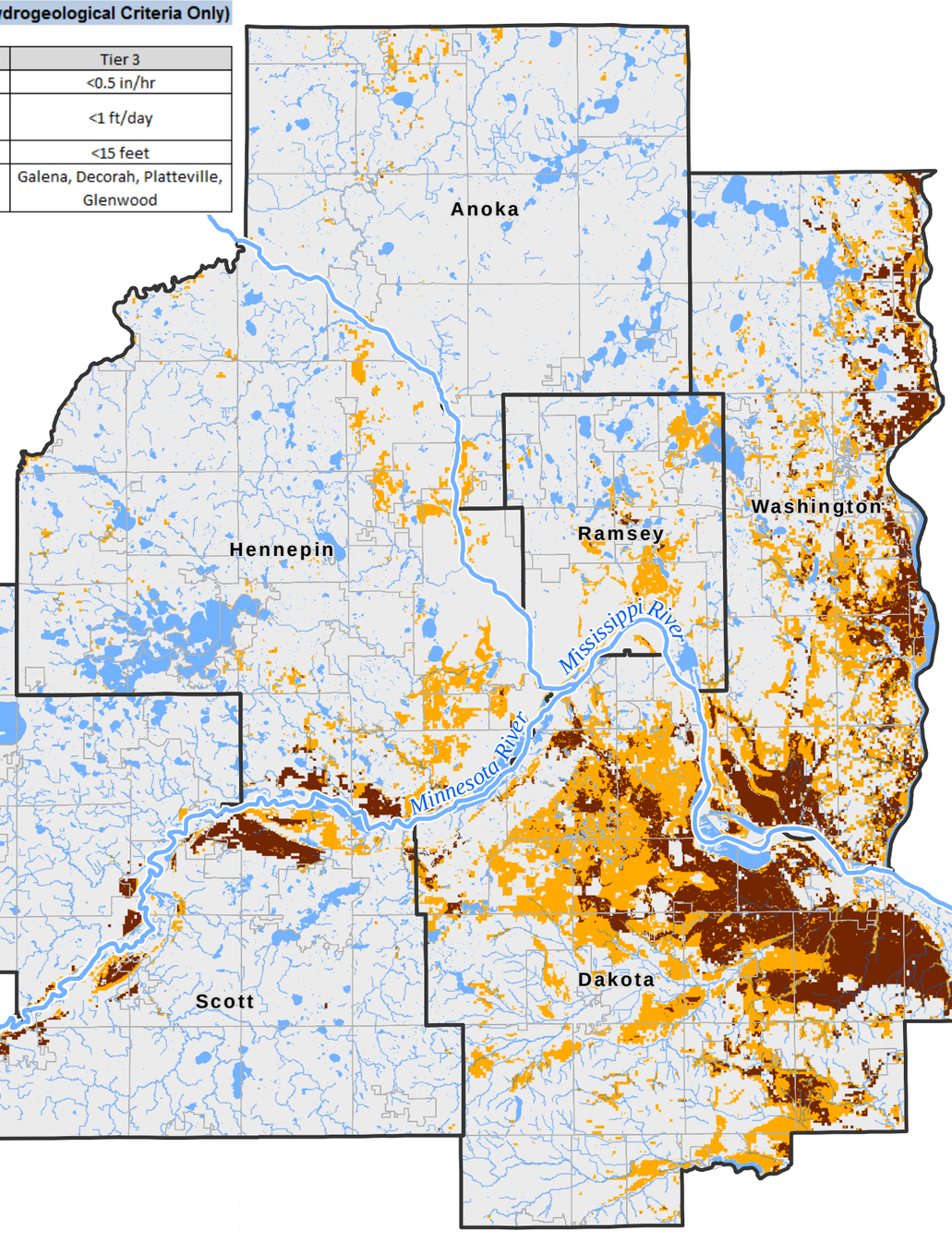
Metropolitan Council
Regional Groundwater Recharge Study

Figure 12
Potential Areas for Enhanced Recharge to Bedrock Drinking Water Aquifers (Hydrogeological Criteria)
Twin Cities Metropolitan Area

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

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



Legend

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

Enhanced recharge areas are based on hydrogeological criteria only.

Sources: USDA NRCS, NHD, DNR

0 40,000 Feet

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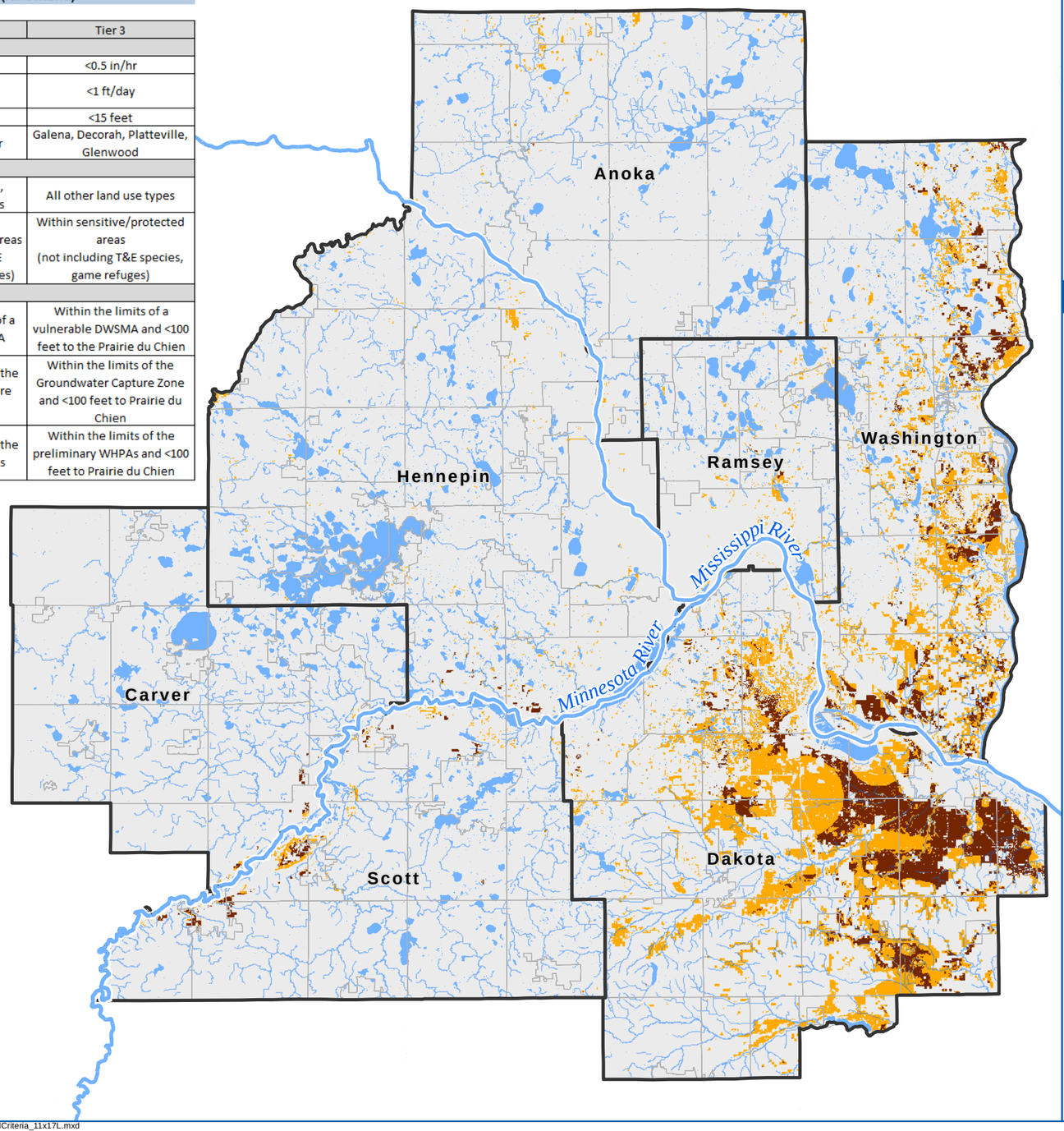
Metropolitan Council
Regional Groundwater Recharge Study

Figure 13
Potential Areas for Enhanced Recharge to Bedrock Drinking Water Aquifers (All Criteria)
Twin Cities Metropolitan Area

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

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

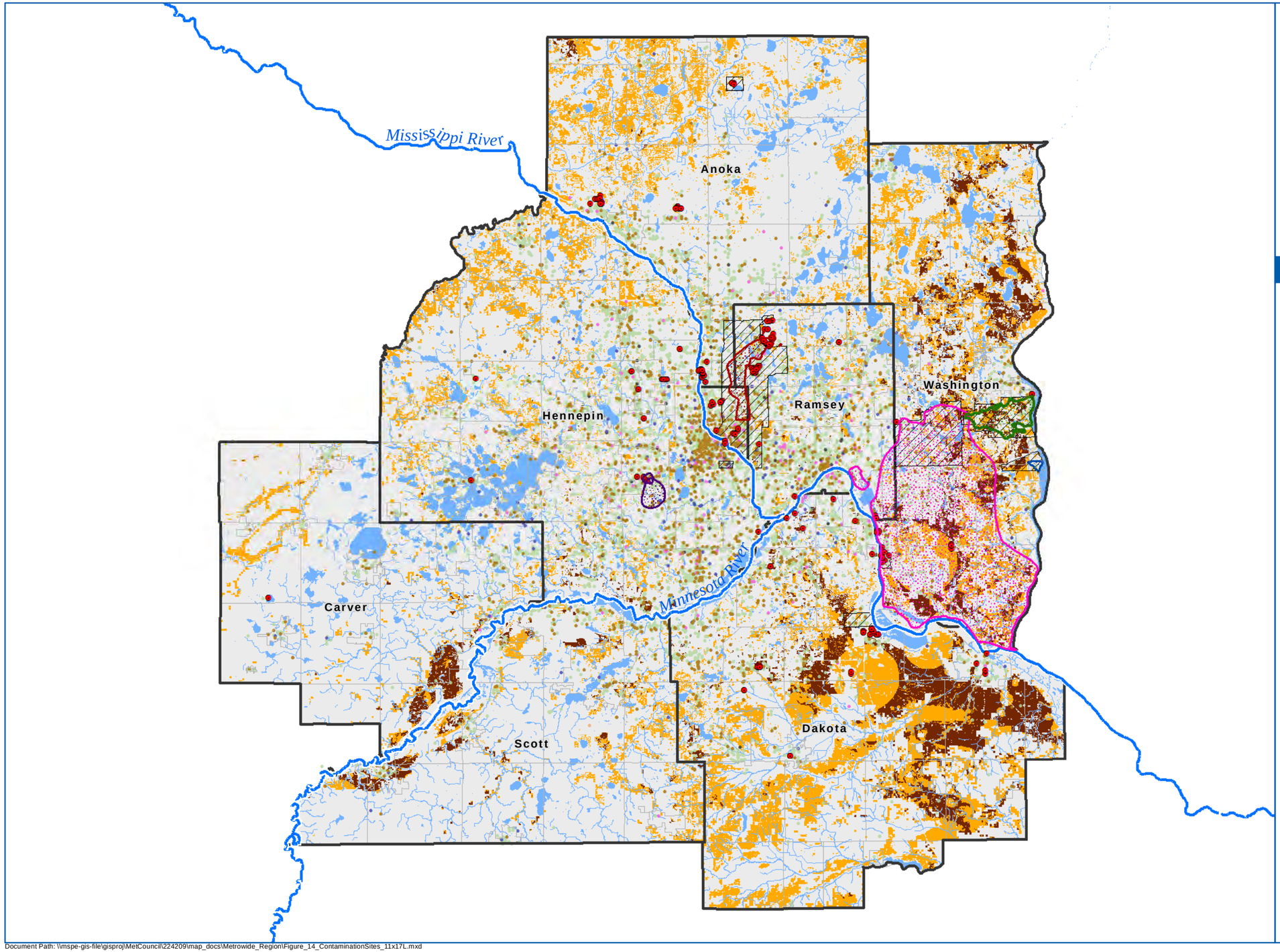
Sources: USDA NRCS, NHD, DNR, MDH

0 40,000 Feet

Document Path: \\mspe-gis-file\GISProj\MetCouncil\224209\map_docs\Metrowide_Region\Figure_13_Suitability_PdCAquifers_AllCriteria_11x17L.mxd

Metropolitan Council
Regional Groundwater Recharge Study

Figure 14
Potential Contamination and Recharge Areas
Twin Cities Metro Study Area



Legend

- Tier 1 Area
- Tier 2 Area
- Tier 3 Area
- Pollution Containment Well (DNR)
- Special Well and Boring Construction Area

MPCA Database Sites

- Landfill, Open
- Leak Site
- Multiple Activities
- Petroleum Brownfield
- Tank Site
- Voluntary Investigation & Cleanup (VIC)

Contaminant Plumes

- Twin Cities Army Ammunition Plant (TCAAP) (2013)
- Baytown Township (2014)
- Lakeland/Lakeland Shores (2014)
- Perfluorochemicals (PFCs) (2014)
- St. Louis Park (2015)
- County Boundary
- City/Township Boundary
- Waterbody
- Perennial Stream

Note: Approximate extents of large contaminant plumes are shown, which may include multiple aquifers. Smaller areas of contamination may exist that are not shown.

Sources: MPCA, MDA, NHD, DNR

0 40,000 Feet

N

HDR

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