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Acknowledgements

The project team gratefully acknowledges the contributions from the following individuals and organizations:

- Scott C. Alexander, University of Minnesota, provided laboratory services and interpretation of chemistry results. His input is incorporated throughout the report;
- Washington Conservation District for their assistance with the monitoring and field data collection portion of this project;
- Valley Branch Watershed District for providing report Chapter 6 – Feasibility Study for Managing Excess Surface Water – Sunnybrook Basin;
- the study Technical Advisory Committee;
- the study Policy Advisory Committee; and
- Washington County Water Consortium.

Executive Summary

Introduction and Project Organization

The *Integrating Groundwater and Surface Water Management – Northern Washington County* project was initiated to provide local decision makers with planning level information on groundwater resources in their area and data to support management strategies and policies protecting lakes, wetlands, streams and water supplies dependent on groundwater resources.

This study was jointly funded by Washington County, Rice Creek Watershed District, Brown's Creek Watershed District, Valley Branch Watershed District, Carnelian-Marine Watershed District and the City of Stillwater, in conjunction with the Board of Water and Soil Resources (BWSR) Challenge Grant Program.

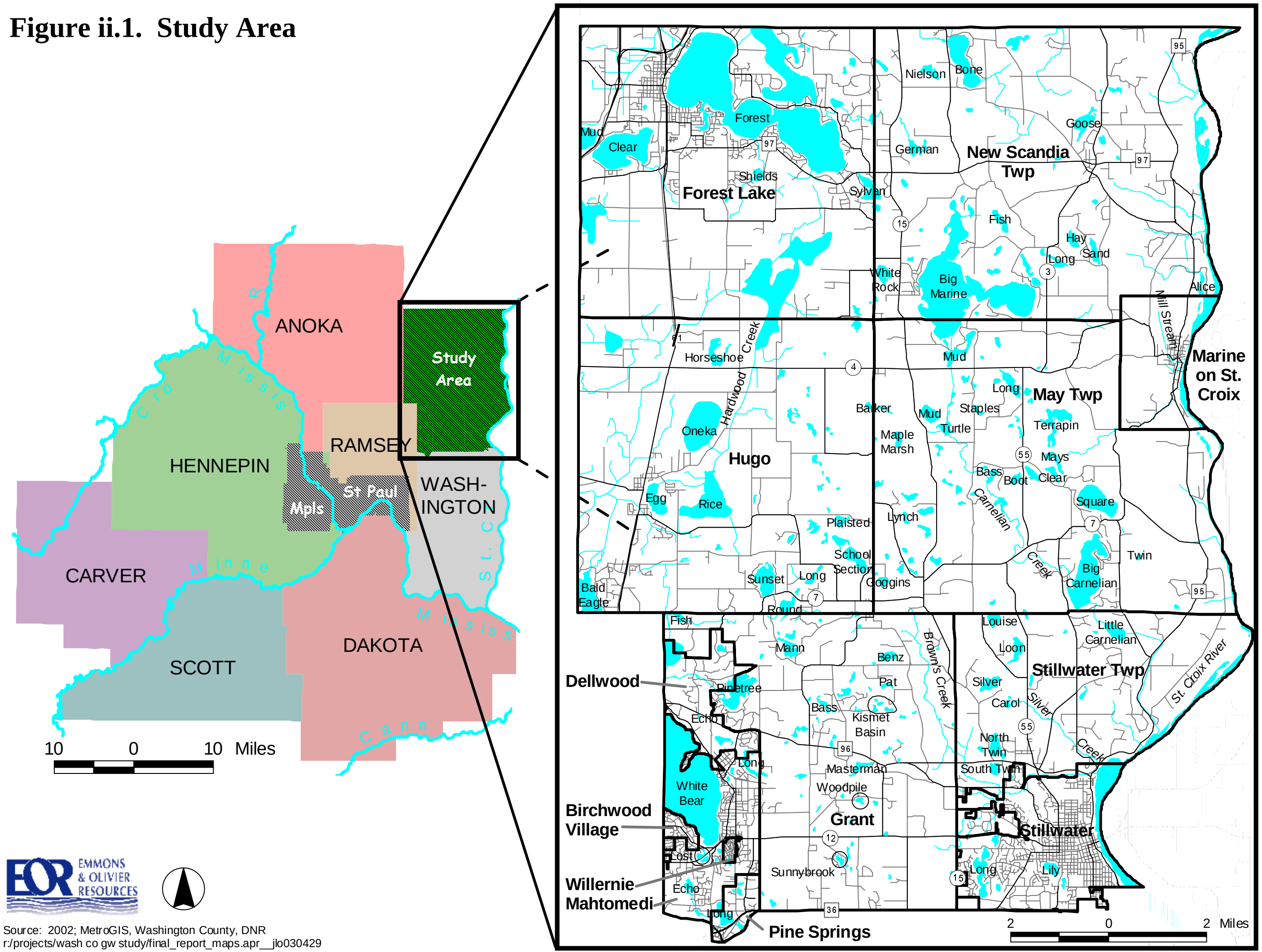
The project was organized into the following main tasks:
- Education and Information. Pre-project and post-project meetings were held with local water management groups.
- Comprehensive Hydrologic Monitoring Plan. New hydrologic data were collected throughout the study area.
- Groundwater Resources Assessment and Classification. Existing data were compiled and analyzed. All data from the study were used to inventory and classify resources including lakes, recharge and discharge areas, and groundwater dependent resources.
- Strategy for Integrating Groundwater and Surface Water Management. Groundwater management policies were developed for drinking water protection, maintaining recharge, and managing high water levels.
- Feasibility Study for Managing Excess Surface Water – Sunnybrook Basin. Valley Branch Watershed District investigated alternatives for retention and infiltration of water in the upper watershed of the Sunnybrook Lake area.
- Cooperative Efforts.

The compact disc that accompanies this report contains additional information not found in the printed report, including:
- Electronic versions of the report text and graphics.
- Complete tables of monitoring data.
- ArcView GIS files and metadata.

Background

The study area for this project includes the northern portion of the County, from State Highway 36 north to the County line, as illustrated on Figure ii.1. The study area covers approximately 215 square miles in the Cities of Birchwood Village, Dellwood, Mahtomedi, Marine-on-St. Croix, Pine Springs, Willernie, Stillwater, Grant, Forest Lake, Scandia, and Hugo, and the Townships of May, New Scandia, and Stillwater.

Figure ii.1. Study Area



Source: 2002; MetroGIS, Washington County, DNR
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Background information and data were collected on:

- Climate and precipitation;
- Soils;
- Geomorphic regions and topography;
- Geology;
- Watersheds; and
- Land use.

The unique geologic characteristics of the study area are illustrated on Figure ii-2. Glacial deposits cover virtually all of the study area. The deposits include glacial tills from the younger Des Moines Lobe (limited to the northwest part of the study area) and the older Superior Lobe glaciation. The Superior Lobe sediments include an area of high topography near the middle of the study area known as the St. Croix Moraine.

The study area is at the edge of the “Twin Cities Basin”. Layers of sedimentary bedrock slope upward to the east toward the St. Croix River. The surface topography slopes downward toward the river, so that deeper bedrock aquifers are exposed at or near the surface. Erosion of the bedrock layers has left deep bedrock valleys filled with glacial sediments.

Groundwater dependent resources occur where the water table intersects the land surface and discharges. Groundwater dependent resources in the study area include some wetlands and lakes, fens, seepage swamps, springs, and spring creeks. All the residents of Washington County get their drinking water from groundwater. Groundwater and groundwater dependent resources are threatened by changes in recharge and patterns caused by changing land use.

Comprehensive Hydrologic Monitoring Plan

Data collected for this study included:

- Lake and wetland monitoring.
- Precipitation monitoring.
- Stream flow measurements.
- Groundwater monitoring including water levels in a well monitoring network. Groundwater levels below some lakes were measured to identify groundwater inflow and outflow from lakes.
- Chemistry analysis of both surface water and groundwater from the well monitoring network and at select lakes. Analyses included major cations and anions, tritium, strontium isotopes, and stable isotopes of water.
- Inventory data on natural resources.

Groundwater elevation contours were generated for each of the aquifers. The groundwater elevation map for the Quaternary, or water table, aquifer is shown on Figure ii.3. As with most other aquifers, groundwater elevations are highest in the middle of the study area, beneath the St. Croix Moraine, and flow east and west from this divide toward the St. Croix and Mississippi Rivers.

Figure ii.2. Generalized Cross Section

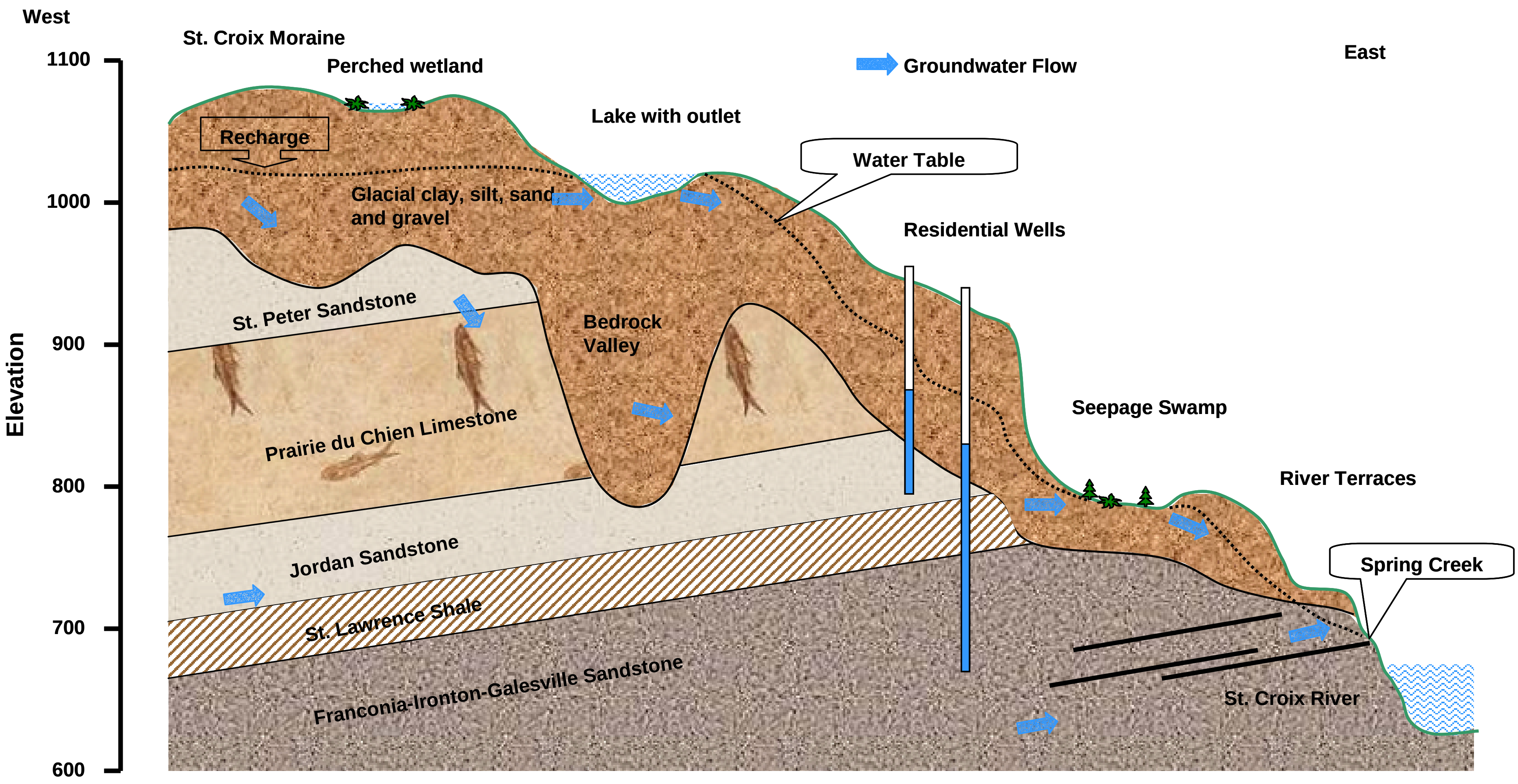
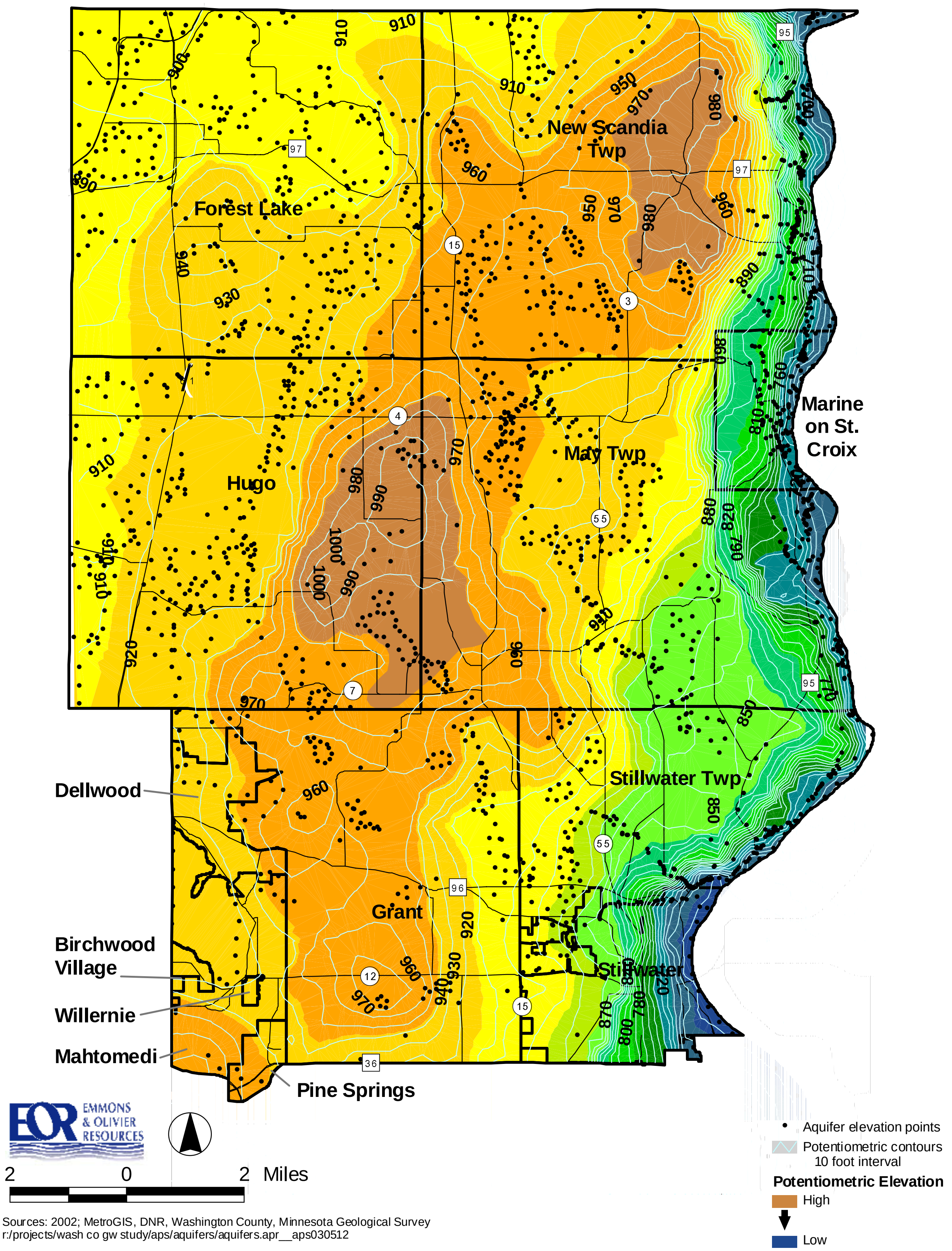


Figure ii.3. Quaternary Aquifer Groundwater Contours.



Sources: 2002; MetroGIS, DNR, Washington County, Minnesota Geological Survey
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Groundwater Resource Assessment and Classification

Surface water resources in northern Washington County are influenced by regional groundwater flow, locally perched groundwater, precipitation, topography, and soils. Many of the water bodies within the study area are of very high quality, providing excellent recreation opportunities and habitat for unique and endangered species. Identifying each water body’s dependence on groundwater resources is critical to managing the surface watersheds and groundwatersheds in order to protect these resources.

The 47 largest lakes in the study area were classified according to three characteristics which make up their “groundwater function”:

- Groundwater recharge (lake loses water), groundwater discharge (lake gains water), or flow-through (lake loses or gains water in different areas);
- Low connection or high connection based on the degree (flux) of groundwater interaction; and
- Precipitation driven or groundwater driven, which influences the chemistry.

Figure ii-4 summarizes the function analysis.

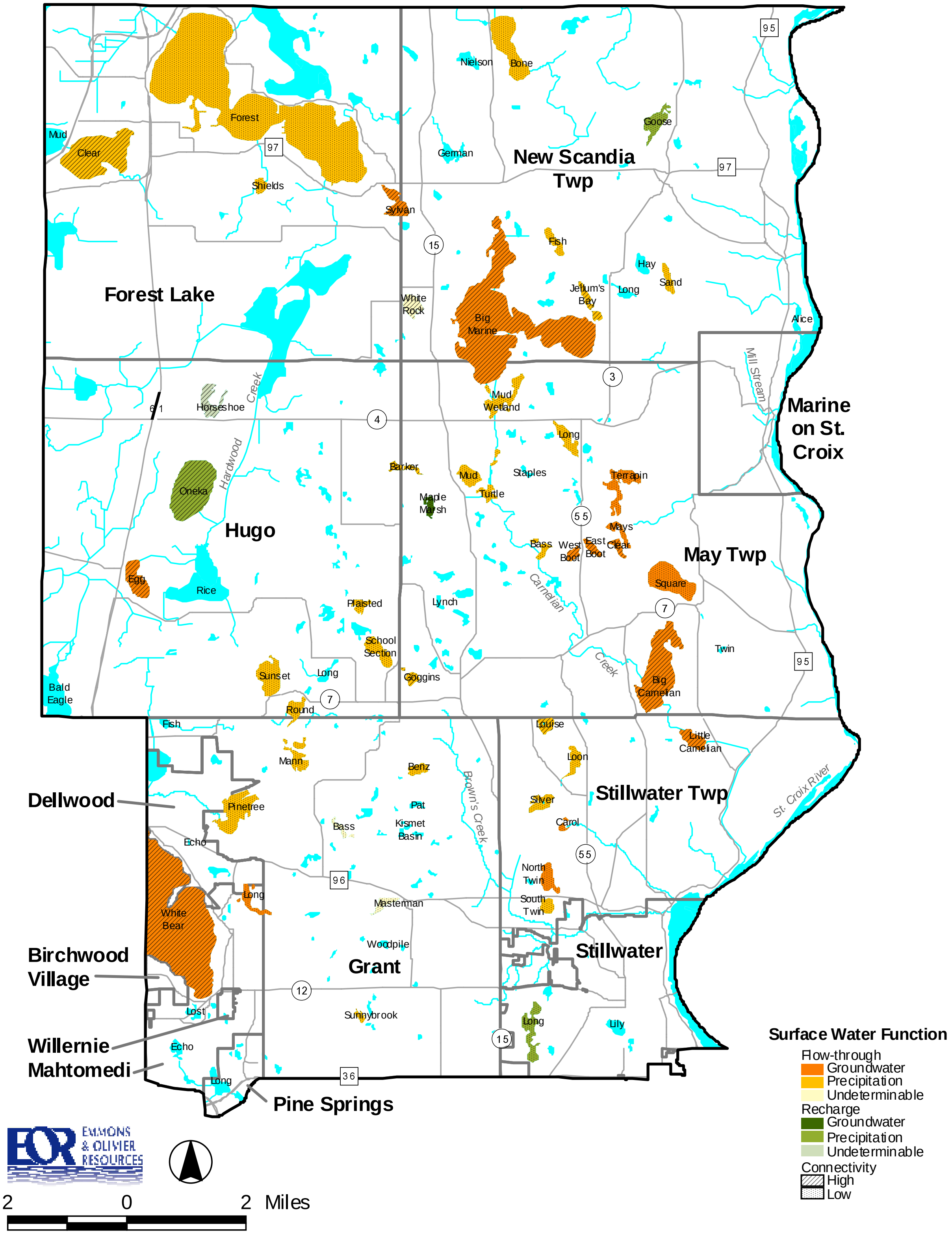
Figure ii-5 shows areas with groundwater dependent natural resources. Natural resource inventories completed by the watershed management organizations were particularly helpful in creating this map. Additional inventory and field verification were done for this project.

The Infiltration Potential Map shown on Figure ii-6 was created by using ArcView GIS to combine and analyze soil types and surficial geology features. The infiltration potential of soils is used to determine the ability of soils to accept and transmit surface water from precipitation to the groundwater system. High infiltration areas are important because recharge to groundwater systems is critical to maintaining groundwater dependent ecosystems.

Figure ii.7 shows the important recharge and discharge zones identified within the study area. The concept of recharge zones and discharge zones is useful for designating groundwater management zones. The recharge and discharge zones only identify areas where recharge or discharge is prevalent. It is important to remember that recharge and discharge occur in all the zones.

Figure ii.8 illustrates useful groundwater management zones. The study area has been broken down into management zones based on similar landscapes and landforms that require varying degrees of management for protection of aquifers and groundwater dependent resources. The infiltration potential, recharge and discharge areas, and presence of groundwater dependent resources were used to generate the management zones. The study area was differentiated geographically into three management zones - 1, 2, and 3. Zone 1 requires the highest level of management and zone 3 requires the lowest.

Figure ii.4. Water Bodies and Function Analysis



Sources: 2002; MetroGIS, DNR, Washington County
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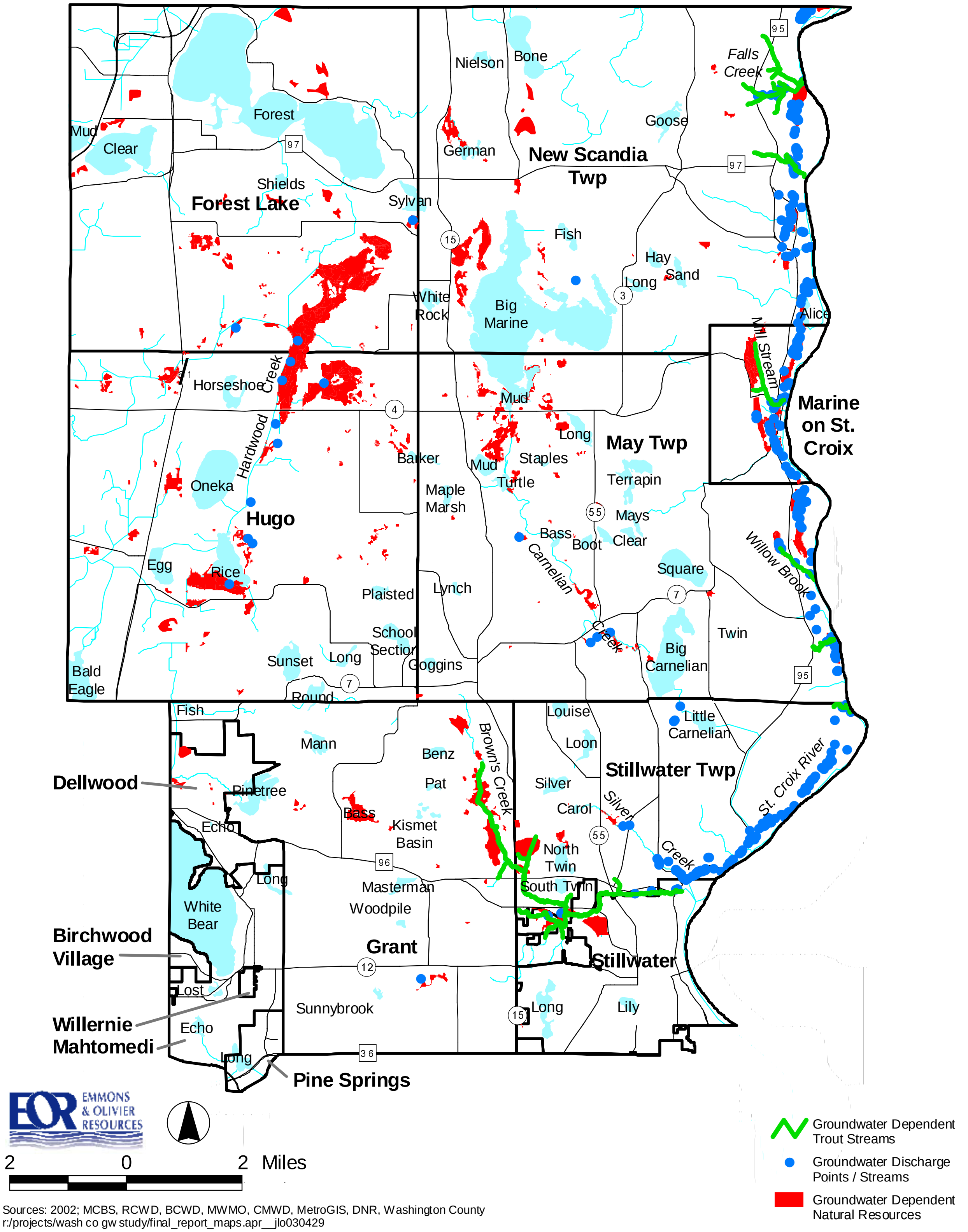
Figure ii.5. Groundwater Dependent Resources



Sources: 2002; MCBS, RCWD, BCWD, MWMO, CMWD, MetroGIS, DNR, Washington County
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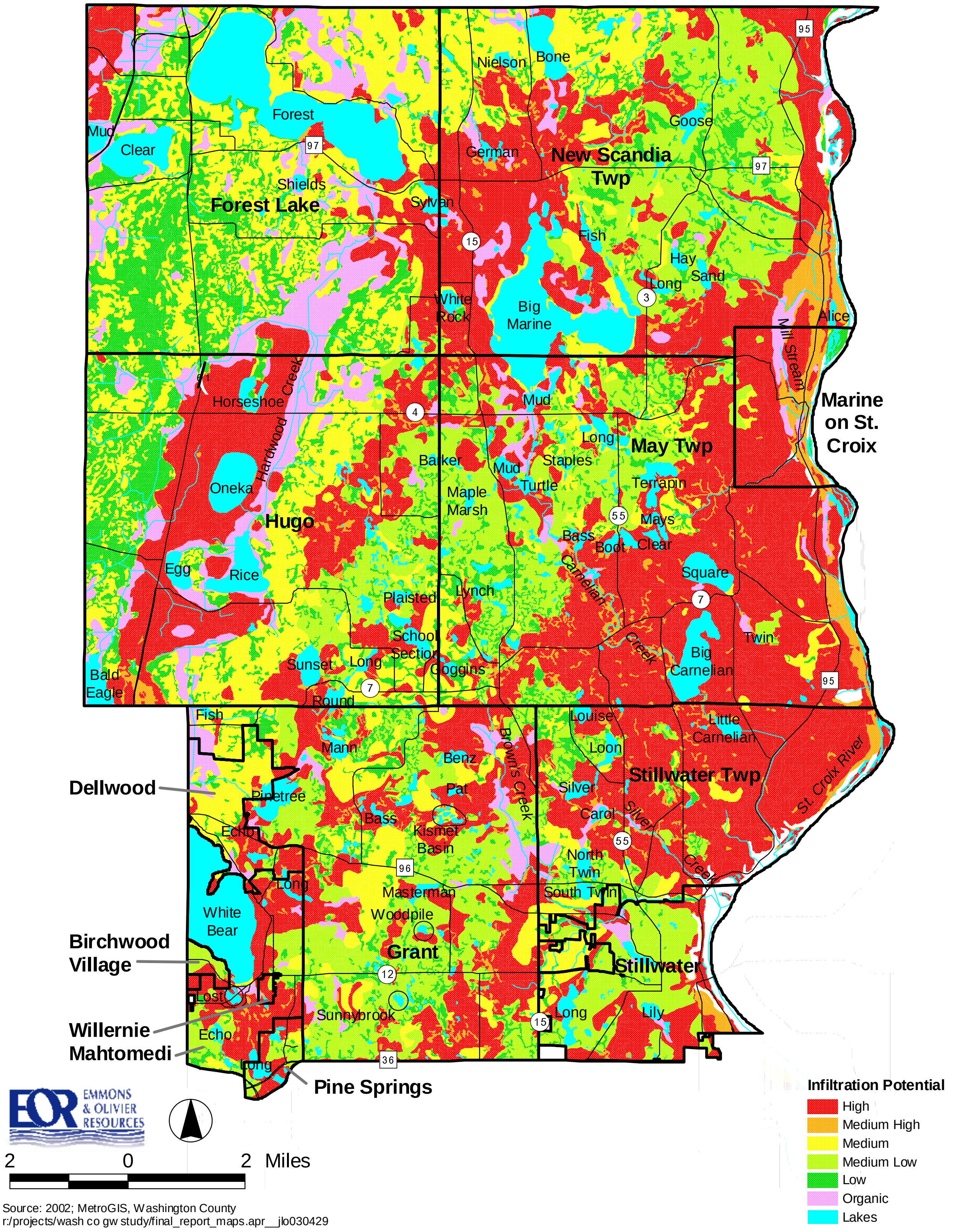
Figure ii.6. Infiltration Potential.



Source: 2002; MetroGIS, Washington County
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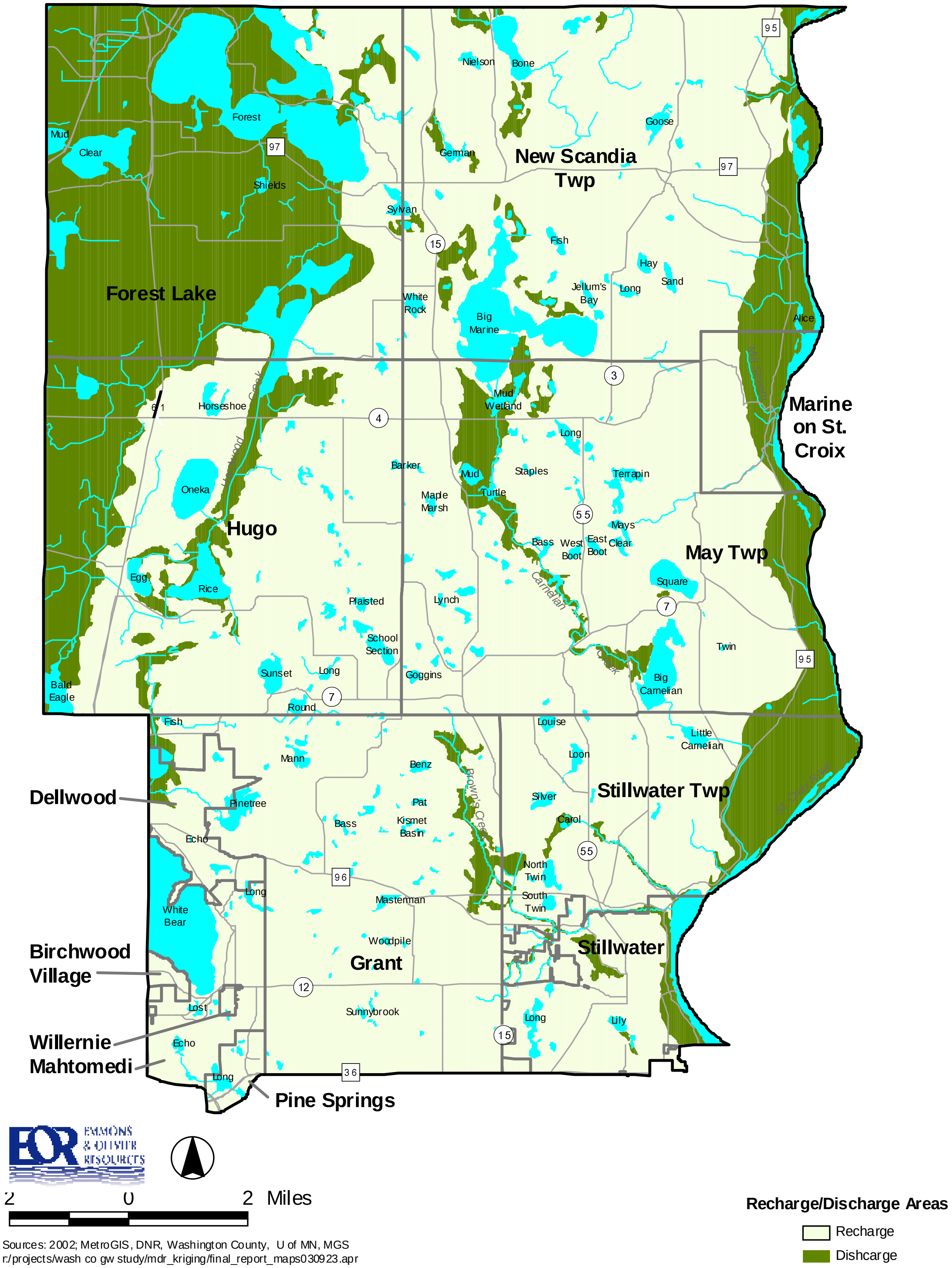
Figure ii.7. Recharge and Discharge Zones



Sources: 2002; MetroGIS, DNR, Washington County, U of MN, MGS
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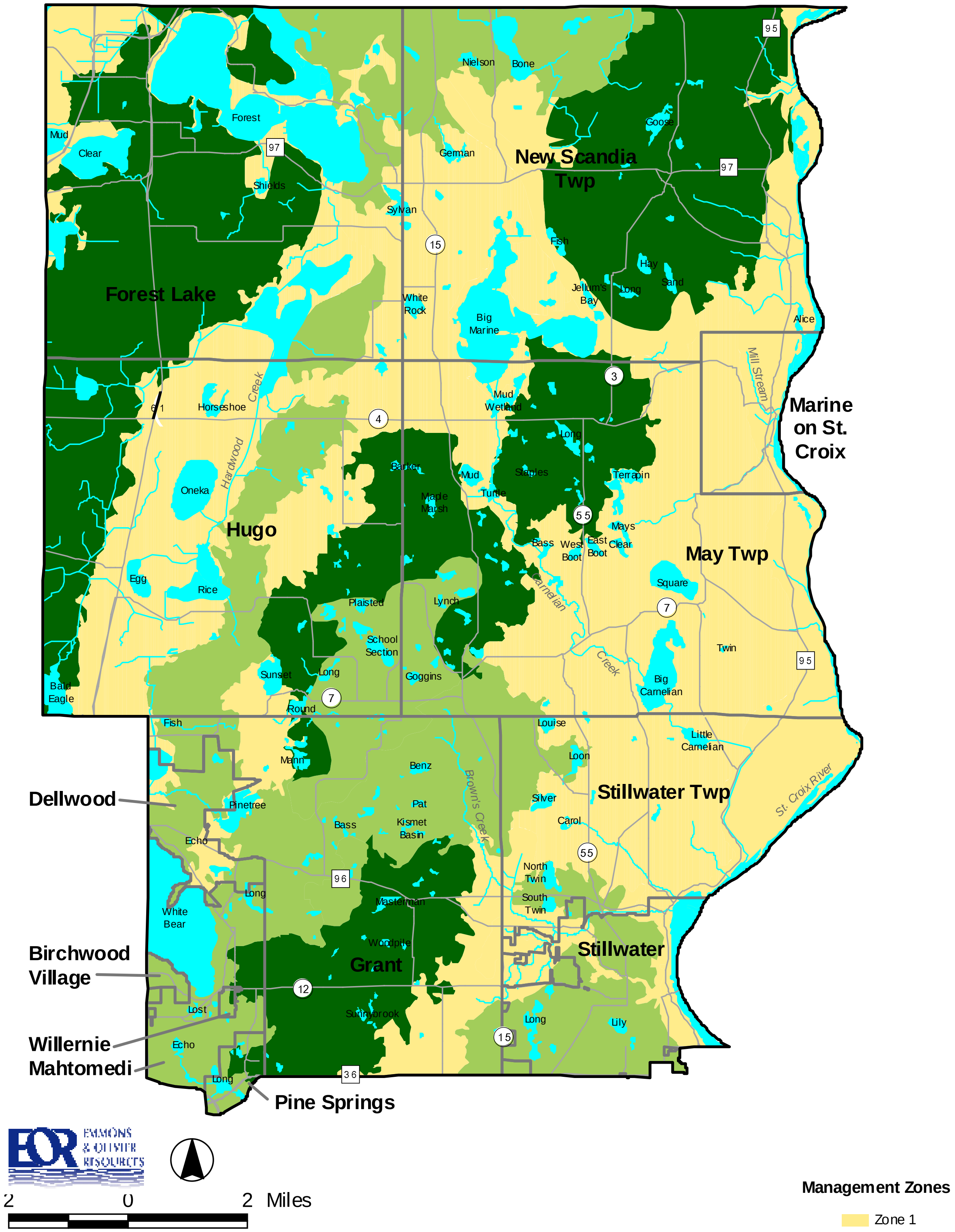
Figure ii-8. Management Zones



Sources: 2002; MetroGIS, DNR, Washington County, U of MN, MGS
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Strategy for Integrating Groundwater and Surface Water Management

The successful implementation of a groundwater protection program for northern Washington County depends largely upon convincing the public and their elected officials of the need to take action. Washington County officials and staff have seen the need and acted through the preparation of the *County Groundwater Plan* and initiation of this groundwater study. The challenge is to actively use the information gained from these efforts during future implementation projects.

Several recommendations are made on how the County can move forward and effectively implement groundwater protection in partnership with many other interested parties. A strategy is developed based on the *County Groundwater Plan* wherein various levels of protection are defined, sample action steps and policies are developed, and a model ordinance is made available to implementing entities. Implementation is suggested through cities, townships and watershed management organizations (WMOs) operating under a County-developed framework.

The following four steps are proposed to initiate discussion and are presented with some flexibility in mind, depending upon all of the political, legal, financial and institutional factors that must be addressed:

1. Adopt policies and recommendations;
2. Determine protective levels;
3. Propose institutional methods to implement; and
4. Provide technical and planning assistance.

A model ordinance that can be adopted by local governmental units (watershed management organizations, cities, townships) is included as an appendix to this study report.

Feasibility Study for Managing Excess Surface Water – Sunnybrook Basin

The Valley Branch Watershed District (VBWD) utilized project funds to investigate the use of innovative strategies to manage high water/flooding issues in the Sunnybrook Lake watershed area. To evaluate the various strategies, the VBWD needed to understand the groundwater – surface water relationship in the area. The VBWD used existing data to construct a long-term, continuous simulation (a hydrologic and hydraulic computer model) of the Sunnybrook Lake watershed. A groundwater model and other data were used to calibrate the surface water model simulation so that its predicted water levels would match observed conditions. Once the surface water model was constructed and calibrated, the VBWD had a powerful tool that it used to predict the impacts of management scenarios. The VBWD used this tool, statistical analyses, and cost estimates to evaluate flood relief management strategies. Information and techniques learned and used in the VBWD's Sunnybrook Lake flood relief study can be applied to other basins requiring a detailed analysis of existing conditions and potential water quantity solutions.

Cooperative Efforts

A key aspect of this project is the cooperative efforts among state and local governmental units. The efforts described in this section show how various organizations have already made use of data and information from this project. Typically they have used the new information from this project as a baseline, or starting point, for their own investigations.

Brown's Creek Watershed District and the Minnesota DNR investigated the source and recharge areas for springs that feed the lower reaches and trout habitats along Brown's Creek. Water chemistry results showed that recharge to the springs in the study was coming from nearby small lakes.

Engineers and policy makers have begun to recognize that groundwater plays an important role in predicting high water levels in land-locked basins. Carnelian-Marine Watershed District was contracted by Washington County to determine 100-year flood elevations in several land-locked basins within their watershed. Some of the lake levels were not significantly influenced by groundwater, but they used the information from this report to significantly improve their predictive models for several other lakes.

Monitoring wells were installed along Hardwood Creek (Judicial Ditch 2) as part of this project. Water level and chemistry data from the wells has shown that groundwater contributes significantly to the overall hydrology of the creek. This has implications for future maintenance of the ditch, the wetlands and other natural resources along the ditch, and the water quality and Total Maximum Daily Load (TMDL) regulations applied to the ditch.

The Lower St. Croix River Spring Creek Stewardship Plan is the "sister project" to this study. Numerous spring creeks emanate from the bluffs along the St. Croix River and run into the River. They have several important features related to groundwater:

- The ravines associated with the spring creeks contain some of the last remnants of pre-settlement ecosystems found in the Twin Cities area.
- Some of the ecosystems supported by the groundwater are highly unusual, typical of ecosystems found only far to the north.
- They provide an important habitat for trout and other fish.
- The creeks support unusual communities of macroinvertibrates, including several species that are newly-described in Minnesota as part of this study.

The Stewardship Plan inventoried the plant and animal communities associated with the spring creeks. This groundwater study contributed chemistry analysis and hydrologic analysis of the springs. The Stewardship Plan also proposed management strategies for protecting the spring creek resources.

1. Introduction and Project Organization

1.1. Project Description and Overview

The *Integrating Groundwater and Surface Water Management – Northern Washington County* project was initiated to provide local decision makers with planning level information on groundwater resources in their area and data to support management strategies and policies protecting lakes, wetlands, streams and water supplies dependent on groundwater resources.

This study was jointly funded by Washington County, Rice Creek Watershed District, Brown's Creek Watershed District, Valley Branch Watershed District, Carnelian-Marine Watershed District and the City of Stillwater, in conjunction with the Board of Water and Soil Resources (BWSR) Challenge Grant Program.

Groundwater components in northern Washington County constitute a major portion of water management. Watershed Districts lack the key groundwater information pieces to assemble and manage the entire hydrologic system puzzle. Precipitation changes and related groundwater quantity increases factor into virtually all of the costly water resource projects and water related litigation that have been undertaken in northern Washington County. Many priority water features and resources in the study area are inextricably dependent on groundwater for their sustainability. The project partners collaborating in this project share a common goal of integrating groundwater and surface water components to holistically manage and protect the entire hydrologic system.

The project was organized into the following actions:

- **Education and Information**

Pre-project meetings and presentations were held with local watershed districts to get feedback on issues of concern before developing the final workplan for the project. Post-project meetings were held to inform watershed districts and local units of government about the results of the project, disseminate information and policies developed during the study, and discuss issues related to integrating groundwater and surface water management.

- **Inventory, Rank, and Compile**

Existing data were compiled on:
  - Groundwater;
  - Surface water;
  - Precipitation and climate; and
  - Natural resources and land use.

The existing data and data gathered in the Monitoring task were used to determine how specific surface water bodies interact with groundwater, and whether they are recharge areas, discharge areas, or both. Recharge and infiltration areas that are not associated with surface water bodies were also identified and mapped. Low-altitude aerial images were taken along the St. Croix River shoreline to identify groundwater discharge areas.

This project was closely aligned with the St. Croix River Spring Creeks Stewardship Plan, which was also funded by a BWSR Challenge Grant. Through that project and other natural resource inventory projects, groundwater dependent natural resources have been mapped

- **Monitoring**

A well monitoring network was established using mostly residential wells and some publicly-owned wells. Groundwater level data were recorded and water quality samples were collected from the wells. The samples were analyzed for major anions and cations, stable isotopes of hydrogen and oxygen, and tritium and strontium isotopes (for age dating of groundwater.)

Water samples from spring creeks were collected and analyzed as part of the St. Croix River Spring Creeks Stewardship Plan. Springs in other areas were also sampled and analyzed for the same parameters listed above.

Surface water elevations were monitored. Lake levels in many lakes are routinely monitored by the Washington Conservation District (WCD), but this project provided staff gauges for several lakes where additional data were needed. Some lakes were sampled and analyzed for stable isotopes of hydrogen and oxygen to determine groundwater/surface water connections.

Precipitation gauges were provided by this project in areas where reliable gauges are not already present. Gauge data will be collected by the WCD after this project is complete.

Washington County has also committed to monitor the long-term performance of at least one policy implemented as a result of this project.

- **Land and Water Treatment**

As part of this project, Valley Branch Watershed District investigated alternatives for retention and infiltration of water in the upper watershed of the Sunnybrook Lake area. Their report is discussed in Chapter 6.

- **Planning and Environmental Control**

Washington County has worked with local governmental units to develop specific management policies for areas with high groundwater levels. Areas critical to groundwater recharge and discharge and groundwater dependent resources have been identified. A Policy Advisory Committee (PAC) was formed (see below.) Groundwater management policies such as overlay districts for critical areas have been developed. Washington County will continue to assist with planning and management of critical areas.

1.2. Project Personnel

Questions or comments regarding this project and this report should be directed to:

Cindy Weckwerth
Project Manager
Washington County Department of Public Health and Environment
P.O. Box 6
Stillwater, MN 55082-0006
(651) 430-6703
weckwerth@co.washington.mn.us

Stuart Grubb
Project Manager
Emmons and Olivier Resources, Inc.
651 Hale Ave N.
Oakdale, MN 55128
(651) 770-8448
sgrubb@eorinc.com

1.3. Pre-project Meetings

Pre-project meetings were held to present the project workplan to interested parties. The meetings also provided an opportunity to incorporate information or suggestions about how to improve the project. Table 1.1 lists project meetings and dates. Before the watershed district meetings, Washington County sent a notice to each of the cities and townships in the study area inviting them to attend and participate.

Table 1.1. Pre-Project Meetings.

Date	Meeting
April 8, 2002	Mill Stream Association
May 4, 2002	Mill Stream Day – Display Booth
May 6, 2002	Carnelian-Marine Watershed District
May 8, 2002	Rice Creek Watershed District
May 13, 2002	Brown’s Creek Watershed District
September 17, 2002 September 19, 2002	Washington County Groundwater Public Information Meetings – Display Booth

1.4. Technical Advisory Committee

This study was presented at several technical meetings including:

Table 1.2. Technical Meetings.

Date	Meeting
October 16, 2001 October 15, 2002 October 23, 2003	St. Croix River Research Rendezvous, Marine-on-St. Croix, MN
Sept. 24, 2002	Minnesota Water Planners Conference, Hinckley
May 7, 2003 Sept.3, 2003	Washington County Water Consortium Meeting, Stillwater, MN
Sept. 16, 2003	Metro MAWD
November 2, 2003	Geological Society of America Conference, Seattle, WA (Presented by Scott Alexander, U of M)

A Technical Advisory Committee (TAC) was developed to provide overall technical guidance by local experts and agency input to the Study. TAC members are listed in Table 1.3. The TAC met on the following dates:

- January 30, 2002
- April 10, 2002
- July 30, 2002

Table 1.3. Technical Advisory Committee.

TAC Member	Affiliation
Jim Almendinger	Science Museum of Minnesota, St. Croix Watershed Research Station
Scott Alexander	University of Minnesota, Department of Geology and Geophysics
Jon Michels	Washington County Department of Health and Environment (formerly)
Cindy Weckwerth	Washington County Department of Health and Environment
Dale Setterholm	Minnesota Geological Survey
Mark Doneux	Formerly Washington Conservation District
Bob Fossum	Washington Conservation District
Tony DeMars	Emmons & Olivier Resources, Washington County St. Croix Spring Stewardship Study Project Manager
John Hanson	Valley Branch Watershed District, BARR Engineering
Bob Tipping	Minnesota Geologic Survey
Tony Runkel	Minnesota Geologic Survey
Klayton Eckles	City of Stillwater
Jason Moeckel	Minnesota Department of Natural Resources
Julie Westerlund	Minnesota Department of Natural Resources

1.5. Policy Advisory Committee

A Policy Advisory Committee (PAC) was developed to provide guidance on developing the goals and policies to implement the outcomes of this Study. PAC members are listed in Table 1.4.

Table 1.4. Policy Advisory Committee.

PAC Member	Affiliation
Craig Leiser	Brown's Creek Watershed District
Jim Leroux	Rice Creek Watershed District
Steve Hobbs	RCWD Administrator
Richard Caldecott	Carnelian-Marine Watershed District
Dan Fabian	EOR, CMWD Administrator
Jim Shaver	Marine WMO
Dennis Larson	Comfort Lake Forest Lake Watershed District
Bob Fossum	Washington Conservation District
David Beaudet	Middle St. Croix WMO
David Bucheck	Valley Branch Watershed District
John Hanson	BARR, VBWD Administrator
Klayton Eckles	City of Stillwater
Bill Voedisch	May Township Scandia Chair/Supervisor
Dennis Seefeldt	New Scandia Township Chair/Supervisor
Cindy Weckwerth	Washington County Department of Health and Environment
Eric Jensen	Washington County Department of Health and Environment
Jason Moeckel	Minnesota Department of Natural Resources
Travis Germundson	Minnesota Department of Natural Resources
Phil Belfiori	Board of Water and Soil Resources
Tori Dupre	Metropolitan Council

Policy Advisory Committee Meetings were held on the following dates:

- May 27, 2003
- June 4, 2003 (Washington County Water Consortium Meeting)

1.6. Post-Project Meetings

Post-project meetings were held (Table 1.5) to present and discuss the results of the project with the project sponsors. Representatives from state agencies and other local governmental units were invited to these meetings as well.

Table 1.5. Post-Project Meetings.

Date	Meeting
July 14, 2003	Brown's Creek Watershed District
To be scheduled in November 2003	Rice Creek Watershed District
To be scheduled in November 2003	Carnelian-Marine Watershed District
To be scheduled in November 2003	Marine Watershed Management Organization

1.7. Previous Studies

Previous studies conducted on groundwater resources in the area were compiled and reviewed. A bibliography is included in the References section of this report. Copies of the reports are available from Emmons and Olivier Resources, Inc. for a fee to cover reproduction costs.

The Washington County Ground water Plan is expected to be adopted by the County in November 2003. This document will set the overall policy framework for groundwater management within the County.

2. Background

2.1. Study Area

The study area for this project includes the northern portion of the County, from about State Highway 36 north to the County line, as illustrated on Figure 2.1. The study area covers approximately 215 square miles in the Cities of Birchwood Village, Dellwood, Mahtomedi, Marine-on-St. Croix, Pine Springs, Willernie, Stillwater, Grant, Forest Lake, Scandia, and Hugo, and the Townships of May, New Scandia, and Stillwater.

2.2. Climate and Precipitation

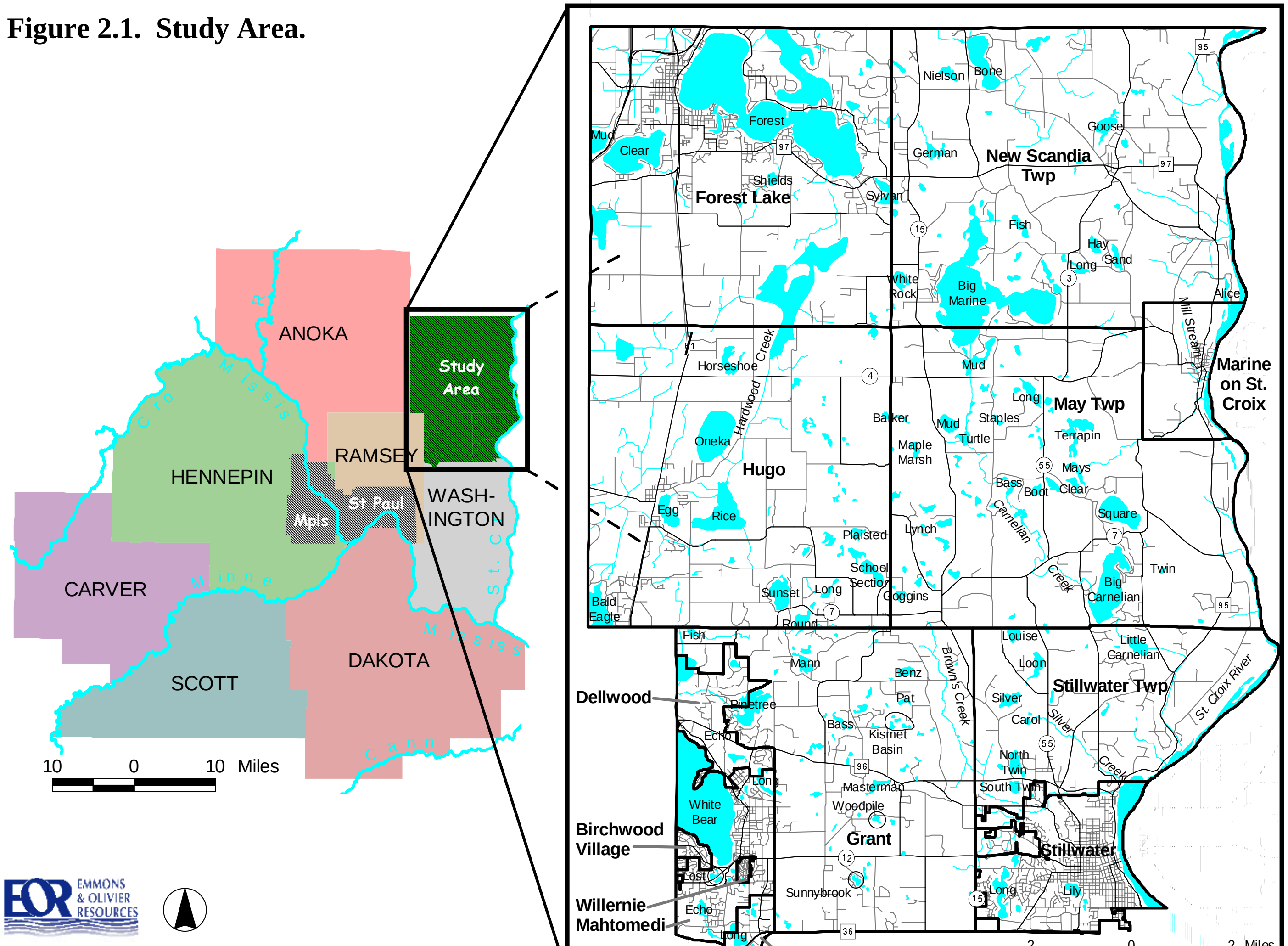
The climate of the study area is consistent with the climate for the Seven County Metropolitan Area. The mean annual temperature at the Stillwater weather station is 46.3 degrees F and the average annual precipitation is 33.61 inches (MRCC, 2003). Winters include long periods of below freezing temperatures with fairly short summers characterized by high temperatures and high humidity.

Precipitation patterns vary across the study area. Figure 2.2 illustrates total annual and normal precipitation for the Stillwater and Forest Lake stations. From 1977 to 1985 and from 1990 to 2002 cumulative annual precipitation was above or near normal at the Forest Lake station. The above includes all years within the stated time periods, with the exception of the years 1992, 1997, and 2000 when annual cumulative precipitation was significantly less than normal at this station. In 1975 and 1977, and from 1982 to 1986 and from 1990 to 2002, cumulative annual precipitation was near or above normal at the Stillwater station. These time periods include all years with the exception of 1996, 1997, and 2000 when precipitation was significantly less than normal at this station. In general, from the end of the 1970s to the mid-1980s and throughout the decade of the 1990s, precipitation recorded throughout the study area was significantly above normal.

2.3. Soils

Figure 2.3 identifies the soils of the study area. Soils are classified based on hydrologic group. The hydrologic group is an indicator of the runoff potential based on vegetation, soils composition, and slope. There are four hydrologic soil groups: A, B, C, and D. Table 2.1 presents a description for each of the hydrologic soil groups.

Figure 2.1. Study Area.



Source: 2002; MetroGIS, Washington County, DNR
r:/projects/wash co gw study/final_report_maps.apr__jlo030429

Figure 2.2. Cumulative Annual Precipitation and Normal Annual Precipitation for the Stillwater and Forest Lake Stations.

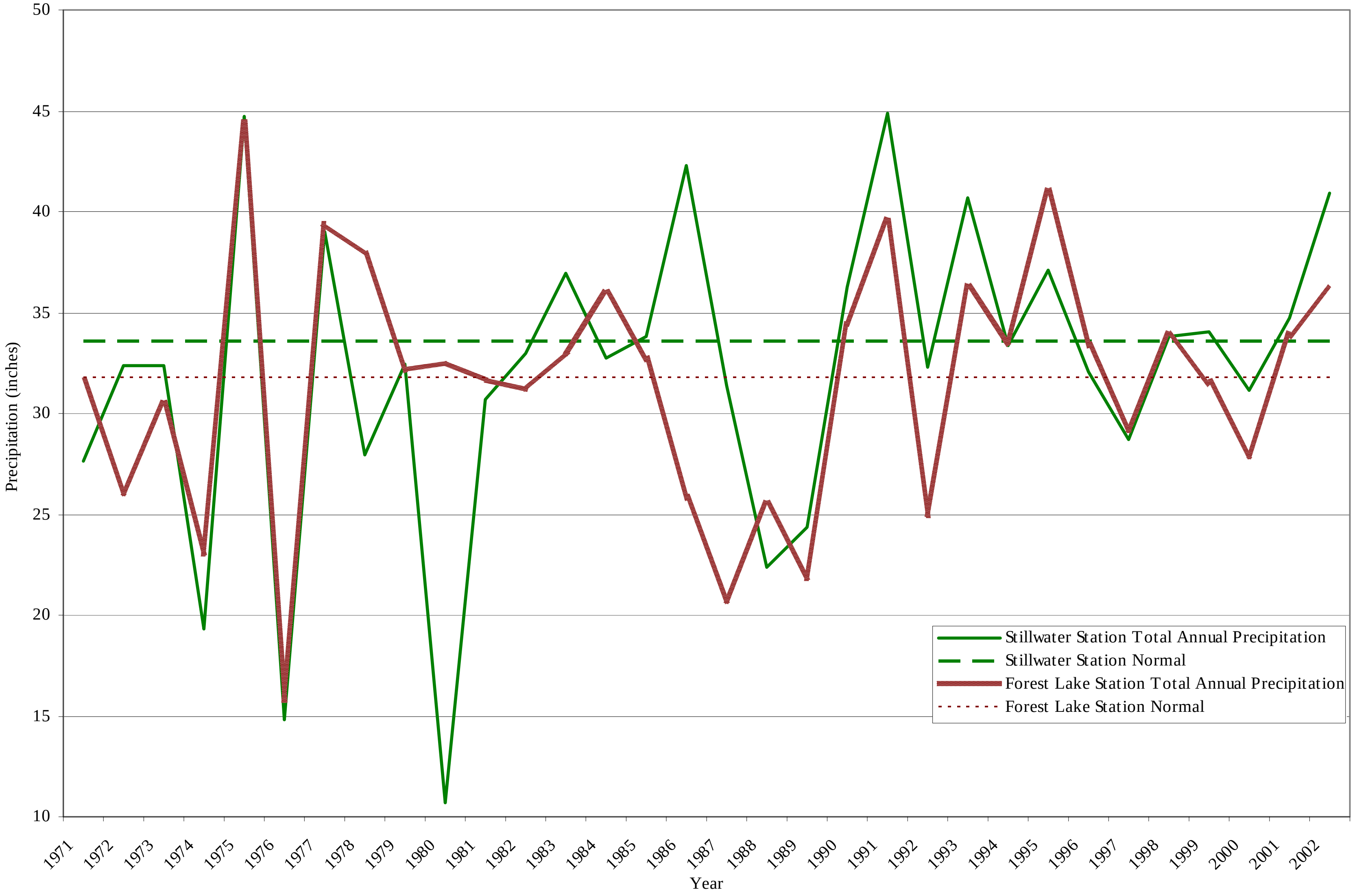
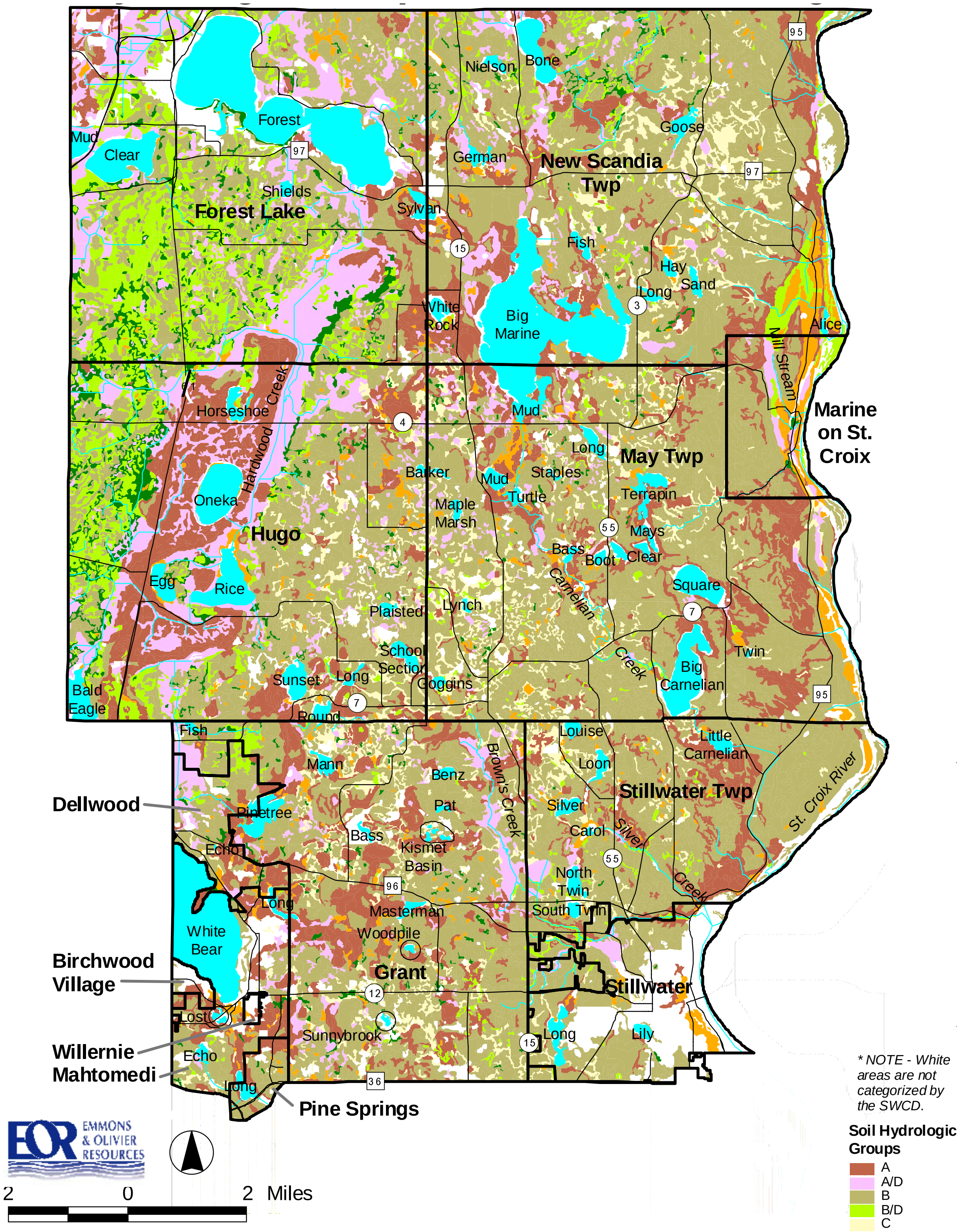


Figure 2.3. Soil Hydrologic Groups.



** NOTE - White areas are not categorized by the SWCD.*

Soil Hydrologic Groups
- 🟫 A
- 🟪 A/D
- 🟫 B
- 🟩 B/D
- 🟨 C
- 🟩 C/D
- 🟧 D

Sources: 2002; DNR, Washington County SWCD
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Table 2.1. Soil Classification.

Hydrologic Group	Description
A	Soils having high infiltration rates when thoroughly wet (low runoff potential). Deep, well drained to excessively drained sand or gravelly sand.
B	Soils having a moderate infiltration rate when thoroughly wet. Moderately deep or deep, moderately well drained or well drained with moderate to moderately coarse texture.
C	Soils having a slow infiltration rate when thoroughly wet: soils have a layer that impedes the downward movement of water or soils of moderately fine texture or fine texture.
D	Soils having very slow rates of infiltration when thoroughly wet (high runoff potential): soils consist of clays with high shrink-swell potential; soils have a high permanent water table; soils that have a claypan or clay layer at or near the surface and soils that are shallow over nearly impervious material.
Urban Land	Areas of development that are covered by asphalt, concrete, and buildings.

Source: USDA-SCS, Soil Survey of Ramsey and Washington Counties, 1977

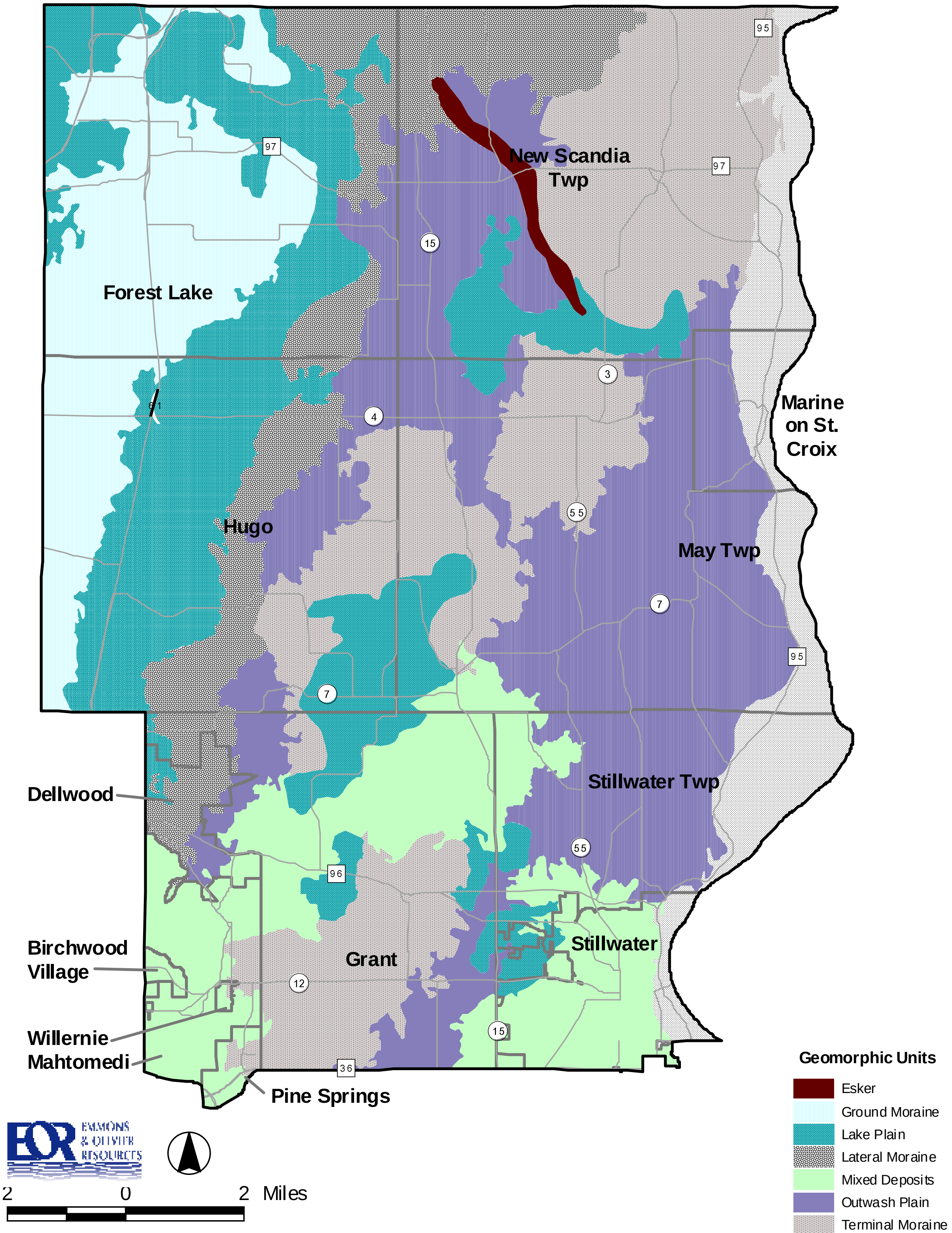
2.4. Geomorphic Regions and Topography

The topography of the study area was formed by glacial and post glacial processes. These processes deposited and eroded the landscape, resulting in geomorphic regions which contain similar characteristics. Geomorphology describes the landforms as they relate to glacial processes, landscape evolution, drainage and topography. The geomorphology of the study area can be broken down into four general categories including melt water deposits, moraine deposits, terrace deposits, and lake plains. Figure 2.4 illustrates the geomorphic units present in the northern portion of Washington County. These geomorphic units were determined based on available surficial geology data and topography.

2.4.1. Melt Water Deposits

Melt water deposits in the study area consist of outwash plains and eskers. Outwash plains are sandy features formed by broad glacial melt plains. They are located within the west central portion of the study area, extending diagonally from Dellwood to New Scandia Township and in the southeastern portion of the study area, encompassing Big and Little Carnelian Lakes and Square Lake. These two outwash plains are connected by a glacial melt water channel south of Big Marine Lake.

Figure 2.4. Geomorphic Regions.



Sources: 2002; MetroGIS, DNR, Washington County, U of MN, MGS
r:/projects/wash co gw study/mdr_kriging/final_report_maps030923.apr

Outwash plains are a result of glacial melting. They are characteristically composed of well sorted sand and gravel deposits. The topography is flat to gently rolling, containing few wetlands. There is a high connection between lakes and groundwater within the outwash deposits. Closed depressions are common throughout. Groundwater fed creeks are also common in the eastern portion of the study area within the outwash plain.

The outwash plain located near the Carnelian Lakes is underlain by a deep buried bedrock valley. This valley, in conjunction with the absence of till in many areas, likely contributes to the high connectivity of groundwater and the surface in these areas. Till holes are common throughout the outwash plains.

Eskers are formed as a result of glacial melt water deposits in ice contact situations. They are sandy and linear in nature, and are deposited along the direction of ice flow. There is one very large esker within the study area. It extends from the eastern edge of Big Marine Lake northwest into Chisago County. Linear lakes and wetlands are common along its margins. Evidence of groundwater dependent resources has been found along the western margin of the esker, indicating connectivity with groundwater. There is also an unusual lack of till deposits within the esker formation.

2.4.2. Moraine Deposits

Moraine deposits common within the study area consist of ground, lateral, and end moraines. Ground moraine forms beneath the glacier and is present in the north and west portion of the study area. Ground moraine within the study area is a result of the Des Moines Lobe of the Wisconsin Glaciation. Common characteristics of ground moraine deposits include flat to gently rolling topography, consisting of poorly sorted sand, clay, and gravel deposits.

A lateral moraine is formed parallel to ice flow during glaciation. The lateral moraine is found in the north and west central portions of the study area, extending diagonally from Dellwood to New Scandia Township. It consists of mixed deposits of the Superior and Des Moines lobes. Common characteristics of this moraine include unsorted sand, gravel, silt, and clay deposits; hummocky topography; and small wetlands present, particularly along the western margin. Springs are common along the western margin of this lateral moraine, indicating some connectivity to groundwater.

End moraine is formed at the furthest extent of glacial flow, perpendicular to ice flow. The end moraine present within the study area is commonly referred to as the St. Croix Moraine. This moraine complex stretches from north to south through the middle of the study area. The St. Croix Moraine consists of poorly graded sand, gravel, clay and silt deposits. The Moraine contains numerous small lakes and wetlands, having less connection with regional aquifers than other moraine deposits. The topography is hummocky.

2.4.3. Lake Plains

Lake plains within the study area are of two distinct types including ice-walled lake plains and glacial lake deposits. Ice walled lake plains are found sporadically within the study area. They are commonly surrounded by moraine deposits. Ice-walled lakes form as depressions in the top of glacial ice which receive meltwater flowing from other parts of the glacier. Over time the lake fills with fine grained sediment, and the surrounding ice melts. The result is a large flat topped hill. Large lakes are commonly found within these deposits including Big Marine, School Section and Goggins Lakes. They were often closed depressions, prior to artificial outlets being installed. The areas exhibit recharge characteristics, but are not very well connected with regional aquifers.

Glacial lake deposits are a result of glacial melting at the ice margin. The lake plain that extends from the City of Hugo to Forest Lake is a remnant of Glacial Lake Hugo. This lake was dammed to the east by the St. Croix Moraine and covered the majority of the northwest portion of the County. This lake plain is flat and consists of mostly fine-sand and silty-sand deposits. The water table is at or near the surface, resulting in large wetland complexes and high connectivity with groundwater.

2.4.4. Terrace Deposits

Terrace deposits are found along the St. Croix River. These deposits were formed as a result of glacial lake melting. Terrace deposits are a remnant of past higher water levels within the St. Croix River. Topography of the upper terraces is generally level. Deposits consist of coarse sand and gravel. The water table is seldom found in these deposits, as bedrock is near the surface. A steep bluff extends along the western margin of the St. Croix River. Topography is very steep and bedrock is commonly exposed along the bluff. Springs are commonly found along the bluff and emanating from the bedrock and terrace deposits.

2.5. Geology

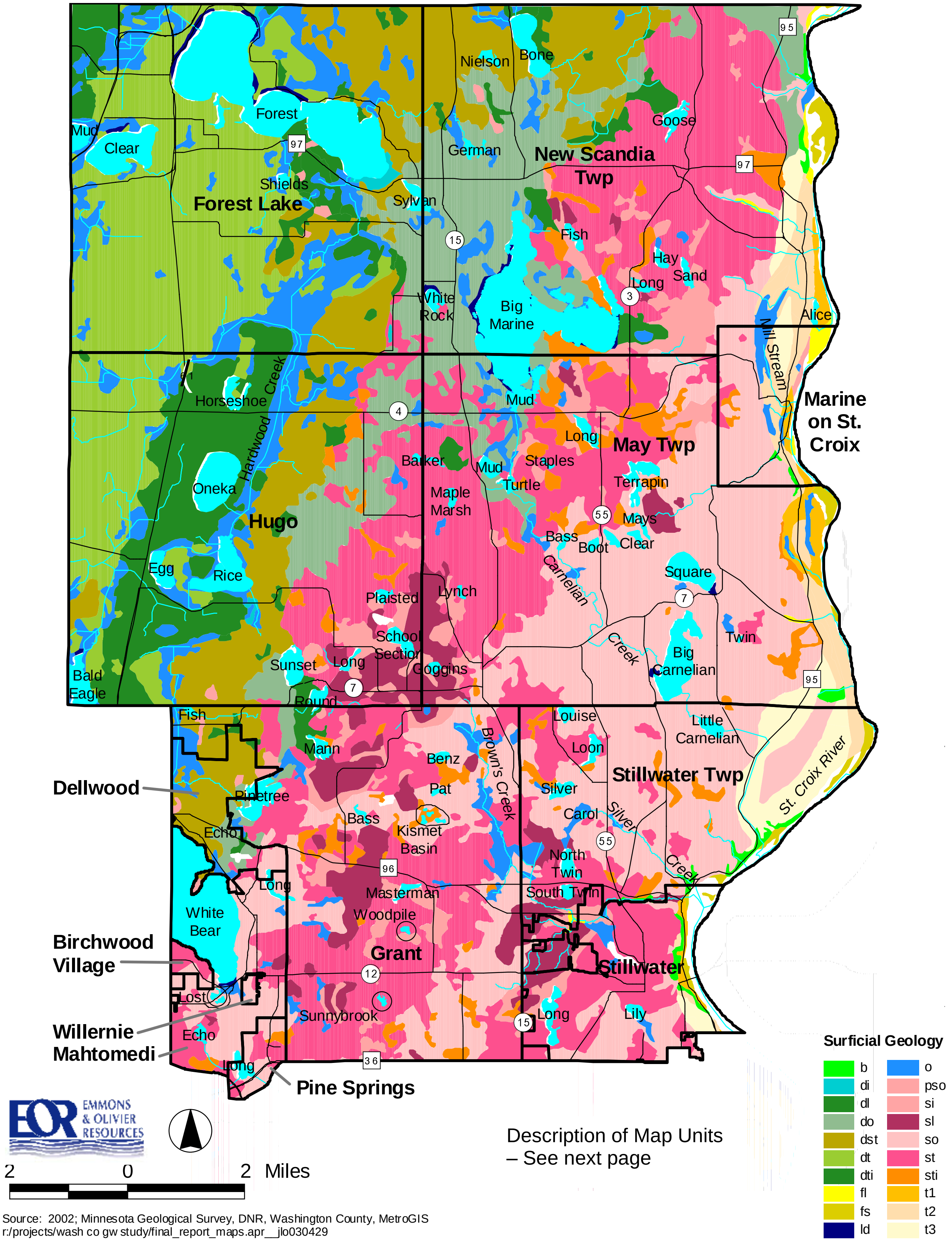
2.5.1. Surficial Geology

The surficial geology map, shown on Figure 2.5, differs from the geomorphic regions map in that more detail is provided about materials and their origin.

Descriptions of the glacial deposits are found in Section 2.4. Glacial materials present at the surface were deposited in two glacial episodes. The Superior Lobe glaciation ended about 25,000 years ago. The Superior Lobe advanced south from the Lake Superior region. It deposited an end moraine and outwash deposits in Washington County. The St. Croix Moraine is an end moraine with relatively high topography that extends northeast-southwest through the study area.

The Des Moines Lobe glaciation, the final glacial episode in Minnesota, ended about 10,000 years ago. The Grantsburg Sublobe of the Des Moines Lobe moved from southwest to northeast through the northwest corner of the study area (Hugo and Forest Lake). This unusual south to north moving glacier deposited a lateral moraine and outwash deposits in the study area. The tills related to the Des Moines Lobe glaciation are more compact, have more clay, and have lower hydraulic conductivity in general than the Superior Lobe tills.

Figure 2.5. Surficial Geology.



Description of Map Units – See next page

Source: 2002; Minnesota Geological Survey, DNR, Washington County, MetroGIS
r:/projects/wash co gw study/final_report_maps.apr__jlo030429

Figure 2.5. (cont.) Surficial Geology - Legend.

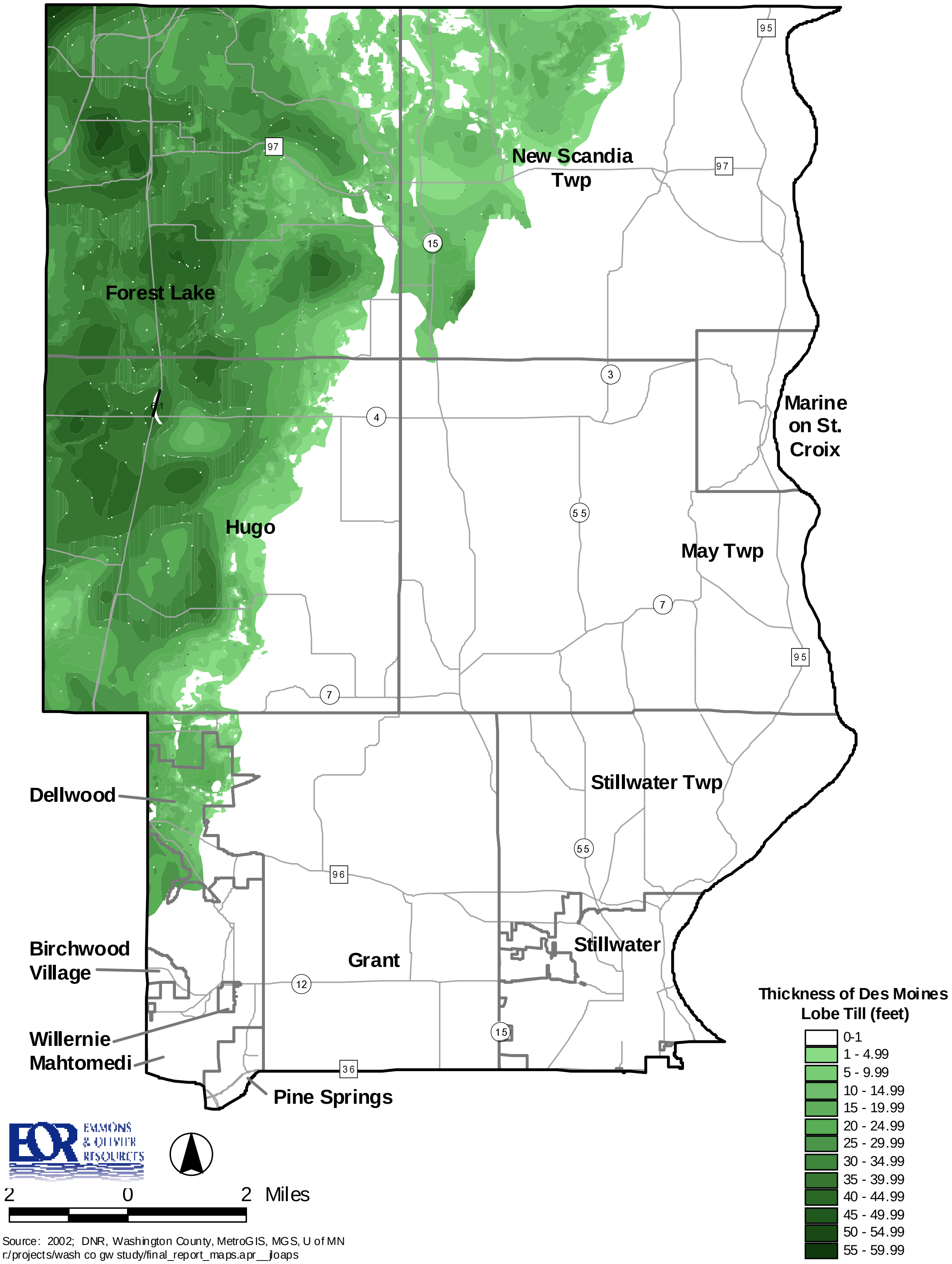
Map Unit	Description
o	ORGANIC DEPOSITS – Peat and organic-rich sediment; includes small bodies of open water.
ld	LACUSTRINE DEPOSITS – Sand and loamy sand with local, organic-rich layers; includes man-made beaches.
fl	FLOODPLAIN ALLUVIUM (LOAMY) – Stratified silt loam, loam, and very fine, sandy loam, with minor interbeds of fine, sandy to clayey sediment and organic matter.
fs	FLOODPLAIN ALLUVIUM (SANDY) – Chiefly loamy sand, sand, and gravelly sand, interbedded and overlain by thin beds of finer sediment and organic matter.
	TERRACE DEPOSITS
t1	LOWER TERRACES – Generally coarse sand and grave, capped in places by as much as 10 feet of loamy sand.
t2	MIDDLE TERRACES – Sand, gravelly sand, and gravel.
t3	UPPER TERRACE – Sand, gravelly sand, and gravel.
	GRANTSBURG SUBLOBE DEPOSITS
dl	LACUSTRINE SAND – Very fine-to fine-grained sand and loamy sand, with minor interbeds of silt and medium-grained sand.
do	OUTWASH – Sand, loamy sand, and gravel. Commonly capped by a mantle of wind-blown silt (loess) less than 4 feet thick.
di	ICE-CONTACT STRATIFIED DEPOSITS – Sand, loamy sand, and gravel; locally interbedded with silt and glacial till.
dt	GLACIAL TILL – Chiefly loam-textured unsorted sediment, with scattered pebbles, cobbles, and boulders.
dti	GLACIAL TILL, SAND, AND GRAVEL – Loamy to sandy till capped by, and/or interbedded with, sand and gravel.
dst	TILL OF MIXED COMPOSITION – Complexly intermixed yellowish-brown to gray, and reddish-brown to reddish-gray, loamy to sandy till.
	SUPERIOR LOBE DEPOSITS (Cromwell Formation)
sl	LACUSTRINE SAND AND SILT – Silt to medium-grained sand; interbeds and lenses of silty clay to gravelly sand, including sandy mudflow sediment.
so	OUTWASH – Sand, loamy sand, and gravel. Cobbly in places, especially near boundaries with unit st.
si	ICE-CONTACT STRATIFIED DEPOSITS – Sand, loamy sand, and gravel. Locally interbedded with units of st and sl.
st	GLACIAL TILL – Chiefly sandy-loam-textured, unsorted sediment, with pebbles, cobbles, and boulders.
sti	GLACIAL TILL, SAND, AND GRAVEL – Sandy till capped by, and/or interbedded with, sand and gravel.
	PRE-LATE WISCONSINAN SUPERIOR LOBE DEPOSITS
pso	OUTWASH AND ICE-CONTACT DEPOSITS – Sand, loamy sand, and gravel.
	ORDOVICIAN AND CAMBRIAN BEDROCK
b	DOLOMITE, LIMESTONE, SANDSTONE, AND SHALE – Discontinuously exposed bedrock generally mantled by less than 5 feet of sandy to rocky colluvium and loess

2.5.2. Quaternary Tills

A detailed mapping effort was performed by the MGS to refine the maps of tills throughout Washington County. The maps were created by using the “combine” function in Arc/Info Grid to identify unique combinations of till and inter-till (sand) thicknesses on a cell-by-cell basis throughout the county. Cell size of thickness grids was 100 meters. The resultant grid was then converted to a polygon cover by using the Arc/Info Grid “gridpoly” function. Small polygons were dropped by using the “majority filter” function, resulting in a polygon cover that gives approximate order of subsurface units (till and/or sand) for each polygon. Horizontal accuracy is estimated to be 300 meters (Meyer et. al, 1998). Thickness maps of the Des Moines (Till 1) and Superior Lobe Tills (Till 2) are shown in Figures 2.6 and 2.7, respectively

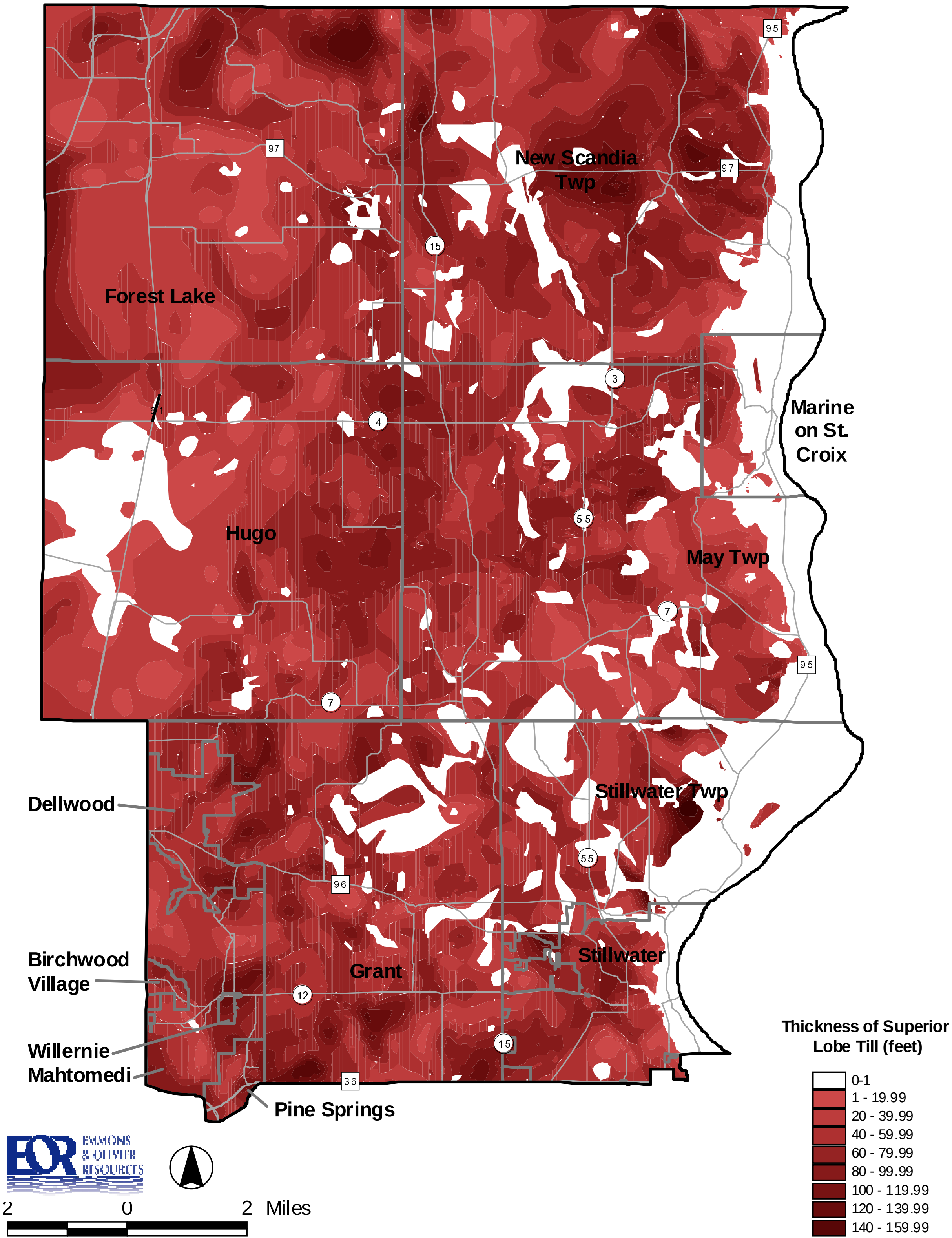
Table 2.2 provides a detailed description of Quaternary tills within the study area mapped by the MGS (Meyer et. al, 1998). The main difference between the till maps and the surficial geology maps above is that the till maps provide information about the three-dimensional distribution of various till layers, not just the tills exposed at the surface. This information was useful for determining where connections exist between groundwater recharge, Quaternary aquifers, and deeper bedrock aquifers.

Figure 2.6. Thickness of Des Moines Lobe Till (Till 1).



Source: 2002; DNR, Washington County, MetroGIS, MGS, U of MN
r:/projects/wash co gw study/final_report_maps.apr__jloaps

Figure 2.7. Thickness of Superior Lobe Till (Till 2).



Source: 2002; DNR, Washington County, MetroGIS, MGS, U of MN
r:/projects/wash co gw study/final_report_maps.apr__jloaps

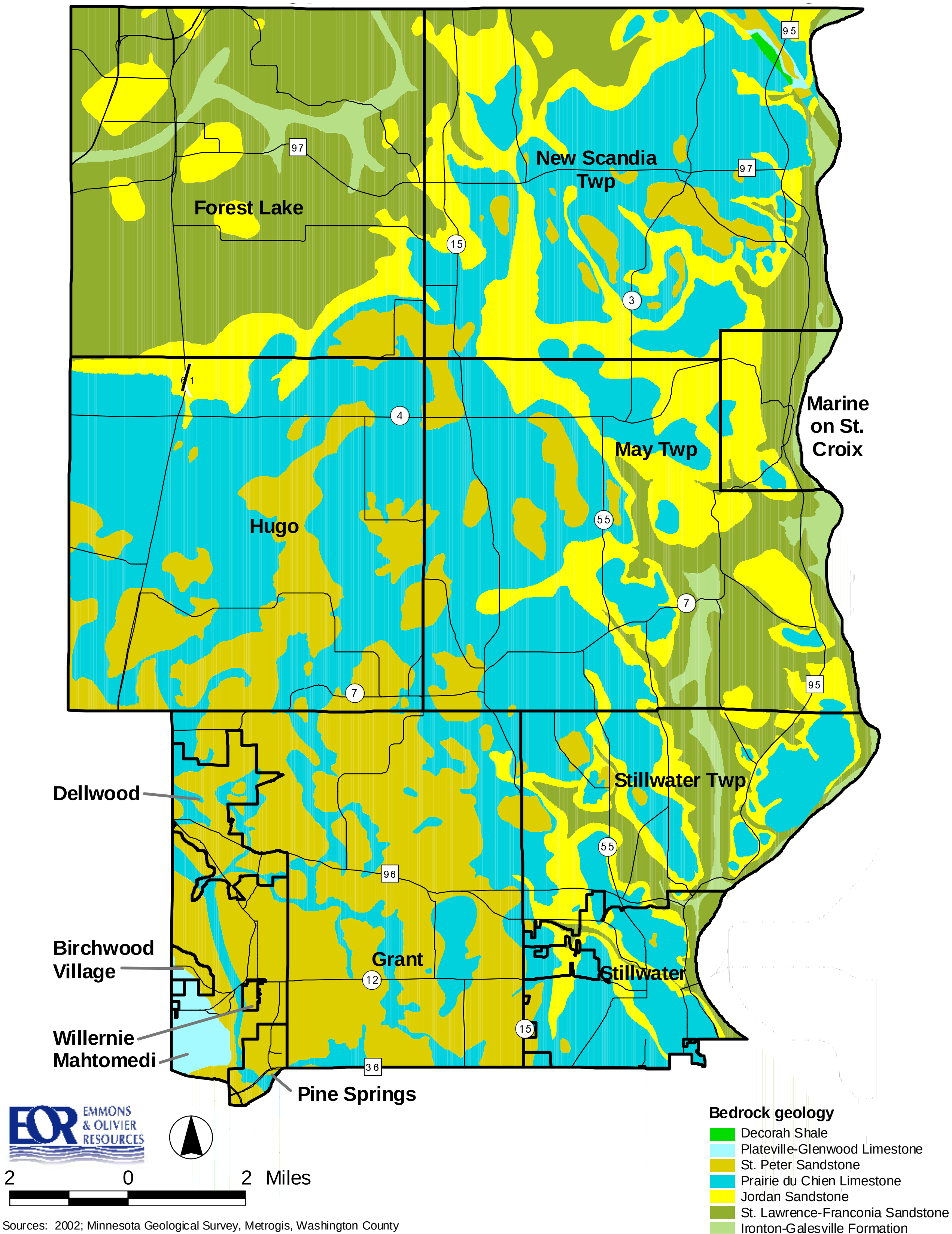
Table 2.2. Quaternary Till Description.

Surface Geology Unit Type	Surface Geology Unit Description
Till 1	*(dt) glacial till (Grantsburg sublobe)* – Chiefly loam-textured, unsorted sediment, with scattered pebbles, cobbles, and boulders; few lenses of stratified sediment. Capped in places by thin sand. Underlain by reddish-brown, Superior lobe stratified sediment or till, generally at a depth of more than 20 feet. Includes small areas of thick, fine, loamy colluvium. *(dti) glacial till, sand, and gravel (Grantsburg sublobe)* – Loamy to sandy till capped by, and/or interbedded with, sand and gravel. Locally patchy till over thick deposits of sand and gravel. Commonly mixes with or thinly overlies Superior lobe sediment. Includes small areas of thick, loamy to sandy colluvium. *(dst) till of mixed composition* – Complexly intermixed yellowish-brown to gray, and reddish-brown to reddish-gray, loamy to sandy till. Locally includes small areas of thick, reddish-brown till and loamy to sandy colluvium. Lenses of sand and gravel are common.
Till 2	*(st) glacial till (Superior lobe)* – Chiefly sandy-loam-textured, unsorted sediment, with pebbles, cobbles, and boulders; sand, gravel lenses, and beds are common. Commonly overlain by 2 to 5 feet of loess or, where in proximity to units sl or so, thin sand. Includes small areas of thick, loamy to sandy colluvium. *(sti) glacial till, sand, and gravel* (Superior lobe) – Sandy till capped by, and/or interbedded with, sand and gravel. Locally patchy till over thick deposits of sand and gravel. Includes areas too small to distinguish till from ice-contact deposits, and small areas of thick, loamy to sandy colluvial and eolian sediment. *(pst) glacial till (pre-late Wisconsin Superior lobe)* – Chiefly sand-loam-textured, unsorted sediment; pebbles, cobbles, and boulders are common, as are sand and gravel lenses and beds. Overlain in places by more than 5 feet of loess near the St. Croix River valley.
Till 3	*(pkt) glacial till (pre-late Wisconsinian Keewatin deposits)* – Loam-to clay-loam textured, unsorted sediment, with scattered pebbles, cobbles, and boulders; uncommon lenses of stratified sediment.
Till 4	*(pst) glacial till (pre-late Wisconsinan Superior lobe)* – Chiefly sand-loam-textured, unsorted sediment; pebbles, cobbles, and boulders are common, as are sand and gravel lenses and beds.

2.5.3. Bedrock Geology

Figure 2.8 shows the bedrock geology within the study area. Lying beneath the Quaternary sediment is marine sedimentary bedrock of Early Paleozoic age (525 to 400 million years old). Shallow seas covered southeastern Minnesota and parts of adjacent states during most of this period. Sand accumulated on near shore beaches and sand dunes, clay and silt accumulated in offshore deeper water areas, and carbonate (which forms limestone and dolomite) formed in banks and reefs just off shore. The six bedrock groups which subcrop (are exposed in the subsurface directly below the Quaternary sediment) or outcrop (are exposed directly at the surface) are from youngest to oldest: Decorah Shale, Platteville and Glenwood Formations, St. Peter Sandstone, Prairie du Chien Group limestone and dolomite, Jordan Sandstone, St. Lawrence-Franconia Formations and Ironton-Galesville Sandstone. Table 2.3 characterizes each unit.

Figure 2.8. Bedrock Geology.



Sources: 2002; Minnesota Geological Survey, Metrogis, Washington County
r:/projects/wash co gw study/final_report_maps.apr__jlo030429

Table 2.3. Bedrock Geology Description.

Age	Bedrock Formation or Groups	Description	Thick-Ness (Feet)
Middle Ordovician	Decorah Shale Platteville Group Limestone Glenwood Shale	These three formations make up the youngest or uppermost bedrock found in Washington County. They are found only in southern portions of the County	0-35
	St. Peter Sandstone	The St. Peter Sandstone consists of poorly cemented (crumbly) medium-grained, pure quartz sandstone. The lower portions contain inter-layered beds of shale and coarse sand. The St. Peter subcrops in much of the western portion of the County, and there are scattered remnants of the unit found throughout the northern and eastern parts of the County	0-66
Lower Ordovician	Prairie Du Chien Group	Dolostone dominates most of this unit. Minor sandstone and shale layers are found in the lower portions. The Prairie Du Chien is known to contain abundant fractures and openings and, in some areas, sinkholes and caves occur. Areas with sinkholes, large fractures and caves are called *Karst areas.* The Prairie Du Chien underlies most of Washington County. Notable absences of this unit occur in deeply *incised bedrock valleys* and in the extreme northwest and eastern parts of the County.	134-203
Upper Cambrian	Jordan Sandstone	The Jordan Sandstone consists of poorly layered, poorly cemented, medium to course sand. The Jordan is found throughout Washington County with notable exceptions in deeply incised bedrock valleys in the north and east and a region in the extreme northwest.	66-96
	St. Lawrence Formation	The St. Lawrence Formation is composed of thin layers of shale and siltstone and is found under all of Washington County except in some areas along the St. Croix River and in the far northwest.	30-58
	Franconia Formation	The Franconia Formation consists mostly of fine-grained sand in southern Washington County and ranges from medium to coarse grained in the north. The thickness of the Franconia ranges from 165 to 166 feet. These units underlie the entire County except a minor area in St. Croix Valley.	165-166
	Ironton-Galesville Sandstone	These sandstone units are composed of fine to course-grained sand. The Ironton/Galesville unit is found underlaying all of Washington County except in one deeply incised portion of the St. Croix Valley in Lakeland.	56
	Eau Claire Formation	This formation consists of shale, siltstone and very fine-grained sandstone. This unit underlies all of Washington County.	63-114
	Mt. Simon Formation	The upper third of this unit consists of very fine grained sand and siltstone beds. The lower two-thirds are composed of medium to course-grained sandstone. The Mt. Simon underlies all of Washington County.	160-255

Age	Bedrock Formation or Groups	Description	Thick-Ness (Feet)
Pre-Cambrian	Undivided	These consist of layers of shale and sandstone overlying volcanic rocks.	Unknown

2.5.4. Aquifers

The St. Peter (OSTP) has been largely eroded within the study area leaving “islands” of sandstone that increase in density to the southwest. As a first bedrock unit it does not make a desirable aquifer. If sufficient potable water cannot be produced from the Quaternary sediments, it is likely that the St. Peter water quality is likewise poor. Drillers frequently continue down into the Jordan or Franconia aquifers where less impacted water can be found.

The Prairie du Chien (OPDC) has significant unconformity with the overlying St. Peter Sandstone. Throughout most of the study area, the upper part of the Prairie du Chien, the Shakopee Limestone, was completely eroded away prior to deposition of the St. Peter. The remaining lower Prairie du Chien, the Oneota Dolomite, was severely weathered resulting in development of large, secondary porosities. These highly permeable weathered layers are most common near the top of the Oneota in a stromatolite-rich zone.

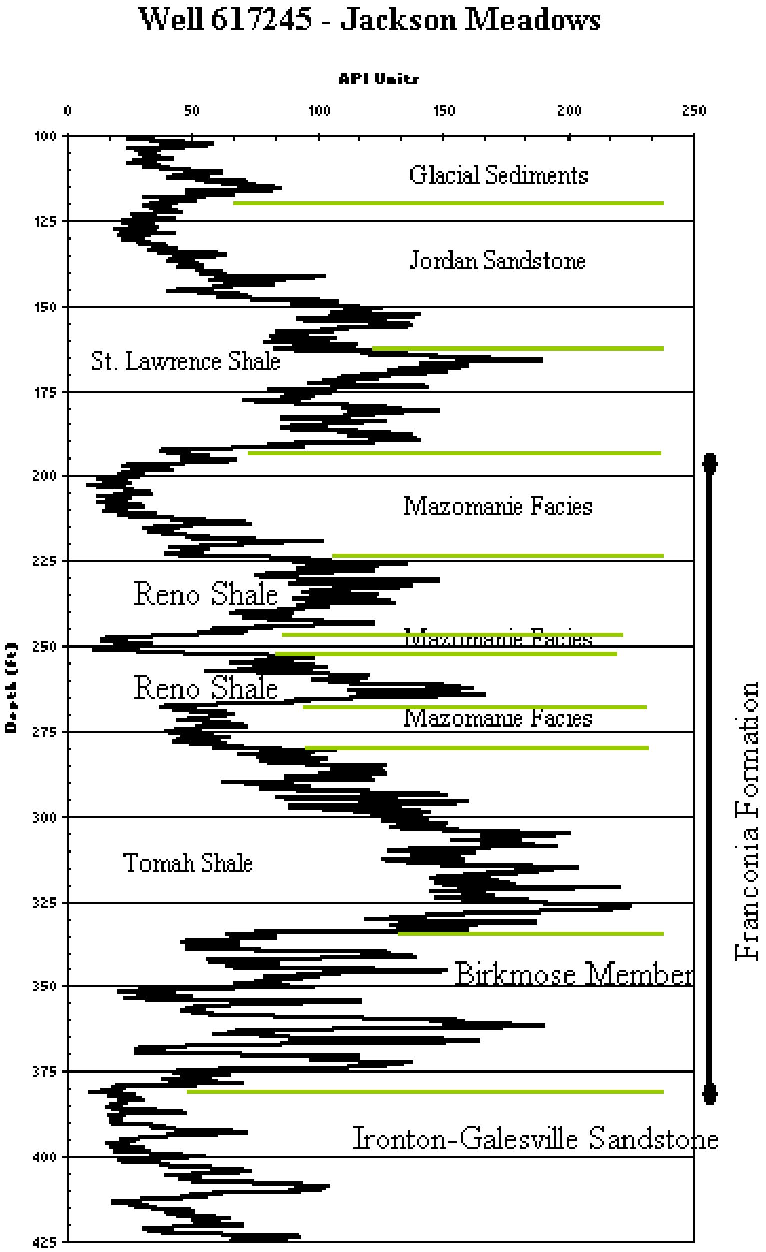
Below the Prairie du Chien is the Jordan Sandstone (CJDN). This is a regionally important aquifer capable of meeting municipal water demands. The Jordan is not a homogeneous aquifer. In particular, there are frequent shale lifts extending into the lower third of the aquifer. A good example of this can be seen along Brown’s Creek, near Stillwater. Along this reach, numerous springs and seeps emerge well above the St. Lawrence-Jordan contact.

The St. Lawrence Formation (CSTL) is not considered to be a significant regional aquifer. Some smaller wells are reported to be completed in the St. Lawrence, either in areas where the upper parts of the formation are fractured or as part of a multi-aquifer well. This shaly unit is genetically very similar to the Reno Member in the Franconia aquifer.

Similar to the Jordan, the Franconia is not a homogenous aquifer. The Franconia aquifer (CFRN) can be subdivided into sandy and shaly facies. The sandy facies are called the Mazomanie member and the shaly facies is called the Reno member. An example gamma log from a well in the Jackson Meadows development near Marine-on-St. Croix is provided in Figure 2.9. The Jackson Meadows log shows the variation from very sandy to very shaly units. This stratigraphy is fairly constant across the study area becoming sandier to the north and shalier to the south as one moves away from the original sediment source near Taylor’s Falls.

The Franconia extends underneath most of northern Washington County. It is cut through only in the deepest bedrock valleys. Within the study area only the present day St. Croix valley, the buried valley extending southward from Square Lake along the Carnelian chain and valley beneath Forest Lake cut entirely through the Franconia. Likewise, the St. Lawrence shale throughout most of the study area confines the Franconia Formation.

Figure 2.9. Gamma Log of the Franconia Formation.



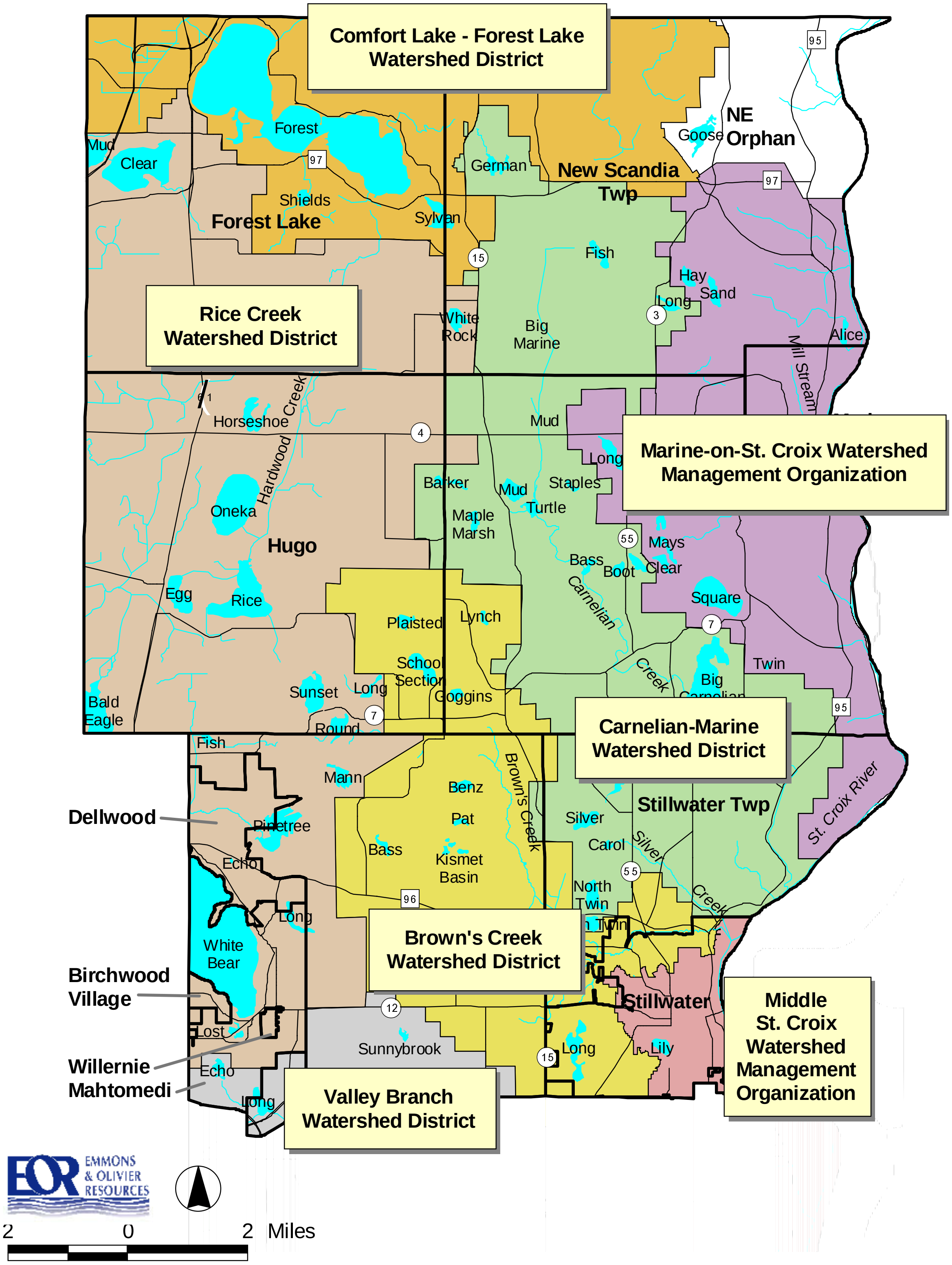
Well log – Minnesota Geological Survey. Interpreted by Scott Alexander, University of Minnesota

The lower portions of the Franconia are the Tomah and Reno Members. In the study area these members are reasonably good aquitards. Below the Franconia are the Ironton and Galesville Sandstones (CIGL). This is a thin but potentially important aquifer, particularly for residential water demands.

2.6. Watersheds

Northern Washington County has a major surface water and groundwater divide. The eastern portion of the study area drains to the St. Croix River while the western portion of the study area drains to the Mississippi River. Figure 2.10 illustrates the surface watersheds within the study area. Within the St. Croix River surface watershed are minor surface watersheds managed by watershed districts and watershed management organizations. Watershed organizations within the St. Croix River drainage basin include Brown’s Creek, Comfort Lake Forest Lake, Carnelian-Marine, and Valley Branch Watershed Districts, and the Marine Watershed Management Organization (WMO) and Middle St. Croix WMO. The Rice Creek Watershed District drains to the Mississippi River.

Figure 2.10. Watershed Districts and Management Organizations.



Source: DNR 2002, Washington County 2003
r:/projects/wash co gw study/final_report_maps.apr__jlo030429

2.6.1. Brown’s Creek Watershed

The Brown’s Creek Watershed District (BCWD) encompasses portions of the Cities of Grant, Hugo, Lake Elmo, Oak Park Heights, and Stillwater, as well as May and Stillwater Townships. The entire watershed is approximately 18,837 acres (29.4 square miles) in size.

The main feature of this watershed is Brown’s Creek, which flows from the upland portions of the watershed southeast to the St. Croix River and drains the majority of the watershed district. Bedrock is often exposed along the lower gorge portion of the creek and topography is steep as the creek approaches the St. Croix River.

Brown’s Creek is a naturally producing trout stream with higher number of trout in the lower half mile of the creek. Lower water temperatures in the lower reach correspond to increased groundwater input to the creek in this portion.

The majority of the area in the west and northwest is landlocked. These areas do not drain to the creek under normal conditions. High water levels and flooding have been a common occurrence throughout the landlocked portion of the watershed during the past decade. Approximately 48.5 percent of the watershed contributes drainage to the St. Croix River. The remaining 51.5 percent of the watershed is composed of a series of landlocked basins.

2.6.2. Carnelian-Marine Watershed

The Carnelian-Marine Watershed District (CMWD) includes portions of May, New Scandia and Stillwater Townships, and the Cities of Grant and Hugo. The entire watershed is approximately 25,500 acres (39.8 square miles) in size. In general, the topography of the watershed district is characterized by steep hills interspersed with deep depressions.

There are two major drainageways within this watershed. In the northern part of the watershed, Carnelian Creek links Big Marine, Big Carnelian, and Little Carnelian Lakes. Historically, no drainageway existed between Little Carnelian Lake and the St. Croix River. In 1985, an outlet and gravity pipe was installed on Little Carnelian Creek to respond to flooding concerns around the lake system. This outlet serves to control water levels in the three major lakes.

Silver Creek is the other significant drainageway in the watershed. Silver Creek begins at Silver Lake, although this lake overflows only intermittently. The stream begins more reliably at Carol Lake and extends southeasterly to its outlet into the St. Croix River north of Stillwater. As the creek approaches the St. Croix River, bedrock is often exposed and topography is steep.

Approximately 65 percent of the watershed contributes drainage to the St. Croix River. The remaining 35 percent of the watershed is composed of landlocked basins located throughout the watershed.

2.6.3. Comfort Lake Forest Lake Watershed

In Washington County, the Comfort Lake Forest Lake Watershed District (CLFLWD) includes portions of the City of Forest Lake and New Scandia Township. The entire district covers 31,488 acres or about 49.2 square miles.

The main hydrologic feature within Washington County is Forest Lake and its associated wetland complexes. Bone and Sylvan Lakes are significant hydrologic features. Forest and Bone Lakes outlet to the Sunrise River, which subsequently outlets to the St. Croix River. Sylvan Lakes does not drain to Forest Lake, but rather outlets to several small landlocked basins to the northwest.

The portion of the District that lies within the study area consists primarily of flat to gently rolling topography. However, between Forest and Sylvan Lakes, there is a sharp decline in elevation. The surface elevation of Sylvan Lake is approximately 40 feet higher than Forest Lake.

2.6.4. Marine-on-St. Croix Watershed

The Marine-on-St. Croix Water Management Organization (MWMO) encompasses portions of Stillwater, New Scandia and May Townships, as well as the City of Marine-on-St. Croix. In size, the WMO totals 18,768 acres or about 29 square miles, and lies wholly within Washington County.

There are three major hydrologic features within this watershed, including a series of large landlocked lakes in the west, Square Lake, and several spring creeks along the valley terraces and bluffs. Long, Terrapin, and Mays Lakes form a chain of lakes interconnected by a defined drainageway that terminates at Clear Lake. Clear Lake is landlocked and likely serves as an important recharge area. Square Lake has perhaps the best water quality of any lake in the Twin Cities Metropolitan Area. This lake maintains a groundwater base flow and continuously outlets through an artificial outlet to the south. The lake is stocked with Rainbow Trout annually by the DNR. The spring creeks that form along the St. Croix River Valley are the subject of a comprehensive study entitled St. Croix Spring Creek Stewardship Plan. Additional detail on this effort can be found in Chapter 6. Two of the spring creeks are identified as trout streams by the DNR including Mill Stream and Willow Brook and two more were identified as trout streams during the St. Croix Spring Creek Stewardship Plan project.

2.6.5. Valley Branch Watershed

The Valley Branch Watershed District (VBWD) covers more than 64 square miles and covers a portion of 14 communities: White Bear Lake, Maplewood, North St. Paul, Mahtomedi, Pine Springs, Oakdale, Grant, Lake Elmo, Woodbury, Oak Park Heights, Baytown Township, West Lakeland Township, Afton, and St. Mary's Point. The portion of VBWD that lies within the study area is approximately 3,685 acres (5.75 square miles).

The portion of VBWD that lies within the study area is comprised of three major surface water bodies that are either Project 1007 waters or landlocked basins. The three major water bodies are Echo, Long, and Sunnybrook Lakes.

Project 1007 waters are water bodies that drain into the District's main drainage system (Project 1007), which conveys water to the St. Croix River. Water bodies within the study area that are considered project 1007 waters include Echo Lake and Weber Pond in Mahtomedi, and Long Lake in Pine Springs.

In the northern portions of the District within the study area, there are numerous landlocked basins. The most significant landlocked water body is Sunnybrook Lake in Grant. This area has experienced high water levels and flooding concerns. A study was conducted to investigate flooding issues within the District. The study is detailed in Section 6.1. There is also a portion of the Geotchel Pond drainage area within the study area. Geotchel's Pond is also landlocked.

2.6.6. Rice Creek Watershed

49,280 acres (77 square miles) of the Rice Creek Watershed District (RCWD) lie within Washington County. This area encompasses portions of Forest Lake, Grant, Hugo, Dellwood, Mahtomedi, Willernie and White Bear Lake.

The portion of the RCWD that lies within the study area consists of flat to gently rolling topography. The majority of the surface drainage is served by a series of ditches that drain to and include Hardwood Creek and Clearwater Creek. Landlocked areas are also common throughout this area.

Hardwood Creek is one of the major hydrologic features of the Washington County portion of the RCWD. Hardwood Creek originates in Rice Lake and joins Rice Creek north of Peltier Lake in Anoka County. A complex of high quality wetlands buffer Hardwood Creek.

Clearwater Creek is the second major tributary to Rice Creek within Washington County. Clearwater Creek originates in White Bear Lake, which discharges intermittently into Bald Eagle Lake. Clearwater Creek also joins Rice Creek at Peltier Lake.

The RCWD also contains several landlocked basins including Oneka, Horseshoe, and White Rock Lakes. Oneka and Horseshoe Lakes are in close proximity to Hardwood Creek. White Rock is not within the defined hydrologic boundary of any watershed and it is unclear at this time where the actual overflow is located.

2.6.7. Orphan Area

An orphan area, unclaimed by any watershed district or water management organization, is located in the northeastern portion of New Scandia Township. The area covers approximately 5,126 acres or about eight square miles.

The major hydrologic feature of the orphan area is the five spring creeks that begin on terraces above the St. Croix River and descend towards the river. These creeks often pass through narrow rock gorges or channels in which bedrock is often exposed. Particularly in their lower reaches, these creeks are fed significantly by groundwater. Three of the streams have been identified as trout habitat including Falls Creek and Gilbertson Creek Goose Lake is located in the Orphan Area as well. Surface water drainage within the orphan area is towards the St. Croix River.

2.6.8. Spring Creeks

For this study, Spring Creeks are defined as creeks that emanate from springs along the bluffs of the St. Croix River. Some of the Spring Creeks also have surface watersheds on top of the bluffs and flow through steep-sided ravines to the river. The watersheds are typically very small relative to the flow rate because of the constant discharge of the springs. Spring Creek locations are shown on Figure 2.11.

The Spring Creeks are located within the Marine-on-St. Croix WMO and the Carnelian-Marine Watershed District. They are mentioned here because of their special significance to this study. The Spring Creeks are considered groundwater-dependent natural resources. The St. Croix Spring Creek Stewardship Plan recommends management policies for each of the Spring Creek watersheds. Those policies were developed in conjunction with the management policies presented in Chapter 5 of this report.

2.7. Land Use

For much of the last 20 to 50 years the land use in the study area has remained much the same. Small lot residential development existed in Stillwater, Forest Lake, Marine-on-St. Croix, and Mahtomedi. The remaining area was largely agricultural and rural residential. Significant areas were and remain as large wetland complexes. Figure 2.12 illustrates the current land uses in the study area.

In recent years the study area has seen increased development as the Twin Cities Metropolitan Area and Stillwater populations steadily expand. Figure 2.13 shows the projected land use for the year 2020, although several areas have been developing more rapidly than planned. Mahtomedi, Hugo, and Forest Lake and Stillwater Township have experienced significant small-lot residential and commercial development near the city centers. Grant and May Township remain in large-lot residential and agricultural land use partly due to zoning restrictions. Portions of Forest Lake, Marine-on-St. Croix, and Scandia have experienced less development pressure, but are expected to see increased development in coming years.

Figure 2.11. Spring Creek Locations and Watersheds.

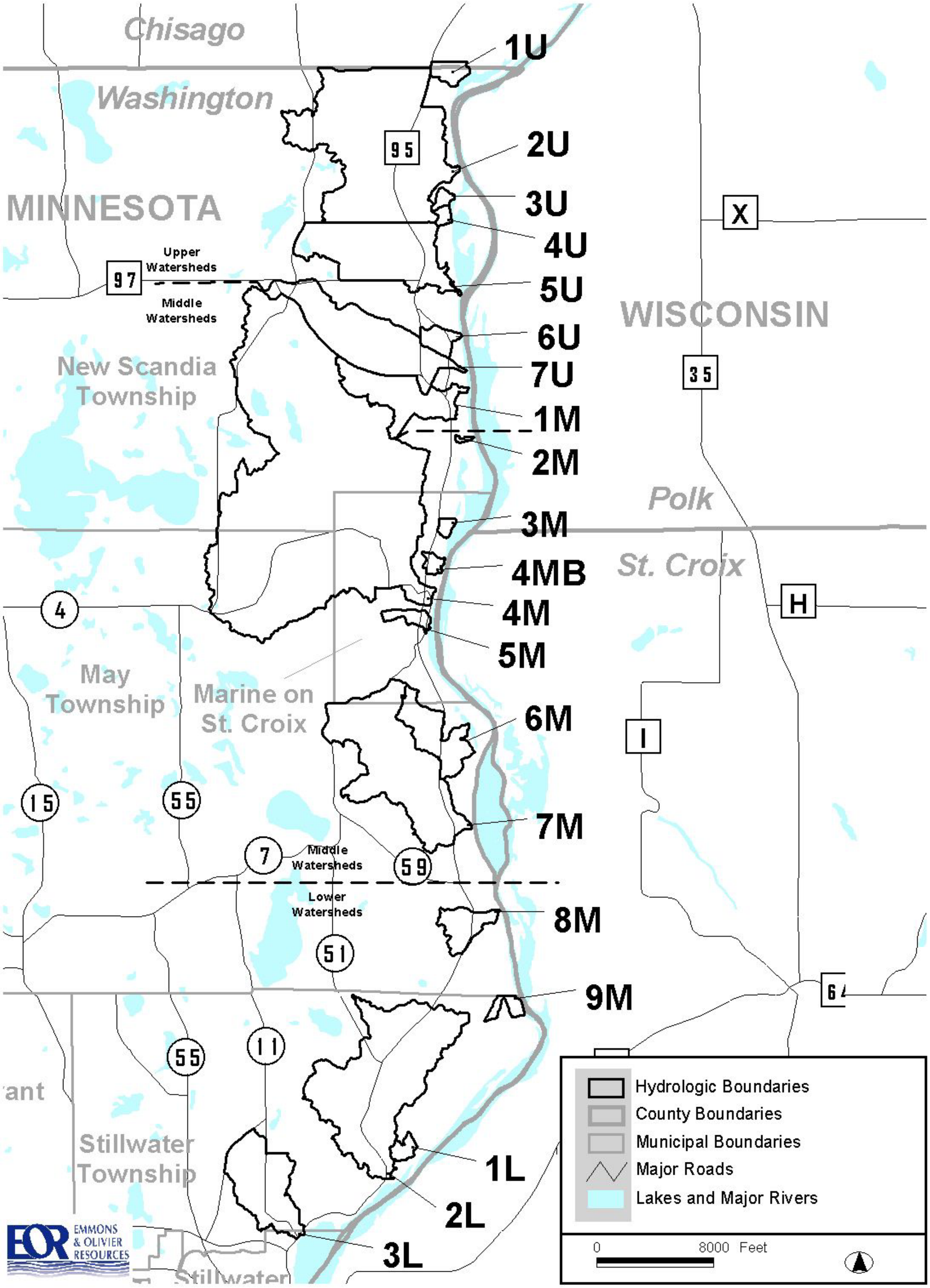
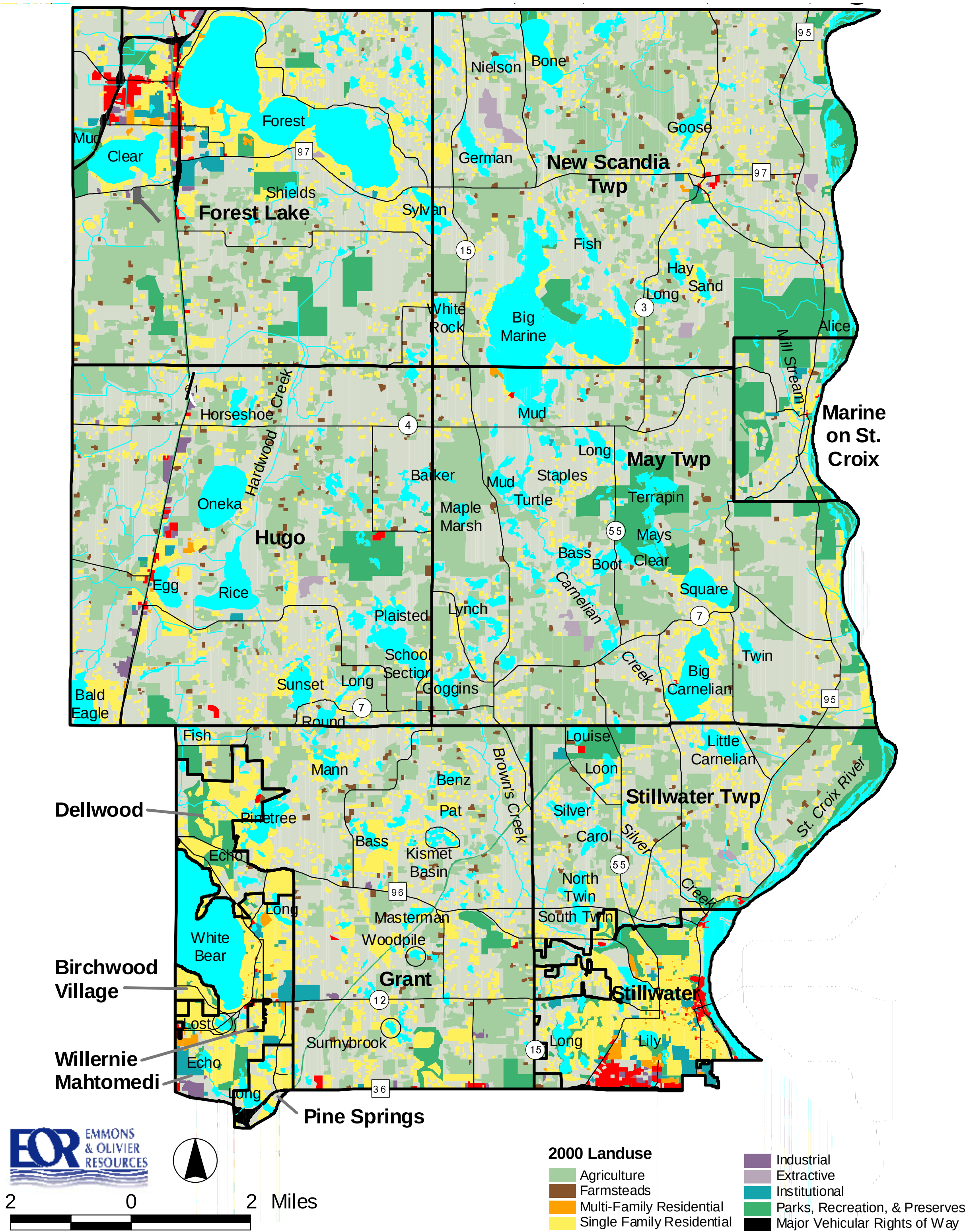


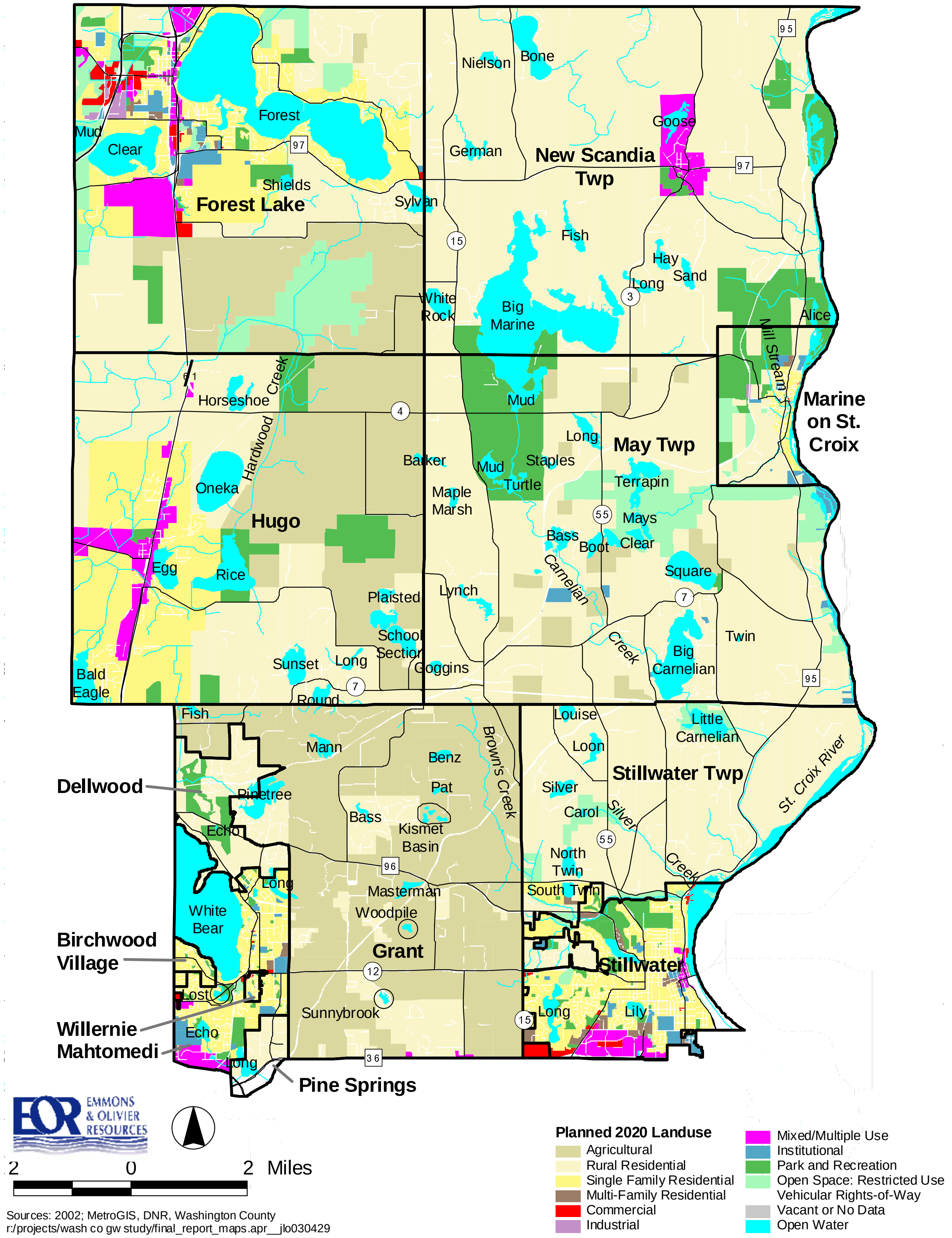
Figure 2.12. 2000 Land Use.



🟩	Agriculture
🟫	Farmsteads
🟧	Multi-Family Residential
🟨	Single Family Residential
🟥	Commercial
▨	Mixed Use
🟪	Industrial
▨	Extractive
🟦	Institutional
🟩	Parks, Recreation, & Preserves
■	Major Vehicular Rights of Way
▨	Undeveloped
🟦	Open Water

Sources: 2002; MetroGIS, DNR, Washington County
r:/projects/wash co gw study/final_report_maps.apr__jlo030429

Figure 2.13. 2020 Land Use.



Sources: 2002; MetroGIS, DNR, Washington County
r:/projects/wash co gw study/final_report_maps.apr__jlo030429

3. Comprehensive Hydrologic Monitoring Plan

3.1. Background

The comprehensive hydrologic monitoring plan developed for this study includes collection of both historical and recently collected monitoring data for the study area. Data elements include lake and groundwater levels, precipitation, stream flow, surface and groundwater chemistry, direct groundwater measurements, and an inventory of natural resources. These data are compiled into Microsoft EXCEL and ArcView spatial databases.

Figures 3.1, 3.4, and 3.7 summarize the locations and period of record for the historical data collected as part of this study. Data gaps were identified within the historical data sets and a monitoring plan was established to collect additional data during the years 2002 and 2003. Monitoring locations added for this project are illustrated in Figure 3.4. Figures 3.5 to 3.7 identify the location and type of all data collected at various sites in the Study Area. The Washington Conservation District (WCD) collected the majority of the data in coordination with the University of Minnesota and Emmons & Olivier Resources, Inc. (EOR). Each monitoring point was located using GPS, parcel data, or digital ortho photography. A list of studies collected as part of this project is included in the Reference section.

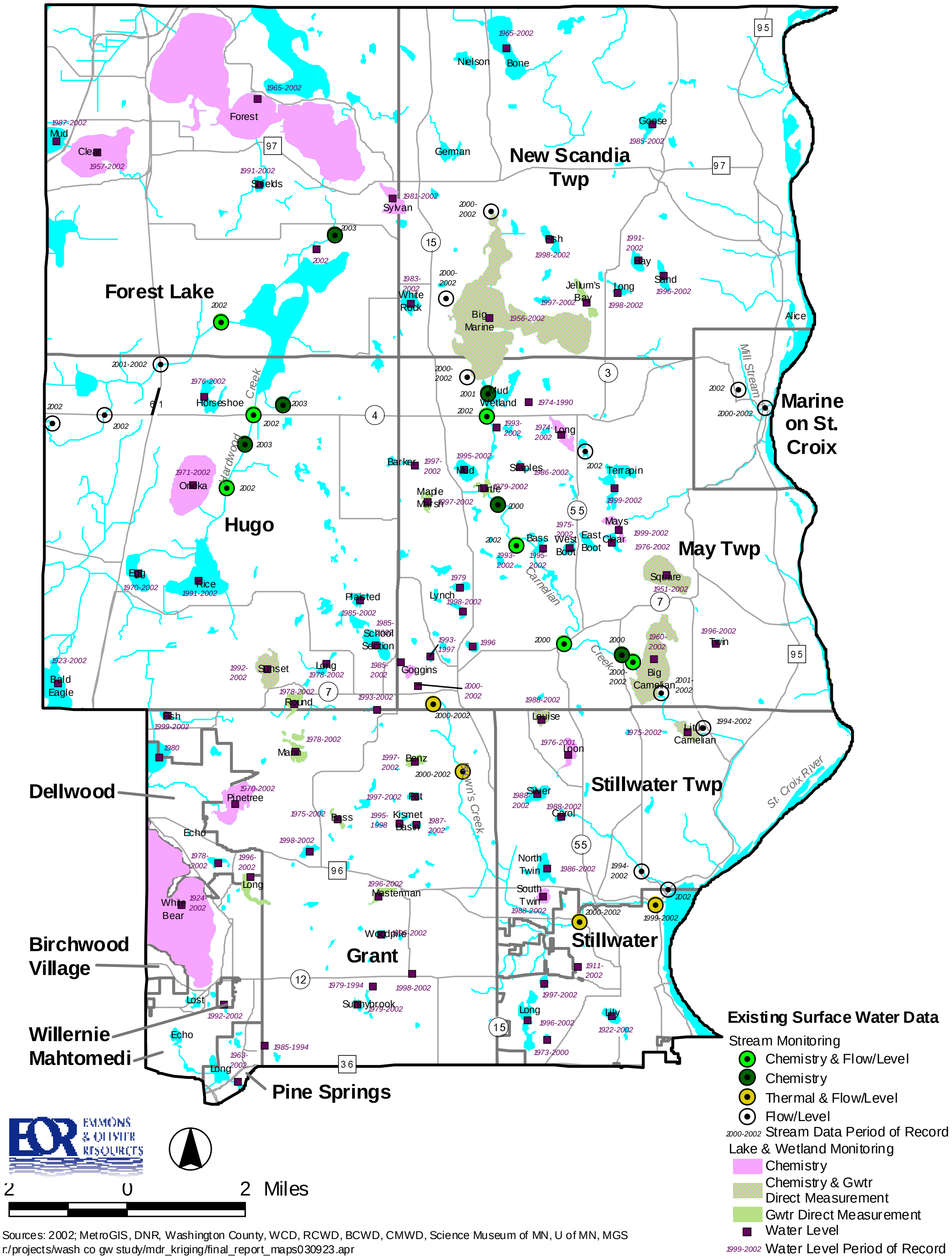
3.2. Lake and Wetland Monitoring

3.2.1. Surface Water Levels

Existing surface water elevations for lakes and wetlands within the study area were obtained from the Minnesota Department of Natural Resources (DNR) Lake Finder website (http://www.dnr.state.mn.us/lakefind/index.html). The WCD works in coordination with the DNR and citizen volunteers to collect and verify lake level data in the County. Staff gauges are installed at most lakes. The consistency of data collection is variable, but a minimum of one reading per month is typical. The period of record varies by water body, but most have been monitored five or more years, while sixteen water bodies have over thirty years of data. A total of 76 lakes were identified in the historical database. Monitoring locations are illustrated in Figure 3.1.

In summer 2002, efforts were coordinated with the WCD and volunteers to collect data on a bi-weekly basis. Automatic stage recorders were purchased and installed at three locations in the study area including the Hardwood Creek wetland, Big Marine Lake outlet, and Long Lake in May Township. Monitoring locations are illustrated in Figures 3.2 and 3.3.

Figure 3.1. Historic Surface Water Monitoring.



Sources: 2002; MetroGIS, DNR, Washington County, WCD, RCWD, BCWD, CMWD, Science Museum of MN, U of MN, MGS
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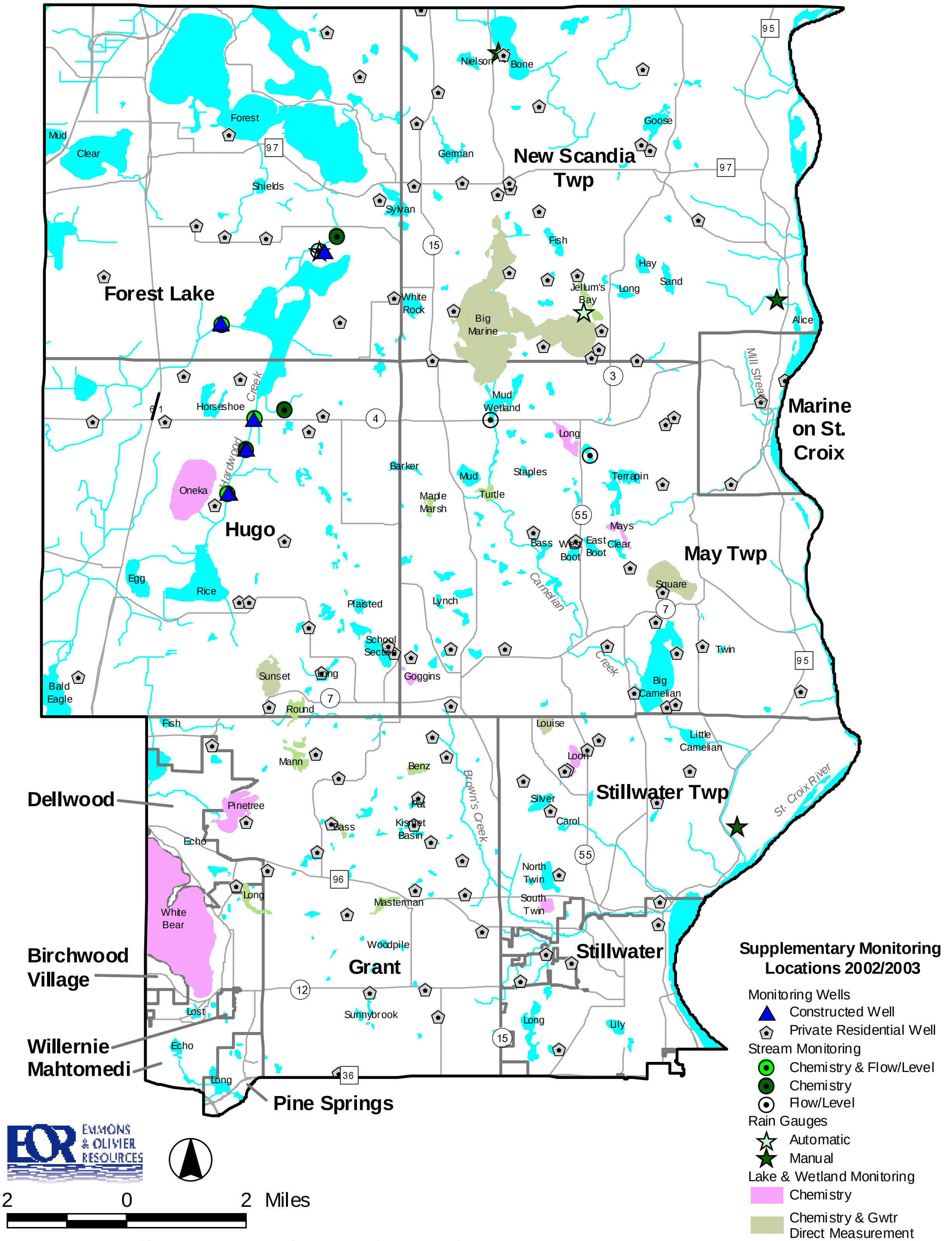
Figure 3.2. Supplementary Monitoring Locations – 2002-2003.



Source: 2002; DNR, Washington County, MetroGIS, Science Museum of MN, WCD, U of MN, MGS
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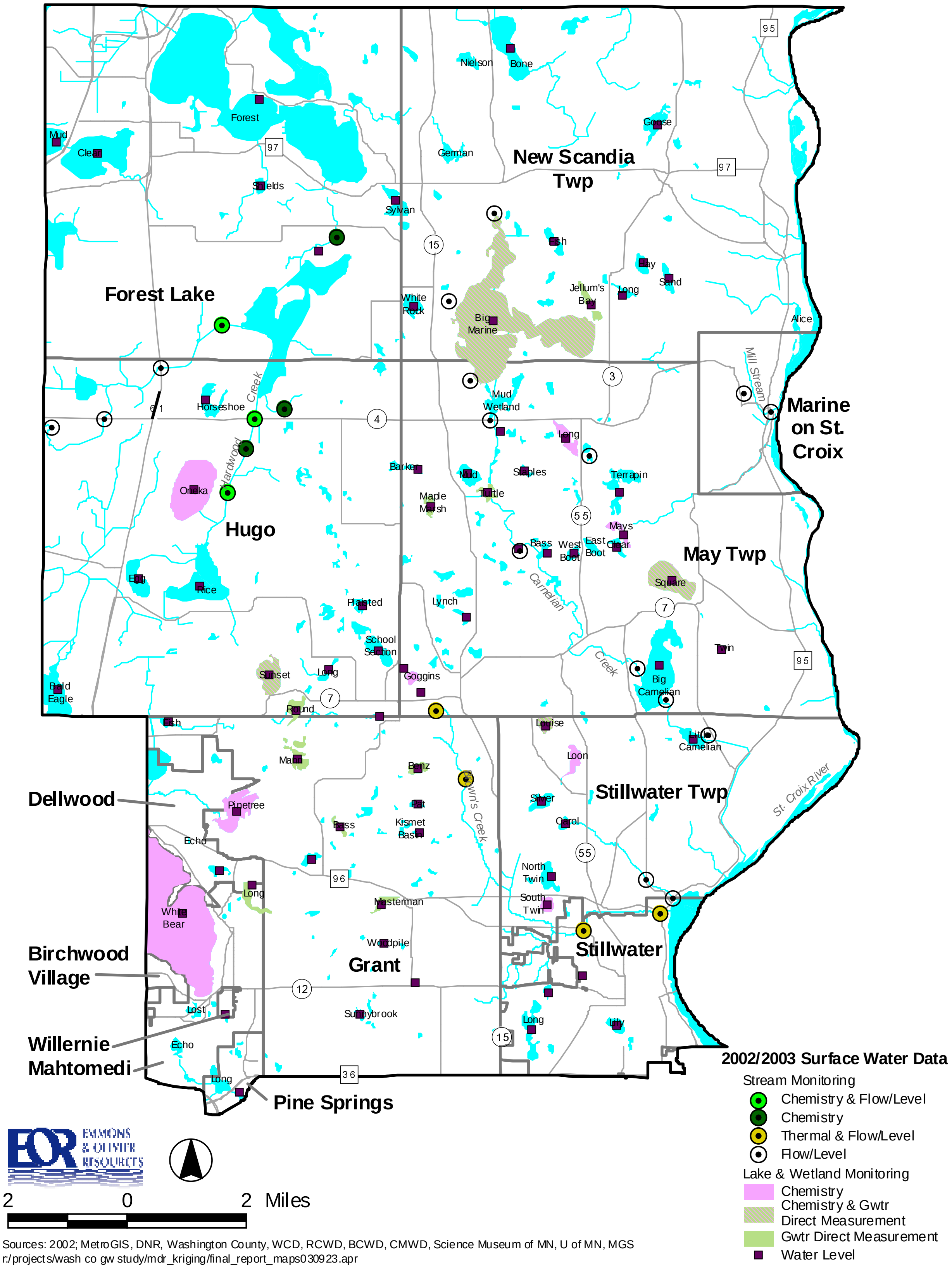
Figure 3.3. 2002 - 2003 Surface Water Monitoring Network.



Sources: 2002; MetroGIS, DNR, Washington County, WCD, RCWD, BCWD, CMWD, Science Museum of MN, U of MN, MGS
r:/projects/wash co gw study/mdr_kriging/final_report_maps030923.apr

3.2.2. Direct Groundwater Measurements

Direct measurements of surface and groundwater interaction were collected for the CMWD in 2001 by the Minnesota Geological Survey (Alexander, 2001). Data included mini-piezometer, temperature, and half-barrel permeameter measurements. The water bodies included Square, Big Marine, Little Carnelian, and Big Carnelian Lakes. Water bodies where data were collected are identified in Figure 3.1. Temperature probes were used to measure the difference in temperature between the lake and the lakebed. The probes were used during summer months, when groundwater is colder than surface water. Lakebed sediments that are colder than the lake indicate groundwater is entering the lake. The mini-piezometer measures the head difference between groundwater and surface water. The piezometer is hammered into the lakebed and the water level within the piezometer is compared to the water level of the surface water body. If groundwater is higher than lake water, groundwater is flowing into the lake. If groundwater levels are lower than the lake, water is flowing out of the lake. The half-barrel permeameter is used to measure the rate of groundwater flow. They were used at locations where temperature probe or mini-piezometer measurements indicated groundwater inflow to a lake. The half-barrel permeameter is inserted into the lakebed and allowed to equilibrate. After equilibrating, a precisely measured weight of water is attached to the port. The change in weight over time is measured and used to calculate the flow rate per areal unit.

Mini-piezometer measurements were also performed by the WCD at Masterman Lake in 2002 and by EOR for the following lakes in 2003:

- Jellum's Bay
- Sunset
- Benz
- Bass (BCWD)
- Maple Marsh
- Mann
- Louise
- Square
- Turtle
- Long Lake (RCWD)

Locations of data collected in 2002 and 2003 are shown in Figure 3.1, 3.2, and 3.3.

3.2.3. Results

Surface water levels were measured at 73 water bodies in 2002. Of these, 61 were monitored at least bi-weekly, with 45 water bodies monitored 20 times or more. Twelve water bodies had less than 10 measurements. Surface water levels were generally decreasing throughout the late 1990s but have been generally rising since 2001 due to a climatic wet period.

Water levels varied dramatically in 2002 at the Hardwood Creek wetland, decreasing sharply through June and July, then increasing throughout August and the early part of September, when the levels dropped again. Water level data were most likely affected by high rates of evapotranspiration associated with the quantity of vegetation within the wetland.

Direct groundwater measurements were obtained at 11 lakes monitored as part of this study. Two major obstacles that were encountered were excessive vegetation and slow recovery in fine-grained materials. Ideally, measurements are not taken near emergent vegetation, given that biological function locally alters surface and groundwater levels. However, due to the amount of vegetation at some water bodies, some measurement near vegetation was unavoidable. Additionally, piezometer response was very slow when used in fine-grained sediments. Measurements taken in fine-grained sediments were allowed longer stabilization periods to allow for slow equilibration. Some measurements taken near emergent vegetation or in fine-grained materials were not used because the results could not be reliably reproduced.

Reliable measurements indicated groundwater inflow to Masterman, Sunset, and Jellum's Bay, outflow from Benz, Maple Marsh, and Turtle Lakes, and outflow on the east side of Long Lake (RCWD). Fine-grained materials on the west shore of Long Lake (RCWD) provided indeterminate results.

3.3. Precipitation Monitoring

Historical precipitation data were obtained from the Minnesota State Climatology Working Group (http://www.climate.umn.edu), National Weather Service, Science Museum of Minnesota, WCD, CMWD, RCWD, and BCWD. In addition, a citizen volunteer network collects manual rain gauge data throughout the study area. A total of 94 sites were identified in the historical database, illustrated in Figure 3.4.

Data were obtained for all rain gauges monitored from 1971 to the present. Data collected by the National Weather Service for Stillwater and Forest Lake were used in the project analysis due to completeness of record. The period of record in Stillwater is 1944-2002 and Forest Lake is 1958-2002. Most rain gauges throughout the study area were not monitored year-round or had large gaps in their period of record.

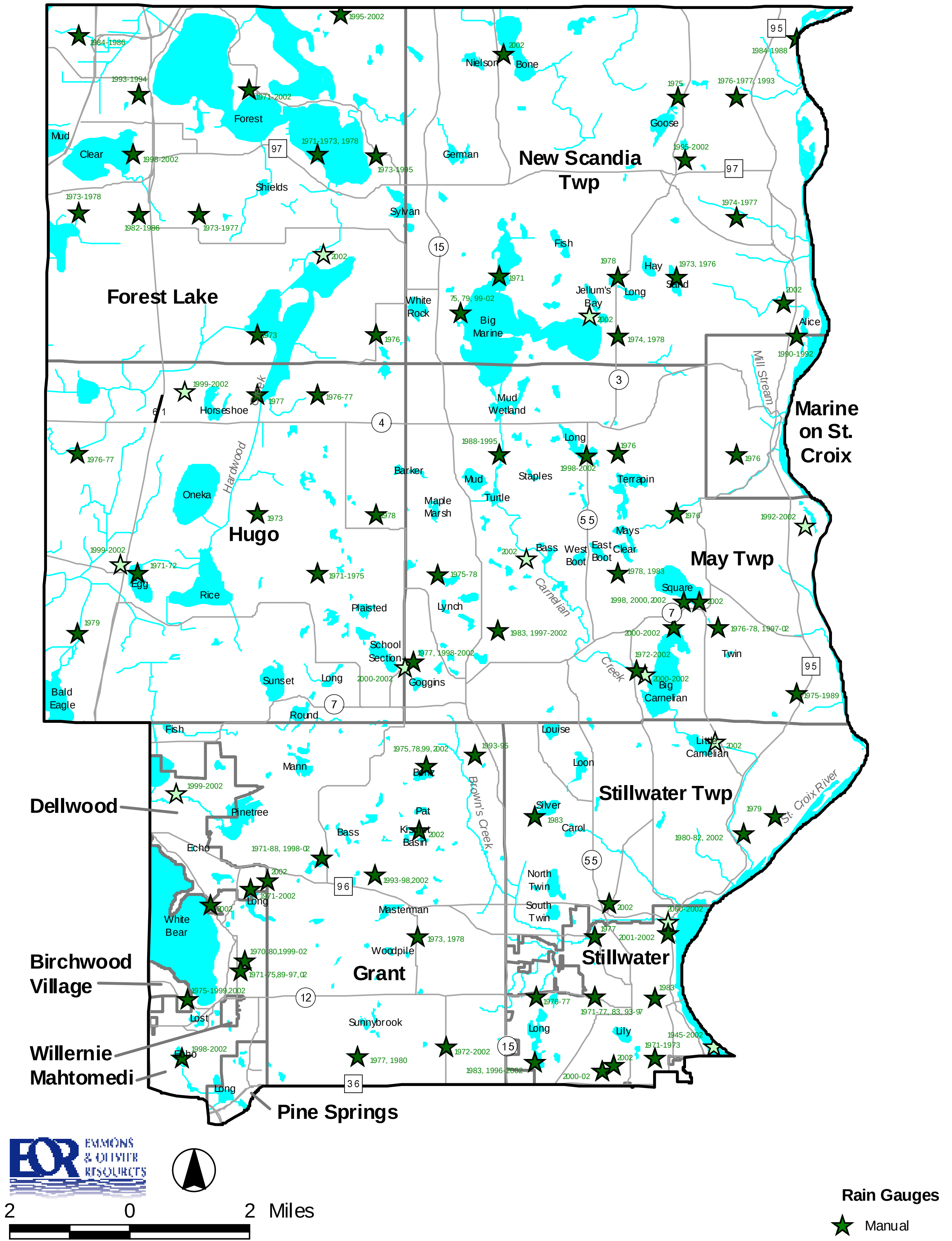
In 2002, five sites were identified as data gaps, and monitoring stations were added to existing networks at these sites as part of this Study. Two automatic rain gauges were installed at the Hardwood Creek wetland and at the outlet of Big Marine Lake. Three manual rain gauges were also installed at private homes. A total of 45 locations were monitored during 2002, illustrated in Figure 3.5.

3.3.1. Results

Figure 3.6 summarizes the variation in total precipitation for the year 2002. Total precipitation ranged from 27.3 inches to 38.1 inches. The highest rainfall totals were located in a band across the center of the study area from Egg Lake in Hugo Township through the Kismet Basin in Grant and extending into Stillwater Township. Twenty-five precipitation stations were used to generate the precipitation variation grid. Nine were automatic and sixteen were manual rain gauges. These stations were used due to the completeness of the data collected at these locations in 2002. The variation grid was generated by performing a Linear Kriging interpolation on the point locations of the stations. Section 3.5.6 provides additional discussion of Kriging methodology.

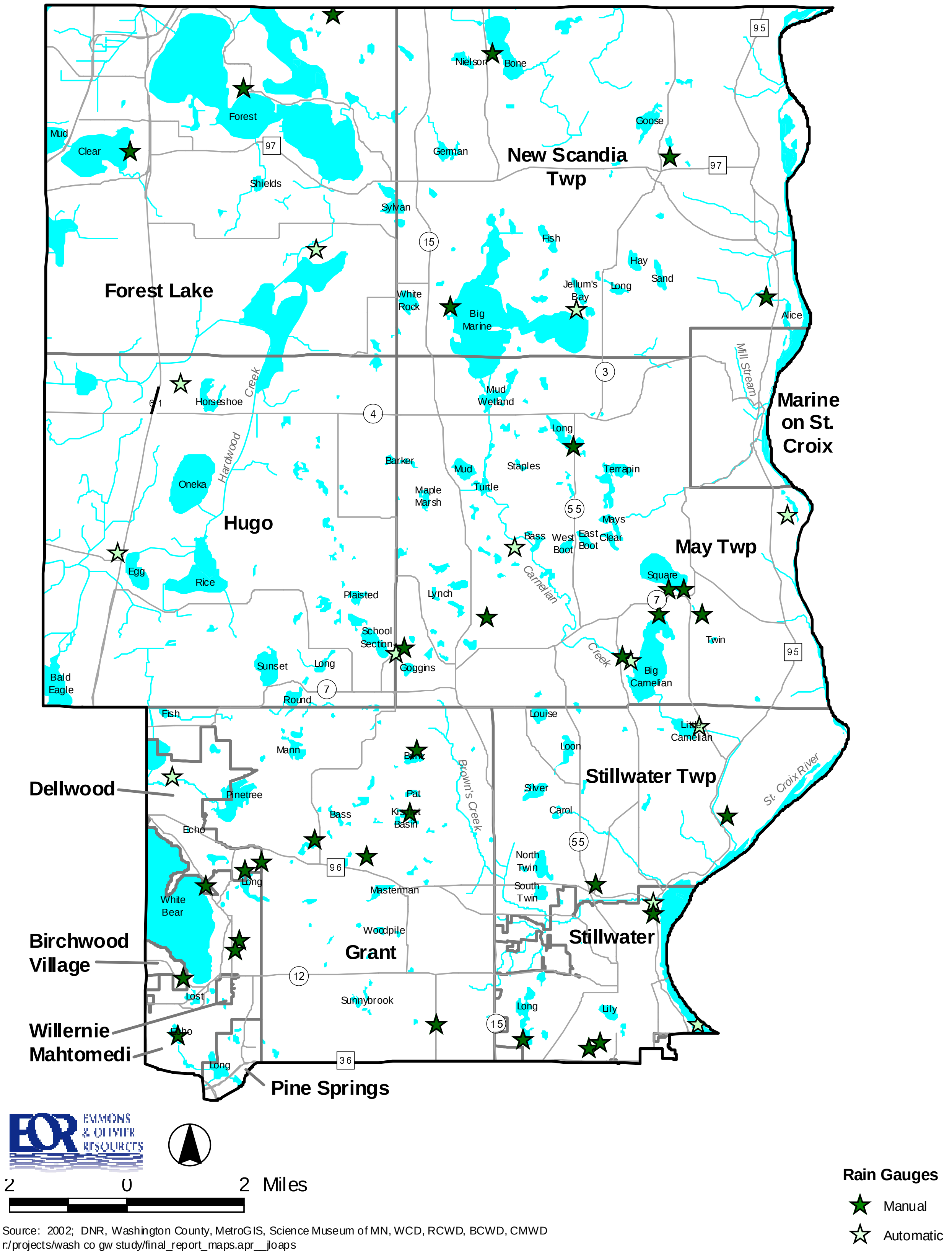
Precipitation in the Twin Cities was generally high throughout the 1980s to mid-90s, with a drier period in the late 90s until 2002. Total precipitation in the Twin Cities during 2002 was 1.7 inches less than the record high, making 2002 the fourth wettest year on record. During 2002, total precipitation was 6 to 16 inches above normal throughout the study area (MRCC, 2003).

Figure 3.4. Historic Precipitation Monitoring.



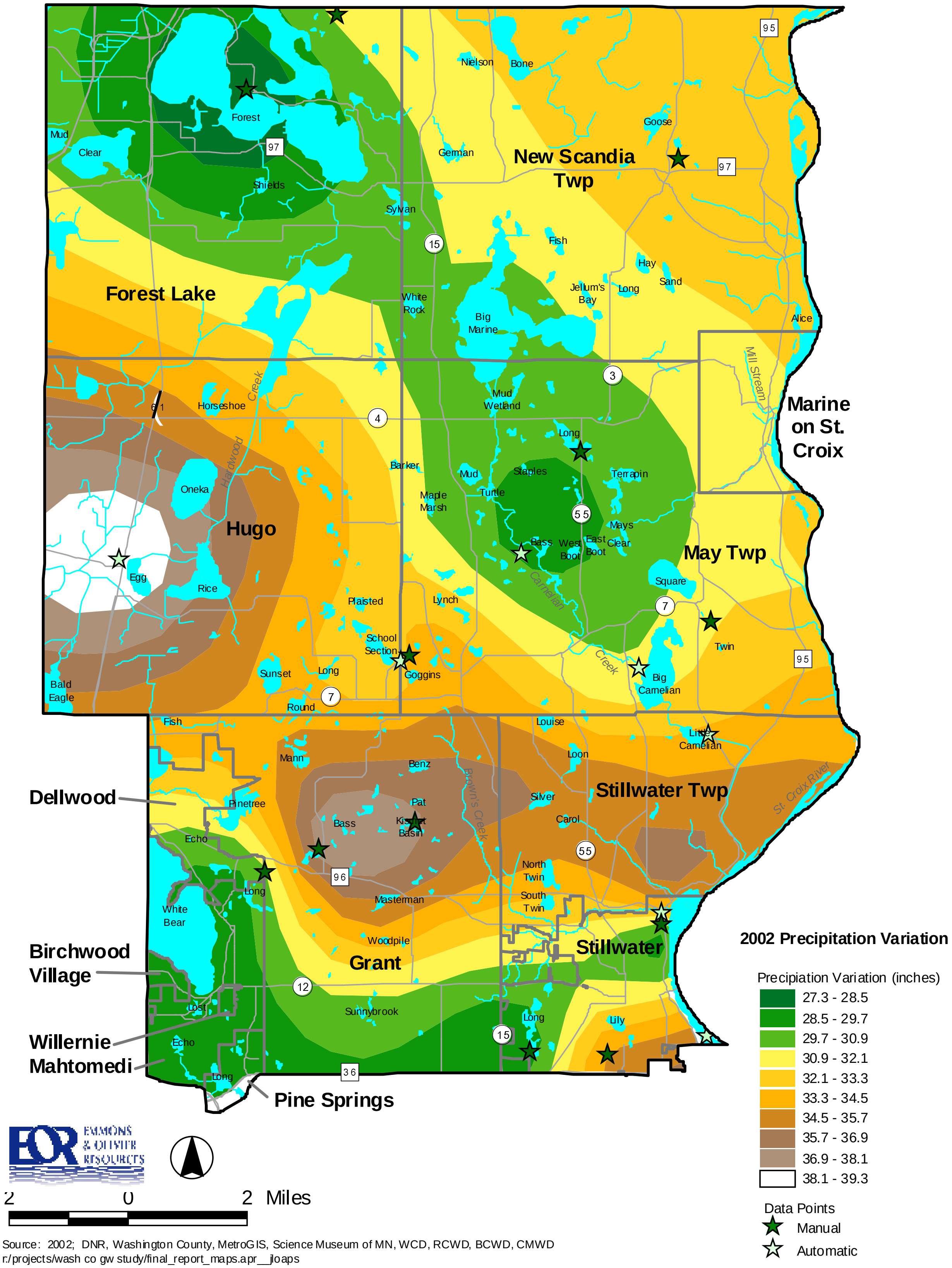
Source: 2002; DNR, Washington County, MetroGIS, Science Museum of MN, WCD, RCWD, BCWD, CMWD
r:/projects/wash co gw study/final_report_maps.apr__jloaps

Figure 3.5. 2002-2003 Precipitation Monitoring Network.



Source: 2002; DNR, Washington County, MetroGIS, Science Museum of MN, WCD, RCWD, BCWD, CMWD
r:/projects/wash co gw study/final_report_maps.apr__jloaps

Figure 3.6. 2002 Precipitation Variation.



Source: 2002; DNR, Washington County, MetroGIS, Science Museum of MN, WCD, RCWD, BCWD, CMWD
r:/projects/wash co gw study/final_report_maps.apr__jloaps

3.4. Stream Flow

Historical stream flow data were obtained from the CMWD, RCWD, BCWD, DNR, and the Science Museum of Minnesota. Twenty-four historical sites were identified. Sites were monitored using automatic area velocity meters or water level meters. At locations where level data are collected, stage discharge relationships were used to calculate flow. Monitoring locations are illustrated in Figure 3.1.

In 2002, five sites were added to the existing stream flow monitoring network as part of this study. New monitoring stations were added at the outlet of Big Marine Lake along County Road 4 and at the outlet of Long Lake in May Township along County Road 55. Additionally, three crest gauges at the inlets on the west side of Big Marine Lake were included in the monitoring plan. In 2002, data were collected at 22 sites within the Study Area. Monitoring locations are illustrated in Figure 3.2 and 3.3.

3.4.1. Results

Monitoring at the Big Marine and Long Lake outlets was influenced by what is known as tail water effect. This occurs when the downstream stage rises without necessarily affecting discharge levels such that it is difficult to develop a good stage/discharge relationship. Therefore, if continued monitoring of stream flow should occur at these locations, an area velocity meter or monitoring locations downstream should be used to alleviate this affect. Level data collected from the outlet of Long Lake indicate a consistent outflow from the Lake.

The inlets to Big Marine had a maximum of 10 measurements in 2002. Collected data indicates variable inflow from these tributaries to the Lake. The more complete data of 2000 and 2001 show a slightly more consistent inflow than 2002, but flow was typically less than 2 cubic feet per second.

Flow data collected at Hardwood Creek indicates that groundwater baseflow increases along the course of the Creek from 157th Avenue to Harrow Avenue.

Data collected from the outlet of Big Carnelian Lake and the outlet of Little Carnelian Lake indicate a greater volume of water enters Little Carnelian than outflows at the surficial from the lake. This indicates, after allowing for evapotranspiration, that water from the lake recharges the groundwater system.

3.5. Groundwater Monitoring

3.5.1. Groundwater Levels

Historical groundwater level data were obtained primarily from the DNR Observation Well Program at (http://www.climate.umn.edu/obwell/ObWlCh.asp). Well locations are shown in Figure 3.7. Thirty-three wells from this network are located within the study area. The wells are screened in various aquifers and have period of records of varying length. Additional groundwater level data were obtained from the following organizations:

- Minnesota Pollution Control Agency Leaking Underground Storage Tank (LUST) program;
- Minnesota Pollution Control Agency Voluntary Investigation and Cleanup (VIC) program;
- Valley Branch Watershed District;
- City of Stillwater; and
- Washington County for community drain field monitoring wells.

The County Well Index (CWI), managed by the MGS, was used to identify potential monitoring locations. The CWI includes a static water elevation taken at the time of well construction for the majority of wells within the database. These elevations were used primarily to develop bedrock groundwater contours.

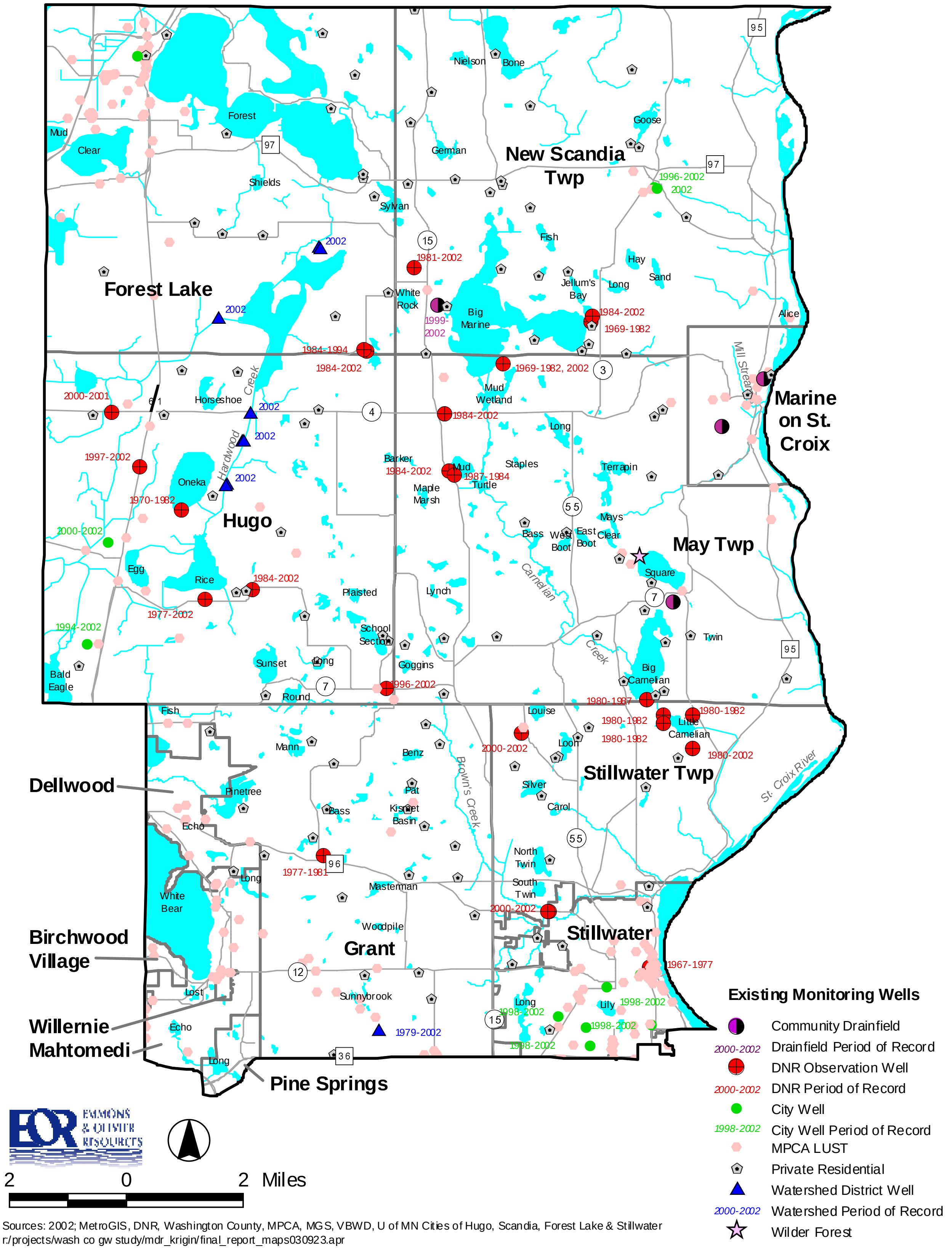
As part of this Study, over 250 residential well owners were contacted in an effort to fill gaps in elevation data that were found throughout the study area. In addition, 10 Quaternary monitoring wells were installed within the RCWD portion of the study area. Additional details on these wells are found in Chapter 6.

Groundwater elevations from residential wells can be difficult to obtain due to well construction. Well caps, pumps, and electrical wires can inhibit or ensnare a water level indicator, preventing accurate data collection. Groundwater level measurements were collected using a small diameter (3/8 inch), Solinst pressure transducer. Decontamination procedures were followed to prevent cross-contamination between wells. Recent water usage was discussed with well owners when present to determine the stability of the water level measurement. The groundwater elevation was then determined using GPS data and County two-foot topography.

A total of 141 wells were included in the 2002 groundwater monitoring network. These included 18 DNR Observation Wells, 10 municipal wells, 11 watershed monitoring wells, one community drainfield well, and 102 residential wells.

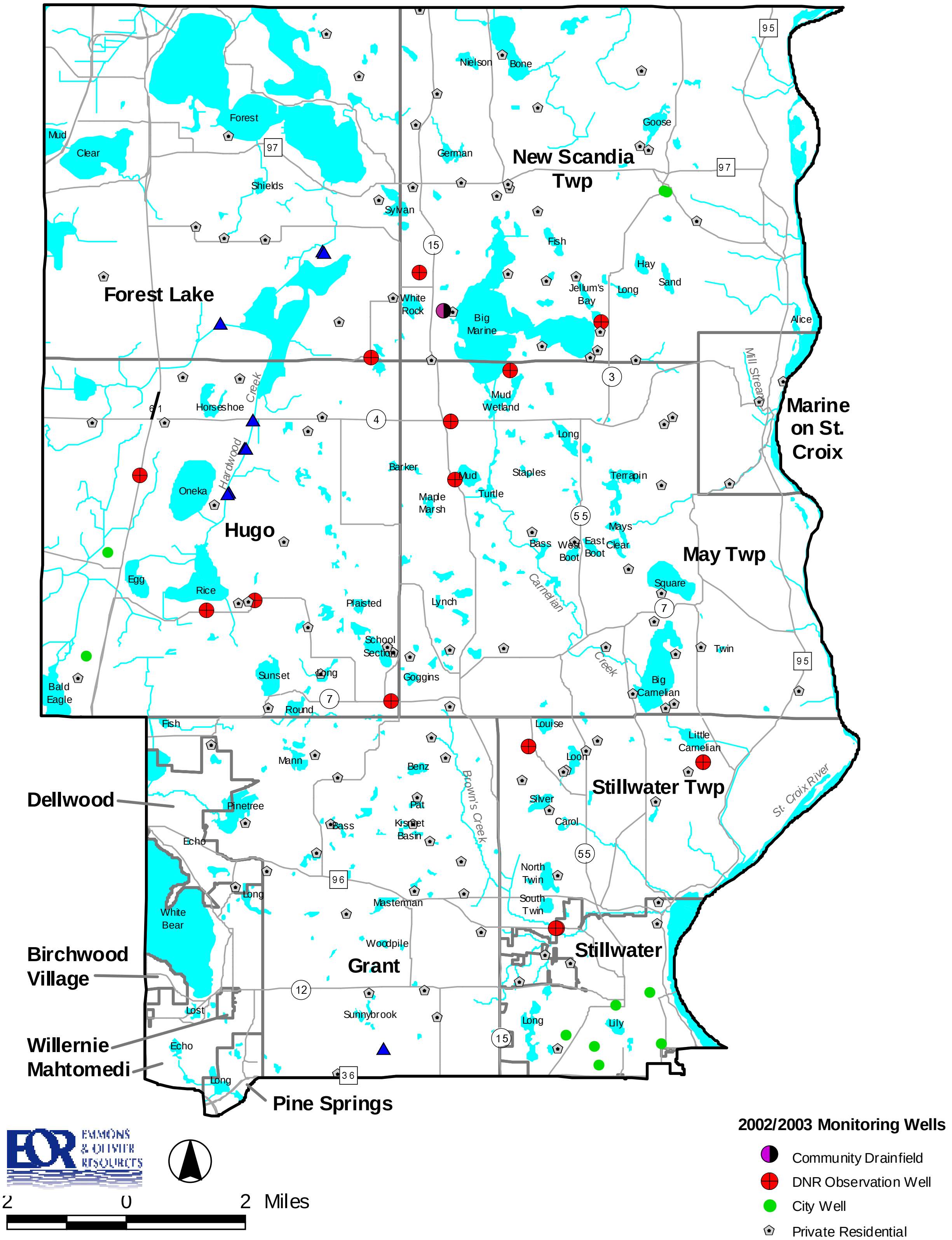
In 2003, an additional nine residential wells were added to the monitoring network to fill data gaps. Water levels data were collected at these wells in September 2003. The final well network used for this study is illustrated in Figure 3.8.

Figure 3.7. Historic Well Locations.



Sources: 2002; MetroGIS, DNR, Washington County, MPCA, MGS, VBWD, U of MN Cities of Hugo, Scandia, Forest Lake & Stillwater
r:/projects/wash co gw study/mdr_krigin/final_report_maps030923.apr

Figure 3.8. 2002-2003 Well Locations.



Sources: 2002; MetroGIS, DNR, Washington County, MPCA, MGS, VBWD, U of MN Cities of Hugo, Scandia, Forest Lake & Stillwater
r:/projects/wash co gw study/mdr_krigin/final_report_maps030923.apr

3.5.2. Results

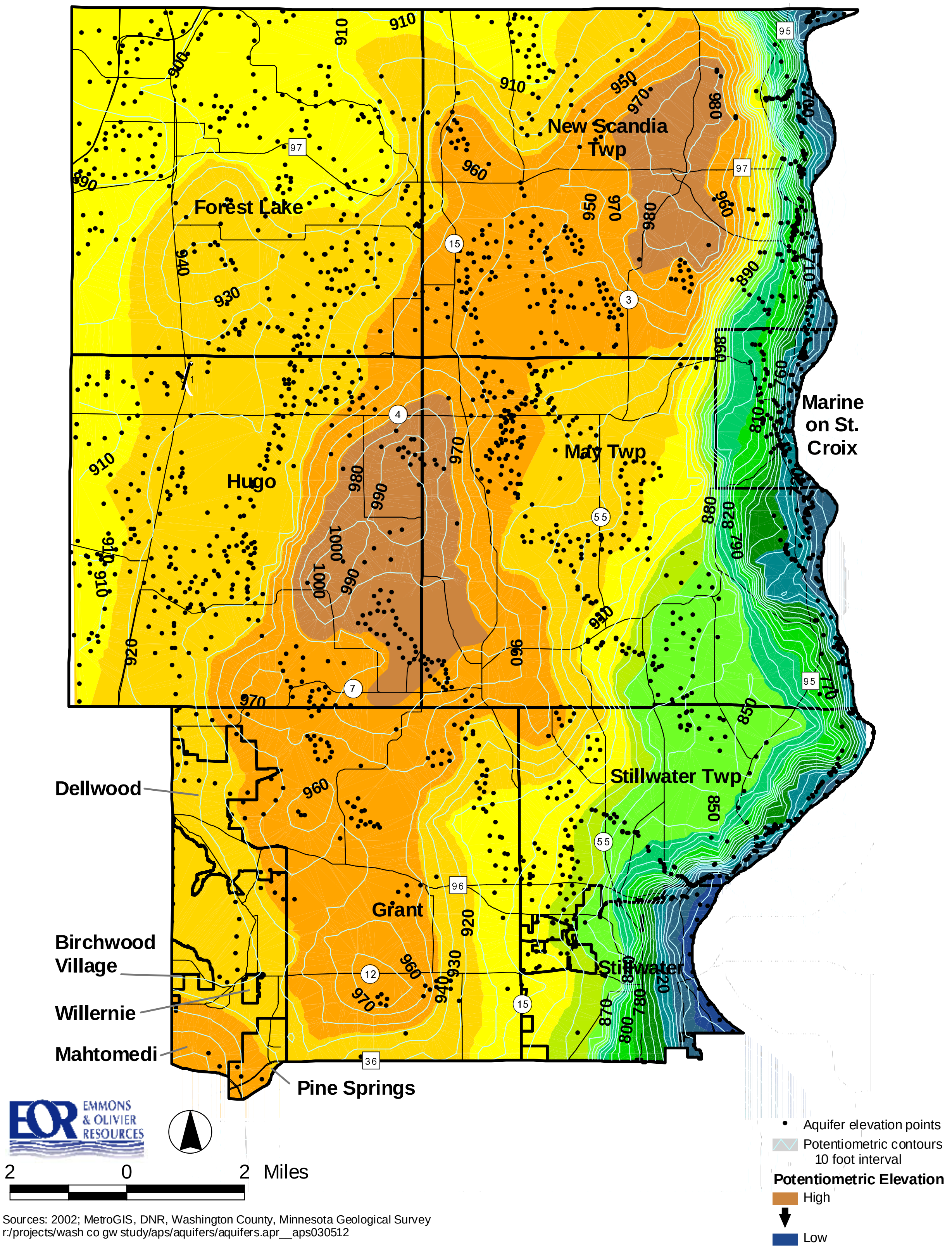
Groundwater level data were collected at 83 residential wells in August 2002 and 68 in October 2002. Level data were collected at six residential wells in September 2003. Out of the 111 residential wells in the network, water level data were obtained for 90 wells. During the October monitoring event, 15 wells from the August sampling were not included to maximize time and efforts on wells that were more easily accessible. During the August monitoring event, four of the residential volunteers experienced a temporary increase in suspended sediments in their tap water. The sediments were mostly iron and magnesium particles that cleared within a few days. We chose not to obtain water level data from these four wells during October monitoring to avoid a similar inconvenience to those volunteers. In addition, municipal wells were excluded from October monitoring due to difficulties obtaining accurate groundwater levels.

3.5.2.1 Groundwater Contours

The process of Linear Kriging, a geostatistical tool used to estimate unknown point values from known point values, was used to generate groundwater contours for the Quaternary, St. Peter, Prairie du Chien, Jordan, and St. Lawrence-Franconia aquifers. Figures 3.9 to 3.13 illustrate the generated contours for each aquifer.

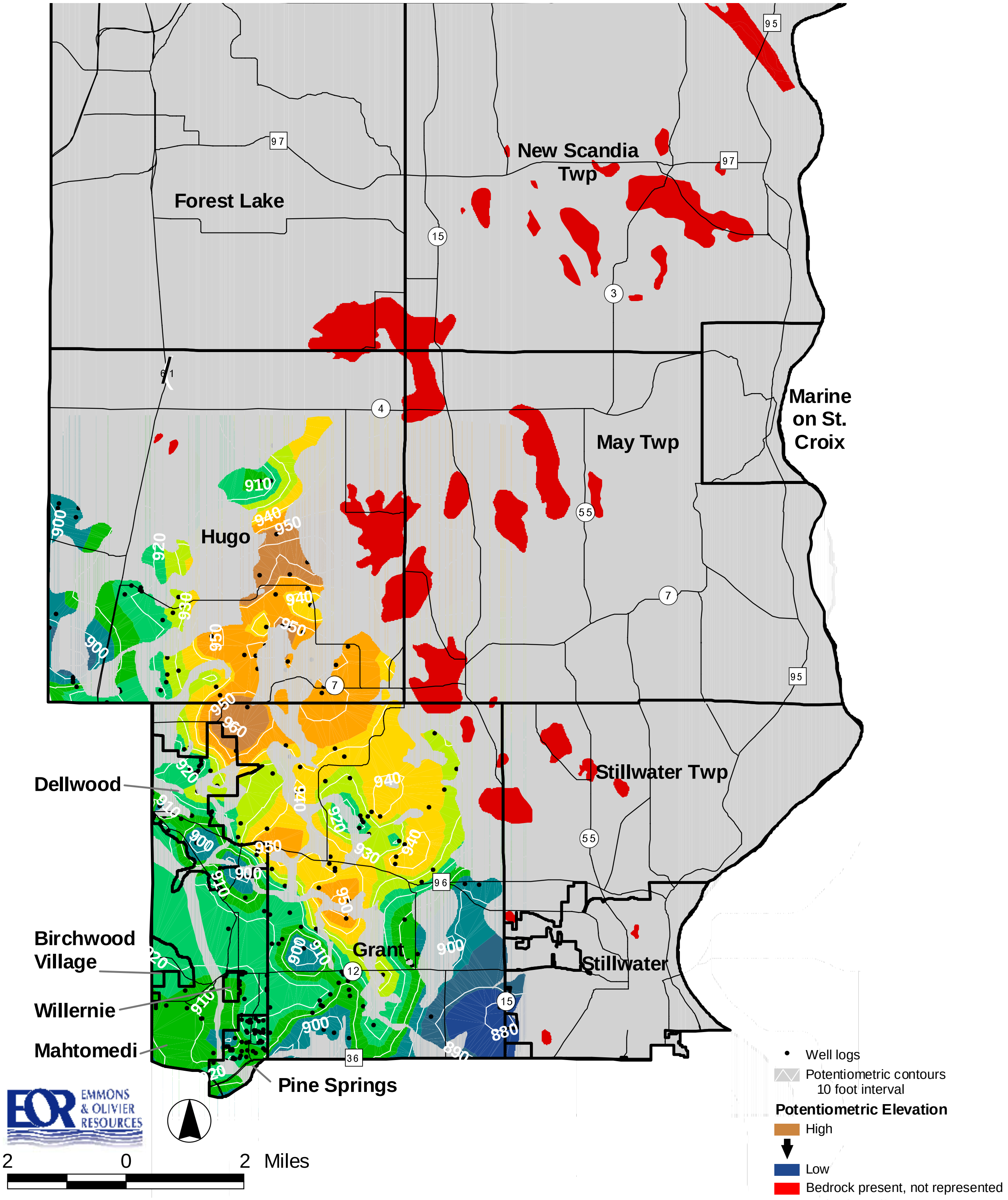
Bedrock aquifer groundwater potentiometric contours were created by kriging data points from the County Well Index (CWI), DNR observation well network, and wells from the 2002 residential network. Points used to generate the Quaternary aquifer contours were obtained using residential volunteer wells, DNR wells, groundwater dependent resources, groundwater dependent lakes, and groundwater discharge points. The kriging interpolation used a minimum of 12 sample points to create the kriged surface. The “cell size” for the kriged surface was chosen small enough so the resultant contour lines were smooth, yet precise based on much trial and error. The final cell size used to generate the contours was 450 pixels. The kriging software used was “Surface Interpolator”, an ArcView GIS extension (Tilton, 2002).

Figure 3.9. Quaternary Aquifer Groundwater Contours.



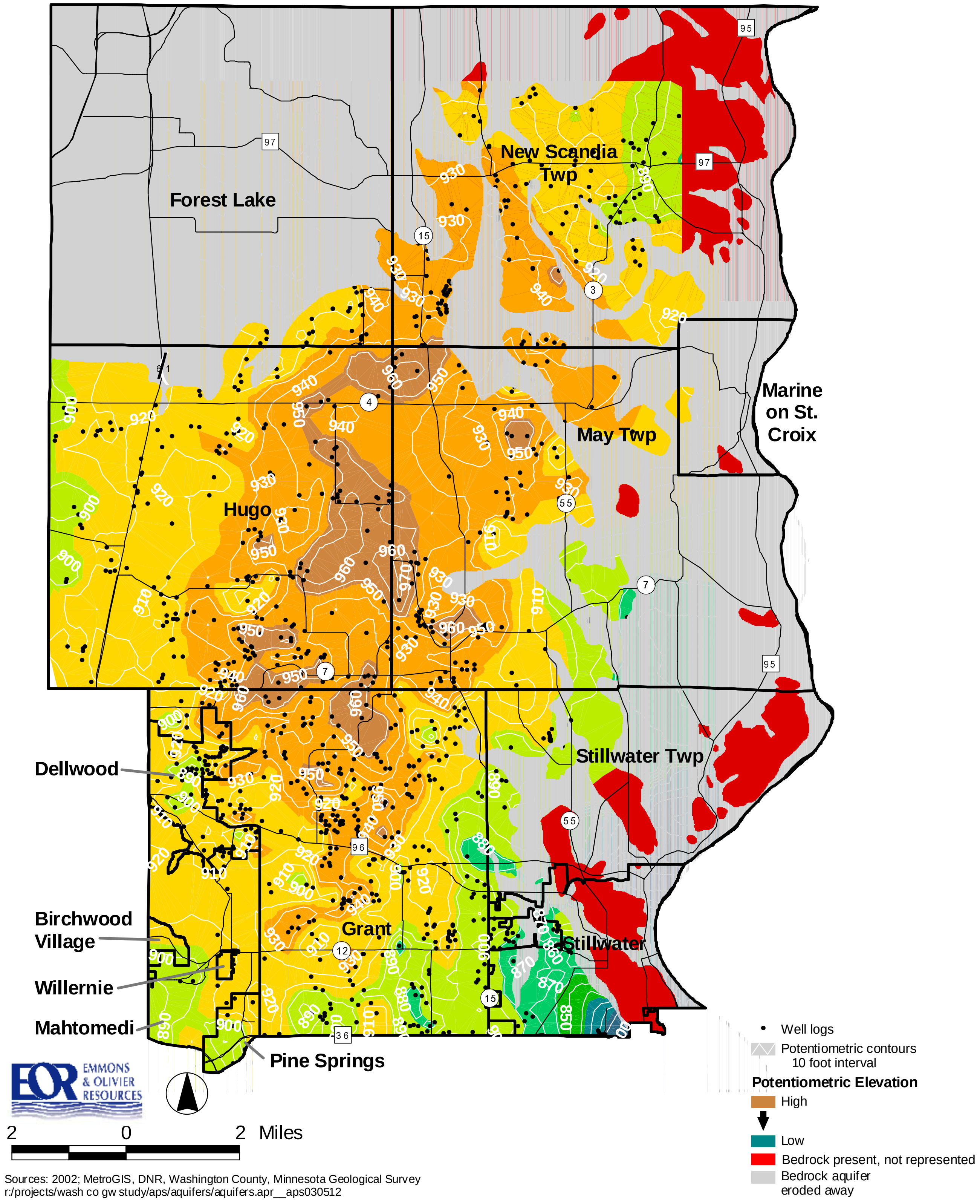
Sources: 2002; MetroGIS, DNR, Washington County, Minnesota Geological Survey
r:/projects/wash co gw study/aps/aquifers/aquifers.apr__aps030512

Figure 3.10. St. Peter Aquifer Groundwater Contours.



Sources: 2002; MetroGIS, DNR, Washington County, Minnesota Geological Survey
r:/projects/wash co gw study/aps/aquifers/aquifers.apr__aps030512

Figure 3.11. Prairie du Chien Aquifer Groundwater Contours.



Sources: 2002; MetroGIS, DNR, Washington County, Minnesota Geological Survey
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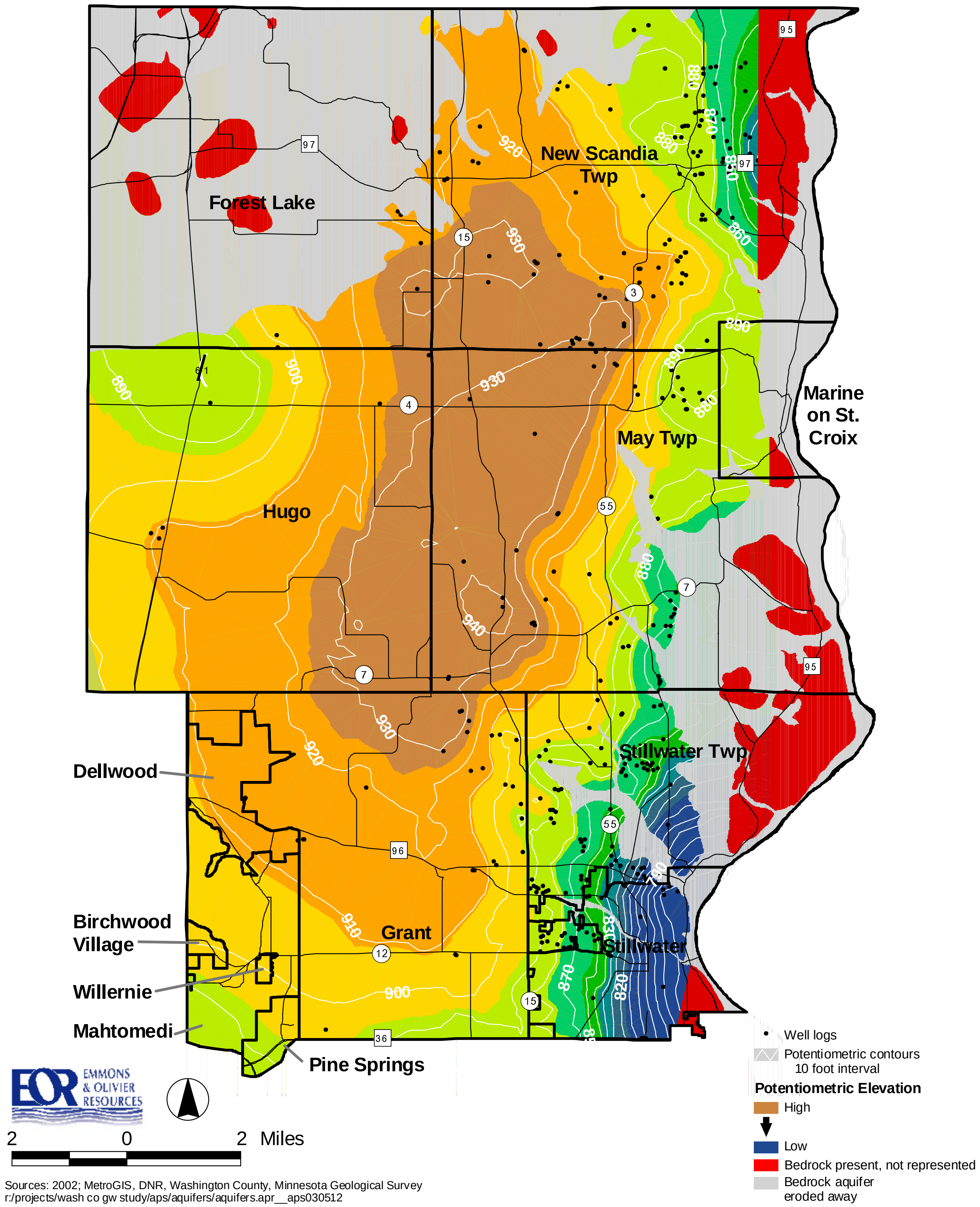
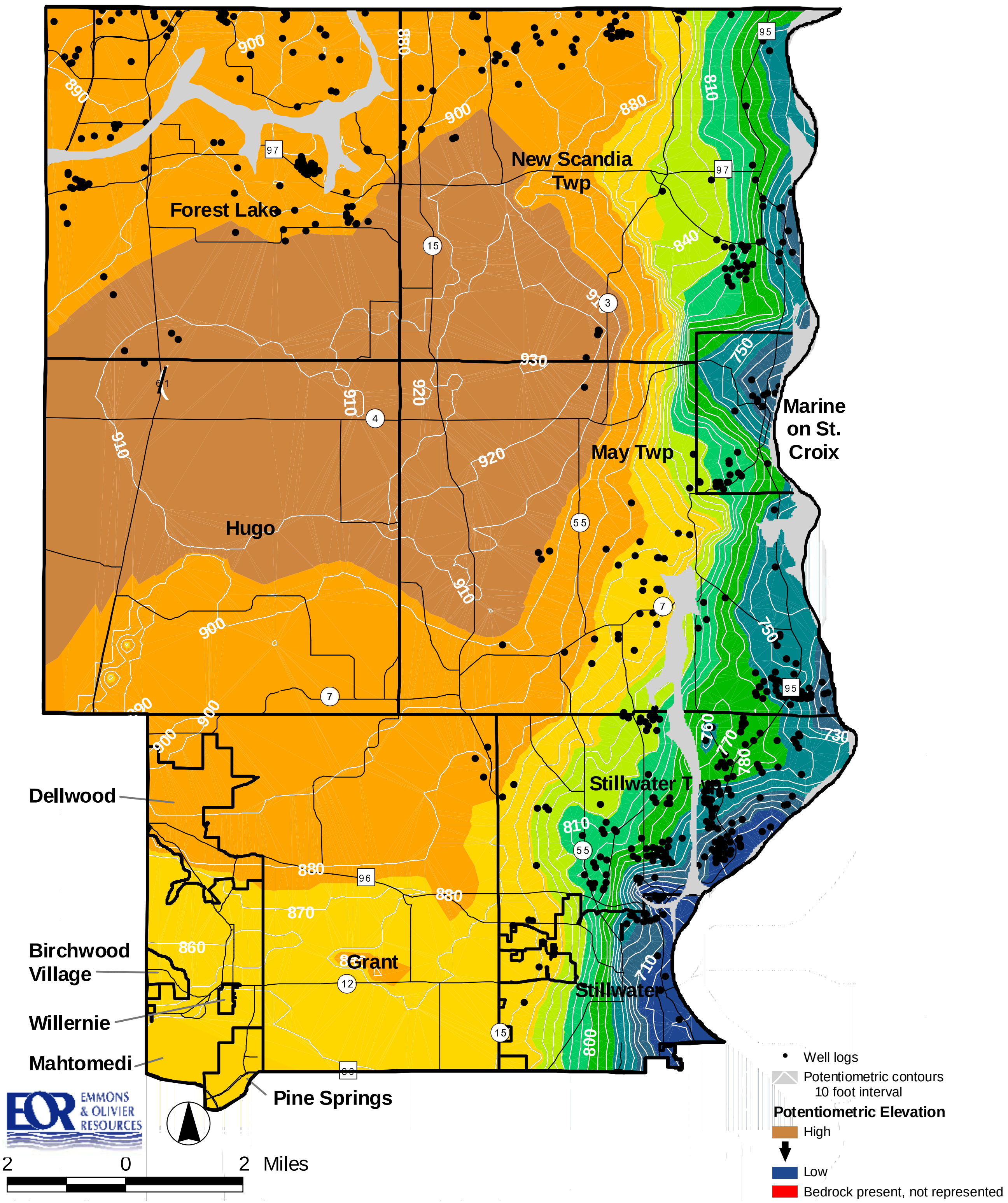
Figure 3.12. Jordan Aquifer Groundwater Contours.



Sources: 2002; MetroGIS, DNR, Washington County, Minnesota Geological Survey
r:/projects/wash co gw study/aps/aquifers/aquifers.apr__aps030512

Figure 3.13. St. Lawrence-Franconia Aquifer Groundwater Contours.



Sources: 2002; MetroGIS, DNR, Washington County, Minnesota Geological Survey
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3.6. Chemistry

3.6.1. Analysis

The University of Minnesota Department of Geology and Geophysics provided analytical services for this study. Duplicates and blanks were collected to verify the accuracy of sampling and analysis.

3.6.1.1. Groundwater Chemistry

Water chemistry data were collected at 47 wells in August 2002 and 20 wells in October 2002. Wells were sampled from the Quaternary (QBAA), Prairie du Chien (OPDC), Jordan (CJDN), and Franconia (CFRN) aquifers. The following parameters were analyzed in each water chemistry sample:

- Calcium;
- Magnesium;
- Sodium;
- Aluminum;
- Iron;
- Manganese;
- Strontium;
- Barium;
- Silicate;
- Alkalinity;
- Chloride;
- Bromide;
- Nitrate;
- Nitrite;
- Sulfate;
- Phosphate;
- Total phosphorus;
- Fluoride.

In addition, during the October sampling event, all twenty wells were sampled and analyzed for tritium (^{3}H) and stable isotopes of water elements (^{2}H and ^{18}O). Thirteen of the wells were sampled and analyzed for strontium isotopes (^{86}Sr and ^{87}Sr). A portion of the sampling and analysis was sponsored by the Minnesota DNR under a separate contract agreement (See Section 7 of this report).

A field nitrate test was conducted on the wells where a complete analysis was not performed.

In 2003, an additional nine residential wells were added to the monitoring network to fill recognized data gaps. Water chemistry data were collected at these wells in September 2003.

3.6.1.2. Surface Water Chemistry

Historical lake water chemistry data were obtained from the University of Minnesota and the CMWD for Square, Forest, Clear, Big Marine, Little Carnelian, Big Carnelian, Sylvan, and White Bear Lakes. Data were collected in 1990 at all of these except the Carnelian Lakes and Square Lake. Square Lake data were collected in 1999 and Carnelian Lake data were collected in 2001. Big Marine data were collected in 1990, 2000, and 2001.

Additional data were collected in 2002 from Goggins and South Twin Lakes, and in 2003 from Big Marine, Square, White Bear, Sunset, Loon, Oneka, Mays, Pine Tree, Long (CMWD), and Louise Lakes, and from a wetland north of Long Lake (CMWD). The data consist of a suite of anions, cations, and alkalinity analyzed from lake samples. Lake samples were obtained from near the lakeshore, typically from a dock or boat launch.

Chemistry data were also collected at streams throughout the study area. Historical data collection sites were located along Carnelian Creek at the outlet of Big Marine, at Ozark Trail, May Avenue, and several other road crossings illustrated in Figure 3.1.

Data were also collected in 2003 at six locations on or around Hardwood Creek, illustrated in Figure 3.5. The data consist of a suite of anions, cations, and alkalinity analyzed from stream samples. Samples were typically collected where streams intersected a road, where sample retrieval was possible without the use of watercraft.

3.6.1.3. Spring Chemistry

Historical spring water chemistry data were obtained from the University of Minnesota, MGS, CMWD, and the MWMO. Data were collected in 2000-2002. The data consist of a suite of anions, cations, and alkalinity analyzed from spring samples.

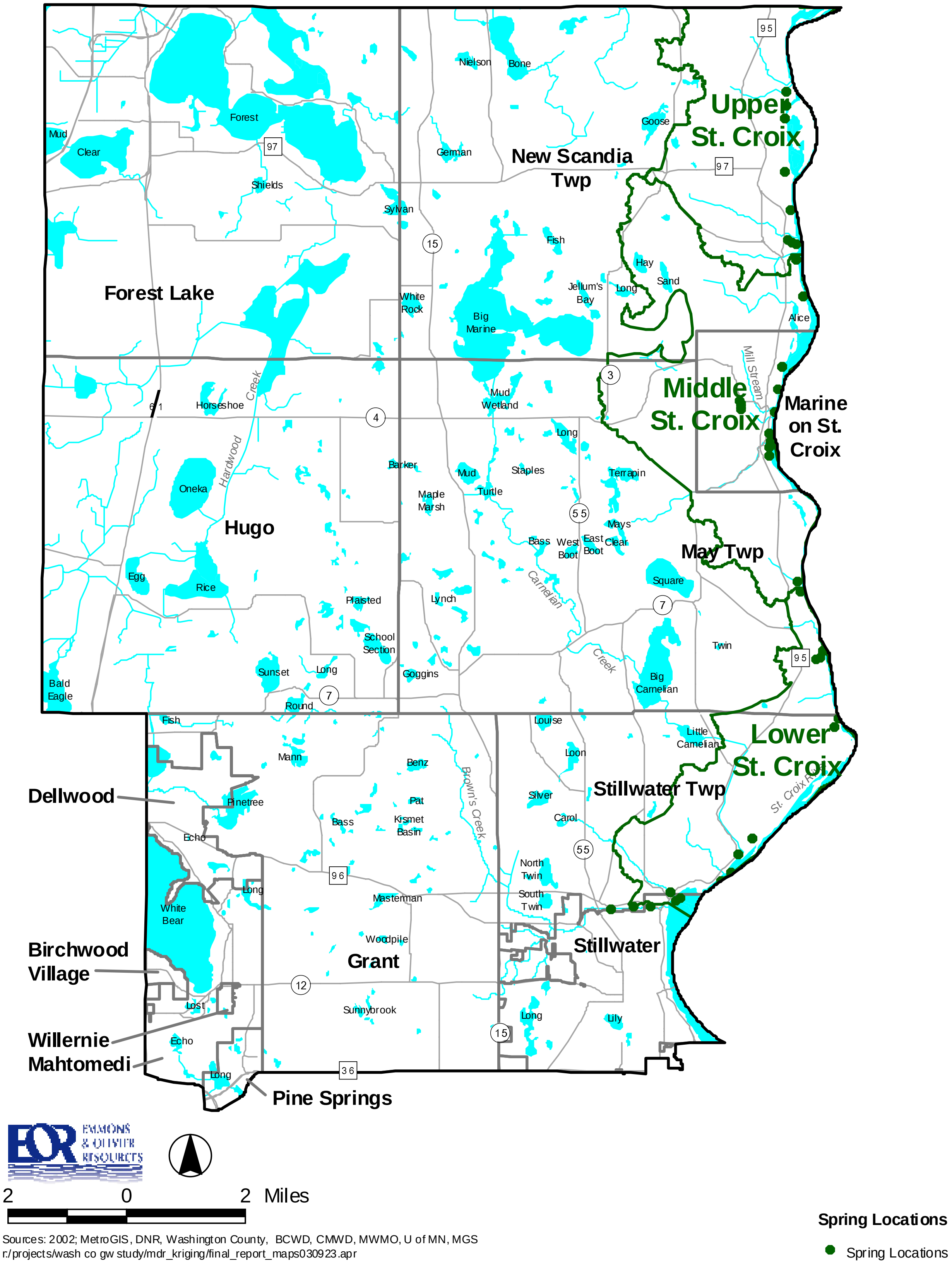
Additional spring samples were collected for the DNR at Brown's Creek in 2003. The data consisted of a suite of anions, cations, alkalinity, enriched tritium, and strontium analyzed from spring samples. Data were collected at spring and seep points identified in Figure 3.14.

3.6.2. Background

All groundwater in northern Washington County originates as precipitation in the form of rain and snow. From this origin, the water can pass through one or more geographic environments before reaching the water table. From the water table, the groundwater then moves laterally through one or more aquifers towards a discharge point. The natural groundwater discharges are springs and seeps feeding wetlands, lakes, and rivers. Wells can intercept this deep, natural flow releasing the "used" water back to the near surface. Chemical and isotopic relationships were used to help delineate sources and paths of groundwater flow both in the modern and pre-development environments.

Quaternary sediments are the closest geologic materials to the surface and are, therefore, encountered first by most infiltrating groundwater in the study area. There are two main Quaternary events recorded in the surficial materials. The first is referred to as the Superior Lobe glacial advance. This glacial advance originated from the direction of Lake Superior to the north-northeast. The deposits left by this glacial advance are typically red in color, containing oxidized basalt cobbles and other mafic igneous rocks. The Superior Lobe sediments contain very little limestone and dolomite from marine deposits. Superior lobe tills are generally rich in sand with lesser portions of silt and clay. The second event is denoted as the Des Moines Lobe glacial advance, and more locally as the Grantsburg Sublobe. The Des Moines Lobe originated to the northwest traveling southward towards Des Moines, Iowa. The Grantsburg Sublobe split off the main glacial advance moving to the Northeast essentially in the tracks of the Superior Lobe. The Des Moines Lobe sediments are rich in shales, marine carbonates, and granitic rocks.

Figure 3.14. Spring Locations.



Sources: 2002; MetroGIS, DNR, Washington County, BCWD, CMWD, MWMO, U of MN, MGS
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Des Moines Lobe tills are very clay-rich. Figures 2.6 and 2.7 showed the aerial distribution and thickness of Des Moines and Superior Lobe deposits.

The main Superior Lobe advance ended along the western edge of Washington County leaving a large terminal moraine, the St. Croix moraine, stretching from the northeast to the south across the study area. This moraine forms the hilly terrain with many closed depressions observed in a large part of the study area. The older Superior Lobe moraine essentially confined the Grantsburg Sublobe. This left Des Moines Lobe sediments as a flat till plain in the northwest portion of the study area.

3.6.3. Parameters

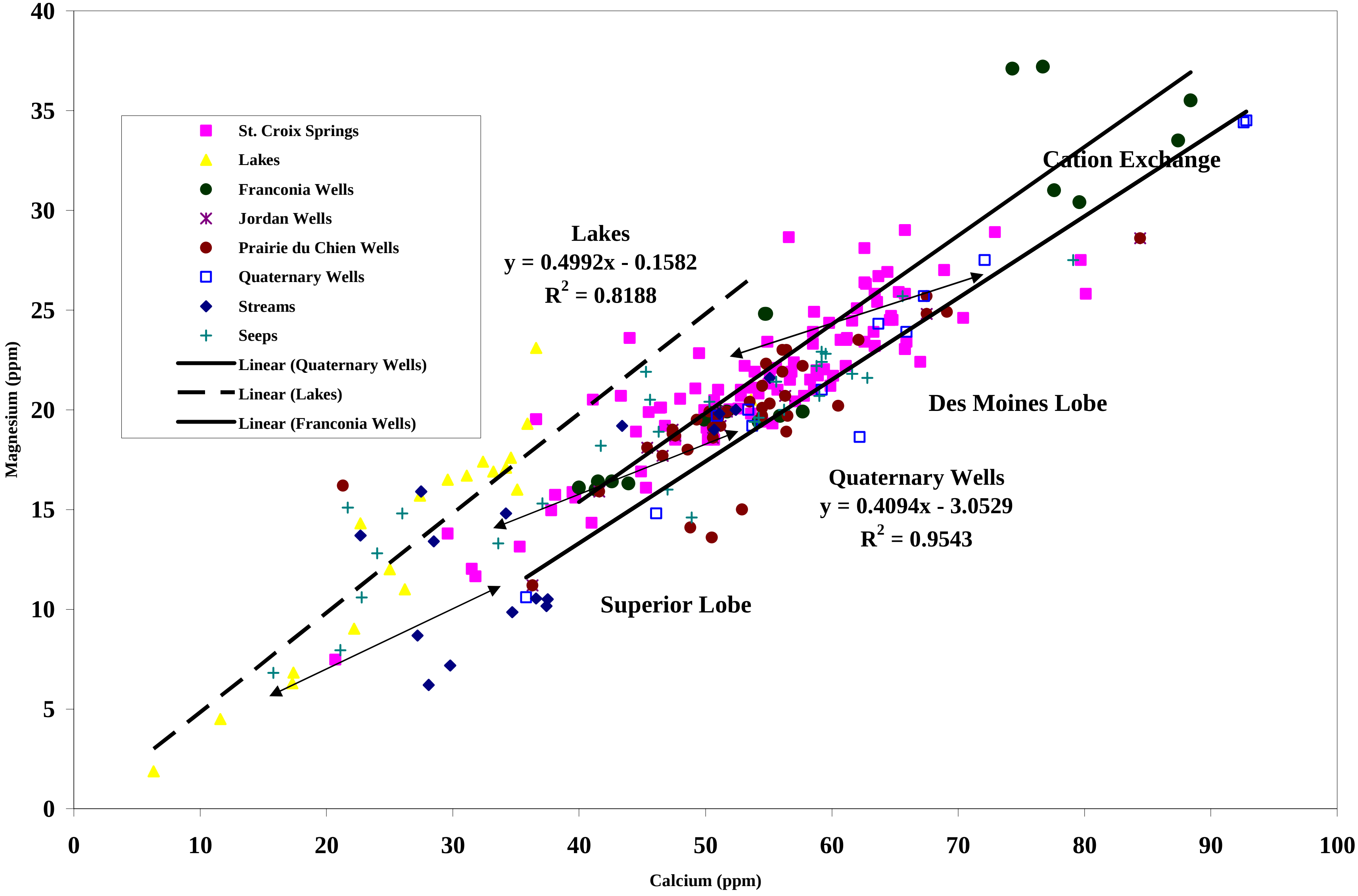
3.6.3.1. Calcium vs. Magnesium and Strontium

Chemically, the Superior Lobe sediments are low in calcium (Ca), magnesium (Mg) and strontium (Sr), which are all elements common in marine carbonate rocks typical of the Des Moines Lobe. The Superior Lobe materials, and well-drained soils that form on Superior Lobe deposits, are also low in organic materials. Waters that recharge through Superior Lobe materials usually carry smaller amounts of dissolved Ca, Mg, and Sr due to a combination of the low levels in the sediments and the low organic content. The dearth of organics limits the accumulation of carbon dioxide (CO_2), which is a primary control on the solubility of carbonate rocks in the water. Conversely, Des Moines Lobe sediments are themselves rich in organics and tend to form very organic-rich soils. This high organic content creates elevated levels of CO_2 in the groundwater, which in the presence of carbonate-rich materials leads to higher dissolved levels of Ca, Mg and Sr. This relationship of dissolved CO_2 to dissolved cations covers a smooth distribution from well-drained upland Superior Lobe sediments to poorly-drained Superior Lobe pothole wetlands, to Des Moines outwash channels, to peat lands developed over Des Moines Lobe till. Figure 3.15 is a plot of Ca versus Mg.

The distribution of dissolved Ca and Mg of well water in the study area is shown in Figure 3.16. The Quaternary wells have fairly constant ratio of Ca to Mg. They form a line on the Ca to Mg plot of $Mg = 0.4094 \times Ca - 3.0529$ with an $R^2 = 0.9543$. The Quaternary wells form a lower limit of calcium-rich waters ranging from Superior Lobe sources at lower Ca values to Des Moines Lobe sources at higher Ca.

In addition to the well-drained upland environment of the Superior Lobe moraine and Des Moines Lobe outwash channels, numerous lakes have formed over buried bedrock valleys and within ice block deposits across the study area. These lakes represent a significant source of groundwater recharge although many of these same lakes are also dependent on groundwater discharge. Square Lake is a prime example of a groundwater flow-through lake with both groundwater flowing into the lake on the western end and recharging the groundwater on its eastern end. In the lake environment, CO_2 is lost to plant processes, reducing the solubility of Ca and Mg. However, for chemical reasons only the calcium carbonate ($CaCO_3$) phase can precipitate.

Figure 3.15. Calcium to Magnesium Plot of Washington County Samples.



This removal of calcite enriches the remaining water in Mg. In actuality, some Mg is lost to the aragonite form of $CaCO_3$ leaving the recharging groundwaters slightly depleted in Mg and very depleted in Ca. The lake water samples form a line on the Ca to Mg plot with the equation $Mg = 0.4992 \times Ca - 0.1582$ and $R^2 = 0.8188$. The deeper, bedrock aquifers contain waters that are a mixture of this recharge through Quaternary sediments and lakes. The Franconia wells exemplify this process forming a line between upland and lake recharge. These mixing lines are shown as lines with arrows at both ends on Figure 3.15.

Table 3.1 gives guidance for determining (within this study area) the recharge area of groundwater based on Ca, Mg, and Sr concentrations. It should be noted that the values do overlap and that groundwater conditions can and do vary with climatic and landscape changes. This was only one of several criteria used to determine recharge areas of groundwater for this study.

Table 3.1. Recharge areas and Ca and Mg Concentrations.

Recharge area	Ca (ppm)	Mg (ppm)	Mg:Ca
Lake	1 to 40	1 to 25	0.45 to 0.55
Wetland	60 to 100	25 to 40	0.40 to 0.60
Upland	35 to 75	5 to 30	0.35 to 0.45

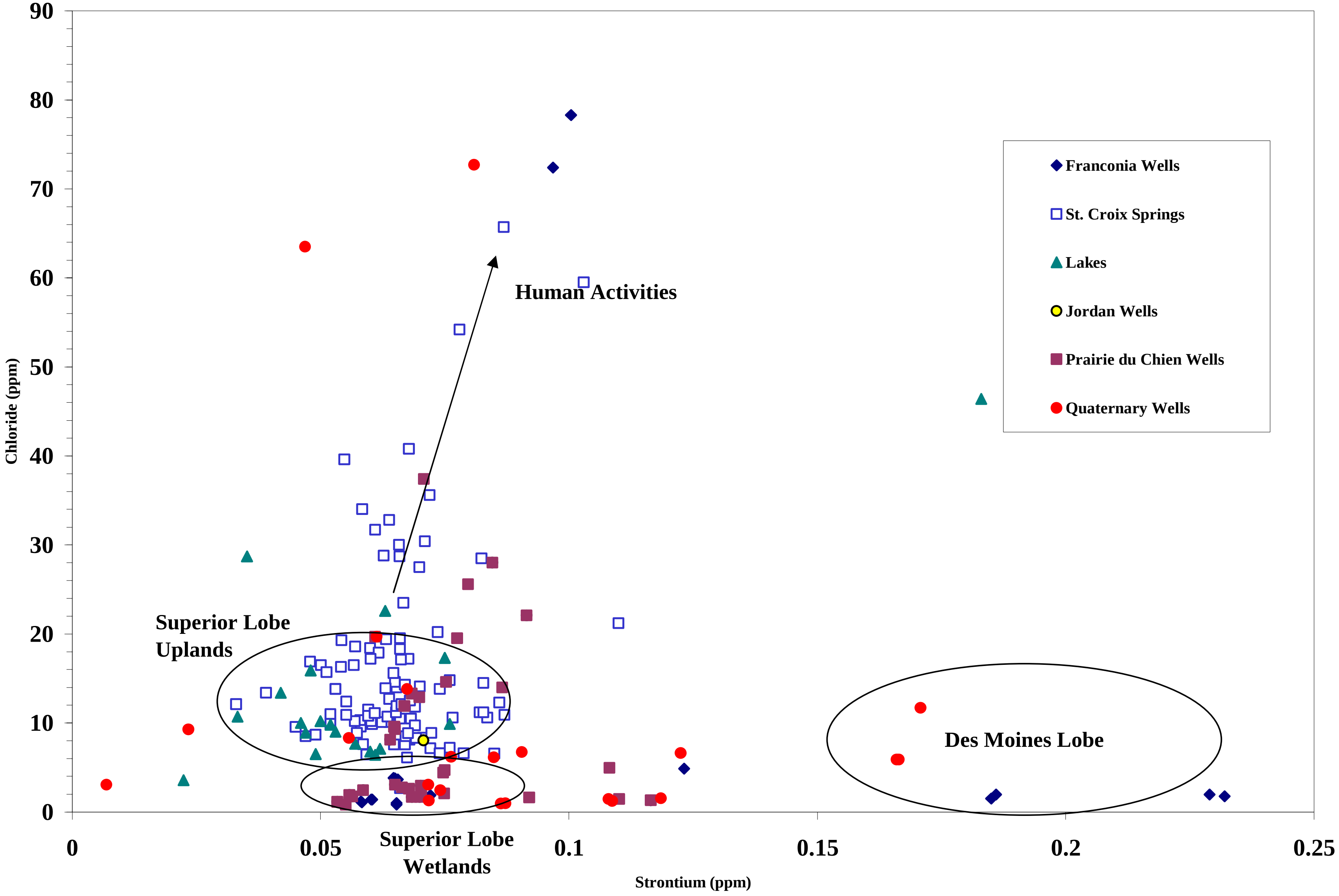
The relationships of recharge environment to groundwater chemistry can be refined beyond the Ca versus Mg plot. Figure 3.16 is a plot of Sr versus chloride (Cl). Here Sr is used as a proxy, lumping the behaviors of Ca and Mg. Sr is also a good indicator of waters recharging through Des Moines Lobe (>0.15 ppm Sr) or Superior Lobe sediments (<0.10 ppm Sr). Some intermediate Sr values may occur where Des Moines Lobe outwash overlies Superior Lobe materials.

Cl, like Ca and Mg, is another good indicator of recharge environments. Additional, Cl is a sensitive indicator of human activities on the land surface. Chloride (Cl) is an anion naturally present in rainwater at levels below one part per million (ppm) in Minnesota. This Cl originates with the evaporation of seawater and is transported inland where it eventually falls to earth with rainwater. Waters in wetland environments have a short residence time and often retain a Cl level close to the 1 ppm precipitation value. In well-drained upland soils, evapotranspiration can return most of the water back to the atmosphere concentrating Cl in the remaining water. Evapotranspiration can naturally increase the Cl level to 20 to 30 ppm. Human beings, as part of their overall environmental impact, use Cl in many everyday products including table salt, water-softener salt, road salt, and fertilizers. This excess of Cl, over natural levels, is a trademark of human activity.

3.6.3.2. Silica

Rainwater has less than 1 ppm silica while most groundwater is 8 to 12 ppm. In lakes, this value is a combination of biologic activity, precipitation, and groundwater inflow. Lakes with high groundwater contribution typically have greater than 4 ppm of silica. However, some aquatic plants use silica which could lower this value artificially.

Figure 3.16. Strontium vs. Chloride Plot of Washington County Samples.



3.6.3.3. Chloride vs. Bromide and Sodium

A distinctive marker of seawater is a high residual content of Bromide (Br); in seawater, Br is typically present at a concentration ratio of 300 Cl to 1 Br. In rainwater this Cl:Br ratio ranges from 100 to 300; starting at 300 in coastal areas and decreasing into continental areas. In contrast most sources of Cl for human activities contain relatively pure Cl. Common sources of bulk Cl include road salt (Cl:Br 10,000:1), water softener salt (up to 20,000:1) and Potassium (K) and ammonia (NH_4-N) fertilizer (up to 10,000:1). Household wastewaters typically have a Cl:Br ratio of 1,000:1 to 2,000:1. Bromide levels are typically quite low throughout the study area. The Cl:Br ratio, while very diagnostic of human activities, was difficult to apply to this study area. The natural waters have low Cl and hence very low Br, particularly for waters recharging through wetlands. Human influenced waters have very little Br simply because human sources of Cl are so poor in Br to start with. Improved analytic techniques could help differentiate between these natural and human influenced waters.

Agricultural sources of Cl can be differentiated from transportation and residential sources by their sodium (Na) content. Common agricultural fertilizers include anhydrous ammonia (NH_4OH), ammonium chloride (NH_4Cl) and potassium chloride (KCl). NH_4OH is strongly adsorbed by clay minerals in the soil releasing excess Ca and Mg to the soil water by cation exchange. Likewise, NH_4Cl and KCl exchange NH_4 and K for Ca and Mg. These waters appear on Figure 3.16 to the upper right of the diagram. Road salt and water softener salt produce elevated levels of both Na and Cl at about a 1-to-1 molar ratio (22.9 ppm Na to 35.5 ppm Cl). Both agricultural and residential sources of chloride are evident within the study area. Road salt may have more local impacts near bulk storage areas and along busy roadways with heavier applications.

Table 3.2 summarizes information that can be inferred from the concentration of Cl and Br in groundwater in the study area.

Table 3.2. Cl and Br Concentrations in Different Environments.

Environment	Cl (ppm)	Br (ppm)	Cl:Br	Na (ppm)
Rainwater	<0.5	<0.005	100:1 to 300:1	<0.5
Wetland recharge areas	1 to 5	<0.020	100:1 to 300:1	1 to 5
Upland recharge areas	5 to 20	0.015 to 0.100	100:1 to 300:1	not applicable
Human impacted groundwater	>20 mg/l	variable	>500:1	variable

3.6.3.4. Tritium

An indicator of rapid recharge and short residence time waters is the radioactive isotope of hydrogen (^1H) called tritium (^3H). Tritium occurs naturally in the atmosphere at levels about 5 to 10 tritium units (TU). A TU is one atom of tritium per 10^{18} atoms of hydrogen. Half of the tritium is removed every 12.7 years by this process of radioactive decay (half-life). Natural groundwaters that have been isolated from the atmosphere for more than a few decades have less than one TU.

About the time this technique was being developed for measuring atmospheric tritium in the 1950s, the United States, Russia, and China began testing nuclear weapons in the Earth's atmosphere. These atmospheric tests, particularly tests of hydrogen fusion weapons in the early 1960s, increased tritium levels to over 3,000 TU. With the test ban on atmospheric testing in 1963, levels of tritium in the atmosphere rapidly began to decrease. This decrease was a combination of both radioactive decay and mixing of tritium into the rather large ocean reservoir. Levels of tritium in the atmosphere have remained in the range of 8 to 15 TU since the late 1960s. Tritium is therefore a very good indicator of how long a groundwater has been isolated from the atmosphere.

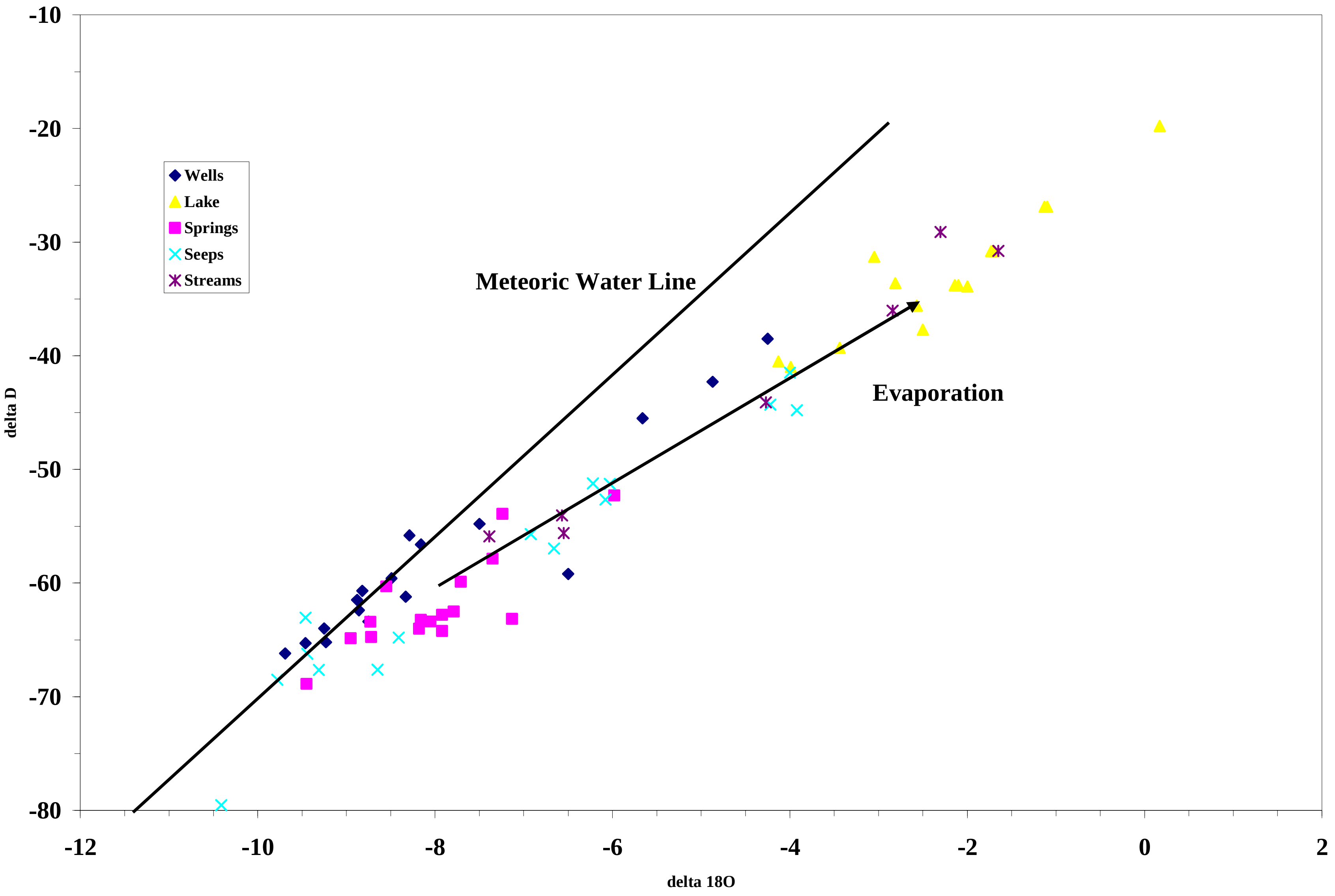
This residence time in an underground aquifer can be broken into three distinct ranges. Water that entered the ground prior to 1950 should have less than 1 TU at the start of the 21st century (Vintage water). Water that recharged in the 1960s can have elevated tritium levels that have partially decayed over time but should still be above 15 TU (Cold War water). Waters that were recharged after 1970 should have between 8 and 15 TU due to residual tritium from atmospheric testing and periodic venting by nuclear power plants (Recent water). Note that there is one additional category representing mixtures of pre- and post-testing waters that can have tritium levels between 1 and 8 TU (Mixed water).

3.6.3.5. Stable Isotopes

Groundwater that is recharged through lakes can be identified by its composition of stable hydrogen and oxygen isotopes. Water is made up of hydrogen and oxygen molecules (H_2O). Naturally occurring hydrogen has two stable, non-radioactive, isotopes referred to as hydrogen (^1H) and deuterium (^2H). The ratio of these two isotopes is denoted as the delta deuterium (δ^2H). Oxygen has several stable isotopes, the most abundant of which are ^{16}O and ^{18}O. The ratio of these two isotopes is referred to as the delta ^{18}O ($\delta^{18}O$). Rainwater around the world falls along a Meteoric Water Line (MWL). The MWL has a consistent ratio of δ^2H to $\delta^{18}O$ across oceans, coasts, plains, and mountains forming a line with a slope of 8. In Minnesota the seasonal average of precipitation is about $\delta^{18}O = -9$ in per mil (‰) and $\delta^2H = -65$ (‰). As water evaporates from a lake the lighter ^1H and ^{16}O atoms are slighter more favored to evaporate. This leaves the remaining lake water slightly enriched in the heavier ^2H and ^{18}O isotopes. The mixture of isotopically heavy water from lakes and lighter meteoric precipitation waters fall along a line with a slope of 5 in Figure 3.17. Wells and springs across the study show the influence of lakes on groundwater recharge. This isotopic data confirms the source of high Mg:Ca waters discussed above.

This lake water recharge is also evident in the barium (Ba) content of the groundwater. As with Ca, Mg, and Sr, Ba is more abundant in Des Moines Lobe than Superior Lobe sediments. However, as water leaves a lake, moving into a groundwater system, sulfate (SO_4) in the lake sediments systematically captures the Ba. Lake water recharge is therefore evident as both isotopically heavy and Ba depleted.

Figure 3.17. δ^{18}O Plot of Washington County Samples.



3.6.4. Sampling Methodology

Chemistry samples were collected after a purging period in which temperature, conductivity, and pH were monitored. Once these parameters stabilized, samples were collected from a flow-through cell. Alkalinity samples were collected in five-hundred milliliter plastic bottles after the bottles were rinsed three times with stabilized sample water. The bottles were filled with no air bubbles in order to prevent degassing. Cation samples were collected in fifteen-milliliter polypropylene bottles after being rinsed three times with stabilized sample water. Bottles were filled to the neck and one drop of 6N reagent grade hydrochloric acid was added to preserve the sample. Anion samples were collected to the neck of a fifteen-milliliter (ml) amber high-density polyethylene (HDPE) bottle after being rinsed three times with stabilized sample water. All samples were packed on ice for transport and storage.

The sample water necessary for stable isotope analysis was extracted from the cation and anion samples in the laboratory. Tritium samples were collected in pre-cleaned one-liter HDPE bottles. Tritium samples bottles were not rinsed on site to avoid atmospheric contamination. These samples need no refrigeration or preservation. Strontium samples were collected in 125 ml HDPE bottles that had been cleaned with ultra-pure, de-ionized water. The samples were preserved with 12 drops of 14N trace metal grade HNO3 acid.

Safety standards and protocol were established for all testing and collection that was conducted at the sites.

3.6.5. Results

3.6.5.1. Groundwater Chemistry Results

Waters sampled from the Franconia aquifer contained either no detectable tritium (<0.8 TU) or levels consistent with the peak of atmospheric testing (>30 TU). These samples therefore represent a time machine documenting the groundwater quality prior to increased usage of agricultural fertilizers and pesticides, and the more recent increased density of housing and associated wastewater systems. In the Franconia aquifer, human impacts are minimal due to the age of the water. In this setting we see one group with a range of Sr, but Cl values below 5 ppm; indicating recharge from wetlands on both Superior Lobe and Des Moines Lobe materials. A second group has Cl levels ranging from 5 to 20 ppm indicative of recharge from upland environments on the Superior Lobe moraine.

Most of the Quaternary well water samples contain recent recharge, with tritium levels consistent with water entering the ground since the 1970s. These samples show the range of current human impacts on the groundwater system. To date these impacts are largely confined to low levels of Cl and nitrate-nitrogen (NO_3-N) from septic systems, small-scale animal feedlots, and road salt. Levels of NO_3-N vary across the study area, but have more frequent detections and higher levels in down-gradient areas towards the St. Croix River and in particular Grant and Stillwater Township. This study was focused on the current, high quality water of the study area. As a result, the only potential contaminants studied were Cl and NO_3-N. Routine testing for coliform bacteria, particularly for Quaternary wells in Stillwater Township, would be a good preventative measure. Due to the highly permeable outwash sands and gravels, combined with several deep buried bedrock valleys, the potential exists for contaminants to move quickly and deeply into the aquifer systems.

3.6.5.2. Surface Water Chemistry Results

Chemistry data were used to determine whether the composition of sampled lakes was principally derived from precipitation or groundwater. The molar sum of Ca and Mg (Ca/20 + Mg/12) divided by the Sr concentration in ppm was the principal indicator used to measure the presence of groundwater or precipitation. This value is an indicator of total dissolved carbonate normalized by the Sr concentration. The normalization corrects for Des Moines versus Superior Lobe sources of carbonate. If the value is less than 50, the primary lake composition is precipitation. When the value is greater than 50, groundwater is the principal lake component. In addition, Si was used as an additional indicator. A concentration greater than 4 ppm indicated the presence of groundwater; a concentration less than 4 ppm indicated the presence of precipitation.

The chemistry results from Big Marine, Goggins, Long (MWMO), Louise, Oneka, Pine Tree, South Twin, Sunset, White Bear, Clear (CLFLWD), and Forest Lakes had [Ca+Mg]/Sr ratios less than 50, indicating the lakes are composed principally of precipitation, not groundwater. The chemistry results from Mays, Square, Big Carnelian, Little Carnelian, and Sylvan Lakes had [Ca+Mg]/Sr ratios greater than 50, indicating these lakes have a higher proportion of groundwater, with less precipitation influence.

Quaternary aquifer wells in the general vicinity of Hardwood Creek have iron concentrations typical of wells throughout northern Washington County (0.5 to 1.5 ppm.) As groundwater flows toward the creek, it becomes increasingly oxygenated, and iron becomes less soluble. The deeper monitoring wells along Hardwood Creek show very low iron concentrations. As groundwater moves upward through the peat toward the creek, the decaying plant material in the peat removes oxygen from the water, creating a reduced condition. Iron becomes soluble under these conditions and is carried by groundwater toward the surface. At the surface, the iron is exposed to oxygen again and precipitates, indicated by red-stained soils around the springs on the banks of Hardwood Creek.

3.6.5.3. Spring Chemistry Results

The majority of the springs sampled along the bluffs of the St. Croix River discharge from Franconia and Jordan bedrock units. The springs are illustrated in Figure 3.14. In the area identified as the Upper St. Croix, springs have moderately high Cl and high Br concentrations indicating that water in the springs is recharged by precipitation falling in upland (as opposed to lake or wetland) areas to the west. The recharge migrates through the Superior lobe till before being discharged at the springs. Some human impacted waters were found, evident by Cl:Br ratios of about 1000:1. In Middle St. Croix, the majority of springs had slightly higher Mg:Ca ratios, indicating that recharge of the water could be coming from a nearby lake or lakes, possibly in the area of Big Marine, Square, or the Carnelian Lakes, depending on spring location. In two springs, low Mg concentrations and a moderate Mg:Ca ratio indicate that recharge is from more upland (as opposed to lake or wetland) areas. Two other springs appear to be a mixture of groundwater recharged in upland and lake areas. The Mg concentrations are relatively high and the Mg:Ca ratio is relatively high, indicating probable recharge from a lake. Cl concentrations range from relatively high to low, indicating some human impacts. In the Lower St. Croix, springs had high Mg concentrations and high Mg:Ca ratio suggesting that the springs are recharged by lake water. A complete discussion of characteristics of the springs and spring creeks can be found in the final report of the St. Croix Spring Creek Stewardship Plan, available from Emmons and Olivier Resources, Inc.

The springs sampled at Brown's Creek discharge from the Jordan Sandstone bedrock unit. The water had high enriched tritium levels and low Mg:Ca ratio, indicating relatively recent recharge. Chemistry of adjacent South Twin Lake had similar chemical characteristics, indicating a hydrologic connection between the lake and the springs. This connection could be due in part to a till hole located to the southeast of the lake. Till holes can act as a conduit, in this case, from the lake to creek. This chemical data, in addition to the geographic setting, indicate recharge is occurring locally.

3.7. Natural Resources

3.7.1. Background

Data on the natural resources of the study area were compiled from existing Natural Resource Inventories, Minnesota Land Cover Classification System, and the Minnesota County Biological Survey. Where both Natural Resource Inventories and Minnesota Land Cover Classification Systems are completed, the result is a comprehensive coverage of the area with more detailed information available for the natural communities.

3.7.1.1. Natural Resource Inventory

A Natural Resource Inventory (NRI) uses a comprehensive "landscape" based approach where the physical and biological features of the landscape and their relationships are determined. Natural communities are determined from NRIs and are assemblages of plants and animals, and include the physical conditions such as soils, slope, aspect and climate upon which plants and animals occur. Forest, woodland, wetland and prairie communities are evaluated. Areas that have been significantly altered by human disturbance are not evaluated.

3.7.1.2. Minnesota Land Cover Classification System

The Minnesota Land Cover Classification System (MLCCS) categorizes natural areas as well as urban and rural areas. Urban and built-up areas are categorized in terms of land cover rather than land use. MLCCS distinguishes between different types and amounts of land cover, vegetation and impervious surfaces. There are five levels of MLCCS with Level 5 being at the greatest level of detail.

3.7.1.3. Minnesota County Biological Survey

As part of the MN DNR Ecological Services, the Minnesota County Biological Survey (MCBS) is a systematic survey of rare biological features. The goal of MCSB is to identify significant natural areas and to collect and interpret information on the distribution and ecology of rare plant species, animals, and native plant habitats. Products of this program result in a map for each county assessing the status and distribution of the state's flora, fauna, and native plant communities.

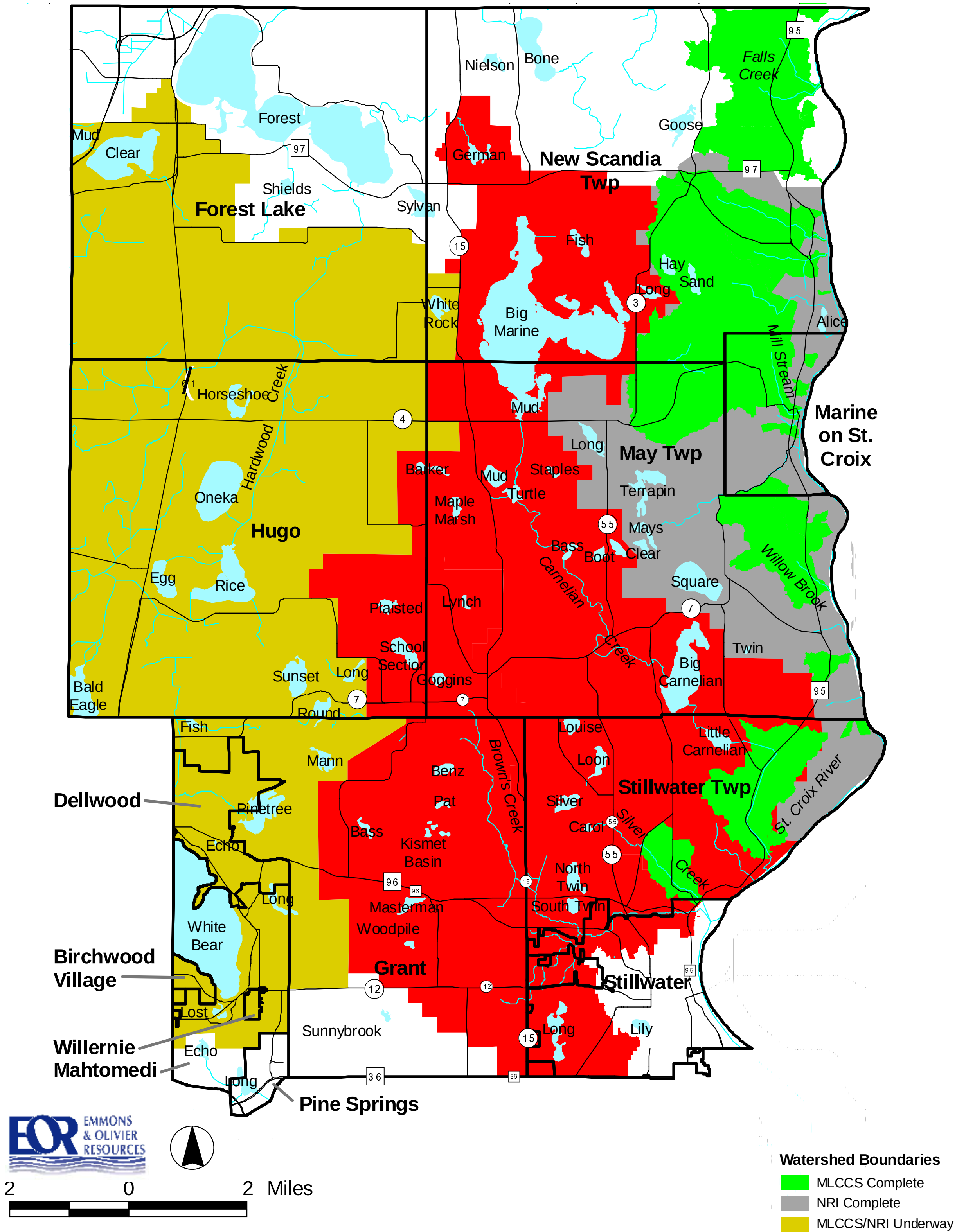
3.7.2. Results

A summary of the data used in this Study are included in Table 3.3 and are illustrated on Figure 3.18.

Table 3.3. Natural Resources Data.

Watershed	NRI		MLCCS (Level 4 or 5)	
	Availability	Completed	Availability	Completed
Brown’s Creek WD	Y	1998	Y	1998
Carnelian-Marine WD	Y	2003	Y	2003
Forest Lake-Comfort Lake WD	N	-	N	-
Marine WMO (Entire watershed)	Y	2000	-	-
Marine WMO (Spring Creek Subwatersheds)	-	-	Y	2000
Middle St. Croix WMO	N	-	N	-
Orphan Area (Spring Creek subwatersheds)	N	-	Y	2003
Rice Creek WD	IP	2004	IP	2004
Valley Branch WD	N	-	N	-

Figure 3.18. Status of Natural Resources Data Collection.



Sources: 2002; RCWD, BCWD, MWMO, CMWD, MetroGIS, DNR, Washington County
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Significant natural areas were identified in each of the inventories. A summary of these natural resources for each watershed district follows.

3.7.2.1. Brown's Creek Watershed District

Key natural areas identified in the BCWD include:

- Some of the natural communities occurring in hummocky, steep terrain at the north end of BCWD, are areas of groundwater discharge supporting Brown's Creek
- A unique seepage fen is located near the western edge of the watershed. Several rare plant species have been identified in the fen.
- Brown's Creek is a DNR protected naturally producing trout stream which flows from the upland portions of the watershed southeast to the St. Croix River. The *lower gorge* is the portion of Brown's Creek running from just below the Oak Glen Golf Course to the St. Croix River. The lower gorge is characterized by steep side slopes cutting into the Franconia formation which contributes large volumes of groundwater to the baseflow of the creek. The significance of the lower gorge is that it provides the habitat for trout in Brown's Creek.
- There are high quality mesic oak forests and maple–basswood forests within the lower Brown's Creek ravine. There is also a dry oak forest along the top of the ravine to the north.
- The most significant lake resources include the large complex of Plaisted, North and South School Section and Goggins Lakes as well as Lynch and Benz Lake. In the Headwaters area there are many large open water wetlands and several small isolated pockets of open water wetlands.
- Several expanses of oak forest occur throughout the watershed. The largest dry oak forest is found northwest of Plaisted Lake.

3.7.2.2. Carnelian-Marine Watershed District

Key natural areas in the CMWD include:

- The German Lake Subwatershed in the very north section of CMWD; containing exceptional oak forest, a pristine tamarack bog, and German Lake itself which is partially covered by a unique floating bog community.
- Big Marine Park Reserve contains a highly diverse assemblage of the largest and highest quality wetland complexes in CMWD. Much of this area has been mapped by MCBS; especially the large, high quality, groundwater dependent wetland systems.
- Big Marine Lake itself is an exceptionally high quality water resource, as are the unique, high quality wetlands hydrologically connected to it such as wet prairies (seepage subtype), tamarack seepage swamps, hardwood seepage swamps, and rich fens.
- The western portion of Warner Nature Center, on the eastern edge of CMWD, contains the highest quality poor fen in the watershed district, surrounded by a pristine and expansive oak forest.
- Little Carnelian Lake has very high water quality and remains well protected by natural communities surrounding much of the entire shoreline, with native prairie remnants.
- A very unique slot canyon runs along a ravine to the St. Croix River at the Historic Boom Site Landing. The St. Croix River itself contains many rare features including floodplain forest;

and many threatened and endangered plants and animals. There is also a moist cliff site within CMWD containing several endangered bryophytes not found anywhere else in Minnesota.

- Many shallow, high quality lake systems occur along the Silver Creek Watercourse starting at Silver Lake; including Carol Lake, North Twin Lake, and South Twin Lake.
- Lower Silver Creek contains many rare features; including maple-basswood forest, mesic oak forest, seepage meadow and dry sand-gravel prairie. Many rare plants and animals are documented along Fairy Falls Ravine Wall and along the St. Croix River. Fairy Falls, a 50-foot waterfall along Silver Creek, is a very unique feature, that includes dry and moist cliff along its walls.

3.7.2.3. Rice Creek Watershed District

Significant natural areas identified in the RCWD include:

- The entire Hardwood Creek Corridor contains a high diversity and extensive assemblage of extremely high quality, groundwater dependent wetlands including hardwood seepage swamps, tamarack seepage swamps, rich fens, shrub swamps, and wet prairie seepage subtypes.
- Corrie's Swamp (Hardwood Creek WMA) contains an extensive tamarack swamp considered to be of the highest quality and largest area extent this far south in Minnesota.
- Rice Lake contains a floating mat of vegetation around its entire edge dominated by narrow-leaved cattail, but also includes a rich array of other native species, including Carex lasiocarpa (wire or wool grass sedge).
- Several expanses of high quality oak forest occur throughout the eastern half of RCWD.

3.7.2.4. Marine-on-St. Croix Watershed Management Organization and Orphan Area (Spring Creek subwatershed)

Key natural areas identified within the MWMO include:

- Long strips of very high quality maple-basswood forests and floodplain forests along the St. Croix River Corridor, some areas with cliff ridges and spring creeks with trout populations. Also, areas along the St. Croix River include seepage swamps, river beach communities, and some remnant mixed white pine-hardwood forests.
- Also within the St. Croix River Corridor is a mosaic of high quality natural areas of extremely high scenic value, including “Greenburg Island”, a significant strandline beach/floodplain forest community, and a unique spring creek flowing out of a black ash seepage swamp and over a rock outcrop.
- The area around the Science Museum of MN St. Croix Field Station contains 11 documented rare features within seven high quality communities, including a rich complex of seepage swamps and fens, lowland hardwood forest, and older visible conifer plantations. This area also provides high quality wildlife habitat along the St. Croix River Corridor.
- Includes Square Lake which is the clearest lake in the Twin Cities Metro area. The area around Long Lake, which has excellent water quality, fish, and wildlife habitat, includes

eleven high quality natural communities including mesic oak and northern hardwood forests, tamarack swamp, wet meadow wetlands, unique ericaceous bog, and other open water.

- The area surrounding Sand and Hay Lakes contain a tamarack swamp between the lakes with a section of ericaceous vegetation including leatherleaf, cranberries, and blueberries that are not generally found in this area.
- Expansive and high quality dry oak forests, mesic oak forests, and maple basswood communities exist on steeply rolling terrain throughout CMWD.
- Unique patches of native prairie exist scattered throughout the landscape, some retaining much of their native plant diversity.

4. Groundwater Resource Assessment and Classification

Surface water resources in northern Washington County are influenced by regional groundwater flow, locally perched groundwater, precipitation, topography, and soils. Many of the water bodies within the study area are of very high quality, providing excellent recreation opportunities and habitat for rare or endangered species. Identifying each water body's dependence on groundwater resources is critical to managing the surface watersheds and groundwatersheds in order to protect these resources.

4.1. Lakes

4.1.1. Background

Forty-seven lakes in the study area were analyzed to determine their relationship to groundwater. Figure 4.1 identifies the water bodies included in this analysis and their assigned function.

In this study, groundwater function is defined as the character of interactions between the lake and the surrounding groundwater. The degree (flux) of groundwater interaction was characterized as high or low connection. Lakes were then classified as groundwater recharge (lake loses water), groundwater discharge (lake gains water), or flow-through (both recharge and discharge occur in different areas). Combinations of these characteristics results in six possible groundwater function classifications:

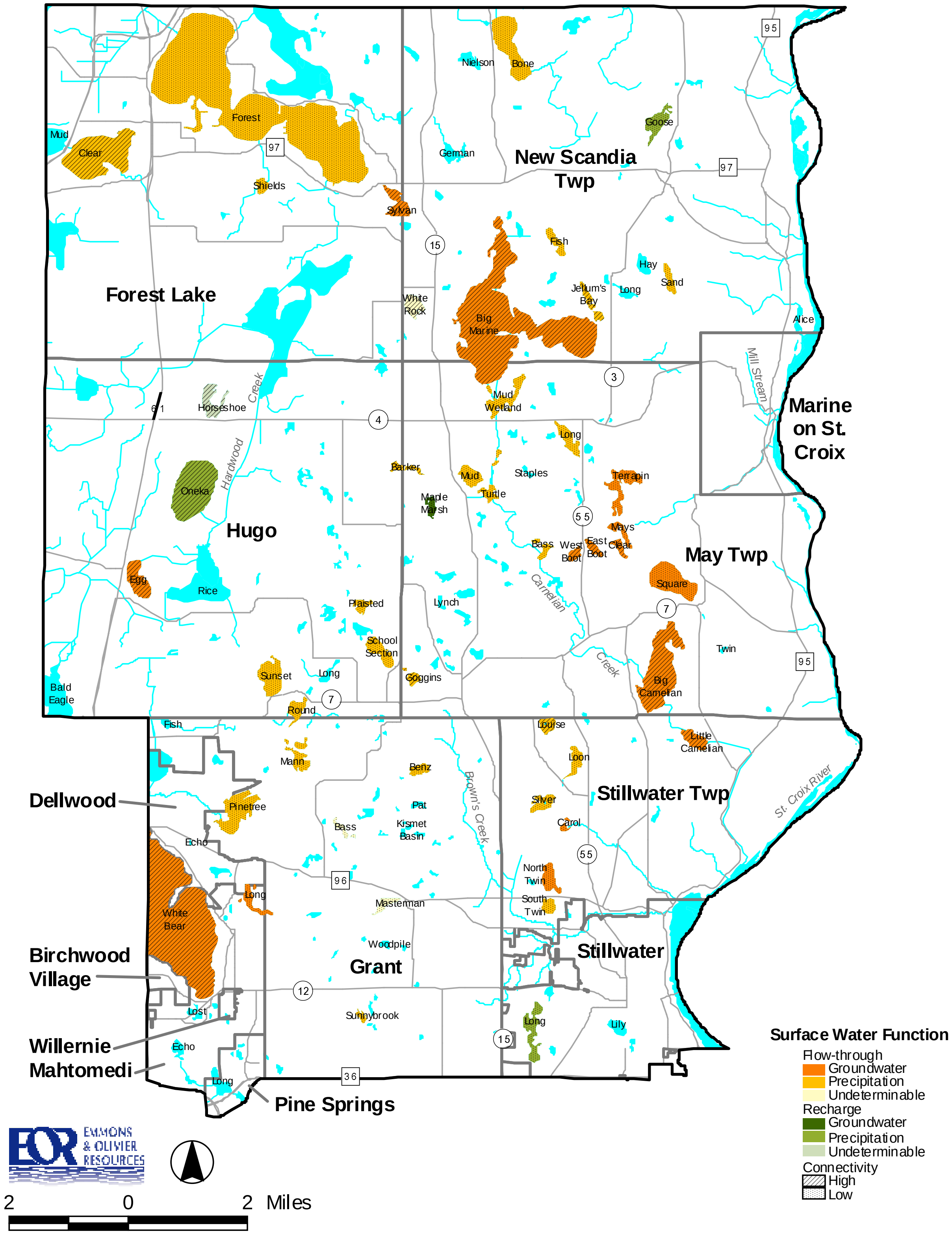
- High recharge;
- Low recharge;
- High discharge;
- Low discharge;
- High flow-through; and
- Low flow-through.

Figure 4.2 shows schematic representations of the different groundwater functions. Each lake was then further classified as precipitation or groundwater driven, resulting in twelve possible scenarios. This classification further refines the character of the source water within the water body.

The groundwater function of each lake was determined based on the following criteria:

1. Correlation to groundwater level fluctuations;
2. Correlation to precipitation trends;
3. Surficial geology based on geomorphic region.
4. Results of in-lake chemistry analysis;
5. Watershed area to water surface area ratio;
6. Water quality based on Trophic State Index;
7. Comparison to nearby groundwater levels;
8. Direct measurement of groundwater inflows and outflows; and
9. Surface water inflow and outflow.

Figure 4.1. Water Bodies and Function Analysis



Sources: 2002; MetroGIS, DNR, Washington County
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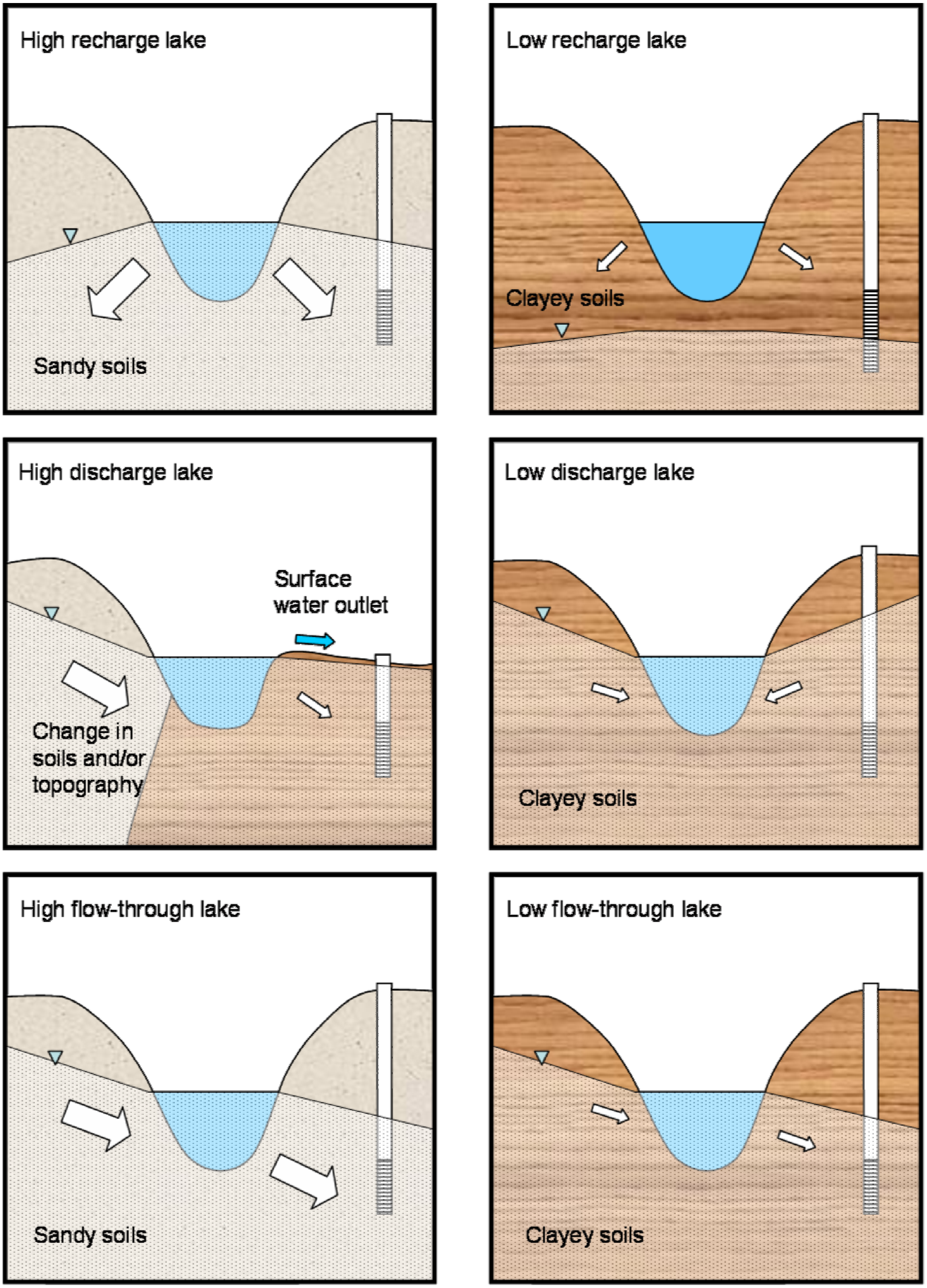
Figure 4.2. Schematic Representation of Lake Classifications.



These criteria were broken down into three separate subgroups that were used to determine the lake's connectivity, source water, and interaction with groundwater. Table 4.1 shows how each of these criteria relate to the groundwater function of the lake.

Table 4.2 summarizes the criteria for each lake. Raw hydrologic data can be found in electronic format on the supplemental report CD.

The following sections describe how data were analyzed to determine the groundwater function. The data were compared to the criteria in Table 4.1, and the lake was assigned the groundwater function that best matched the data. In general, the lake classification corresponds to the majority of indicators within the subgroup. Some data were given greater weight than others including direct measurements, results of chemical analysis, and correlation to groundwater levels. These weights are indicated on Table 4.1.

4.1.2. Correlation to Groundwater Level Fluctuations

The correlation of lake water levels to groundwater level fluctuations is another indicator of the degree of groundwater interaction. Lakes that experienced similar elevation fluctuations as groundwater are considered hydraulically connected to groundwater and have a high degree of groundwater interaction.

Lake elevations recorded over time were plotted against groundwater elevations recorded over time in nearby observation wells. Lakes with a correlation coefficient greater than 0.6 were classified as having high groundwater connectivity and those with a correlation coefficient less than 0.6 were classified as having low groundwater connectivity.

4.1.3. Correlation to Precipitation Trends

The correlation of lake water levels to precipitation trends is an indicator of the degree of groundwater interaction. Water levels in all lakes respond to precipitation trends. Groundwater levels also respond to precipitation, but the response is much more delayed and muted by long-term precipitation trends. Lake levels that respond to long-term trends are more connected to the groundwater system, while lake levels that respond to precipitation patters are less connected with the groundwater system.

Lake water levels were compared to the running average of monthly precipitation totals for the preceding 1-year, 2-year, 5-year, and 10-year time period. A correlation coefficient was calculated between the recorded lake elevation and the running average of the total monthly precipitation. Data sources and techniques are described in Chapter 2 of this study. Precipitation records from the nearest National Weather Service rain gauge (Forest Lake or Stillwater) to the lake were used for the correlation.

Table 4.1. Lake Data and Groundwater Function.

Groundwater Function	Connectivity			Source Water			Interaction		
	High ---------------Weight---------------Low			High ---------------Weight---------------Low			High ---------------Weight---------------Low		
	Correlation to groundwater fluctuations	Correlation to precipitation trends	Typical surficial geology	In-lake Chemistry Analysis	Watershed to surface water ratio	Water quality	Comparison of lake to groundwater elevation	Groundwater direct measurement	Surface water inflow and outflow
High Connection Precipitation Driven Recharge	$r^2 > 0.6$	Correlates better to 5 and 10 year trend	Sandy	Precipitation	>10:1	TSI >50	High	Outflow from lake > inflow to lake	Inflow > outflow
High Connection Groundwater Driven Recharge	$r^2 > 0.6$	Correlates better to 5 and 10 year trend	Sandy	Groundwater	<5:1	TSI <50	High	Outflow from lake > inflow to lake	Inflow > outflow
Low Connection Precipitation Driven Recharge	$r^2 < 0.6$	Correlates better to 1 and 2 year trend	Clayey	Precipitation	>10:1	TSI >50	High	Outflow from lake > inflow to lake	Inflow > outflow
Low Connection Groundwater Driven Recharge	$r^2 < 0.6$	Correlates better to 1 and 2 year trend	Clayey	Groundwater	<5:1	TSI <50	High	Outflow from lake > inflow to lake	Inflow > outflow
High Connection Precipitation Driven Discharge	$r^2 > 0.6$	Correlates better to 5 and 10 year trend	Sandy	Precipitation	>10:1	TSI >50	Low	Inflow to lake > outflow from lake	Outflow > inflow
High Connection Groundwater Driven Discharge	$r^2 > 0.6$	Correlates better to 5 and 10 year trend	Sandy	Groundwater	<5:1	TSI <50	Low	Inflow to lake > outflow from lake	Outflow > inflow
Low Connection Precipitation Driven Discharge	$r^2 < 0.6$	Correlates better to 1 and 2 year trend	Clayey	Precipitation	>10:1	TSI >50	Low	Inflow to lake > outflow from lake	Outflow > inflow
Low Connection Groundwater Driven Discharge	$r^2 < 0.6$	Correlates better to 1 and 2 year trend	Clayey	Groundwater	<5:1	TSI <50	Low	Inflow to lake > outflow from lake	Outflow > inflow
High Connection Precipitation Driven Flow-Through	$r^2 > 0.6$	Correlates better to 5 and 10 year trend	Sandy	Precipitation	>10:1	TSI >50	Middle	Inflow >= Outflow	Outflow >= Inflow
High Connection Groundwater Driven Flow-Through	$r^2 > 0.6$	Correlates better to 5 and 10 year trend	Sandy	Groundwater	<5:1	TSI <50	Middle	Inflow >= Outflow	Outflow >= Inflow
Low Connection Precipitation Driven Flow-Through	$r^2 < 0.6$	Correlates better to 1 and 2 year trend	Clayey	Precipitation	>10:1	TSI >50	Middle	Inflow >= Outflow	Outflow >= Inflow
Low Connection Groundwater Driven Flow-Through	$r^2 < 0.6$	Correlates better to 1 and 2 year trend	Clayey	Groundwater	<5:1	TSI <50	Middle	Inflow >= Outflow	Outflow >= Inflow

Table 4.2. Lake Data and Groundwater Function.

* Data not available to determine the source water
O-Outflow, I-Inflow
FT – Flow through; Rech - Recharge

Lake name	Groundwater Function	Connectivity			Source Water			Interaction		
		High ---------------Weight---------------Low			High ---------------Weight---------------Low			High ---------------Weight---------------Low		
		Correlation to groundwater fluctuations	Correlation to precipitation trends	Typical surficial geology	In-lake Chemistry Analysis	Watershed to surface water ratio	Water quality	Comparison of lake to groundwater elevation	Groundwater direct measurement	Surface water inflow and outflow
Barker	High Precip FT	>0.60	No correlation	Clayey		>10:1	>50	Middle		I>O
Bass (CMWD)	Low Precip FT	<0.60	No correlation	Sandy		>10:1	>50	Middle		
Bass (BCWD)	Low FT*	>0.60	5 or 10 year	Sandy		Mid-range	No data	Middle	inconclusive	
Benz	Low Precip FT	<0.60	1 or 2 year	Sandy		Mid-range	>50	Middle	O>=I	
Big Marine	High Gwtr FT	>0.60	No correlation	Sandy	Precipitation	<5:1	<50	Middle	O>=I	
Bone	Low Precip FT	<0.60	No correlation	Clayey		>10:1	>50	Middle		
Boot Lakes	High Gwtr FT	>0.60	5 or 10 year	Sandy		<5:1	<50	Middle		
Carnelian Big	High Gwtr FT	>0.60	5 or 10 year	Sandy	Groundwater	Mid-range	<50	Middle	O>=I	O>I
Carnelian Little	High Gwtr FT	>0.60	5 or 10 year	Sandy	Groundwater	Mid-range	<50	Middle	O>=I	I>O
Carol	Low Gwtr FT	<0.60	No correlation	Sandy		Mid-range	<50	Middle		O>I
Clear (CLFLWD)	High Precip FT	>0.60	1 or 2 year	Clayey	Precipitation	Mid-range	>50	Middle		
Clear (MWMO)	High Gwtr FT	>0.60	1 or 2 year	Sandy		<5:1	<50	Middle		I>O
Egg	High Gwtr FT	<0.60	5 or 10 year	Sandy		<5:1	>50	Middle		
Fish	Low Precip FT	<0.60	1 or 2 year	Clayey		>10:1	>50	Middle		
Forest	Low Precip FT	<0.60	No correlation	Clayey	Precipitation	<5:1	>50	Middle		
Goggins	High Precip FT	>0.60	5 or 10 year	Sandy	Precipitation	>10:1	>50	Middle		I>O
Goose	Low Precip Rech	<0.60	1 or 2 year	Clayey		Mid-range	>50	High		
Horseshoe	Low Rech*	<0.60	1 or 2 year	Sandy		Mid-range	No data	High		I>O
Jellum's Bay	High Precip FT	>0.60	1 or 2 year	Clayey		Mid-range	>50	Middle	O>=I	O>=I
Long (BCWD)	Low Precip Rech	<0.60	No correlation	Clayey		>10:1	>50	High		
Long (MWMO)	Low Precip FT	<0.60	No correlation	Clayey	Precipitation	>10:1	>50	Middle		O>I
Long (RCWD)	Low Gwtr FT	<0.60	No correlation	Sandy		Mid-range	<50	Middle	inconclusive	
Loon	Low Precip FT	<0.60	No correlation	Clayey		>10:1	>50	Middle		
Louise	High Precip FT	>0.60	5 or 10 year	Sandy	Precipitation	>10:1	>50	Middle	inconclusive	I>O
Mann	Low Precip FT	<0.60	1 or 2 year	Clayey		>10:1	No data	Middle		
Maple Marsh	Low Gwtr Rech	<0.60	1 or 2 year	Clayey		<5:1	>50	High	O>I	

Table 4.2. Lake Data and Groundwater Function.

*Data not available to determine the source water
O-Outflow, I-Inflow
FT – Flow through; Rech - Recharge

Lake name	Groundwater Function	Connectivity			Source Water			Interaction		
		High ---------------Weight---------------Low			High ---------------Weight---------------Low			High ---------------Weight---------------Low		
		Correlation to groundwater fluctuations	Correlation to precipitation trends	Typical surficial geology	In-lake Chemistry Analysis	Watershed to surface water ratio	Water quality	Comparison of lake to groundwater elevation	Groundwater direct measurement	Surface water inflow and outflow
Masterman	Low FT*	<0.60	1 or 2 year	Clayey		Mid-range	No data	Middle	O=I	
Mays	Low Gwtr FT	<0.60	No correlation	Sandy	Groundwater	Mid-range	>50	Middle		
Mud	Low Precip FT	<0.60	No correlation	Sandy		Mid-range	>50	Middle		
Oneka	High Precip Rech	>0.60	5 or 10 year	Sandy	Precipitation	<5:1	>50	High		I>O
Pine Tree	Low Precip FT	<0.60	No correlation	Sandy	Precipitation	>10:1	>50	Middle		
Plaisted	Low Precip FT	<0.60	5 or 10 year	Clayey		>10:1	No data	Middle		
Round	Low Precip FT	<0.60	No correlation	Clayey		>10:1	No data	Middle		
Sand	Low Precip FT	<0.60	1 or 2 year	Clayey		>10:1	>50	Middle		
School Section	Low Precip FT	<0.60	No correlation	Sandy		>10:1	>50	Middle		I>O
Shields	Low Precip FT	<0.60	No correlation	Clayey		>10:1	>50	Middle		
Silver	Low Precip FT	<0.60	1 or 2 year	Sandy		Mid-range	>50	Middle		I>O
Square	Low Gwtr FT	<0.60	No correlation	Sandy	Groundwater	<5:1	<50	Middle	O>=I	
Sunset	Low Precip FT	<0.60	No correlation	Sandy	Precipitation	<5:1	>50	Middle	inconclusive	
Sunnybrook	Low Precip FT	<0.60	No correlation	Clayey		>10:1	<50	Middle		I>O
Sylvan	High Gwtr FT	>0.60	No correlation	Sandy	Groundwater	<5:1	<50	Middle		I>O
Terrapin	Low Gwtr FT	<0.60	No correlation	Sandy	Groundwater	Mid-range	>50	Middle		
Turtle	Low Precip FT	<0.60	No correlation	Sandy		>10:1	>50	Middle	O>I	
Twin North	Low Gwtr FT	<0.60	1 or 2 year	Clayey		<5:1	>50	Middle		
Twin South	Low Precip FT	<0.60	1 or 2 year	Clayey	Precipitation	<5:1	>50	Middle		
White Bear	High Gwtr FT	>0.60	No correlation	Variable	Precipitation	<5:1	<50	Middle		
White Rock	High FT*	>0.60	No correlation	Sandy		Mid-range	No data	Middle		I>O

Lakes that correlated better to 1-year and 2-year trends are classified as having a low degree of groundwater connection. Lakes that correlated better to 5-year and 10-year trends are classified as having a high degree of groundwater connection. In some lakes, no clear differences, trends, or correlations were observed. Lakes levels were also compared to 1-month precipitation trends, but none of the lakes showed good correlation.

4.1.4. Surficial Geology Based on Geomorphic Region

Surficial geology can be used as an indicator of the degree of surface water/groundwater interaction. In general, sandy soils indicate a higher connection to groundwater; clayey soils indicate a lower connection to groundwater. A description of the geology and soils of the study area is found in Chapter 2. Lakes located in sandy materials, such as outwash and terrace deposits, were classified as having a high connection to groundwater. Lakes located within clayey materials, including moraine deposits, were classified as having a low connection to groundwater.

4.1.5. Chemistry

In-lake chemistry data were available for sixteen of the classified lakes. The data were used to determine if groundwater or precipitation was the primary source of water in the lake. Various factors were analyzed, based on lake location and composition of surrounding geological materials. The molar sum of Ca and Mg (Ca/20 + Mg/12) divided by the Sr concentration in ppm was the principal indicator used to measure the presence of groundwater or precipitation. A value greater than 50 was used as an indicator that the majority of water in the lake was derived from groundwater sources. A value less than 50 indicated precipitation as the primary source. In addition, Si was used as an additional indicator. A concentration greater than 4 ppm indicated the presence of groundwater; a concentration less than 4 ppm indicated the presence of precipitation. Typically, data consisted of chemical results from one sampling event taken in the fall. As chemical composition can change seasonally and annually, additional data collection may be needed to verify results over time. Chapter 3 contains a detailed discussion on the chemical analysis and interpretation.

4.1.6. Watershed Area to Water Surface Area Ratio

The watershed area to water surface area ratio is used as an indicator of the lake’s degree of groundwater interaction. A higher ratio is an indication that a greater volume of surface runoff will reach the lake. Presumably, lakes with a lower ratio receive relatively more of their water from groundwater.

The area of the watershed and surface water body was measured using ArcView GIS techniques. Watershed areas were obtained from the Department of Natural Resources (DNR), BCWD, CMWD, RCWD, and available published reports for the CLFLWD and the VBWD. Surface water area was obtained using the aerial photographs of water levels from 1996 provided by the WCD.

A watershed area to lake surface area ratio greater than 10:1 is evidence of a low interaction groundwater interaction lake, while a ratio of less than 5:1 is evidence of a high groundwater interaction lake. Mid-range ratios between 5:1 and 10:1 do not strongly indicate either type of lake.

4.1.7. Water Quality

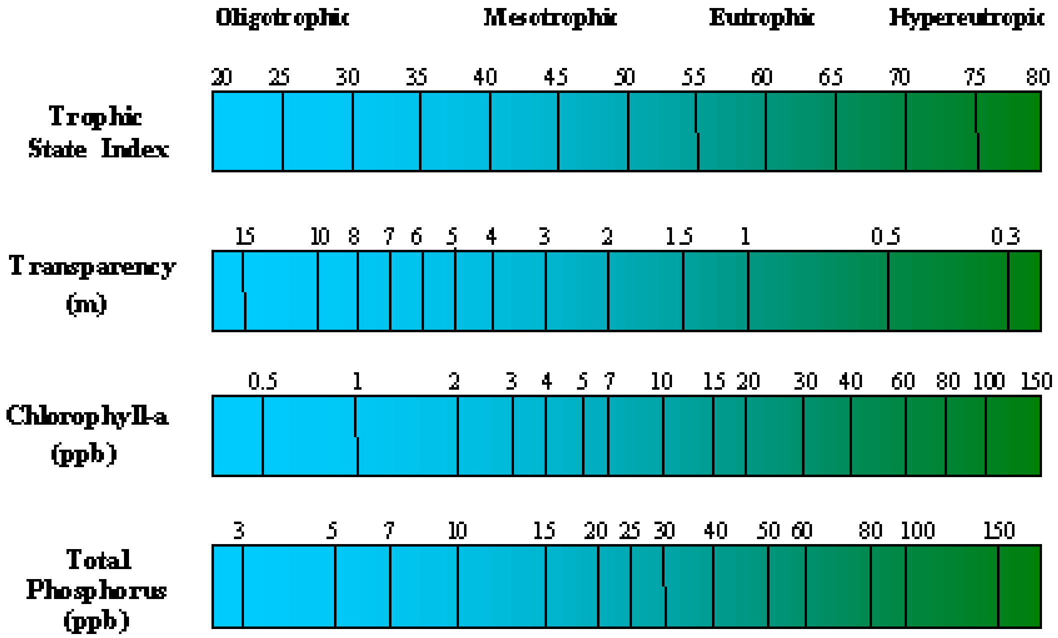
A lake's water quality is dependent on many factors, including groundwater interaction. While quality alone is not a completely reliable indicator of groundwater interaction, it does provide some indication when considered along with other criteria. The best available data for lakes in the study area are the Minnesota Pollution Control Agency (MPCA) Lake Water Quality Assessment Program database and the Metropolitan Council Environmental Services Citizen-Assisted Monitoring Program (CAMP) database. In addition, water quality data were obtained from watershed monitoring programs.

This assessment considered the Carlson Trophic State Index (TSI). The TSI of a lake is calculated based on total phosphorus, chlorophyll *a*, and secchi disk measurements, and is used to determine the trophic state of a lake. Trophic state classifications include (from best water quality to worst) oligotrophic, mesotrophic, eutrophic, and hypereutrophic. The relationship to trophic state and TSI are described by the MN Department of Natural Resources as:

> **TSI <30** Classic oligotrophy; clear water, oxygen through the year in the hypolimnion, salmonid fisheries possible in deep lakes.
>
> **TSI 30-40** Deeper lakes still exhibit classical oligotrophy, but some shallower lakes will become anoxic in the hypolimnion during the summer.
>
> **TS 40-50** Water moderately clear, but increasing probability of anoxia in hypolimnion during summer.
>
> **TS 50-60** Lower boundary of classical eutrophy: Decreased transparency, anoxic hypolimnion during the summer, macrophyte problems evident, warm-water fisheries only.
>
> **TSI 60-70** Dominance of blue-green algae, algal scums probable, extensive macrophyte problems.
>
> **TSI 70-80** Heavy algal blooms possible throughout the summer, dense macrophyte beds, but extent limited by light penetration. Often would be classified as hypereutrophic.
>
> **TSI > 80** Algal scums, summer fish kills, few macrophytes, dominance of rough fish.

Figure 4.3 illustrates the TSI and associated trophic states.

Figure 4.3. Trophic States.



After Moore, I. and K. Thornton, [Eds] 1988. Lake and Reservoir Restoration Guidance Manual. U.S. EPA, EPA 440/5-88-02.

Groundwater usually has low phosphorous concentrations relative to surface water. High phosphorous concentrations in lake water therefore are indicative of surface water runoff into the lake. It should be noted that in lakes with low phosphorous concentrations, a significant portion of the phosphorous (and other nutrients) load can come from groundwater (Alexander et. al, 2001).

The absence of cold water fisheries, a groundwater dependent resource, is characterized by a TSI value greater than 50. This value can be used to generally categorize lakes into high and low connection to groundwater. Lakes in the study area with an average TSI greater than 50 were classified as having a low connection to groundwater, lakes with a TSI less than 50 were classified as having a higher connection to groundwater.

4.1.8. Comparison to Groundwater Elevations

Lake elevations when compared to surrounding groundwater elevations is a strong indicator of the groundwater function. Lakes gain or lose water to the surrounding aquifers depending on the elevation of the lake water level relative to the groundwater level in the aquifers. The surrounding aquifers may have different groundwater elevations on different sides of the lake, resulting in aquifer recharge or aquifer discharge in different areas on the same lake (flow-through function.)

Elevation comparisons to one or two nearby wells is inadequate to determine the groundwater function because water levels in wells can vary depending on location (up-gradient or down-gradient), distance from the lake, well depth, aquifer materials, etc. Instead, the lake elevation was compared to a number of features including:

- Mapped groundwater elevation contours (based on water levels in several nearby wells);
- Elevation of other nearby surface water bodies;
- Regional topography; and
- Elevation of nearby groundwater discharge points such as springs or seeps.

Lakes with high elevations relative to these features were assigned a recharge function. Lakes with low elevations relative to these features were assigned a discharge function. Flow-through function lakes are higher than groundwater in some parts of the lake and lower than groundwater in other parts of the lake (described as “Middle” in Table 4.1).

4.1.9. Direct Measurement

Direct measurements of head differences within the littoral (shallow) zone of lakes can be used to quantify groundwater inflow and outflow within the lake. Measurements were taken with the use of a mini-piezometer and half barrel permeameter. Four to twelve measurements were taken at each water body, depending on size. Measurements were not taken near emergent vegetation where biological function locally alters surface and groundwater levels.

Measurements were taken at 10 lakes within the study area and included:

- Masterman (BCWD)
- Long (RCWD near White Bear Lake)
- Benz (BCWD)
- Bass (BCWD south of Hwy 12)
- Jellum’s Bay (CMWD near Big Marine)
- Louise (CMWD)
- Mann (RCWD)
- Maple Marsh (CMWD)
- Sunset (RCWD)
- Turtle (CMWD)

These lakes were chosen based on their lack of available data on which to base the function and connectivity with groundwater. In addition, data collected for the CMWD (Alexander et. al, 2001) were used in this analysis.

Differences in water levels within and below the lakes were used to determine the interaction of each lake. Higher water levels in the lake indicate flow of water into the groundwater system and a recharge function. Lower water levels in the lake indicate flow of water into the lake and a discharge function. Flow-through lakes were determined when there was a similar amount of inflow and outflow from the lake to the groundwater system.

The use of the mini piezometer has been well documented to be unreliable in fine-grained sediments. The stabilization period for fine-grained materials is considerably longer than for coarse-grained materials and was not cost effective for this study. Measurements taken in fine-grained sediments were not utilized in the final classification.

4.1.10. Surface Water Inflow and Outflow

Surface water inflow and outflow can be an indicator of groundwater interaction in a lake. A water balance approach is used to determine the function of the lakes. A recharge lake is identified when there is a large influx of surface water to a lake that has very little or no outflow. Discharge lakes are defined by having more surface water outflow than inflow. Flow-through lakes are defined as having approximately equal inflows and outflows. Stream inflow and outflow was monitored for several lakes as described in Chapter 3.

Table 4.1 describes the relationship between surface water inflow and outflow, and groundwater function. In the study area, stream inflow and outflow was not a quantitative indicator of groundwater function for most lakes, due to limited data. The complete water budget of most lakes was not known, so it was difficult to assess whether small or intermittent streams were significant or insignificant in the overall water budget.

4.2. Groundwater Dependent Resources

Groundwater dependent resources, or ecosystems, are defined by those natural resources that are dependent on sources of groundwater to maintain their structure, function, and diversity. The presence of these ecosystems in northern Washington County is a result of limited imperviousness and development, intact natural areas, minimal groundwater consumption for water supply, and the St. Croix River. The quality of these ecosystems is an indication of the impact that human activities are having on the environment. They serve as a barometer for the health of the environment and ecosystems.

Groundwater dependent ecosystems in northern Washington County include groundwater dependent lakes, cold water trout streams, spring creeks, and groundwater dependent plant communities and wetlands. Groundwater dependent lakes have been identified in Section 4.1 of this report and are not discussed here in any further detail. Data collected as part of natural resource inventories, Minnesota Land Cover Classification System (MLCCS) studies, and the Minnesota County Biological Survey database were used to identify the location of groundwater dependent streams, creeks, plant communities and wetlands. Figure 4.4 identifies the groundwater dependent ecosystems that have been mapped within the study area. Data are currently being collected and analyzed within the RCWD, and therefore additional information may become available at a later date for this area.

4.2.1. Streams and Creeks

Cold water trout streams and spring creeks are found throughout the eastern portion of northern Washington County. Specifically, Brown's Creek, Mill Stream, Falls Creek, Gilbertson Creek, Willow Brook, and three spring creeks studied as part of the St. Croix Spring Creek Stewardship Plan have been identified as containing and capable of maintaining a trout population. Trout are only found within surface waters that maintain constant temperatures and are well oxygenated and free of pollutants. Temperatures greater than 77 degrees Fahrenheit are believed to be lethal to adult brown trout (Moeckel, 1999). Groundwater fed streams and creeks, in addition to Square Lake, provide the entire trout habitat within northern Washington County.

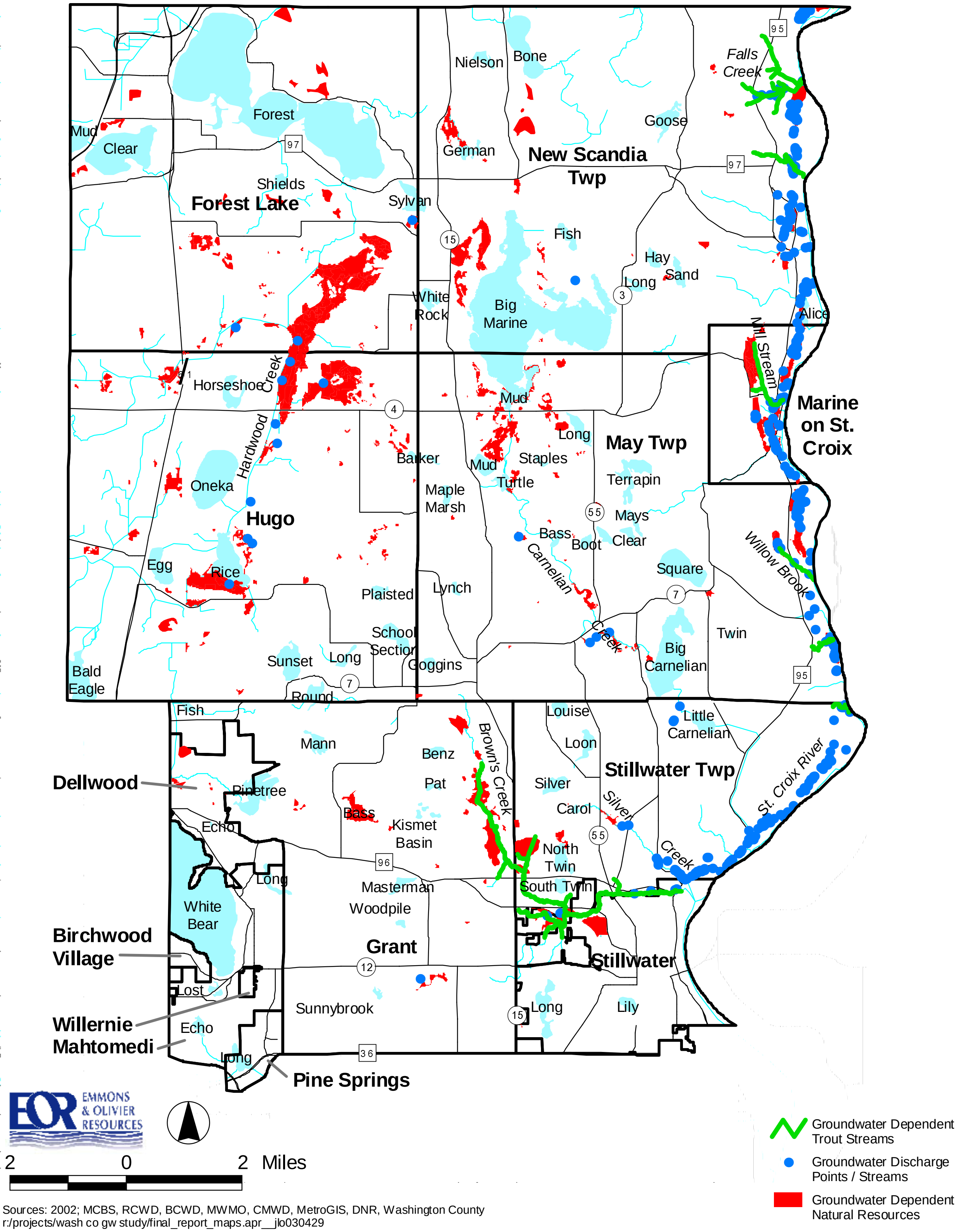
4.2.2. Springs

Springs, or groundwater discharge points, were identified throughout the study area using several methods. The MGS and the University of Minnesota identified forty springs as part of a groundwater interaction study in the CMWD. They also identified an additional thirty-six springs along the St. Croix in coordination with the St. Croix Spring Study. Spring locations were also obtained from natural resource inventories for the BCWD, RCWD, MWMO, and CMWD.

Thermal imagery identified additional groundwater discharge points along the St. Croix (EOR, 2002). The aerial photography was flown April 2002 when groundwater is warmer than surrounding surface water and snow. The groundwater signature is shown as a bright white spot on the thermal imagery. False signatures were also identified. Several points identified using thermal imagery matched points ground-truthed by the Spring Study, while several others were checked specifically to ensure accuracy.

Identified springs are concentrated along Hardwood Creek, Brown's Creek, Carnelian Creek, Silver Creek and the St. Croix River valley. It is difficult or impossible to generalize about the characteristics of the springs in the study area. Some receive their water from large, regional bedrock aquifers, while some receive water from local quaternary aquifers. Consequently, some have steady flow year-round, while others respond to changes in precipitation. Groundwater chemistry and surrounding ecosystems can also vary significantly.

Figure 4.4. Groundwater Dependent Resources



Sources: 2002; MCBS, RCWD, BCWD, MWMO, CMWD, MetroGIS, DNR, Washington County
r:/projects/wash co gw study/final_report_maps.apr__jlo030429

4.2.3. Plant Communities and Wetlands

Plant communities and wetlands associated with groundwater discharge are key natural resources within the study area. Field investigations (CMWD, 2003; BCWD, 2001; MWMO, 2000; RCWD, 2003) and GIS analysis support a groundwater discharge model (Novitski, 1979) for many of the wetlands in the study area. The biotic description of these wetlands fits the minerotrophic classification associated with groundwater infiltration wetlands (Moore et. al, 1974). Minerotrophic wetland communities including sedge meadow/rich fen wetland system and chara/potomogeton aquatic beds, develop from groundwater high in soluble calcium, magnesium, phosphorus, and other minerals that dissolve out of the rock type in the discharging region.

Groundwater dependent wetlands have the following characteristics:

- Dominant plant cover in bogs and fens and seepage swamps, the community development predominantly driven by the mineral-rich content of the groundwater;
- Locations at base of a slope (spring seep) and basins with only inflow from groundwater seepage;
- Water level lower than the water table immediately surrounding; and
- Minor seasonal fluctuation in hydroperiod.

Groundwater seepage to the surface environment provides highly specialized hydrologic conditions (i.e. low bounce, cooler temperatures, and circumneutral pH) that support numerous plant species and natural communities. Groundwater seepage areas in wetlands create favorable conditions for hardwood seepage swamps, fens, and wet meadows.

Groundwater dependent plant communities identified in this study include:

- White cedar swamp;
- Black spruce swamp;
- Mixed hardwood swamp;
- Tamarack swamp;
- Shrub swamp;
- Alder swamp;
- Wet prairie;
- Wet-brush prairie, seepage subtype;
- Black ash swamp;
- Rich fen;
- Poor fen;
- Calcareous seepage fen;
- Wet meadow;
- Seepage meadow;
- Talus slope; and
- Moist / maderate slope.

A detailed description of each groundwater dependent plant community is included in Appendix D.

There are four notable areas of concentrated groundwater dependent wetlands including along Hardwood Creek, Brown's Creek, Big Marine Lake, and the St. Croix River. The Hardwood Creek area, Big Marine Lake and Brown's Creek receive groundwater discharge along the edge of the St. Croix Moraine, and is mainly derived from upland recharge within surficial deposits. The wetlands along the St. Croix River valley are mainly derived from springs within bedrock aquifers and are often a result of lake and wetland recharge. Differences in these areas result in varying water chemistry, as described in Chapter 3, as well as unique and rare flora and fauna.

4.3. Infiltration and Recharge Potential

Understanding the ability of soils and underlying geology and aquifers to accept recharge from precipitation at the surface is important when identifying areas in need of aquifer protection. Infiltration potential and the locations of important recharge and discharge areas within the County have been investigated. The infiltration potential of soils is used to determine the ability of soils to accept and transmit recharge from precipitation. The locations of important recharge areas are not necessarily coincident with high infiltration potential areas because conditions under the infiltration zone are more critical to deeper water movement. These locations, however, are found to be important areas where recharge to groundwater systems is critical to maintaining groundwater dependent ecosystems.

4.3.1. Infiltration Potential

The methodology used to map the infiltration potential, or runoff characteristics, of the study area was based on work that had been completed for the RCWD and BCWD. The mapping consists of intersecting the soils and surficial geology data in a GIS based on infiltration characteristics. Figure 4.5 summarizes the infiltration potential for northern Washington County.

Spatial soils data and associated attribute tables were obtained from the DNR and the NRCS, respectively. These data are based on the Washington and Ramsey County Soil Survey (USDA SCS, 1977). Soil hydrologic groups were used to determine the soil's runoff characteristics. Soils were classified into four categories as follows:

1 – High infiltration potential (hydrologic soil group A)

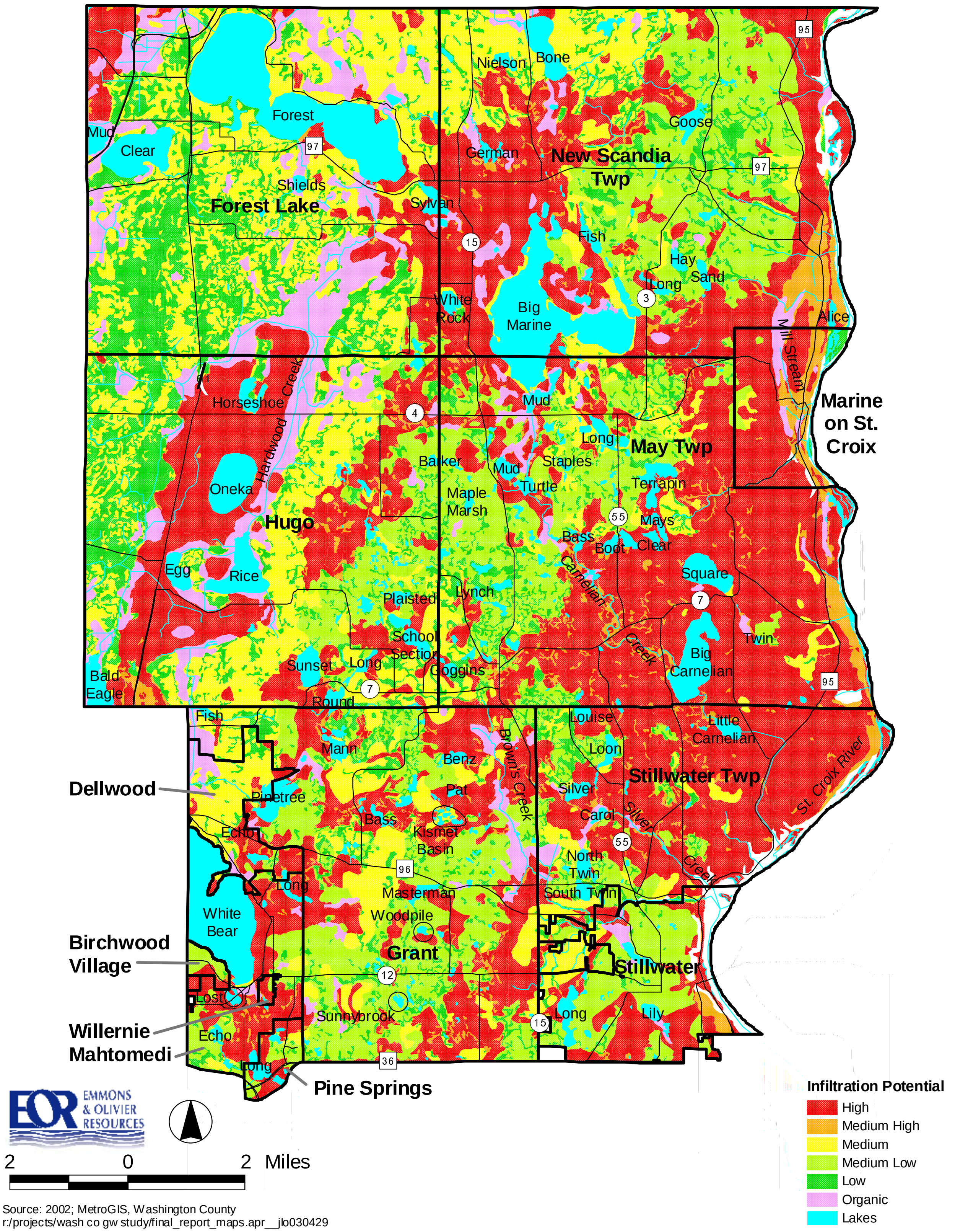
2 – Moderate infiltration potential (hydrologic soil group B and A/D)

3 – Low infiltration potential (hydrologic soil group C, D, B/D, C/D)

4 – Waterbodies

Soil types that did not have a soil hydrologic group including urban land categories, undorthents, undifluvents, rock outcrops, and pits were hand classified into the above categories based on descriptions found in the Soil Survey.

Figure 4.5. Infiltration Potential.



Source: 2002; MetroGIS, Washington County
r:/projects/wash co gw study/final_report_maps.apr__jlo030429

Digital surficial geology data were obtained from Washington County. The surficial geology was classified into seven groups as follow:

1 – Excellent Permeability (Gravel)
    - Outwash (Superior)
    - Outwash (Des Moines)
    - Terrace Deposits (Upper, Middle, and Lower)

2 – Good to Moderate Permeability (Sand)
    - Floodplain Alluvium (Sandy)
    - Lake Sand (Des Moines)
    - Ice Contact Deposits (Superior and Des Moines)

3 – Moderate to Poor Permeability (Silt)
    - Till (Des Moines)
    - Glacial Till, Sand, and Gravel (Superior)
    - Mixed Till (Des Moines)
    - Lacustrine Deposits
    - Lacustrine Sand and Silt (Superior)
    - Floodplain Alluvium (Loamy)

4 – Poor Permeability (Clay)
    - Till (Superior)

5 – Organic Material

6 – Waterbodies

7 – Bedrock Near Surface

The soils and surficial geology data are classified into infiltration potential categories based on the matrix in Table 4.3.

Table 4.3. Infiltration Potential.

Soils (1-4)	**Surficial Geology (1-7)**	**Infiltration Potential**
1,2	1,2	High
3	1,2	Moderate high
1,2	3	Moderate
1,2	4	Moderate Low
3	3,4	Low
1,2,3	5	Organics
1,2,3	6	Water
4	1,2,3,4,5,6,7	Water
1,2,3	7	Bedrock at surface

The depth to the water table was not included in the infiltration potential analysis. It should be noted that in areas where groundwater is found within the first few feet of soils, infiltration of stormwater runoff may not be suitable without extensive pretreatment to remove contaminants. Three feet has been designated by the MPCA as the desired depth of unsaturated material separating the water table from surface infiltration to allow for adequate water quality treatment.

4.3.2. Groundwater Recharge and Discharge

4.3.2.1 General Observations

Groundwater recharge and discharge patterns in Washington County are extremely complex. On a regional scale, recharge is prevalent along the relatively high areas of the St. Croix Moraine. Groundwater then flows downward to deeper aquifers and flows east and west from this groundwater divide toward discharge points along the St. Croix and Mississippi Rivers. However, local geologic and hydrologic conditions can significantly alter these general recharge and discharge patterns.

“Till holes” are areas within the Superior Lobe till where the clayey till is absent or very thin. These holes developed over buried bedrock valleys as well as from ice block melt-outs in the glacial moraine. The holes are filled with coarse sands and gravels. The till holes apparently play a role in both groundwater recharge and discharge. They serve as vertical conduits for groundwater to move up or down, depending on the direction of the vertical groundwater gradient. For example, an isolated till hole exists in the area of Tingley Springs near the northeast part of Hardwood Creek. This till hole could be serving as a conduit for upwelling groundwater, and thus determining the location of the springs. Till holes also exist along the east side of Little Carnelian Lake and Twin Lakes. Nearby springs show indications of surface water influence. The till holes could provide a conduit for movement of surface water downward and toward the springs. The significance of the till holes to groundwater recharge and discharge warrants further study.

Bedrock valleys also play a dual role in groundwater recharge and discharge. Glacial advances left large bedrock valleys that were filled with Superior and Des Moines Lobe sediments. Bedrock valleys bring Quaternary sediments in contact with deep bedrock units. This interaction can recharge these deeper units or can provide a pathway of discharge. The most significant valley extends northwest from the Stillwater area passing beneath Little Carnelian, Big Carnelian, and Square Lakes. This valley cuts deeply into the Franconia bedrock, passing entirely through the Jordan and Prairie du Chien Formations. The Franconia aquifer is recharged by the surface water bodies above the valley and then discharges along the St. Croix River.

It is not possible to display recharge areas and corresponding discharge areas on a single map or set of maps for the entire study area. To be accurate the map would need to illustrate the following information about groundwater flow:

- Three-dimensional movement – both horizontal and vertical through different aquifers
- Time-dependent variability, especially seasonal variations
- Probability of groundwater encountering geologic variability, dividing, and moving in different directions (i.e. dispersion).

The information contained in this report is very useful for analyzing specific problems and cases where groundwater recharge and discharge is important. To illustrate how this information can be used and how mapping recharge and discharge is difficult, consider the following example case.

> A domestic well is located in the north central part of the study area and is screened in the Prairie du Chien Formation. Chemistry analysis shows that the water is soft (low magnesium and calcium concentrations) and enriched in ^{18}O and ^{2}H, indicating the influence of surface water. Where is the recharge area for this well?
>
> We begin by observing that the well is located on the southern end of a till hole. The till hole likely provides a conduit for groundwater to migrate downward from the shallow surficial aquifers to the Prairie du Chien aquifer. Comparison of groundwater elevation contour maps indicates that groundwater elevations are higher in the Quaternary deposits than in the underlying bedrock aquifers, meaning that groundwater flow has a vertically downward flow component as well as a north to south horizontal component. We also observe that Big Marine Lake is a high flow-through lake located near the north end of the till hole, so it probably is responsible for the surface water influence. We then conclude that the recharge area for the well includes Big Marine Lake and the immediate area of the till hole.
>
> The difficulty in mapping the recharge area described above is that not all the water in Big Marine Lake is going to reach the well. Of the precipitation that falls in the Big Marine Lake watershed, some will infiltrate, some will runoff to the lake and reach the well, and some will runoff to the lake and discharge somewhere else. It would be impossible to determine and illustrate all the possible flowpaths and discharge points for groundwater in the area. Another nearby well or spring might be outside the influence of the till hole and have a very different, possibly overlapping recharge area.

4.3.2.2 Groundwater Recharge and Discharge Zones

The concept of recharge zones and discharge zones is useful for designating management zones, as described in Section 4.4. The recharge zones and discharge zones only identify areas where recharge or discharge is prevalent. It is important to remember that recharge and discharge occur in all the zones. Figure 4.6 shows the recharge and discharge zones for the study area.

Groundwater recharge zones have some or all of the following characteristics:

- Fewer groundwater dependent resources;
- Recharge lakes;
- Greater depth to the water table; and
- Higher groundwater elevations relative to discharge zones.

Groundwater discharge zones have some or all of the following characteristics:

- Multiple groundwater dependent resources;
- Discharge or flow-through lakes;

- Organic and mucky soils; and
- Water table close to the surface.

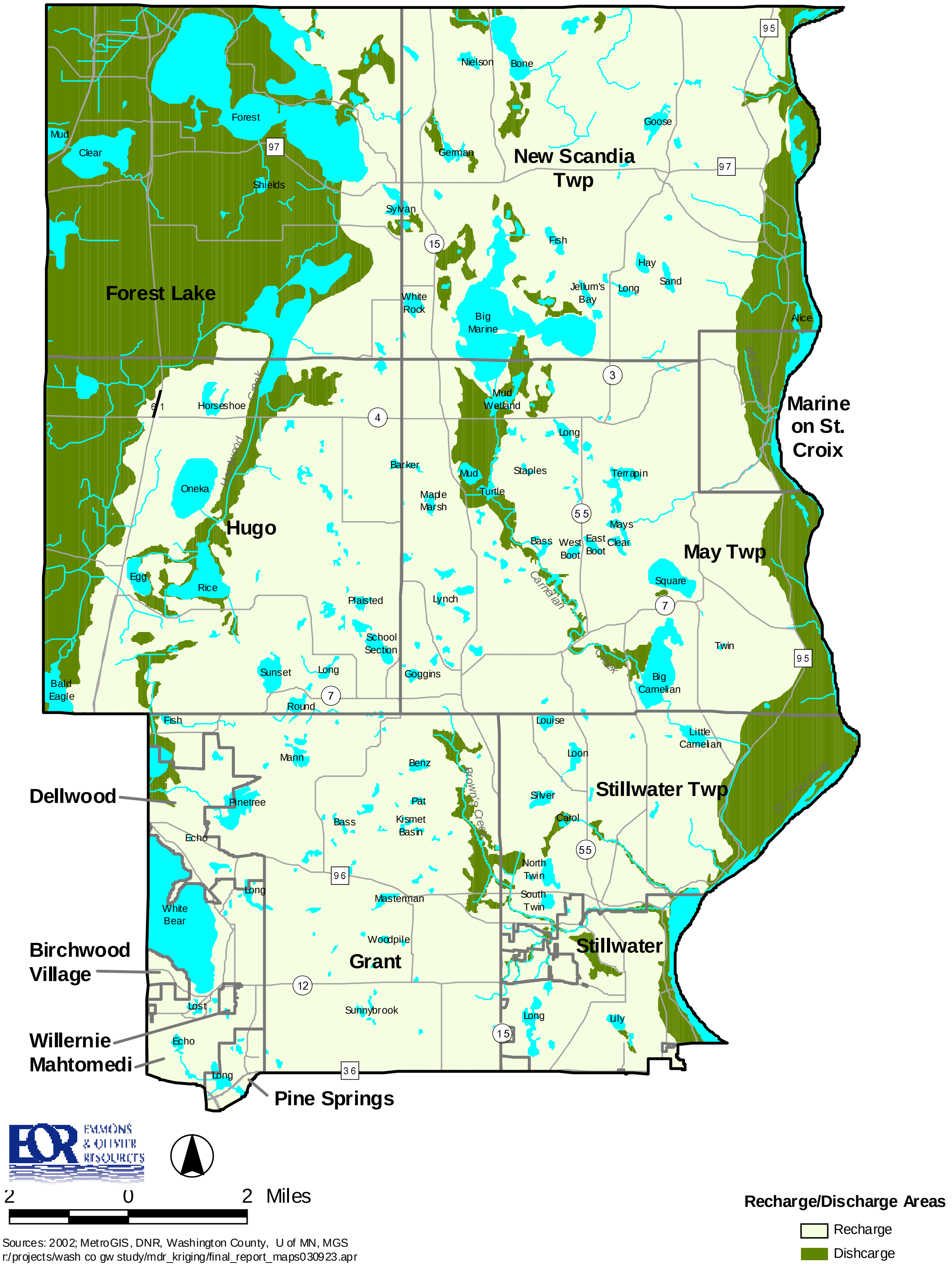
Organic deposits were identified using surficial geology maps and soil surveys. The presence of organic deposits tended to coincide with identified groundwater dependent natural resources and mucky soils. Typical soils associated with the organic deposits of the study area are the Seelyeville, Rifle, Markey, and Cathro mucks. These soils are characteristically poorly drained, with moderate permeability and a high water capacity. The organic and mineral content of the soils is high, with the water table characteristically less than two feet from the surface, indicating a groundwater discharge environment.

The northwest part of the study area is classified as a discharge zone because it is underlain by thick Des Moines lobe till deposits. The clayey till restricts recharge of underlying bedrock aquifers. Organic and muck soils are common. Groundwater is encountered at shallow depths and wetlands are common.

The area around Oneka and Horseshoe Lakes has similar characteristics to those just described. However, this area was classified as a recharge zone because the lakes show clear signs of groundwater recharge (See Figure 4.1.)

The St. Croix Moraine area (middle part of the study area) and associated outwash plains are generally considered recharge zones. Landlocked basins hold water and prevent runoff so that precipitation has time to infiltrate. Local areas of sand and gravel deposited by various glacial features are also important recharge areas. High topography and greater depth to the water table also indicate this is a recharge zone. Areas where the Superior Lobe till is sandy or absent likely serve as important recharge areas for deeper aquifers.

Figure 4.6. Recharge and Discharge Zones



Sources: 2002; MetroGIS, DNR, Washington County, U of MN, MGS
r:/projects/wash co gw study/mdr_kriging/final_report_maps030923.apr

Within the St. Croix Moraine, important discharge zones exist along Carnelian Creek, Brown's Creek, and the lakes in the north central part of the study area. These zones include large wetlands, organic soils, flow-through lakes, and groundwater dependent resources. The groundwater recharge for these features generally comes from nearby high infiltration potential areas and surficial aquifers.

The east part of the study area is classified as a discharge zone. It has many groundwater dependent resources such as springs, spring creeks, and seepage swamps, especially along the St. Croix River bluffs. Recharge likely comes from several sources. The St. Croix River terrace deposits and sandy soils provide local recharge. Bedrock valleys and glacial outwash deposits provide conduits for water infiltrating a few miles to the west. Finally, it is likely that deep aquifers such as the Franconia Formation transmit some water from areas in northwestern Washington County. This is difficult to verify or quantify because these aquifers are also recharged with younger water throughout the study area, especially where these deeper aquifers are closer to the surface and subcrop below glacial deposits in the east.

The total area and percentage per area type is summarized in Table 4.4.

Table 4.4. Recharge and Discharge Areas.

Area Type	Total Square Miles	Percentage of Study Area
Recharge	129.135	72.88%
Discharge	48.057	27.12%

4.4 Management Zones

The study area has been broken down into management zones to classify similar landscapes and landforms that require varying degrees of management for protection of aquifers and groundwater dependent resources. The infiltration potential, recharge and discharge areas, and surficial geology were all used to generate the management zones. The study area was differentiated geographically into three management zones - 1, 2, and 3. Zone 1 requires the highest level of management and zone 3 requires the lowest. Management and policy application for these areas is discussed in Chapter 5.

> *Zone 1: Critical Groundwater Quality Impact Zone* - Zone 1 is primarily high quality discharge and recharge areas with high infiltration potential. This zone characteristically has very rapid infiltration and poor soil treatment capacity. Typically these areas are outwash plains or terrace deposits where sand and gravel comprise the primary geologic material.
>
> *Zone 2: Groundwater Quality Impact Zone* - Zone 2 is primarily recharge areas with medium infiltration potential. Typically these areas have more clay and silt as part of a glacial till formation or a remnant lake bed.

> *Zone 3: General Groundwater Quality Protection Zone* - Zone 3 is primarily areas with low infiltration potential. This final area generally covers the upland glacial till portions that do not rapidly infiltrate, but still infiltrate and recharge to the groundwater system.

Figure 4.7 illustrates the management zones generated for this study.

Most discharge areas were classified as Zone 1. However, based on geologic material and existing land use, some discharge areas were classified Zone 3. In particular, the discharge area around Forest Lake, on the west side of the study area, was determined to be Zone 3 because of the low infiltration potential of the geologic materials. The low infiltration potential is due to the dense, impermeable nature of the clay-rich Des Moines Lobe till and the upward gradient of groundwater flow beneath the till, providing longer travel time and better protection to the deep groundwater system. Additionally, there are not significant numbers of groundwater dependent natural resources in this area, in part due to extensive ditching.

The total area and percentage of study are illustrated in Table 4.5.

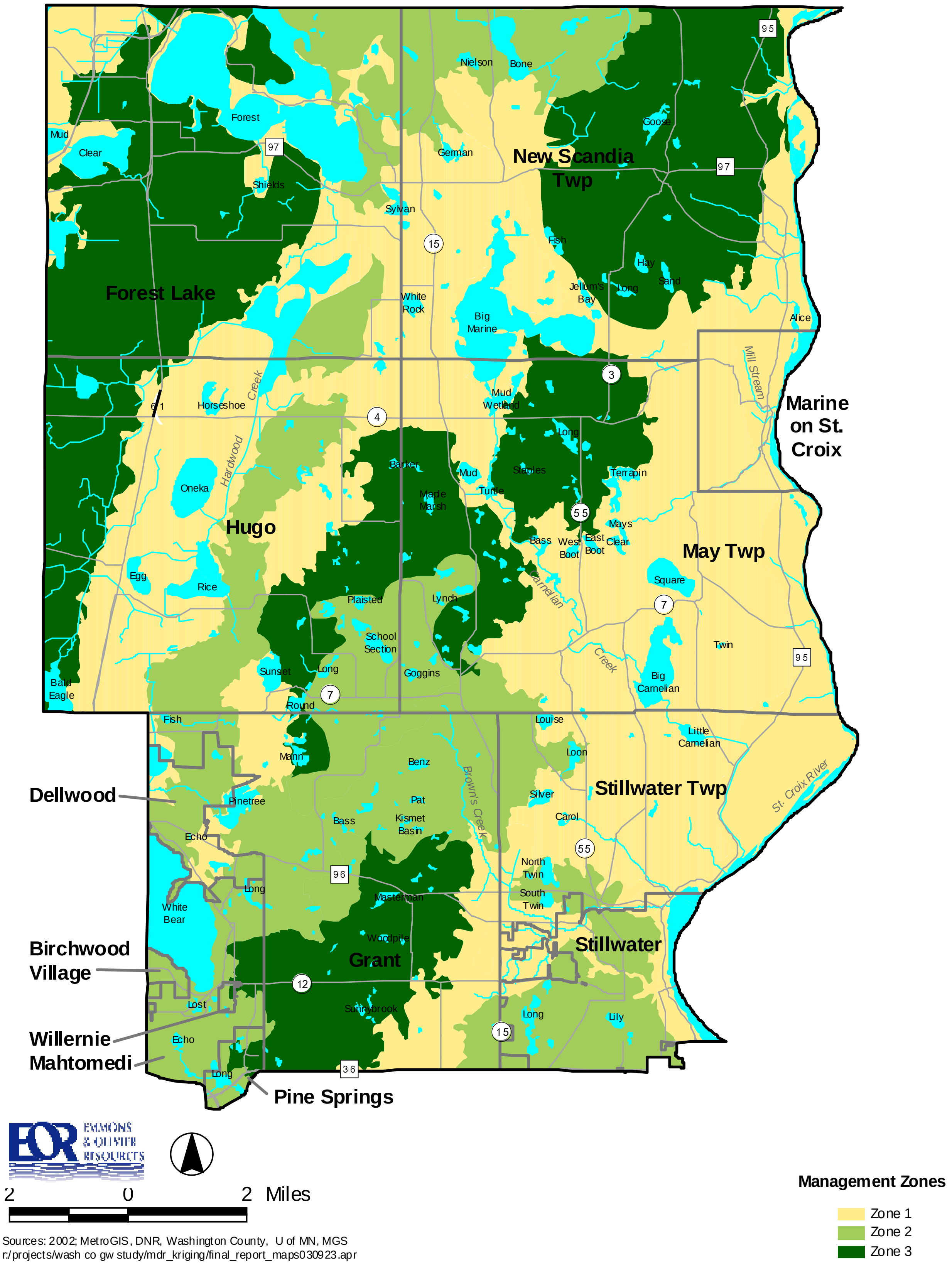
Table 4.5. Management Zones.

Management Zone	Total Square Miles	Percentage of Study Area
1	82.843	46.75%
2	41.433	23.38%
3	52.915	29.86%

The recharge area for the St. Croix spring creeks, determined by chemistry data, was found to be the area just west of the creeks including Square Lake, the Long, Terrapin, Mays and Clear chain of lakes, and the Carnelian Creek corridor. These areas were classified as Zone 1 due to the high infiltration potential of the geologic materials which results in a shorter travel time and less natural protection to the groundwater system.

The majority of the area encompassing the St. Croix Moraine is identified as Zone 3. This area provides sufficient protection for underlying aquifers and does not contain many groundwater dependent resources. The headwaters to Brown’s Creek is classified as a Zone 2 based on its proximity to Brown’s Creek and the infiltration potential and recharge characteristics of the geologic material.

Figure 4.7. Management Zones



Sources: 2002; MetroGIS, DNR, Washington County, U of MN, MGS
r:/projects/wash co gw study/mdr_kriging/final_report_maps030923.apr

5. Strategy for Integrating Groundwater and Surface Water Management

5.1. Statement of Need

This section outlines recommendations for strategies, policies, and rules to be adopted by Washington County and Local Governmental Units (LGUs) including watershed districts, watershed management organizations, cities, and townships. The Policy Advisory Committee for this project noted that the need for additional governmental action and the consequence of no governmental action should both be clearly articulated.

The consequence of no governmental action is the degradation and loss of groundwater and surface water resources. Development pressures in Northern Washington County threaten to alter groundwater and surface water resources, as outlined below. Other parts of the Twin Cities have developed with little or no governmental attention to water resources, especially groundwater resources. The cost of these policies is difficult to quantify since examples of groundwater resource degradation are difficult to identify. This is largely because groundwater resources and groundwater-dependent resources were not inventoried while they still existed. Anecdotal evidence is all that remains of many springs, streams, and wetlands that once thrived in Minneapolis, St. Paul, and their suburbs. Now that Washington County governmental units have identified groundwater resources and acknowledged their value, they have an obligation to protect and preserve them.

5.1.1. Protection of Groundwater Recharge

All of Washington County relies on groundwater as a sole source of water supply. Maintaining its viability is essential to the continued physical and economic health of the entire County. Protection of the resource begins with assuring that it is replenished with a continuing flow of good quality water. Groundwater recharge occurs when surface water or precipitation infiltrates into the soils and percolates to the water table. From here, groundwater flows towards a spring, lake, wetland, stream, or lower aquifer unit. Increases in imperviousness within critical groundwater recharge areas can limit the volume of water being infiltrated at the surface, resulting in decreased groundwater levels and flow volumes. A small change in the local water table can also have a detrimental effect on groundwater dependent ecosystems that rely on constant groundwater inflow and water levels.

5.1.2. Protection of Groundwater Quality

The high quality of groundwater within the northern portion of Washington County has been maintained by limited use of the land within this area and by careful land management practices. Any degradation in the quality of water infiltrating the ground surface translates directly into reduction in water supply quality for the residents and businesses of the County, as well as for many groundwater dependent surface water sources. Maintaining a vigilant approach to activities on the land's surface means that long-term quality of the County's groundwater system can be assured.

5.2. Existing Groundwater Goals and Policies

Within Washington County, there are many policies and goals for groundwater management used by different units of government. The challenge, therefore, becomes the integration of these efforts to a common end, which is a reliable, high quality groundwater resources.

The *Washington County Comprehensive Plan: A Policy Guide to 2015* was adopted by the County in 1997 as a "…policy guide to decisions about the physical development of the County." The *Comprehensive Plan* identifies as one of the County Values the conservation and preservation of natural resources. It also adopts the following overall goals that relate in some manner to resource protection:

- To foster environmentally sound economic growth and development
- To be proactive in planning for change and growth
- To encourage and foster problem prevention strategies
- To increase communication and collaboration with other jurisdictions, agencies and the private sector

The *Comprehensive Plan* sets overall land use, open space and natural resource policy for the County to use in guiding growth and conducting its routine operations. Each chapter devoted to these topics contains a description of existing conditions; a summary of the issues; a statement of specific goals, objectives, and policies; and an implementation program. These are all structured to achieve the above goals and relate to the central *Comprehensive Plan* theme of maintaining natural resources in undiminished condition for future generations.

The *Washington County Groundwater Plan* (approved by the BWSR on October 22, 2003 and slated for adoption by the County Board in December 2003) identifies many goals and implementation strategies to achieve the goals. The *County Groundwater Plan* recognizes that no single entity can adequately protect the resource and calls for increased groundwater management and implementation at the State, County, watershed and local level. A previously prepared summary of existing groundwater management policies and standards for watershed districts in Washington County is found in Appendix C. This summary is an excerpt from the report to Washington County and the Washington County Water Consortium summarizing existing groundwater management standards and rules in the County. In addition to areas within the study area and Washington County, a cursory review was completed of other community and watershed plans and rules with respect to groundwater management.

All of the state and federal regulatory and planning programs (see Appendix F) relating to groundwater will clearly remain in force. These programs provide many of the necessary regulatory provisions that assure such things as adequate hazardous materials handling, pollution control and wellhead protection.

5.3. Strategy for Implementation of Countywide Groundwater Resources Protection

The successful implementation of a groundwater protection program for northern Washington County depends largely upon convincing the public and their elected officials of the need to take action. Washington County officials and staff have seen the need and acted through the preparation of the *County Groundwater Plan* and initiation of this groundwater study. The challenge is to actively use the information gained from these efforts during future implementation projects.

Several recommendations are made on how the County can move forward and effectively implement groundwater protection in partnership with many other interested parties. A strategy is developed based on the *County Groundwater Plan* wherein various levels of protection are defined, sample action steps and policies are developed, and a model ordinance is made available to implementing entities. Implementation is suggested through cities, townships and watershed management organizations (WMOs) operating under a County-developed framework.

5.3.1. County Oversight

The responsibilities of the County in groundwater protection are well founded in water, pollution prevention, and environmental planning law. What is less clear is the desired method(s) for taking that responsibility and getting it implemented in a broad way across the County. This groundwater study can be used as the vehicle to initiate that action.

With the *Washington County Groundwater Plan* and supporting documents providing the foundation, a case is easily made that protecting the County's sole source of drinking water is in the best interest of all of its citizens. The over-arching policy statement in the next section is that the County will maintain the existing volume of water entering the groundwater system, while assuring that the quality of water infiltrating into the system does not degrade the aquifers. In instances when re-development occurs, the County can actually increase recharge by incorporating management practices where they previously did not exist.

5.3.2. Strategy Steps

With the above charge in mind, the following strategy is proposed to implement the findings of the Northern Washington County Groundwater Study, with possible application eventually to the southern part of the County. The following four steps are proposed to initiate discussion and are presented with some flexibility in mind, depending upon all of the political, legal, financial and institutional factors that must be addressed:

1. Adopt policies and recommendations;
2. Determine protective levels;
3. Propose institutional methods to implement; and
4. Provide technical and planning assistance.

5.3.2.1. Step 1. Adopt Action Steps and Policies

The *County Groundwater Plan* identifies a framework of goals that the County will follow to achieve groundwater protection. The following areas of County involvement have been identified by this study:

A) Protection and Management of Groundwater Recharge and Discharge Areas
B) Areas Susceptible to High Water Levels
C) Protection of Groundwater-Surface Water Interaction and Groundwater-Dependent Resources
D) Education

Following are some suggested actions and policies for the County to consider when pursuing goals for the area covered by this study:

A) PROTECTION AND MANAGEMENT OF GROUNDWATER RECHARGE AND DISCHARGE AREAS

POLICY

Groundwater is the sole source of water supply for the citizens and businesses of northern Washington County. The County promotes protection of both the quantity and quality of the groundwater system in perpetuity to assure the physical and economic health of the County.

RECOMMENDATIONS

The County recommends that:

1) the groundwater resource and any potential problems related to it be identified, and the problems be addressed first through planning and then through remediation;
2) existing infiltration volumes be maintained whenever any construction, re-construction, building activity or land alteration occurs;
3) water resources within the County be maintained as near to their pre-development condition as reasonably possible for the safeguarding of public health and, that the use of all available practical methods of preventing and controlling water pollution be required;
4) groundwater quality be protected by ensuring that any development that occurs has no adverse effect on groundwater;
5) the proper design, building, operation and maintenance of effective septic systems be required;
6) assistance for abandoning and sealing unused wells be provided;
7) land uses that generate, use or store dangerous pollutants in critical recharge areas be restricted or prohibited;
8) existing and native vegetation and corridors be preserved as filters;
9) DNR be provided with available local knowledge of groundwater dependent resources that relate to potential water appropriations;
10) groundwater protection be incorporated as an essential element in all of the county emergency and contamination response programs;
11) available protection under state and federal law be supplemented with a model groundwater protection ordinance (Appendix F), adapted for the local situation; and
12) the County participate in a Joint Powers Agreement with communities and watershed organizations for the protection of groundwater resources.

B) AREAS SUSCEPTIBLE TO HIGH WATER LEVELS

POLICY

Groundwater is a significant part of the hydrology of many area lakes. The County recognizes the interaction between groundwater and surface water, and promotes accounting for the influence of groundwater when establishing Ordinary High Water Levels, construction permitting rules, flood insurance maps, and other policies.

RECOMMENDATIONS

The County and watershed districts are responsible for developing policies related to construction and other activities that could be influenced by high water levels. The County recommends that:

1) the groundwater component of the hydrology of individual lakes be identified;
2) the understanding of geology and hydrogeology around the lakes be further refined by gathering and analyzing available data;
3) groundwater inflows and outflows, where significant, be quantified in the modeling and prediction of lake levels; and
4) groundwater be recognized as having a significant effect on most lake water levels when establishing rules related to lake levels.

C) PROTECTION OF GROUNDWATER-SURFACE WATER INTERACTION AND GROUNDWATER DEPENDENT RESOURCES

POLICY

The County will strive to retain the ecological integrity of groundwater dependent resources through protection of groundwater quality and quantity as well as avoidance of surface water-related impacts to these resources. The County will strive to protect the connection(s) between surface water and groundwater dependent resources.

RECOMMENDATIONS

The County recommends that:

1) groundwater and the resources dependent on it be identified, inventoried and evaluated;
2) baseline data on groundwater and groundwater dependent resources be collected;
3) groundwater recharge functions within critical recharge areas be protected and maintained;
4) all new development and re-development be required to offset reduced infiltration that results from increased imperviousness;
5) the potential impacts of public or private infrastructure (including private and municipal groundwater appropriations) and interference of flows, on groundwater recharge, transmission and discharge be carefully evaluated;
6) the use of groundwater dependent wetlands to pre-treat, store or convey stormwater be avoided;

7) riparian corridors along spring creeks be established and protected to stabilize streambanks, provide thermal protection and support riparian plant and animal communities;
8) land owners and local officials be educated on the value of groundwater dependent resources and their protection; and
9) the physical and biological health of groundwater dependent resources be monitored on an ongoing basis.

D) EDUCATION

POLICY

The County will strive to have all the citizens, businesses and public entities of the County knowledgeable about care of the groundwater system. Knowledge of the impact of one's actions on groundwater forms the basis for individual stewardship of the resource.

RECOMMENDATIONS

The County recommends that:

1) basic educational material about the groundwater system and its relationship to surface water be provided;
2) local citizens and users be given a voice in determining the level of protection and priorities for the protection of groundwater;
3) a means be provided for citizens to be protective of groundwater through such programs as waste recycling, household hazardous waste disposal, lawn and yard maintenance, education programs, and used oil disposal; and
4) resource agencies work with businesses and public entities on their planning and protection approaches to achieve groundwater protection.

5.3.2.2. Step 2. Determine Protective Levels

The groundwater resources within the study area require various levels of protection dependent on the differing physical conditions and their relation to infiltration and recharge. This section proposes a general county overlay and a three-level system of groundwater resources protection with supporting model ordinance in Appendix F. Washington County will work with local governmental units (watershed districts, WMOs, cities, townships) to continually revise, improve, and implement the Study's recommendations.

General County Overlay

The goals in the *County Groundwater Plan* and the policies in the previous section state that the infiltration of water into the ground must be maintained at existing levels throughout the County to support groundwater dependent ecosystems and drinking water supplies. Determination of pre-development infiltration should be part of an overall infiltration management element required for a site as it develops or re-develops. As a result, the use of volume control strategies and low impact development design are necessary. In addition, the location of groundwater recharge, or infiltration, should be in the same general area as under existing conditions.

Altering the location of recharge or infiltration could negatively affect groundwater dependent resources that rely on specific groundwater inputs.

Management practices that would best address this need include:

- basic soil erosion control necessary to prevent the wash-off of soil that could clog infiltration surfaces;
- a suite of infiltration basins, surfaces, trenches, tubes, or pipes preceded by some form of pre-treatment (settling, filtration);
- bioretention or vegetative plantings (swales, rain gardens) that promote infiltration; and
- reduced imperviousness.

These and many other management approaches are described in the links referenced in Step 4 that follows. Use of these approaches can vary from diversion of roof runoff to yards on a small-scale development, to diversion of a large housing development to a regional infiltration basin, to maximum water quality protection through treatment train and infiltration practices on a commercial site. Examples of each of these approaches currently exist within the County.

Protection Levels

With the requirement in mind to maintain the quantity of water infiltrating into the ground, the other major component to address is the quality of water being infiltrated. To protect the groundwater resources which receive all of the infiltrating waters, three zones of groundwater quality protection are being proposed. The zones could be used as the basis for establishing overlay districts for the County and LGUs involved in planning and permitting. The hydrology of the proposed zones is discussed in Section 4.4, and the boundaries of the zones are shown on Figure 4.7.

> *Zone 1: Critical Groundwater Quality Impact Zone* - This is the most protective zone established. In this zone there is a high potential for pollution within the groundwater system if any contaminating material were to be introduced at the surface. Retaining the infiltration character within this zone should be easily met since infiltration is rapid. However, stringent pre-treatment requirements should be established prior to allowing water to enter the ground. Land uses with minimum impervious area are encouraged, while those associated with large areas of paved surface and/or chemicals or activities more likely to contaminate the groundwater will require extensive water quality protection measures.
>
> *Zone 2: Groundwater Quality Impact Zone* - In this zone, the infiltration is not as rapid , but water quality must still be protected to preserve the integrity of the groundwater system. Although the amount of infiltration capacity is less than Zone 1, the requirement for maintaining the predevelopment recharge volume must be met. Because of the additional filtering and soil treatment afforded by these soils, the requirements for pre-treatment will not be as stringent as Zone 1.

Zone 3: General Groundwater Quality Protection Zone – In this zone, the infiltration is slower. Pre-treatment of any infiltrating water is still recommended as part of any development plan, but the required components are limited. As with the other zones, the policy still applies to not allow the groundwater system to be impacted and to maintain predevelopment infiltration volumes. Land use restrictions are fewer and chemicals and/or activities that have the potential to contaminate groundwater are discouraged but not prohibited.

5.3.2.3. Step 3. Propose Institutional Methods to Implement

To implement a program of county-wide groundwater protection, suitable institutional arrangements must be put in place to handle the day-to-day requirements of the program. A program such as the one proposed herein is best implemented by local entities under the overall policy framework developed by the County. Watershed management organizations, cities and townships largely have programs in place that could fit into this implementation framework.

The primary programs likely to be used for groundwater protection are subdivision/development approval, wastewater disposal, chemical storage and handling, and surface water management programs. In addition, special efforts, such as the wellhead protection program, are implemented through the Minnesota Department of Health for public water suppliers. These programs and others could be used without prescriptive direction by the County, as long as the performance standards set by the County policies and recommendations are met.

Once a local entity receives County approval for its groundwater protection program, then it would be the primary implementing agency. The level of County oversight needs to be discussed and agreed upon through the political process. The model groundwater protection ordinance provided in Appendix F could be adapted by an implementing agency for use in the program.

5.3.2.4. Step 4. Provide Technical and Planning Assistance

As the oversight agency for groundwater protection, the County should be prepared to provide assistance to the implementing agencies. The protective zones will need to be agreed upon by affected parties and final mapping and distribution will be necessary.

The County can provide some guidance or references to documents that could be used by the implementing agencies in the application of management practices required for the various levels. A set of possible references would include the following:

- Center for Watershed Protection - http://www.stormwatercenter.net/ and http://www.CWP.org

- Metropolitan Council - http://www.metrocouncil.org/environment/Watershed/BMP/manual.htm

- Stormwater News - http://www.stormwater-resources.com/index.htm

- Low Impact Development Center - http://www.lid-stormwater.net/

- Minnesota Pollution Control Agency - http://www.pca.state.mn.us/water/stormwater/index.html

- Project NEMO (Nonpoint Education for Municipal Officials) - http://nemo.uconn.edu/

- U.S. EPA - http://cfpub.epa.gov/npdes/stormwater/menuofbmps/menu.cfm and http://www.bmpdatabase.org/

- State BMP Manuals –

  Virginia - http://www.dcr.state.va.us/sw/stormwat.htm#pubs

  Illinois - http://www.il.nrcs.usda.gov/engineer/urban_orig.htm

  New York - http://www.dec.state.ny.us/website/dow/swmanual/swmanual.html

Planning assistance will also be needed to help the implementing agencies put effective programs in place. The following agencies provide assistance that could be of value to implementing agencies:

- Minnesota Board of Water and Soil Resources
- Washington Conservation District
- Minnesota Pollution Control Agency
- Metropolitan Council
- Minnesota Office of Environmental Assistance
- Minnesota Department of Natural Resources
- Minnesota Geological Survey
- University of Minnesota (various departments and the Extension Service)
- Project NEMO (http://nemo.uconn.edu/)

If the County proceeds with a groundwater protection program, it should prepare a manual of guidance that would assist local implementing agencies in all facets of the program. Such an effort could pull together all of the technical and planning components and provide example applications on how the program could be implemented under differing physical and political conditions.

6. Feasibility Study for Managing Excess Surface Water – Sunnybrook Basin[1]

The Valley Branch Watershed District (VBWD) contributed $20,000 to the "Integrating Groundwater and Surface Water Management-Northern Washington County, 2002/2003 BWSR Challenge Grant" and received $40,000 to develop innovative strategies to manage high water/flooding issues in the Sunnybrook Lake watershed area. To evaluate the various strategies, the VBWD needed to understand the groundwater – surface water relationship in the area. The VBWD first compiled existing data and collected new data. Then the VBWD used the data to construct a long-term, continuous simulation (a hydrologic and hydraulic computer model) of the Sunnybrook Lake watershed. A groundwater model and other data were used to calibrate the long-term, continuous surface water model simulation so that its predicted water levels would match observed conditions. Once the surface water model was constructed and calibrated, the VBWD had a powerful tool that it used to predict the impacts of management scenarios. The VBWD used this tool, statistical analyses, and cost estimates to evaluate flood relief management strategies. Information and techniques learned and used in the VBWD's Sunnybrook Lake flood relief study can be applied to other basins requiring a detailed analysis of existing conditions and potential water quantity solutions.

In March 2002, the VBWD completed the draft report, *Sunnybrook Lake Flood Relief Feasibility Study*. The complete report is available from the VBWD. The following is a summary from the report and the VBWD 2002 Annual Report.

6.1. Background

Sunnybrook Lake is a 16-acre lake located in the City of Grant, approximately one mile north of T.H. 36, between Jamaca Avenue North and Keats Avenue North. Figure 6.1 shows the location of the lake and the surrounding neighborhood. The lakeshore homes of the Sunnybrook Lake neighborhood were constructed in the late 1960s and early 1970s prior to the VBWD Board of Managers implementing a permit program. At that time, Washington County issued development and housing permits for Grant Township (which became the City of Grant in 1996).

During the mid-1980s and several years in the mid-1990s, the water levels of the lake and surrounding lowlands inundated roads, flooded basements and septic systems, and forced residents to sandbag their properties for flood protection. There are nine homes below the 1% probability flood level (or within the 100-year floodplain). Figure 6.2 shows the low homes, the 100-year floodplain, drainage patterns, and other features in the neighborhood.

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[1] Prepared by Valley Branch Watershed District, 10-16-2003.

Figure 6.1. Sunnybrook Lake Neighborhood Location.

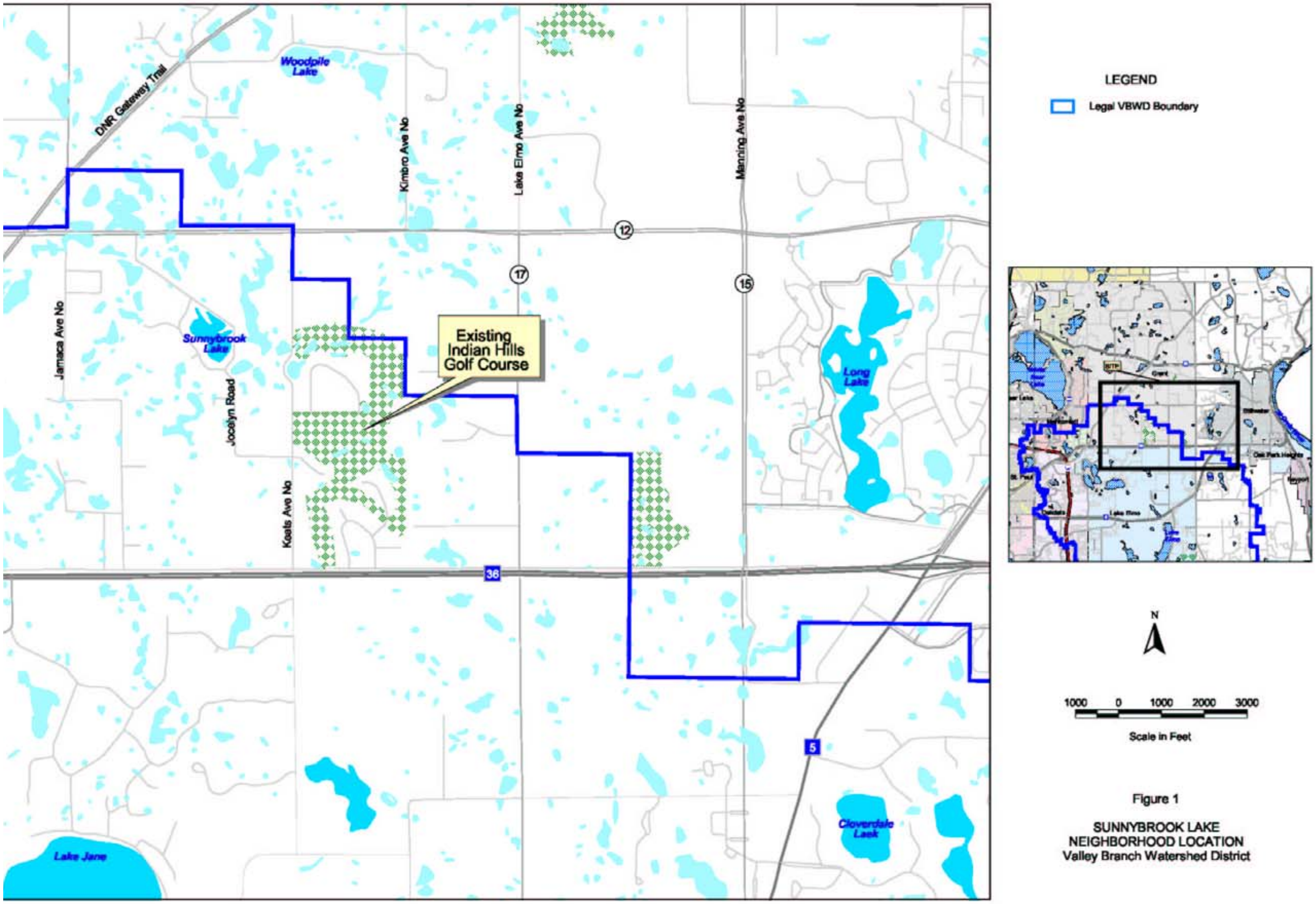
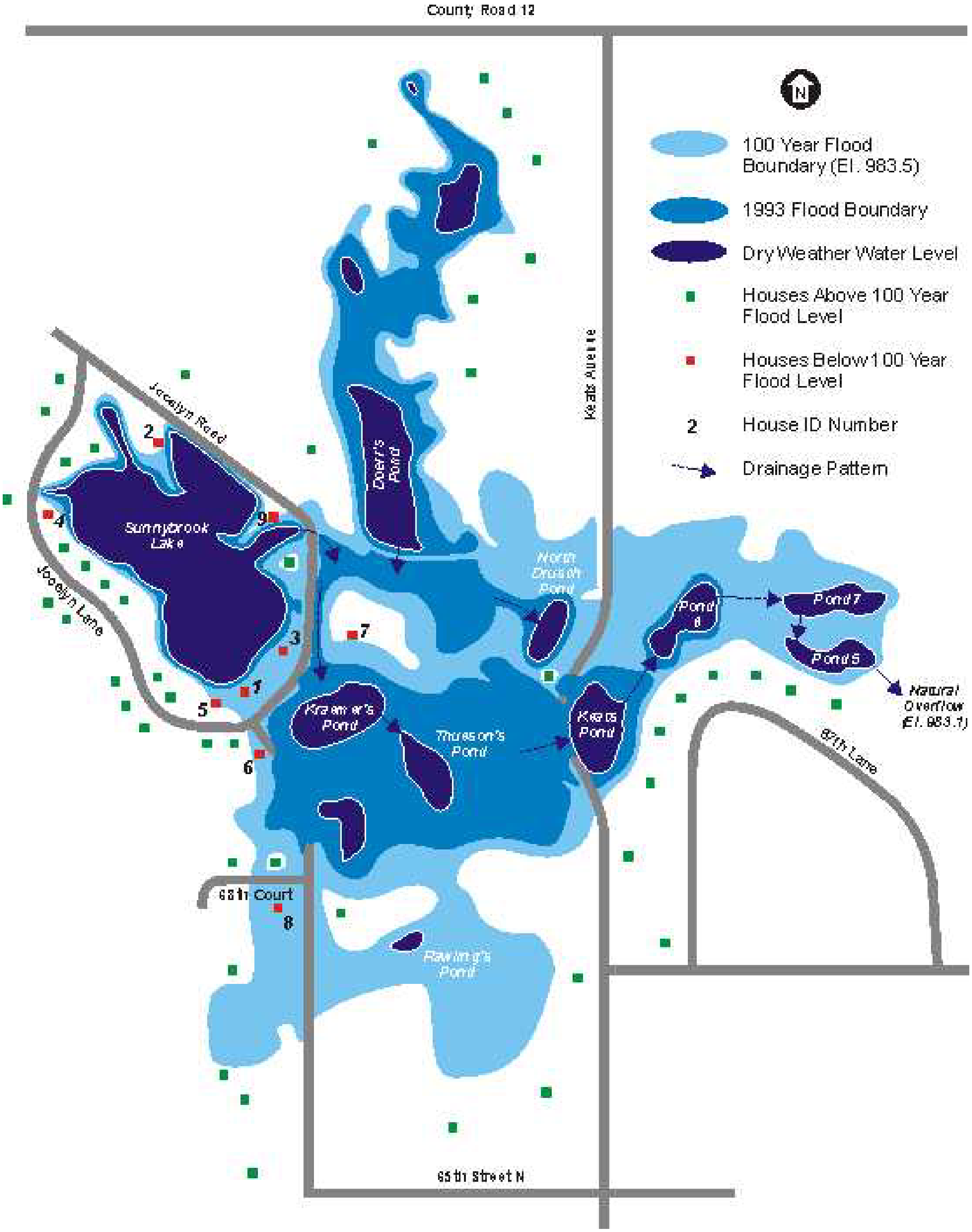


Figure 6.2. Floodplain Areas.



The VBWD Board of Managers has taken the lead in trying to find and implement a solution to the flooding problems. The VBWD Board of Managers has attempted to implement several projects to provide flood protection to the neighborhood, but no project has ever been constructed due to cost, disagreement on acceptable solutions, and other higher District priorities. Most recently, the VBWD Board attempted to implement one of the flood relief projects listed in its 1995 Water Management Plan (Plan), which was approved by all the State Review Agencies and Washington and Ramsey Counties. The Plan includes a capital project involving the construction of an outlet from Sunnybrook Lake to Brown's Creek. The Plan also includes an alternative of implementing a flood relief project for Sunnybrook Lake and several other VBWD landlocked lakes in the eastern portion of the District. Because Brown's Creek is a trout stream and has some existing water management problems, the Board, as demanded by those who attended an open public meeting in 1998, attempted to implement the alternative listed in the Plan. However, when the VBWD Managers submitted a draft Plan amendment to allow for further study and the ultimate construction of the alternative project, the proposal met strong opposition from Washington County and some of the local and state agencies. The VBWD Board rescinded the draft Plan amendment in 2001.

Later in 2001, the VBWD developed a specific strategy for managing the flooding at Sunnybrook Lake. Generally, the strategy included the following:

1) Work with Washington County to establish a more accurate 100-year flood level on Federal Emergency Management Agency (FEMA) floodplain maps.

2) Evaluate the status of flood insurance purchases and educate those who do not have flood insurance.

3) Prepare a system plan for moving water more efficiently out of Sunnybrook Lake to infiltration areas to the east (roughly along County Highway 12).

4) Evaluate available storage capacity in upstream areas and develop these areas to the extent that they reduce the overall project cost.

5) Attempt to use floodproofing of homes and roads to reduce cost of required system.

6) Once the system size has been determined, offer to cost-share floodproofing and/or relocation of homes that remain within the 100-year floodplain.

7) Once the with-system 100-year flood level has been determined, work with City of Grant to cost-share road improvements required for emergency access and flood protection.

The VBWD Managers met with BCWD Managers to review strategy and determine if an emergency overflow from Sunnybrook Lake to Brown's Creek would be feasible. The BCWD Managers were open to the idea, but they requested details regarding the frequency of overflow, the quantity of water that would overflow, and the impact on Brown's Creek.

In late 2001, the Indian Hills Golf Club management contacted the VBWD Managers and offered to allow some of their proposed expansion lands to be used for relieving flooding at the Sunnybrook Lake neighborhood. The golf club owner planned to expand to the east and wanted to start construction in the spring of 2002. Because this offer presented the VBWD Managers with a potential solution at probable huge cost savings to the taxpayers, the VBWD Managers ordered a detailed study that would determine the benefits of using golf course lands for flood relief and would answer the questions asked by the BCWD Managers. The study was begun in 2001 and a draft report was completed on March 11, 2002.

6.2. Sunnybrook Lake Flood Relief Feasibility Study ("Study")

For this Study, several alternatives and combinations of alternatives were analyzed to determine the level of protection to the low homes they would provide and the cost of the alternative. These alternatives included two groups: 1) lowering the 1% probability flood level and 2) maintaining the existing 1% probability flood level. The goal of the study was to provide 1% probability protection to all the low homes around the lake. The goal was not to provide 1% probability protection to the roads.

A computer model was developed to evaluate various scenarios for lowering the 1% probability flood level. The model used existing land conditions and climatologic data from 1948 to 1999 to develop 1% probability flood levels. Details of the computer model are discussed within the Study report. The scenarios evaluated in the Study are shown on Figures 6.3.a through 6.3.g and include:

Scenario 1 (Figure 17 from the Study): Optimize Existing Storage (Figure 19 from the Study), Install a 0.2 cubic foot per second (cfs) Lift Station Pumping to a 4-Acre Constructed Infiltration Basin

Scenario 2 (Figure 22 from the Study): Optimize Existing Storage (Figure 19 from the Study), Install a 1 cfs Lift Station Pumping to a 9.4-Acre Constructed Infiltration Basin, and a 0.5 cfs Emergency Overflow to Brown's Creek (Figure 23 from the Study)

Scenario 3 (Figure 25 from the Study): Optimize Existing Storage (Figure 19 from the Study), Install a 5 cfs Lift Station Pumping to a 42-Acre Constructed Infiltration Basin, and a 0.5 cfs Emergency Overflow to Brown's Creek (Figure 23 from the Study)

Scenario 4 (Figure 27 from the Study): Optimize Existing Storage (Figure 19 from the Study), Install a 10 cfs Lift Station Pumping to a 4-Acre Constructed Infiltration Basin, and a 10 cfs Emergency Overflow to Brown's Creek (Figure 23 from the Study)

Scenario 5 (Figure29 from the Study): Optimize Existing Storage (Figure 19 from the Study), Construct Upstream Storage Areas, Install a 10 cfs Lift Station Pumping to a 4-Acre Constructed Infiltration Basin, and a 10 cfs Emergency Overflow to Brown's Creek (Figure 23 from the Study)

In addition to these scenarios, alternatives that would not lower the 1% probability flood level, but would provide protection to the low homes were evaluated. These alternatives included buying out the low homes and floodproofing. A combination of Scenario 2 and floodproofing was also evaluated and designated Scenario 6.

Figure 6.3.a. Scenario 1.

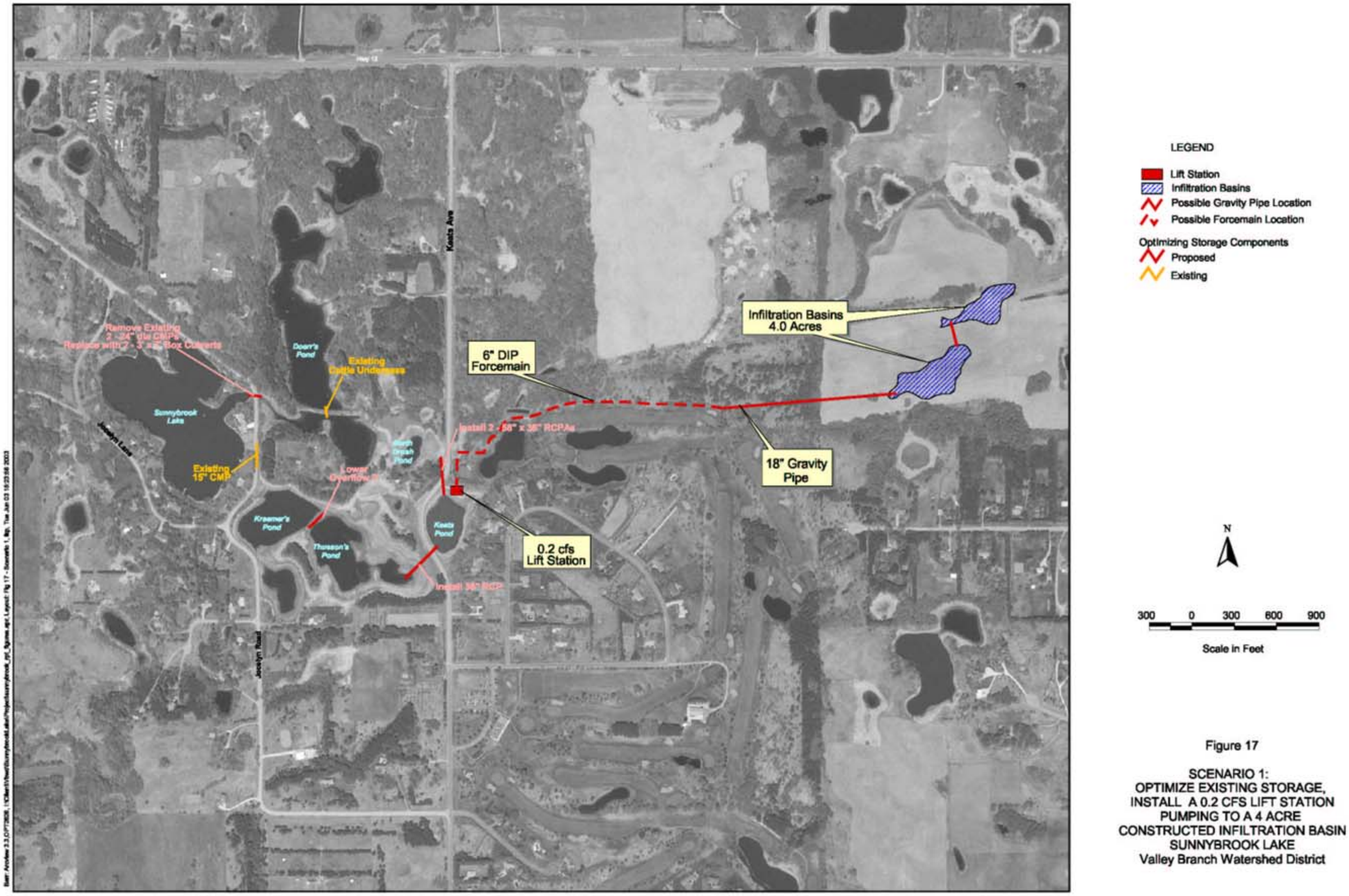


Figure 6.3.b. Optimizing Existing Storage.

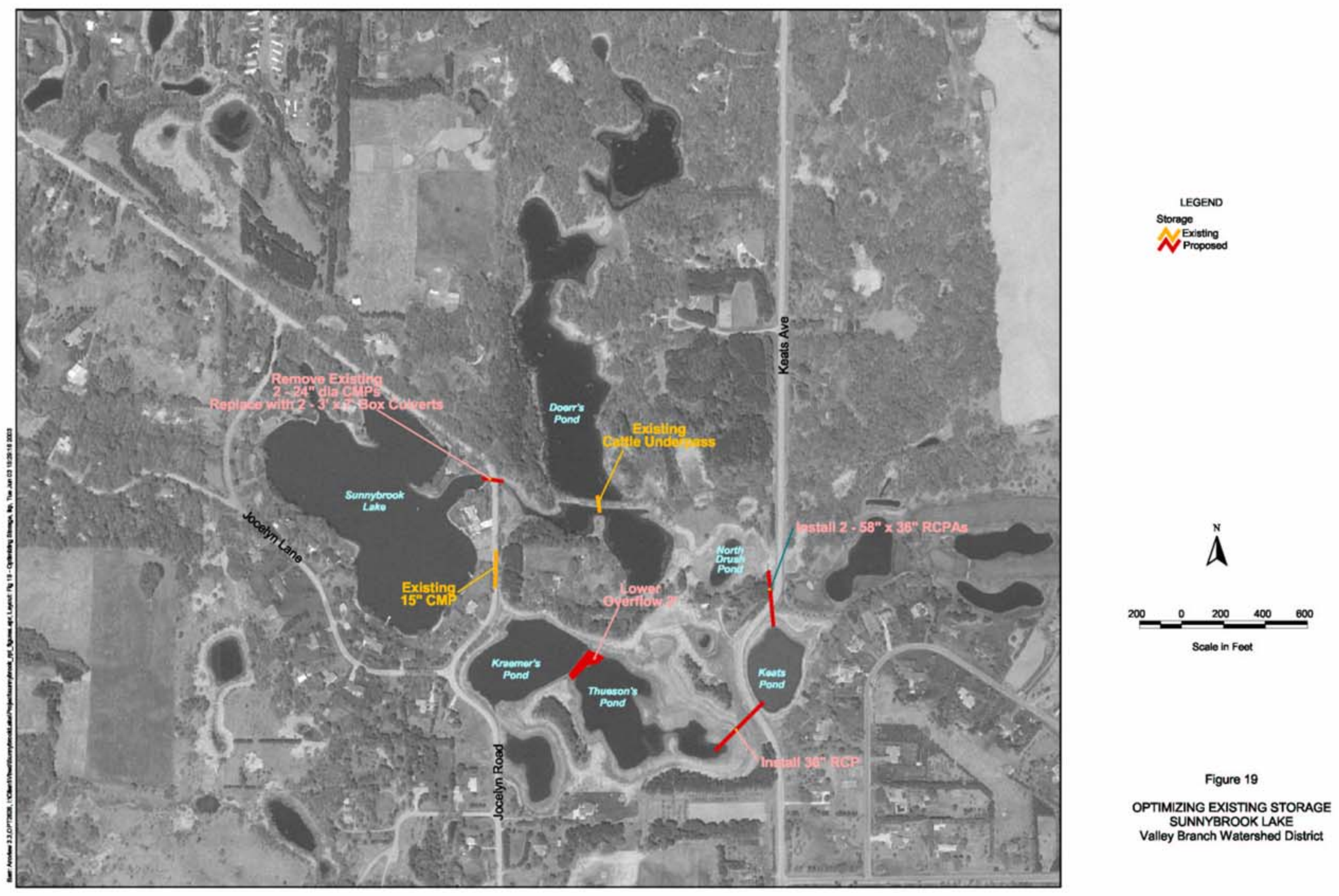


Figure 6.3.c. Scenario 2.

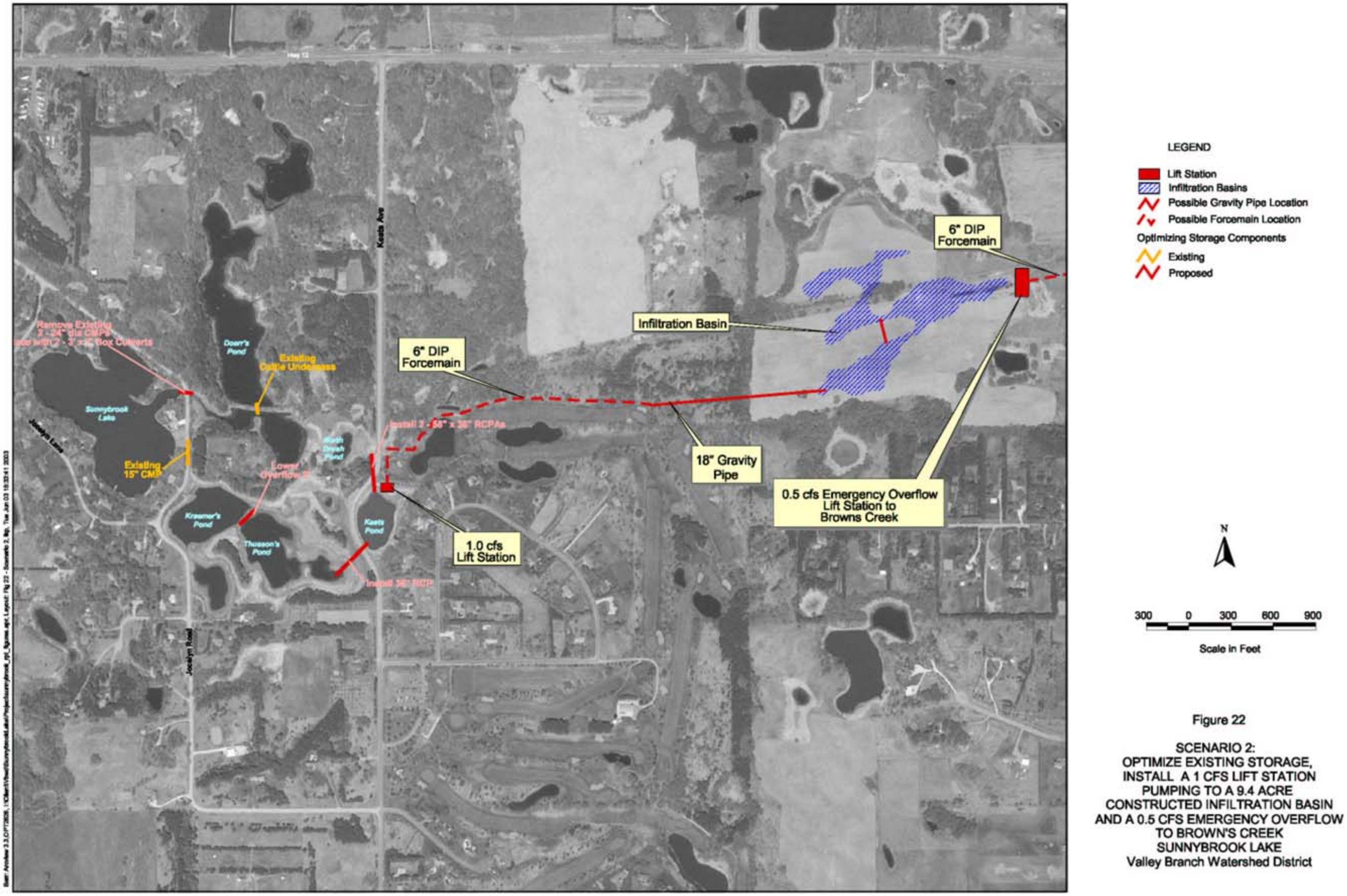


Figure 22

SCENARIO 2:
OPTIMIZE EXISTING STORAGE,
INSTALL A 1 CFS LIFT STATION
PUMPING TO A 9.4 ACRE
CONSTRUCTED INFILTRATION BASIN
AND A 0.5 CFS EMERGENCY OVERFLOW
TO BROWN'S CREEK
SUNNYBROOK LAKE
Valley Branch Watershed District

Figure 6.3.d. Conceptual Overflow Path to Brown's Creek.

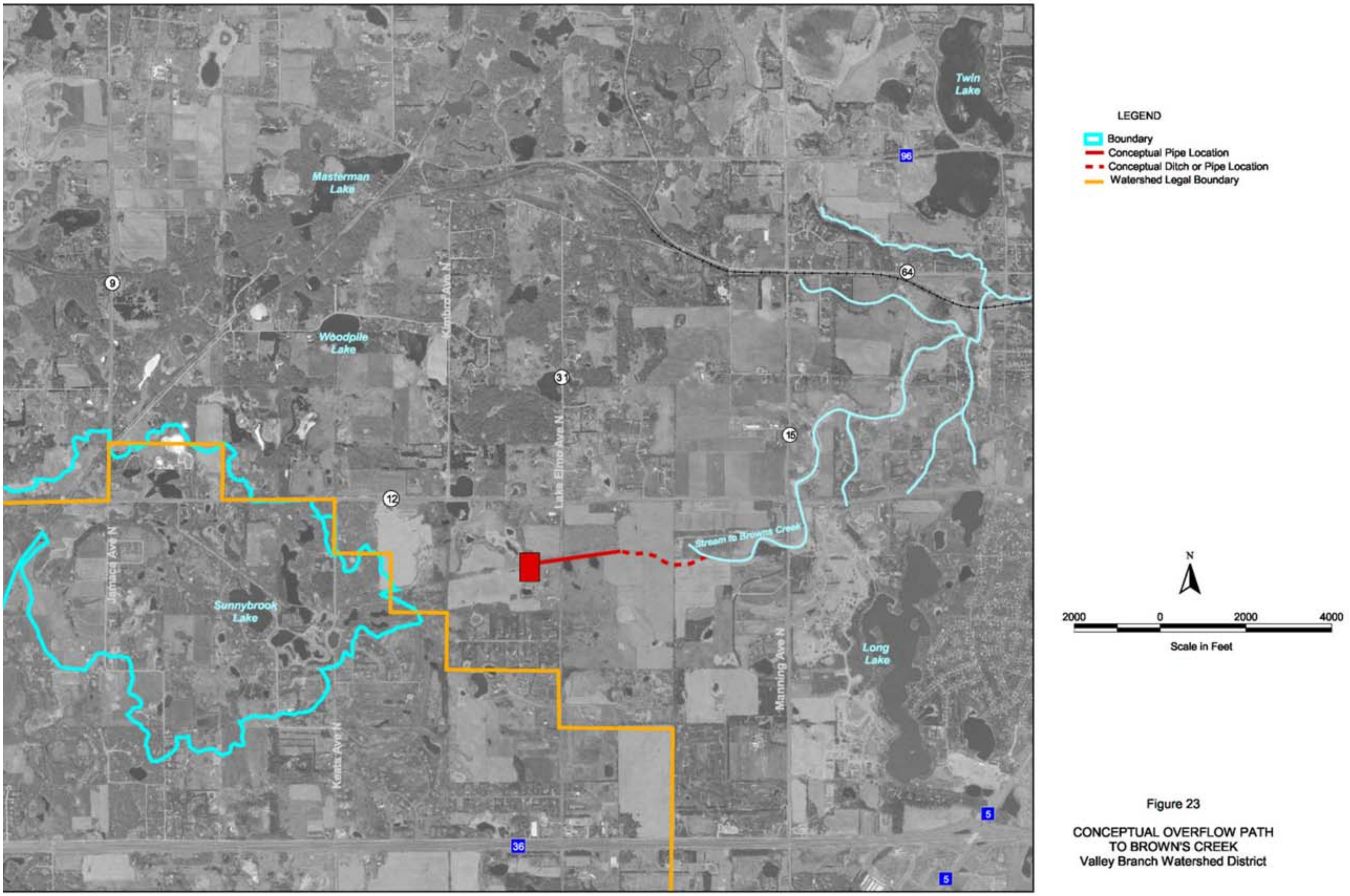


Figure 6.3.e. Scenario 3.

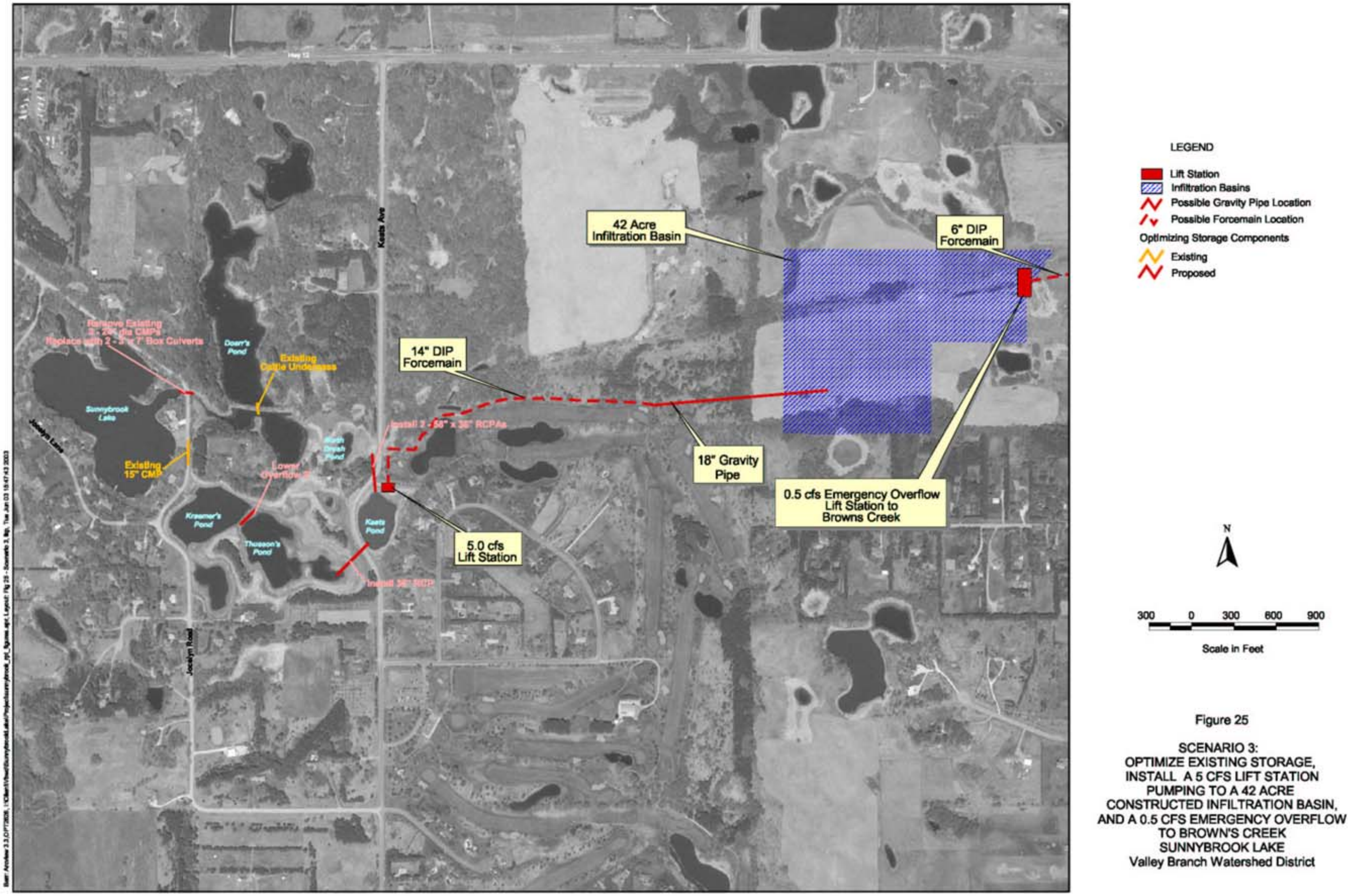


Figure 25

SCENARIO 3:
OPTIMIZE EXISTING STORAGE,
INSTALL A 5 CFS LIFT STATION
PUMPING TO A 42 ACRE
CONSTRUCTED INFILTRATION BASIN,
AND A 0.5 CFS EMERGENCY OVERFLOW
TO BROWN'S CREEK
SUNNYBROOK LAKE
Valley Branch Watershed District

Figure 6.3.f. Scenario 4.

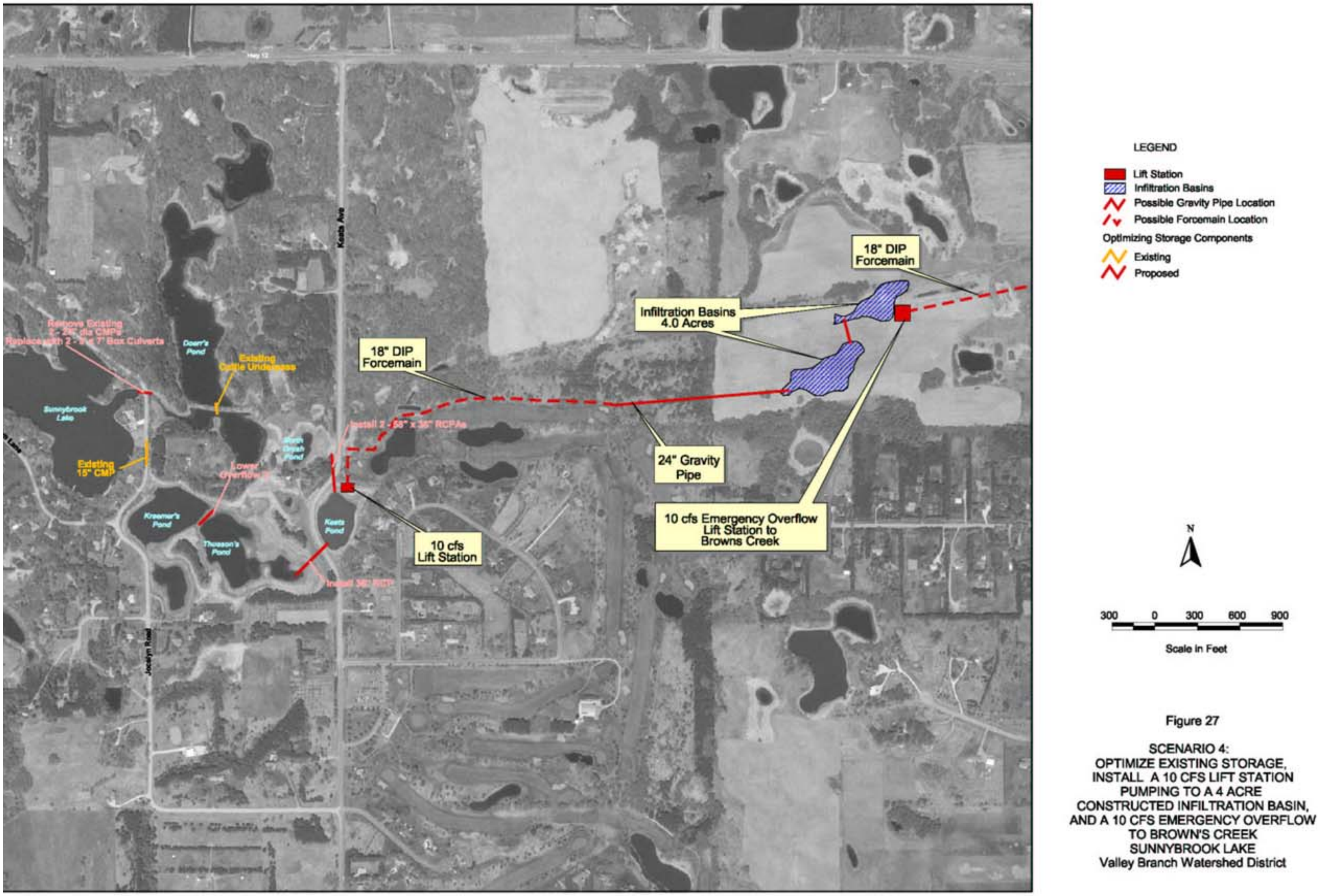
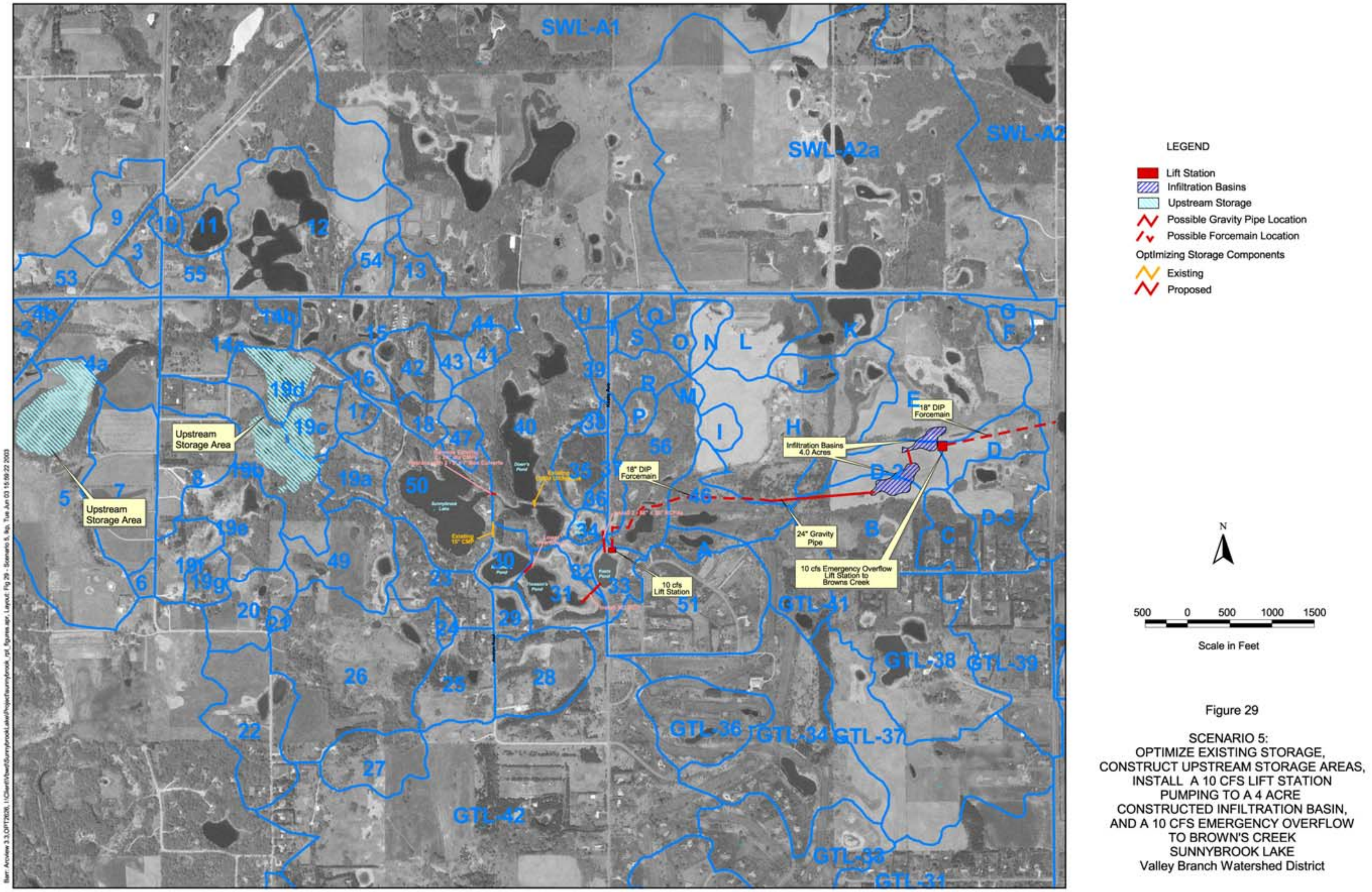


Figure 6.3.g. Scenario 5.



After the hydrologic and cost analyses, some of the alternatives were eliminated from consideration. Scenario 4 and Scenario 5 were not considered feasible because of the negative impacts they would likely produce on Brown's Creek; the 10-cfs pump of these alternatives would cause bank erosion and flooding at the creek. Scenario 1 only provided protection to one of the nine low homes, and Scenario 3 was estimated to be about 1.4 times more expensive than buying out the low homes. Therefore, these scenarios were also eliminated from consideration.

The only alternatives that provided protection to all of the homes are buying out all of the low homes, floodproofing all of the low homes, and Scenario 6. Scenario 6 is the same as Scenario 2 with floodproofing two low homes. The scenario involves optimizing existing storage between Doerr's Pond and Keats Pond, installing a 1 cfs lift station at Keats Pond, pumping water from Keats Pond to a new 9.4-acre infiltration basin within the proposed Indian Hills Golf Club, and constructing a 0.5 cfs emergency overflow lift station that would pump water to the east where it would ultimately drain into Brown's Creek near Manning Avenue and County Highway 12. The estimated costs of these alternatives are as follow:

Buying Out All Low Homes	$ 3.5 Million
Floodproofing All Low Homes	$ 1.7 Million
Scenario 6	$ 2.9 Million

Although Scenario 6 is an expensive solution to the problem at the Sunnybrook Lake neighborhood, the VBWD Managers say that it has several benefits. It would lower the 1% probability flood level enough to protect all but two homes and those homes would be floodproofed. The alternative would move the floodwaters out of the system, which in turn greatly shortens the duration of flooding in the neighborhood. Based on the 50-year simulated computer modeling, the duration of flooding above the low entry of the low home would go from the current 960 days to 12 days. The alternative would not prevent roads from flooding, but it would greatly reduce the duration of flooding.

The VBWD Managers also saw benefits in floodproofing. It is less expensive and it would not impact Brown's Creek. However, floodproofing would not reduce the duration of flooding or the probability of flooding.

The recommendations of the report included:

- The VBWD Board needs to determine an acceptable solution cost. If the VBWD Board prefers Scenario 6, but BCWD or other agencies refuse to allow it, the VBWD Board should not participate in any project within the Indian Hills Golf Club and should instead set up a floodproofing program similar to the VBWD's Project 1007 residual floodproofing program. A flood insurance educational program should also be implemented.

- Whichever alternative that is implemented to provide protection to the low homes at Sunnybrook Lake, the 1% probability flood level should be mapped on FEMA floodplain maps.

- The VBWD Board should also work with the City of Grant regarding the low roads in the area. Scenario 6 would lower the depth and duration of flooding at Keats Avenue and Jocelyn Road, but the roads would still be susceptible to up to about 2.4 feet of flooding.

The VBWD Managers preferred Scenario 6.

6.3. Timeline of Actions since the Completion of the Study

The draft report, *Sunnybrook Lake Flood Relief Feasibility Study*, was submitted to Brown's Creek Watershed District (BCWD) and Washington County on March 18, 2002. The VBWD Engineer met with Washington County staff, the BCWD administer, a BCWD manager, and DNR staff to review the study with them and answer their questions.

On March 25, 2002, two VBWD Managers and the VBWD Engineer presented the report to the BCWD Managers. The BCWD Managers requested that their engineering consultant review the report.

On March 28, 2002, the VBWD Managers approved a resolution to pay the BCWD engineering consultant to review the report. The VBWD Engineer met with BCWD's engineers on April 1 to discuss the study.

The VBWD Engineer and a VBWD Manager presented the report to the Washington County Commissioners at their regular meeting on Tuesday, April 2nd.

The BCWD engineers required that the VBWD collect additional soils information. The soils borings were completed on April 17, and the collected data was submitted to the BCWD engineers.

On May 23, two BCWD managers and the BCWD engineers attended a VBWD meeting and presented their findings. Although the BCWD engineers agreed that the emergency overflow from the Sunnybrook Lake area to Brown's Creek would not harm the creek, they would not endorse the VBWD Managers' preferred plan. Instead, the BCWD engineers recommended a more complex system of pumping water from the proposed infiltration basins to a wetland complex to the north and a wetland to the south.

The VBWD Managers directed their engineer to review the BCWD recommendations. By this time, the Indian Hills Golf Club expansion was on hold.

On July 11, the VBWD Engineer presented the VBWD Managers a review of the BCWD recommendations. In general, the VBWD Managers concluded that the BCWD recommendation would be more expensive, add additional roadblocks (and eliminate others), and give the VBWD Managers less control over potential flooding. The VBWD Managers directed the VBWD Engineer to evaluate the benefit of only optimizing the existing floodplain storage. The cost and benefits of this option were discussed with the Board in the fall. The Managers then directed the

District Engineer and Attorney to work with an appraiser to determine the cost of required easements. The appraiser prepared a preliminary cost estimate in December 2002.

As of July 16, 2003, the VBWD Managers are in the process of obtaining the necessary easements to make the modifications that will optimize the storage. In the future, the VBWD Managers will continue discussions with the owner of the once-proposed Indian Hills Golf Club expansion land in order to construct an infiltration basin on the land and construct the other phases of Scenario 6. The VBWD Managers will work with the City of Grant, BCWD, DNR, and other regulatory agencies to obtain the necessary permits for the project.

7. Cooperative Efforts

A key aspect of this project is the cooperative efforts among state and local governmental units. The project was initiated and funded by the BWSR, Washington County, local watershed districts, and the City of Stillwater. Consequently, these organizations and others should all benefit over time from the results of the project. The efforts described in this section show how various organizations have already made use of data and information from this project. Typically they have used the new information from this project as a baseline, or starting point, for their own investigations.

7.1. Brown's Creek Age Dating and Groundwater Inflow Study

7.1.1. Background

Brown's Creek runs from the north part of the City of Grant through Stillwater Township and the City of Stillwater, finally discharging to the St. Croix River. Brown's Creek receives a significant percentage of its base flow from groundwater. Flow volume in the creek increases from the Oak Glen golf course downstream through the Brown's Creek valley toward the St. Croix River. The creek cuts down through layers of bedrock as it moves downstream, from the Prairie du Chien through the Jordan and St. Lawrence, and finally into the Franconia formation at the St. Croix River. The groundwater flowing from these aquifers is relatively cool and clean and is critical to maintaining the native population of brown trout in the creek.

The temperature study completed by the DNR (Moeckel, 1999), indicates that cooler water temperatures in the lower reach of the creek were critical to the development of adolescent trout. The cool temperatures were found to be a result of increased groundwater inflow in this portion of the creek. The DNR is committed to preserving and protecting the Brown's Creek trout fishery, and are therefore concerned with groundwater flow to the creek. They have been working to study and monitor creek conditions, improve habitat along the creek, and assist local governmental units with management practices.

Dr. Jim Almendinger of the St. Croix Watershed Research Station collected samples from wells in the headwaters area of Brown's Creek, from wells near Brown's Creek, and from the creek itself. The samples were analyzed for tritium, deuterium, and ^{18}O to determine the age of the water. Results of this analysis have not yet been published, but Dr. Almendinger reports the following findings (personal communication, 5/20/2002):

- Samples from Quaternary wells and from the creek had high concentrations of tritium, indicating relatively recent water.
- Samples from the Jordan Aquifer had low concentrations of tritium, indicating older water or a mixture of recent and vintage water.
- One sample from a Prairie du Chien well in the headwaters area had no tritium, indicating vintage water (or a false negative analysis). This was surprising because recent water had been detected in the Jordan aquifer underlying the Prairie du Chien.

- Water in the Prairie du Chien and Jordan wells had characteristics similar to water that had recharged in upland areas rather than in lakes.

7.1.2. Monitoring

Monitoring that occurred in 2002 and 2003 was detailed in Chapter 3 and illustrated in Figure 3.2. All of the samples were analyzed for major cations and anions and alkalinity. Several sampling points were also analyzed for stable isotopes, tritium, or isotopes of Sr. Specific analytical results are included in the data section of the CD that accompanies this report. Collected data used specifically for this project are listed in Table 7.1.

Table 7.1. Monitoring Locations and Type.

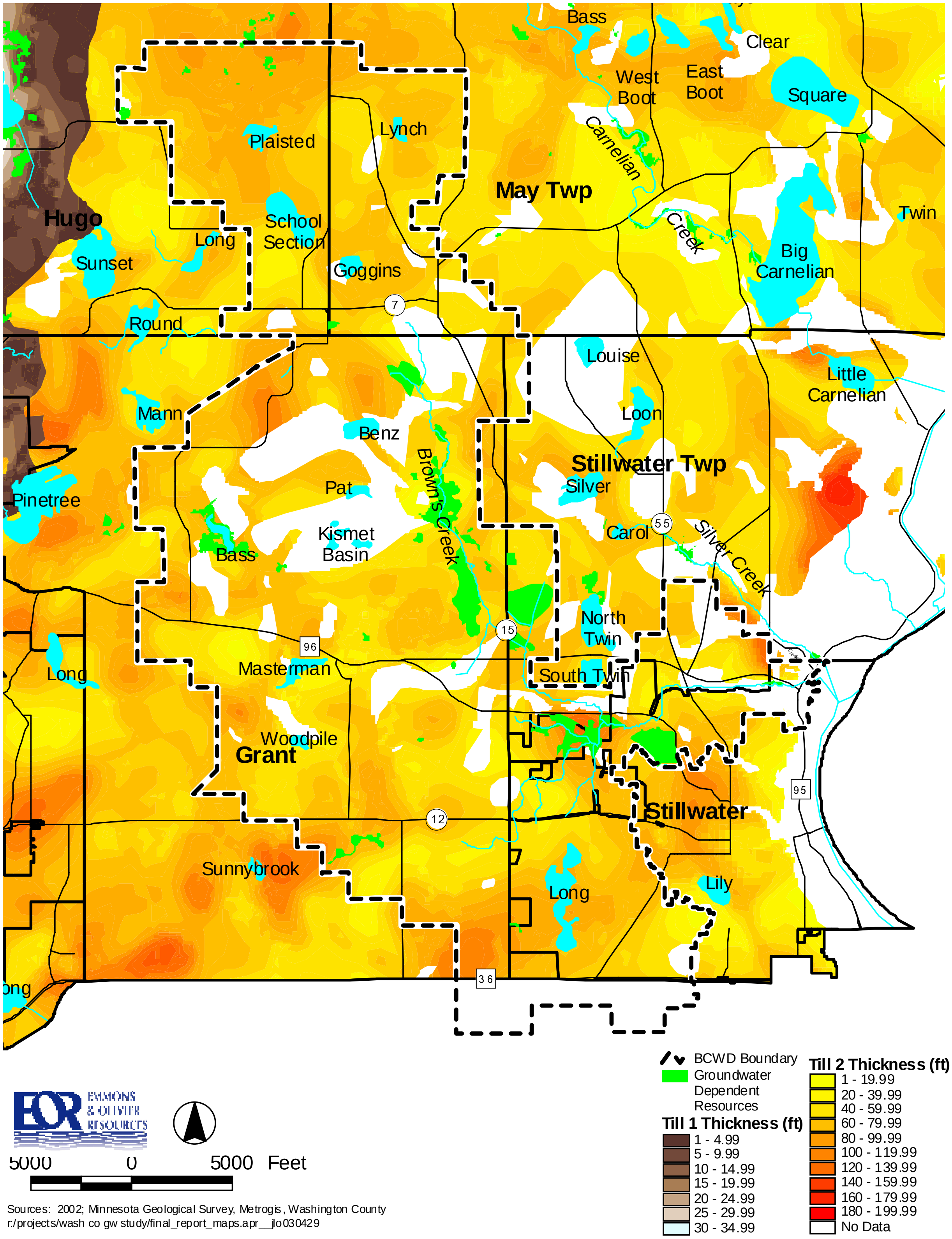
Location	Water source	Analyses
Upper watershed	Goggins Lake	Stable isotopes
Lower watershed	South Twin Lake	Stable isotopes
Brown's Creek lower reach	CJDN spring	Tritium, stable and Sr isotopes
Lower watershed, DNR nested observation well	CFRN aquifer	Tritium, stable isotopes
Lower watershed, DNR nested observation well	QBAA aquifer	Tritium, stable isotopes
Upper watershed, residential well	OPDC aquifer	Tritium, stable and Sr isotopes
Upper watershed, residential well	CJDN aquifer	Tritium, stable and Sr isotopes
Upper watershed, residential well	CFRN aquifer	Tritium, stable and Sr isotopes
Lower watershed, residential well	OPDC aquifer	Tritium, stable isotopes
Lower watershed, residential well	CJDN aquifer	Tritium, stable isotopes
Lower watershed, residential well	CFRN aquifer	Tritium, stable and Sr isotopes

7.1.3. Chemistry Results

In the upper watershed, wells typically had higher Mg:Ca ratios and lower tritium levels than in the lower watershed. This indicates lake recharge and a mixing of recent and vintage water. In the lower watershed, lower Mg:Ca ratios and higher tritium levels indicate upland and recent recharge.

The spring sampled at Brown's Creek discharges from the Jordan Sandstone bedrock unit. The water had high enriched tritium levels and low Mg:Ca ratio, indicating relatively recent recharge. The water was soft and had a low Mg:Ca ratio, indicating it had chemistry similar to surface water rather than groundwater that had traveled long distances through an aquifer. Adjacent South Twin Lake had similar chemical characteristics, indicating a possible hydrologic connection between the lake and the springs. This connection could be due in part to a till hole located to the southeast, or downgradient side, of the lake, as shown on Figure 7.1. Till holes can act as a conduit, in this case, from the lake to spring. This chemical data, in addition to the geographic setting, indicate recharge is occurring locally to Brown's Creek.

Figure 7.1. BCWD Location Map and Till Thickness Map



Sources: 2002; Minnesota Geological Survey, Metrogis, Washington County
r:/projects/wash co gw study/final_report_maps.apr__jlo030429

7.2. Carnelian Creek Landlocked Basin Study

7.2.1. Background

Modeling of landlocked basins is a technique that holds promise for evaluating groundwater and surface water interactions. However, the currently available modeling methods have not produced reliable results. A "Landlocked Basins Pilot Study" (Washington County, 2002) attempted to model and predict water levels in landlocked basins for Federal Emergency Management Agency (FEMA) flood insurance mapping. They used a "Daily Time Step Hydrologic Model" and a "Monthly Water Budget Model". One conclusion of the report was that when lake levels were "highly dependent" on groundwater, these modeling methods did not work well, at least without more groundwater data. Therefore, in order to understand and evaluate landlocked basins, the groundwater contribution to the system must be evaluated.

Washington County contracted with CMWD to determine flood elevations for lakes in landlocked basins within the watershed. The lakes analyzed as part of the study were German, Fish, Rasmussen Pond, Barker, Maple Marsh, Staples, East Boot, and West Boot. For some of the lakes, "standard" modeling methods were adequate. That is, groundwater was not a significant part of the lake hydrology. Some models only required a constant exchange of groundwater to or from the lake. For the recharge lakes, head-dependent movement of water from the lake into groundwater was added to the model. For the high-connection lakes, time-dependent movement of water between the lake and groundwater (based on long-term regional groundwater elevation fluctuations) was added to the model. In each case the groundwater input to the model was based on observed geologic and hydrogeologic data from the North Washington County Groundwater Study, and in each case calibration of the model was improved

7.2.2. Groundwater Inputs to the Models

The function of each lake in this study was determined using the methodology discussed in Chapter 4. German Lake and Rasmussen Pond did not have significant amounts of water level data, making correlations to groundwater and precipitation impractical. Therefore, the function of these water bodies was assumed to be similar to neighboring lakes in the same geologic setting. Rasmussen Pond sits between Big Marine Lake, Jellum's Bay, and Fish Lake. These adjacent lakes are classified as flow-through lakes. Additionally, Rasmussen Pond has identified groundwater dependent natural resources and a groundwater discharge point in its immediate vicinity. Therefore, Rasmussen Pond was classified as a flow-through lake.

German Lake sits on the edge of the St. Croix Moraine and has groundwater dependent natural resources on the groundwater upstream and downstream sides of the lake. In this way, it is similar to Sylvan Lake in the CLFLWD, which also sits on the edge of the St. Croix Moraine and has groundwater dependent natural resources on the upstream and downstream sides of the lake. Lake level fluctuations of Sylvan Lake were found to correlate with groundwater fluctuations and correlated better with five-year trends in precipitation. Sylvan Lake was therefore classified as a high flow-through lake. Because of the similarities between German and Sylvan Lakes, German Lake was classified as a high flow-through lake.

Groundwater input and output were calculated for Fish Lake. Mini-piezometer measurements taken at Jellum's Bay indicate that water outflows on the west side of the lake into the sand and gravel esker (a remnant glacial feature) that abuts the lake on that shore. Because the west shore of Fish Lake also abuts the esker, it was assumed that Fish Lake also outflows into the esker. Groundwater was assumed to inflow to the lake from the east. Using a Darcy's Law equation, an appropriate hydraulic conductivity for sand and gravel, and half the surface area of the lake, outflow was calculated in cubic feet per second (cfs). Gradient was calculated from the elevation difference between Fish Lake and Jellum's Bay and was used in both inflow and outflow equations. The result was a net outflow of 2.7 cfs.

7.2.3. XP-SWMM Model Construction

XP-SWMM hydrologic models of lakes in the CMWD were created to estimate 100-year flood elevations for use in flood mapping by Washington County.

Models were constructed using Green-Ampt infiltration methodology, which uses saturated hydraulic conductivity, initial moisture deficit, and average capillary suction pressure to determine runoff from a watershed. These parameters for lake watersheds were determined by overlaying land cover and soils information in a GIS database developed as part of the CMWD natural resource inventory.

The watershed boundaries and subwatersheds were delineated based on Washington County 2000 two-foot contour mapping. Area, width, slope, and stage-storage for each subwatershed were determined from the contour map. Depressions not explicitly defined by the stage-storage were incorporated into the depression storage depth parameter in the model. Impervious surface percentages were determined from land cover information in the GIS database. Overflow elevations and channel cross-sections and lengths were determined for each subwatershed from the contour map. Information for existing culverts, including invert elevations, was obtained from the CMWD structure inventory and field verified.

7.2.4. XP-SWMM Simulations for German Lake.

Analysis and results for German Lake are presented as an example of the model work performed on lakes in this study.

7.2.4.1. Long-Term Continuous Simulation

German Lake is a landlocked basin and the DNR, as the agent for FEMA, recommended calibrating a model to measured lake levels and running a 50- to 55-year continuous simulation to predict 100-year flood elevations for landlocked basins. Based on this recommendation, a 55-year simulation was performed with rainfall and temperature data from 1948 to 2002. Data were taken from the Stillwater weather station, which was the closest station with a data record of sufficient length.

Lake levels for German Lake were not collected on a regular basis prior to 2003 so the model was calibrated to two lake level readings taken in 1986 and a 2000 water level determined from

Washington County two-foot contour maps. The model was calibrated by adjusting the lake infiltration rates until lake levels were within ±1 foot of the 1986 and 2000 water levels. The ordinary high water level (OHW) of 955.5 feet, established by the DNR, was used as the starting water elevation.

To determine the lake elevation for a 100-year flood event, a statistical analysis was performed on the annual maximum water elevations, based on the Log-Pearson III distribution, which is commonly used in flood-frequency analysis. To reduce the effects of the starting water elevation on the results, the first five years of the simulation from 1948 to 1952 were not used in the analysis.

7.2.4.2. Single Event Simulations.

Since there is a lack of lake level monitoring data prior to 2003, confidence in the long-term analysis is lower due to the lack of calibration data. Therefore, the 100-year 10-day rainfall and snowmelt events were also simulated to provide additional information for determining the 100-year flood elevation. The 100-year 10-day snowmelt event is the current CMWD accepted methodology for establishing the 100-year flood elevation of a landlocked basin. The 100-year 10-day rainfall event was simulated by a 10.8-inch rainfall and summer impervious values. The 10-day snowmelt was simulated by a 7.3-inch runoff event with 100 percent impervious surfaces to represent frozen ground. These simulations also used the OHW level of 955.5 feet as the starting water elevation.

7.2.5. Results for German Lake.

As shown in Table 7.2, which summarizes the results of the model simulations, the 100-year flood elevation is highest for the 10-day snowmelt, which therefore becomes the critical event. Results from the 50-year continuous simulation fall in between the 10-day rainfall and 10-day snowmelt, with an elevation 0.9 ft lower than the 10-day snowmelt. Based on these results, the 100-year flood elevation would be 958.7 feet, and the required lowest floor elevation for a building will need to be at least three feet above this flood elevation.

Table 7.2. Comparison of 100-year flood elevations.

Basin	Starting Water Surface Elevation (ft)	Basin Overflow Elevation (ft)	100-year Flood Elevation (ft)		
			50-year continuous simulation	10-day rainfall (10.8 inches)	10-day snowmelt (7.3 inches)
German Lake	955.5	971.0	957.8	956.6	**958.7**

7.3. Hardwood Creek Baseline Assessment and Restoration Study

7.3.1. Background

The Hardwood Creek area (also known as Judicial Ditch 2 or JD2) has been designated as an area for on-going monitoring of surface water and groundwater. Project Task Mon-4 called for ongoing monitoring to demonstrate the effectiveness of policies coming from this project.

7.3.2. Characteristics.

Hardwood Creek flows from the north end of Rice Lake in Hugo. It flows northward through predominantly wetland areas. North of 170th Street, the creek turns west and ultimately discharges to Lake Peltier (Anoka County) and the Mississippi River.

In the upstream areas within the City of Hugo, a number of springs are evident flowing into Hardwood Creek. Among these are the springs along the southern shore of Rice Lake, the "Tingley Springs" area to the northeast between 165th and 170th Streets, and numerous small springs entering the banks of the creek and nearby wetlands. In many cases the springs can be easily identified by the red-orange color of precipitating iron near the discharge point.

Hardwood Creek has been extensively dredged and straightened from the headwaters area to the area near Harrow Avenue in Forest Lake. The ditching was done to drain the surrounding area for agriculture. Minimal maintenance has been done on the ditch since about 1985. New culvert crossings were recently constructed at 157th, 165th, and 170th Streets and Harrow Avenue.

7.3.3. Monitoring Well Installation.

Five sets of monitoring wells were installed in the area of Hardwood Creek. The following organizations contributed to the installation, monitoring and sampling of the wells:

- RCWD (monitoring equipment, installation costs, and on-going monitoring);
- DNR (well drilling);
- University of Minnesota (well sampling and analysis); and
- Washington County and the sponsors of this study (well materials).

Well locations are shown on Figure 3.4. Wells were located at the intersection of Hardwood Creek and 157th St., 165th St., 170th St., and Harrow Avenue, and in the Hardwood Creek Wildlife Management Area (WMA). The well locations along the creek were selected to monitor the influence of new culvert installations on groundwater and wetland conditions. The wells located in the Hardwood Creek WMA monitor "background" regional conditions.

Well logs are included in Appendix E. Shallow wells (approximately 15 ft deep) were screened to monitor the water table. Deeper wells (approximately 30 feet deep) were screened to monitor deeper sand deposits (if encountered) and to provide data regarding vertical gradients.

7.3.4. Groundwater Flow and Chemistry.

Groundwater is a significant part of the hydrology of the Hardwood Creek area. Springs in the area contribute to the baseflow of the creek. The upward gradient noted in the nests of monitoring wells above indicates that groundwater is flowing vertically upward in the immediate area of the creek and discharging to the creek and wetlands.

Groundwater flow paths can be determined by examining the groundwater contour maps found previously on Figures 3.9 through 3.13. A generalized cross-section of the headwaters area is shown on Figure 7.2. Groundwater in the Quaternary deposits flows from high areas along the St. Croix Moraine to the east toward the creek. Groundwater elevations are higher in the Quaternary aquifers than in the underlying bedrock aquifers (St. Peter Sandstone and Prairie du Chien Group). The infiltration potential map shown in Figure 4.5 shows areas with sandy soils and high infiltration potential along the moraine area. Rainfall in these areas recharges the Quaternary aquifer, which in turn recharges the lower bedrock aquifers. Groundwater movement is likely predominantly vertical with some horizontal movement along relatively impermeable Quaternary deposits such as till layers.

Mapping of the till units by the MGS indicates several areas where Till 2 (Superior Lobe till) is absent. These “till holes” appear as white areas on Figure 2.7. Presumably the till holes provide high-permeability, preferential flow paths for vertical flow of groundwater. Note that the vertical flow may be either upward or downward depending on the head gradients.

Figure 7.3 indicates wetlands and other groundwater-dependent resources along the contour of the thickness of Till 1 (Des Moines Lobe till.) The Tingley Springs area corresponds to a till hole in Till 2. The thickness of till seems to correspond with groundwater flow and the occurrence of groundwater-dependent resources, but further study is required to fully understand this relationship. Chapter 8 discusses further the potential for till hole study.

Groundwater samples were collected from the monitoring wells along Hardwood Creek and several nearby residential wells (See Figure 3.4). The samples were analyzed for major anions and cations.

Figure 7.2. Generalized Cross Section – Hardwood Creek Area.

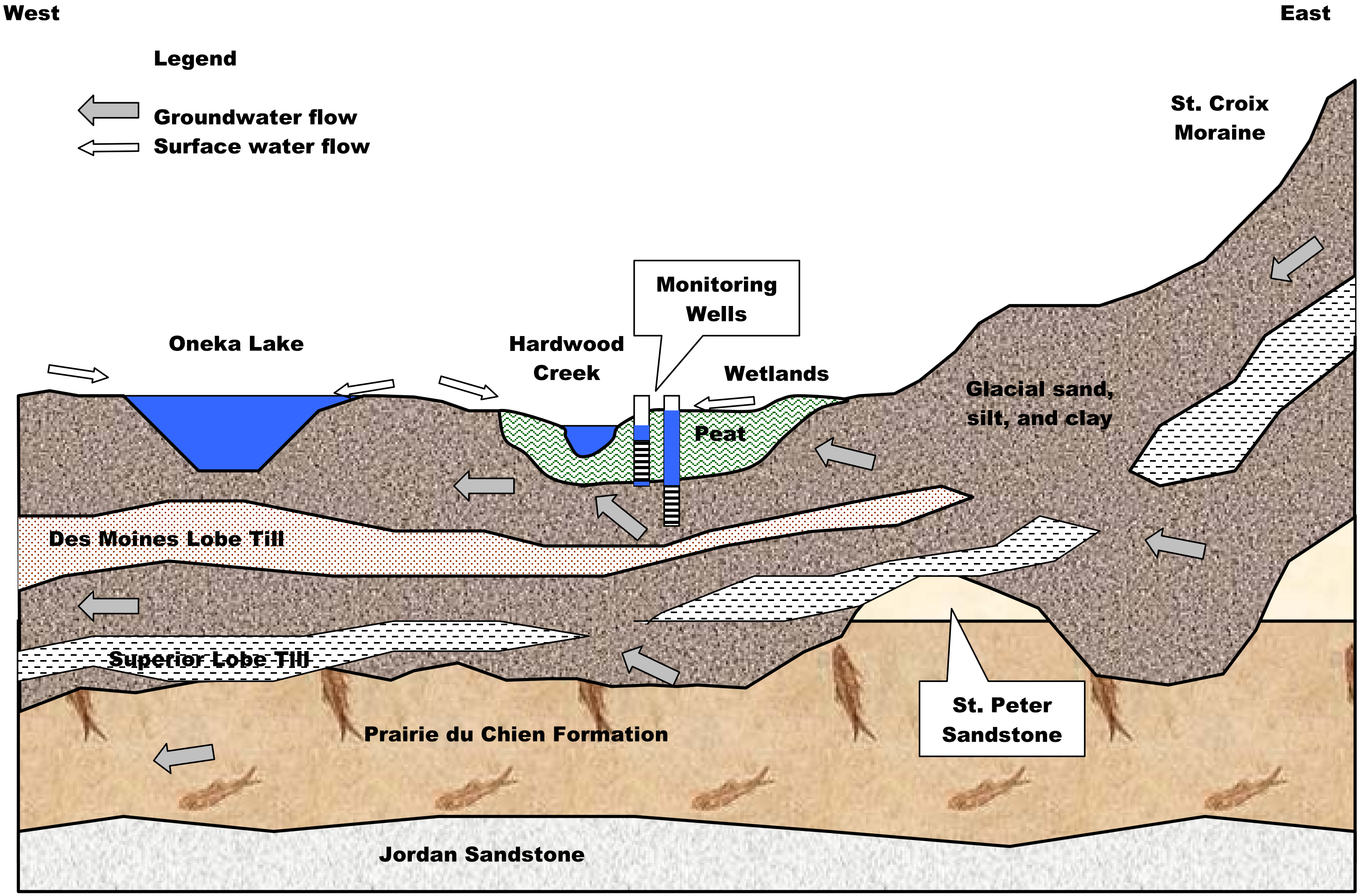
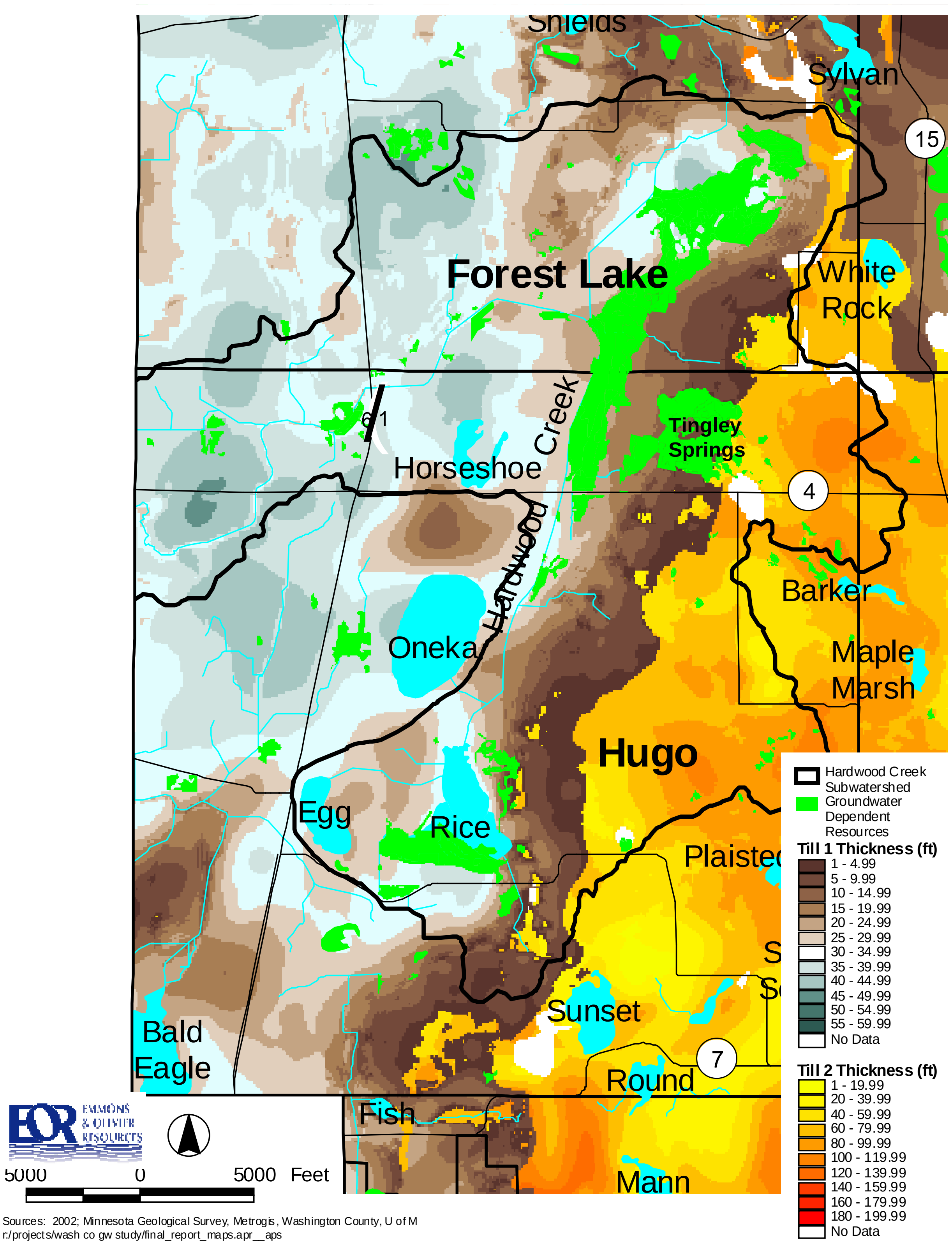


Figure 7.3. Till Thickness and Groundwater Dependant Natural Resources



Sources: 2002; Minnesota Geological Survey, Metrogis, Washington County, U of M
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Iron (Fe) concentrations give an indication of changes in the character of groundwater along the flowpath toward Hardwood Creek. Iron concentrations in Quaternary aquifer wells away from the creek have concentrations typical of wells throughout northern Washington County (0.5 to 1.5 ppm.) As groundwater flows toward the creek, it becomes increasingly oxygenated. The iron in the water becomes oxidized, creating iron oxides that precipitate. Iron concentrations in deep wells by 170th Street and the WMA have no detectable iron because it has precipitated. As groundwater moves upward through the peat toward the creek, the decaying plant material in the peat removes oxygen from the water, creating a reduced condition. Iron in the peat becomes soluble under these conditions and is carried by the groundwater to the surface. At the surface, the iron comes in contact with oxygen again and precipitates, as indicated by the red-stained soils found near springs along the banks of Hardwood Creek.

This reducing environment also lowers Mg:Ca ratios. Samples taken at Hardwood Creek had low Mg:Ca ratios and high strontium levels. These data indicate groundwater is a significant contributor to the creek.

Because the upstream areas of the creek are flat and slow-moving, the water is oxygenated slowly compared to fast-moving creeks with lots of riffles. The contribution of low-oxygen groundwater to the water budget of the creek should be considered when making policy decisions related to dissolved oxygen concentrations.

7.3.5. Outcomes

Washington County, the WCD, and RCWD will continue to monitor precipitation, surface water, and groundwater according to the monitoring plan included with this report. Washington County will also monitor and report on how this information influences policy decisions. Specifically, they will report on how groundwater/surface water interactions influence management of JD2 for drainage and flood control and influence the Total Maximum Daily Load (TMDL) program currently being developed.

7.4. Lower St. Croix River Spring Creek Stewardship Plan

7.4.1. Background

This project was funded in part by the BWSR, MWMO, CMWD, and New Scandia Township. Participants also included the Mill Stream Association; the University of Minnesota Dept. of Entomology, Dept. of Geology and Geophysics, and Dept. of Plant Biology; MGS; Science Museum of Minnesota - St. Croix Research Station; Washington County Dept. of Public Health and Environment; DNR; and National Park Service. The goal of this project is to facilitate effective management strategies for groundwater dependent resources in the Lower St. Croix Valley. In addition, key stewardship strategies and landscape based policy recommendations are identified to improve and protect the natural resources of these individual systems and ultimately the Lower St. Croix River. It is intended that future watershed planning efforts will use the data and findings of this report toward the development of a 2nd Generation Watershed Plan. Many of the management strategies identified and described in this report can also provide the basis for development of watershed protection standards.

Due to the nature and geology of the landscape, groundwater recharge to Quaternary and bedrock aquifers and groundwater discharge to seeps and spring creeks are dominant features of the hydrologic system. These spring creeks and their associated ecosystems harbor a disproportionate share of unique and rare natural communities, flora and fauna found near the Twin Cities Metro Area.

As urban areas in the Lower St. Croix River Valley expand, associated land cover changes and increases in ground water consumption pose a threat to water quality. As populations grow, watershed districts and other local governments will be faced with the challenge of managing water resources and will need the key information necessary to manage and protect groundwater and the resources dependent on them.

The ubiquitous spring creeks and seeps located along the bluffs of the St. Croix River are not only unique and important community resources for residents that reside in northern Washington County, they also are crucial to the overall health of the St. Croix River. Considered to be headwater systems, this network of small streams that blanket the repetitive landscape of the St. Croix River are like the capillary system of the watershed.

As headwater streams, the spring creeks serve as a portion of the base of the St. Croix River's food web and are a critical food source for the river. Due to their intimate connection to the surrounding landscape, these creeks deliver nutrients and organic material, such as fallen leaves, to downstream regions, supplying essential food resources to aquatic life.

The spring creeks also influence downstream conditions in numerous ways. In addition to providing food, these creeks provide materials such as water and sediments, essential to the river's health, while at the same time controlling the quantity of these materials. Interconnected with wetlands, groundwater, and subsurface flow, the creeks also help regulate the natural flow of the St. Croix River and are critical flood controls.

In addition to their downstream influences, headwater streams are also important in their own right as geologically and biologically distinctive and diverse ecosystems. As this report documents, these spring creeks and their associated watersheds support rich and varied communities of plants and animals, many of which are not found elsewhere in the Twin Cities Metro Area.

With little known about the hydrologic systems that feed groundwater to these ubiquitous spring creeks, and little known about how changes in the landscape may impact the ecology of these systems, the Lower St. Croix River Spring Creek Stewardship Plan focused on defining the interconnection of groundwater and surface water systems in this portion of Washington County. The study also focused on gaining a better insight into the unique groundwater dependent resources associated with the Lower St. Croix River Valley.

Twenty-one spring creeks were extensively monitored from Stillwater to the Chisago County line. Data collected included groundwater chemistry data, groundwater discharge points, thermal imagery, in-stream data (biological, chemical, and physical), and riparian and upland vegetation.

7.4.2. Chemistry Results

The majority of the springs sampled along the St. Croix discharge from Franconia and Jordan bedrock units. The springs are illustrated in Figure 3.14. In the area identified as the Upper St. Croix, springs have moderately high Cl and high Br concentrations indicating that water in the springs is recharged by precipitation falling in upland (as opposed to lake or wetland) areas to the west. The recharge migrates through the Superior Lobe till before being discharged at the springs. Some human impacted waters were found, evident by Cl:Br ratios of about 1000:1. In Middle St. Croix, the majority of springs had slightly higher Mg:Ca ratios, indicating that recharge of the water could be coming from a nearby lake or lakes, possibly in the area of Big Marine, Square, or the Carnelian Lakes, depending on spring location. In two springs, low Mg concentrations and a moderate Mg:Ca ratio indicates that recharge is from more upland (as opposed to lake or wetland) areas. Two other springs appear to be a mixture of groundwater recharged in upland and lake areas. The Mg concentrations are relatively high and the Mg:Ca ratio is relatively high, indicating probable recharge from a lake. Cl concentrations range from relatively high to low, indicating some human impacts. In the Lower St. Croix, springs had high Mg concentrations and high Mg:Ca ratio suggesting that the springs are recharged by lake water.

7.4.3. Biology Results

Groundwater plays a significant role in defining the unusual qualities of the spring creeks sampled. Those systems that are predominantly groundwater fed were not necessarily the most biologically diverse systems but had populations of the most unusual biological taxa. This included 44,953 samples collected, 147 taxa identified, three new species of chrinomidae, and a rediscovery of *Parapsyche*, which was thought to be no longer found in the State of Minnesota, and several rare bryophytes known only to exist in northern Minnesota.

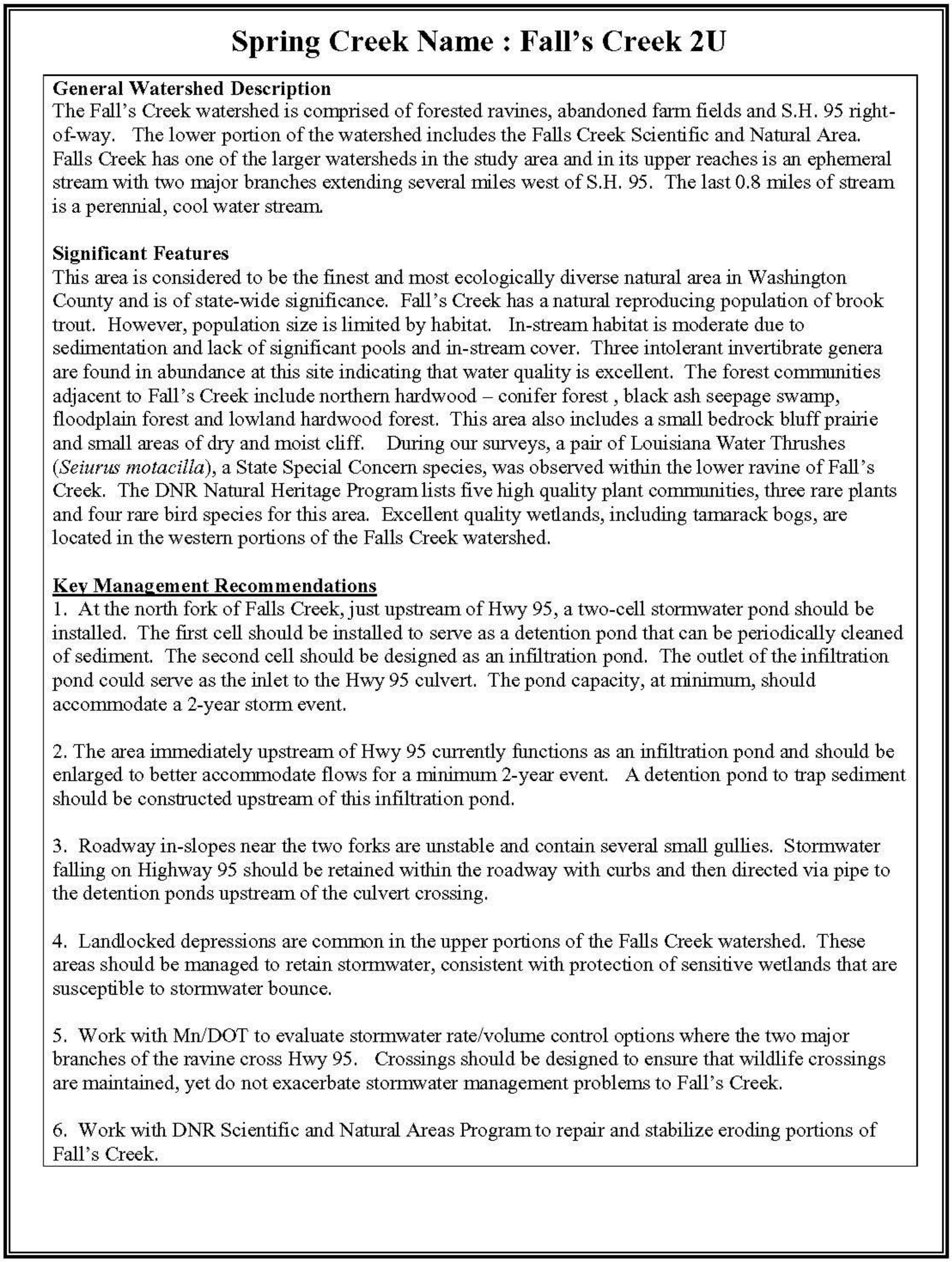
7.4.4. Neighborhood Meetings

As part of the study, five neighborhood meetings were conducted. Within each neighborhood group, a meeting was held to discuss the findings of the study and possible recommendations for resource protection. These neighborhood meetings were conducted as a collaborative effort with the Minnesota Department of Natural Resources Neighborhood Wilds Program. The Neighborhood Wilds Program is designed to help metro area residents understand, protect, and restore the natural resources in their neighborhoods. The program aims to link and buffer existing natural areas by coordinating landscaping and land management among neighbors.

7.4.5. Outcomes

One outcome of the study was the creation of spring creek fact sheets. The sheets give a brief, yet complete description of the site, describe significant features, discuss management and policy recommendations, and summarize collected data. Figure 7.4 illustrates one of the fact sheets (Falls Creek) included in the report.

Figure 7.4. Spring Creek Fact Sheet.



Spring Creek Name : Fall's Creek 2U

General Watershed Description
The Fall's Creek watershed is comprised of forested ravines, abandoned farm fields and S.H. 95 right-of-way. The lower portion of the watershed includes the Falls Creek Scientific and Natural Area. Falls Creek has one of the larger watersheds in the study area and in its upper reaches is an ephemeral stream with two major branches extending several miles west of S.H. 95. The last 0.8 miles of stream is a perennial, cool water stream.

Significant Features
This area is considered to be the finest and most ecologically diverse natural area in Washington County and is of state-wide significance. Fall's Creek has a natural reproducing population of brook trout. However, population size is limited by habitat. In-stream habitat is moderate due to sedimentation and lack of significant pools and in-stream cover. Three intolerant invertibrate genera are found in abundance at this site indicating that water quality is excellent. The forest communities adjacent to Fall's Creek include northern hardwood – conifer forest , black ash seepage swamp, floodplain forest and lowland hardwood forest. This area also includes a small bedrock bluff prairie and small areas of dry and moist cliff. During our surveys, a pair of Louisiana Water Thrushes (*Seiurus motacilla*), a State Special Concern species, was observed within the lower ravine of Fall's Creek. The DNR Natural Heritage Program lists five high quality plant communities, three rare plants and four rare bird species for this area. Excellent quality wetlands, including tamarack bogs, are located in the western portions of the Falls Creek watershed.

Key Management Recommendations
1. At the north fork of Falls Creek, just upstream of Hwy 95, a two-cell stormwater pond should be installed. The first cell should be installed to serve as a detention pond that can be periodically cleaned of sediment. The second cell should be designed as an infiltration pond. The outlet of the infiltration pond could serve as the inlet to the Hwy 95 culvert. The pond capacity, at minimum, should accommodate a 2-year storm event.

2. The area immediately upstream of Hwy 95 currently functions as an infiltration pond and should be enlarged to better accommodate flows for a minimum 2-year event. A detention pond to trap sediment should be constructed upstream of this infiltration pond.

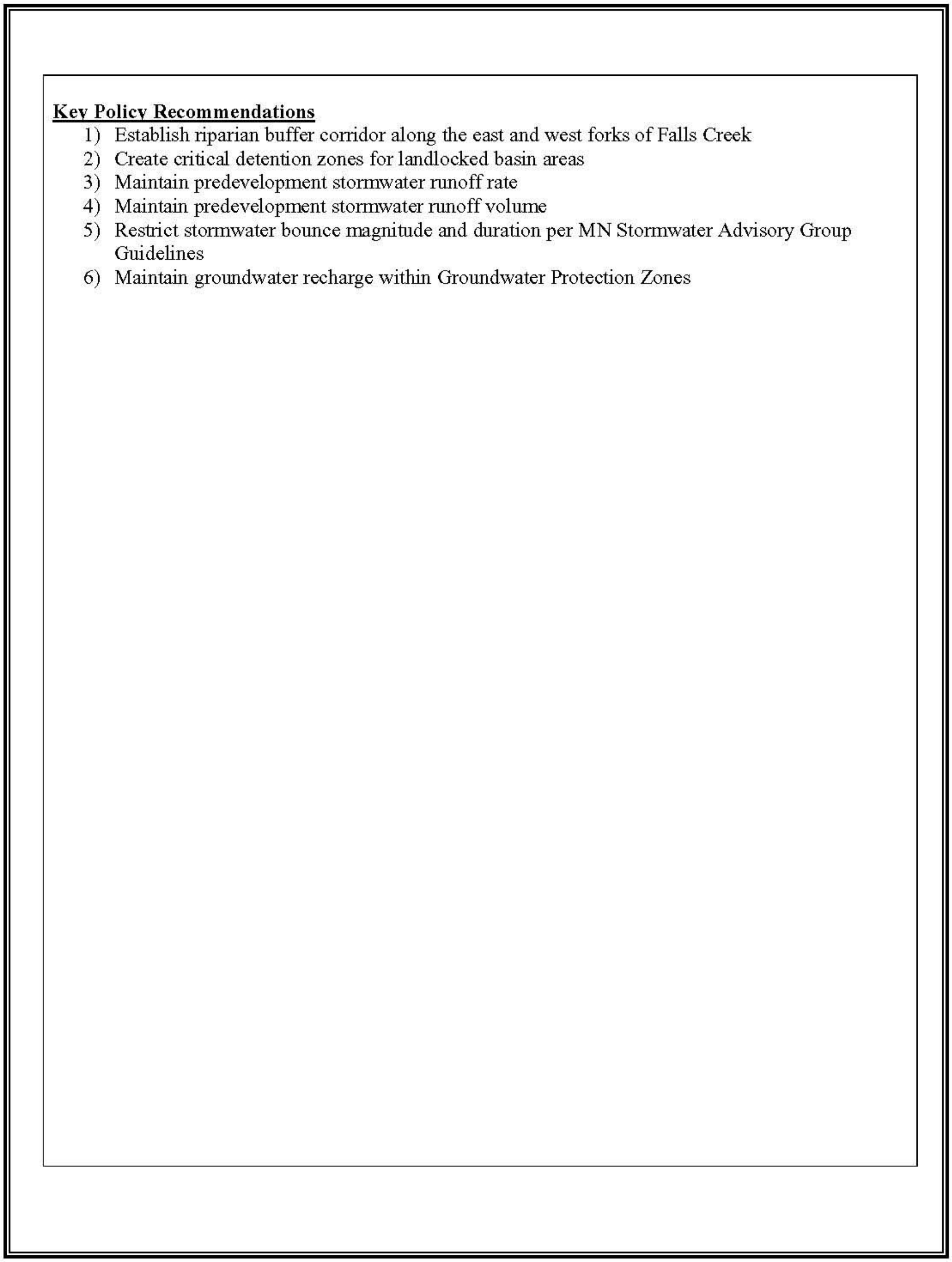
3. Roadway in-slopes near the two forks are unstable and contain several small gullies. Stormwater falling on Highway 95 should be retained within the roadway with curbs and then directed via pipe to the detention ponds upstream of the culvert crossing.

4. Landlocked depressions are common in the upper portions of the Falls Creek watershed. These areas should be managed to retain stormwater, consistent with protection of sensitive wetlands that are susceptible to stormwater bounce.

5. Work with Mn/DOT to evaluate stormwater rate/volume control options where the two major branches of the ravine cross Hwy 95. Crossings should be designed to ensure that wildlife crossings are maintained, yet do not exacerbate stormwater management problems to Fall's Creek.

6. Work with DNR Scientific and Natural Areas Program to repair and stabilize eroding portions of Fall's Creek.

Figure 7.4. (continued) Spring Creek Fact Sheet.



Key Policy Recommendations

1) Establish riparian buffer corridor along the east and west forks of Falls Creek
2) Create critical detention zones for landlocked basin areas
3) Maintain predevelopment stormwater runoff rate
4) Maintain predevelopment stormwater runoff volume
5) Restrict stormwater bounce magnitude and duration per MN Stormwater Advisory Group Guidelines
6) Maintain groundwater recharge within Groundwater Protection Zones

Figure 7.4. (continued) Spring Creek Fact Sheet.

Spring Creek Name : Fall's Creek 2U

Watershed Size 1967.35 acres
Total Stream Length mile
Stream Type

Unstable, incised, highly erodible channel primarily comprised of an unconsolidated, heterogeneous mixture of gravel, some small cobble, and sand.

Land Cover Category	%
Grassland	**28.20**
Agricultural Land	**14.34**
Forest and Woodlands	**36.53**
Lakes and Open Water Wetlands	**0.46**
Maintained Natural Areas	**0.21**
Wetlands	**10.13**
0%-10% Impervious Cover	**5.25**
11%-25% Impervious Cover	**3.16**
26%- 50% Impervious Cover	**1.7**
51%-75% Impervious Cover	**0**
6%-100% Impervious Cover	**1.57**

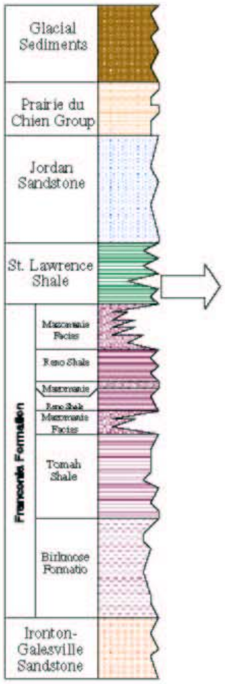
Macroinvertebrate Data

Metric	Score	Among Springs Mean[c]
Chironomidae Species Richness	20	21
Invertebrate Taxa Richness	33	31.75
HBI	4.61	4.4
%EPT	41.55	36.9
% Dominance	32.42	35.5
Most Common Families	Midges, Black Flies and Small Minnow Mayfly	

Hydrology

Base flow	1.98 cfs
Estimated Bank full flow	5.94 cfs

Groundwater source



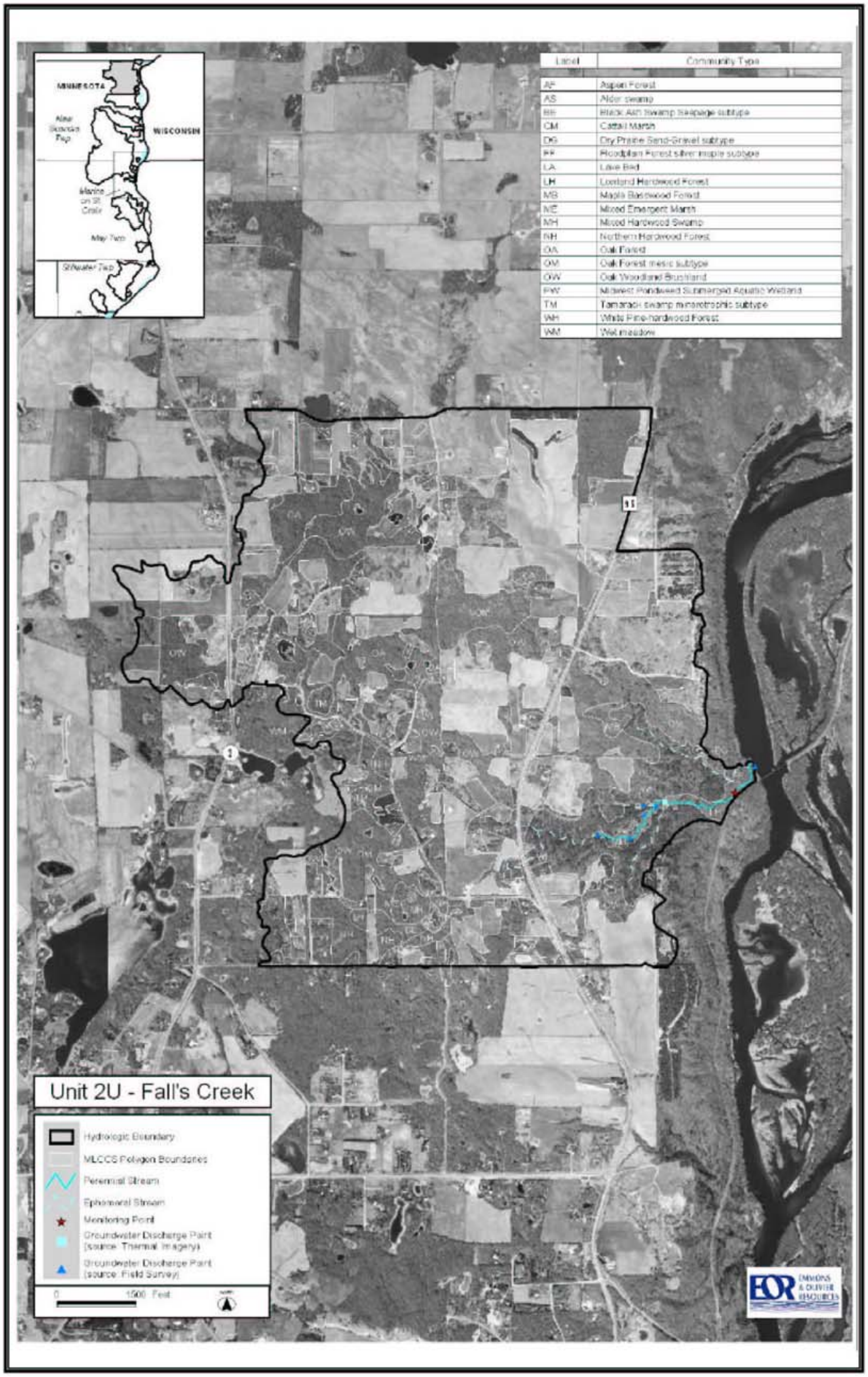
Springs at this location lie along the southwest edge of the Cedar Bend fault zone. Bedrock layers have likely been shifted and deformed by the faulting. Consequently, springs emanate from a relatively low in the stratigraphy.

Moderately high chloride and high bromide concentrations indicate that water in the springs is recharged by precipitation falling in upland (as opposed to lake or wetland) areas to the west. Recharge areas may be from relatively far west where the Franconia Formation is the first bedrock encountered below glacial sediments. The groundwater in the Franconia Formation has relatively little interaction with groundwater in upper aquifers because it is isolated by a fairly continuous layer of Superior Lobe glacial till and several less-permeable bedrock units.

Water Chemistry

Parameter	Site Mean	Site σ	MPCA NCHF Benchmark MIS[a]/St. Croix River[b]		Among Springs Mean[c]
TP [µg/L]	33.57	3.38	90	55	42.47
NO_2+NO_3 [mg/L]	2.49	.74	.1	.203	2.15
TSS [mg/L]	4.83	5.14	8.8	7.5	15.96
Temperature [C]	6.90	3.98	13.0	10.30	9.95

Figure 7.4. (continued) Spring Creek Fact Sheet.



Label	Community Type
AF	Aspen Forest
AS	Alder swamp
BB	Black Ash Swamp Seepage subtype
CM	Cattail Marsh
DG	Dry Prairie Sand-Gravel subtype
FF	Floodplain Forest silver maple subtype
LA	Lake Bed
LH	Lowland Hardwood Forest
MB	Maple Basswood Forest
ME	Mixed Emergent Marsh
MH	Mixed Hardwood Swamp
NH	Northern Hardwood Forest
OA	Oak Forest
OM	Oak Forest mesic subtype
OW	Oak Woodland Brushland
PW	Midwest Pondweed Submerged Aquatic Wetland
TM	Tamarack swamp minerotrophic subtype
WH	White Pine-hardwood Forest
WM	Wet meadow

8. Findings and Recommendations

The *Integrating Groundwater and Surface Water Management – Northern Washington County Study* has provided the necessary technical data and background to enable local decision makers to develop policies and ordinances for the protection of lakes, wetlands, streams and water supplies dependent on groundwater resources. Specific conclusions of this study are presented throughout the body of the text. The principal study findings are included in the following figures:

- Water bodies and function analysis (Figure 4.1);
- Groundwater dependent resources (Figure 4.4);
- Infiltration potential (Figure 4.5);
- Recharge and discharge zones (Figure 4.6); and
- Management zones (Figure 4.7).

General findings that relate to future studies and recommendations are presented in the following sections.

8.1 Findings that Relate to Future Studies

1. Volunteer rain gauge data were not useful due to variability and inconsistencies in data collection.

2. A monitoring database that includes a minimum of 15 years is recommended for use in determining correlations.

3. Thermal imaging did not provide the necessary detail without field investigation to map spring discharge points. Due to several elements, the data required additional analysis and review than was initially expected. False signatures were common and had to be re-analyzed. The signatures that were considered reliable were typically streams that were visible in Digital Orthophoto Quadrangles (DOQs) without thermal photography.

4. Direct measurements of groundwater within lakes proved to be the most reliable data in determining the lake function. However, direct measurements taken in fine-grained material were not reliable or used in the analysis. Correlations of lake levels to groundwater levels were only reliable when there was an extensive database of both water levels and the well was located within one-half mile of the lake.

5. Chemistry data interpretation provided valuable information for the determination of recharge and discharge areas in the study area. Tritium data provided valuable information on groundwater residence time within the various aquifers. Stable isotopes and the suite of cations, anions, and alkalinity provided valuable data on the location and method of recharge and lake function. Strontium isotopes did not provide applicable data.

8.2 Recommendations

Recommendations are broken down into monitoring, analysis, and implementation.

8.2.1 Monitoring

Monitoring, by either watershed districts or the County, should be continued to develop additional reliable databases of surface water and groundwater interactions. These data will help to refine the data elements provided in this report. Due to the seasonal and climatic variations present in surface water and groundwater hydrology, a long term data base may provide additional insight to these interactions during prolonged wet and dry periods, leading to better planning and protection of flood prone areas and groundwater dependent resources.

Specific monitoring recommendations for the northern portion of Washington County follow:

1. Replace select manual rain gauges with automated gauges in order to improve the breadth and success of precipitation data collection.

2. Conduct annual or biennial monitoring of water levels within the recommended well network and chemistry monitoring within a select set of wells illustrated on Figure 8.1. Monitoring these wells over time will provide valuable insight on changes in the groundwater system and potential effects on groundwater dependent resources and water supplies.

3. Conduct annual or biennial monitoring of surface water chemistry. Expand chemistry monitoring to all lakes where surface water groundwater interactions are in question.

4. Conduct seasonal (spring, summer, and fall) mini-piezometer measurements to obtain seasonal variability and data on lakes that have varying interactions with groundwater.

5. Add observation wells near Forest Lake, New Scandia Township, the City of Marine-on-St. Croix, and east of White Bear Lake. Observation wells could be added for long term continuous monitoring through the DNR network or a watershed district. A nested pair of wells is ideal for monitoring within Quaternary and bedrock aquifers in order to acquire vertical gradient data and maximize monitoring efficiency.

6. Conduct additional flow monitoring. Recommended flow monitoring locations include the north outlet of Hardwood Creek wetland, the outlet of Sylvan Lake, the Tingley Spring outlet, the inlet or outlet of Bone Lake, or the inlet of Big Marine Lake at Jellum’s Bay.

7. Collect natural resource inventory and MLCCS data in the CLFLWD, VBWD, and remaining area within the orphan area and City of Stillwater based on high potential for the presence of groundwater dependent resources.

8.2.2. Analysis

1. Expand lake function analysis to all lakes where suitable data is available. Special attention should be paid to landlocked lakes and those areas where floodplain is being mapped.

2. Additional analysis is needed to determine the significance of till holes and thin till thicknesses within the study area. These areas have the potential to act as preferential flow paths for groundwater and surface water. Understanding their role in the overall context of surface water groundwater interactions is important in developing aquifer protection strategies.

8.2.3. Implementation

Implementation of this study's outcomes and recommendations is the next step to ensuring protection of the County's groundwater. Implementing partners now have the necessary tools and data to develop groundwater protection ordinances and rules. Recommendations on the implementation of this study include:

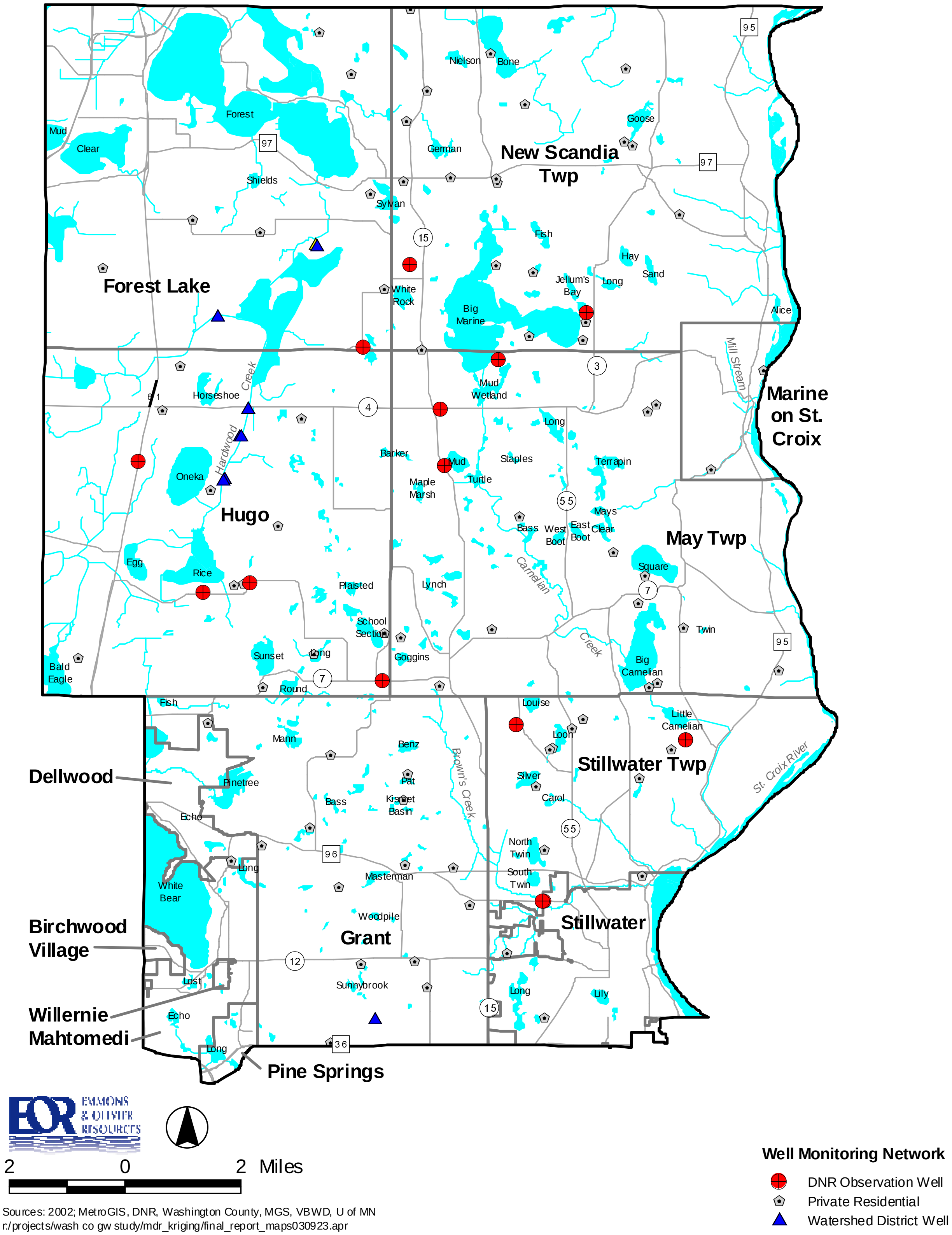
1. Adopt the findings and data included in this study as supplements to the *Washington County Groundwater Plan*.

2. Hold additional public and informational meetings to increase public awareness and educate local planning commissions, city councils, and township boards on the outcomes of this study and the available data.

3. Prepare a guidance document for local implementing agencies to assist in implementing the recommendations of this study. Such an effort could pull together all of the technical and planning components and provide example applications on how the program could be implemented under differing physical and political conditions.

4. Prepare an interactive website to disseminate the study results.

Figure 8.1. Well Network for Continued Monitoring



Sources: 2002; MetroGIS, DNR, Washington County, MGS, VBWD, U of MN
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Appendix A
BWSR Challenge Grant Application

2002/2003 BWSR Challenge Grant Application

1.REFERENCE INFORMATION

Applicant:	Washington County, Rice Cr. WD, Carnelian-Marine WD, Brown's Creek WD, Valley Branch WD, Marine WMO
Project Title:	Integrating Groundwater and Surface Water Management-Northern Washington County
Project Manager:	Jon Michels-Washington County Senior Environmental Specialist-Groundwater Program
Fiscal Agent:	Washington County
Mailing Address:	Box 3803 Stillwater, MN 55082-3803
Telephone/Fax:	651-275-7301/ 651-430-6730
Email:	michels@co.washington.mn.us
Total Amount Requested:	$ 125,000
Match Category:	Cash Match Only

2. PURPOSE: *Groundwater's role in surface water management is vital, but poorly understood. Watershed Districts will integrate groundwater elements into their management strategies and policies protecting lakes, wetlands, streams and water supplies dependent on groundwater.*

3. PROJECT SUMMARY: *Groundwater components in northern Washington County constitute a major portion of the water management puzzle. Watershed Districts lack the key groundwater pieces to manage the entire hydrologic system. Groundwater components factor into virtually all of the costly water resource projects and water related litigation that have been undertaken in northern Washington County. Many priority water features and resources in the study area are inextricably dependent on groundwater for their sustainability. Managing surface water through infiltration is an emerging strategy but key groundwater data and understanding are lacking.* ***Washington County along with the Watershed Districts and Cities collaborating in this project have the mutual goal of integrating groundwater components with surface water components to holistically manage and protect the entire hydrologic system.***

3-A. Relationship to Comprehensive Local Water Plans: *Table A. outlines key relationships between Comprehensive Local Water Plans and the goals and objectives of the proposed project:*

Table A. Relationship to CLWP:

CLWP Plan	Driving Issue Statement	Goals and Objectives
Washington County	***pg. 114: There is a "Lack of understanding of surface and groundwater interconnection"***	***Develop and implement public and agency awareness and knowledge of groundwater resources. Develop technical basis for planning and controls in managing interconnected surface and groundwater resources.***
BCWD	***pg. 9: "Land use changes and increased urbanization threatens to reduce local groundwater recharge, negatively impact groundwater quality and reduce the sustainability of unique natural resources"***	***pg. 103: Goal: To maintain the present integrity of groundwater quantity and quality."***
CMWD	***pg. III-47 "Groundwater is the sole source of drinking water and is of high importance in maintaining water levels in lakes and streams. It also has been tied directly to land values in the area because of its impact on the ability to develop a given piece of property"***	***"CMWD will regulate new development and groundwater recharge area land use through its "Rules of the District" which are based on the resource goals of the groundwater management plan.***
RCWD	***pg. 5-15 RCWD "will pursue a cost-shared project demonstrating infiltration BMP's.***	***"To maximize infiltration and control runoff volume"***
VBWD	***Section 4.2.20: Flooding issues in Sunnybrook Lake Landlocked Basin.***	***VBWD proposed a traditional outlet project to the St.Croix River. Local Government and State agencies have recommended infiltration as a solution.***

3-B. DESIRED OUTCOMES

Outcome # 1: Watershed Districts will adopt policies based in science to protect groundwater recharge and discharge areas.

Measurable Benefit: Resources dependent on groundwater input will be sustained in their natural condition with a steady supply of clean groundwater. **Water quality and quantity will be maintained or improved.**

Outcome # 2: Water Management Units will adopt policies based in science to manage surface water runoff using infiltration techniques **in suitable areas.**

Measurable Benefit: Watershed Districts and Local Government will have hard data and facts to make sound decisions on the viability of infiltration in differing areas of their watersheds. Successful infiltration projects will **reduced runoff volume minimize erosion and maintain base flow.** Efforts to infiltrate water in unsuitable areas will be avoided **increasing cost effectiveness and efficiency.**

Outcome # 3: Water Management Units will adopt policies that regulate land use in areas susceptible to water level fluctuations due to long term climatic trends and high groundwater. Water management units will enhance landlocked basin policies with improved understanding of groundwater interaction (currently, a pilot landlocked basin study is underway funded with BWSR Challenge Grant monies). Washington County and Watershed Districts will work with local municipalities to promote the adoption of sound land use policies in these areas.

Measurable Benefit: Development will be sited in areas least susceptible to impacts from high groundwater/surface water levels. Costly projects to outlet landlocked basins will be reduced . Cities and watershed districts will have the data to factor in groundwater influences on water control projects increasing cost efficiency. With the backing of sound science, landlocked areas will maintain their natural function as important groundwater recharge areas supporting base flow to priority water resources.

3-C. ACTIONS: The following specific actions will be carried out to complete the proposed project:

3-C-I. Education and Information: The following actions will be implemented.

1.Hold local pre-project information forums with Watershed Districts and Local Government.
2. Provide post project individual workshops and training with Watershed District Managers and Local Elected Officials.
3. It is anticipated that techniques and policies developed from this project will have regional and statewide applications. Following the project, the participants will host a statewide workshop on "Integrating groundwater and surface water management".

3-C-II. Inventory: The following actions will be implemented.*

1. Inventory and rank surface water bodies and their groundwater function (i.e. recharge area, discharge area).
2. Inventory and rank groundwater recharge areas and infiltration potential.
3. Inventory and rank groundwater discharge areas.
4. Inventory and rank groundwater dependent resources such as trout streams, lakes and unique wetland systems.
5. Inventory Climatic data (specifically precipitation)

*** The participants in this project will develop innovative inventory and ranking systems that will have regional and statewide applications.**

3-C-III. Monitoring: The following actions will be implemented.

1. Monitor surface and ground water levels concurrently. Develop a project area wide monitoring network.
2. Monitor surface and groundwater chemistry to develop data for assessing groundwater recharge function.
3. Monitor precipitation.
4. Develop strategy and policy performance monitoring plans for adoption by Watershed Districts.

3-C-IV. Land and Water Treatment: The following actions will be implemented.

1. Develop policies, maps and data identifying infiltration management areas for treating stormwater runoff. Assessment monitoring will be conducted.

3-C-V. Planning and Environmental Control: The following actions will be implemented.

1. Develop groundwater recharge area management policies (including performance monitoring).
2. Develop maps and overlay districts for groundwater management providing documentation of "Lakes, Streams and Wetlands and associated groundwater resources". The maps will provide quality ranking and related groundwater management strategies for individual water features.
3. Develop policies that regulate land use in areas susceptible to high groundwater levels. Provide maps and documentation to assess high water level or flooding potential. Conduct performance monitoring**.**
4. Develop infiltration management policies. Provide maps and documents ranking "infiltration potential".

Note: Watershed Districts will adopt newly developed strategies and policies into their Comprehensive Local Water Plans.

<u>3.D.1 PROJECT EVALUATION:</u> Three outcomes were outlined in section 3.B. The following methods will be used to evaluate the projects achievements.

Evaluation of Outcome # 1: a). The project manager will audit Watershed District Plans to evaluate if strategies and policies to integrate groundwater and surface water management have been adopted. **b).** Ongoing water quality, quantity and precipitation data will be assembled and evaluated and provided in a five year reporting cycle. These data will be used to assess the performance of newly adopted policies and strategies.

Evaluation of Outcome # 2: a). The project manager will audit Watershed District plans to evaluate if infiltration policies and strategy recommendations have been adopted. **b).** Ongoing water quality, quantity and precipitation data will be assembled and evaluated and provided in five year reporting cycles.

Evaluation of Outcome # 3: a). The project manager will audit Watershed District and Local Government planning documents to evaluate land use policies and planning in areas susceptible to high groundwater and flooding. Land use cover maps will be used to assess the performance of these policies. Flooding damage will be documented. The results of the audit and land cover assessment will be included in the five year reports.

<u>3.D.2 PROJECT DISSEMINATION:</u> The initial product of this project will be a report : **"Integrating Groundwater and Surface Water Management-North Washington County".** The report will include data, maps, discussion and recommended policies for adoption by Watershed Districts. The report will be disseminated to Watershed Districts, agencies and municipalities in the project area. Efforts will be made to make the data, maps and reports internet accessible. Educational workshops will be conducted with Watershed Districts and Local Government officials. Because there will be new innovative techniques and policies developed, an informational workshop and field trip will be held with participants invited from the entire region. The participants will make every effort to share the value of this project regionally and statewide.

Once the project is completed, a five year reporting cycle will be initiated. These reports will assemble performance monitoring data and audits interpreting results and gauging success. The reports will be disseminated to Watershed Districts, communities and resource management agencies.

<u>4. BUDGET</u>: Table 4.0 presents the project budget:

Project Budget

CLWP Category	**Grant Contribution**	**Cash Contribution**	**Cash Source**
Project Management	10,000	10,000	Wa.Co.
Education/Information	7,500	7,500	Wa.Co.
Monitoring	20,000	20,000	Wa.Co.
Inventory	70,000	70,000	BCWD,RCWD,VBWD,Wa.Co
Planning/Environmental Controls	10,000	10,000	CMWD,Wa.Co.
Land and Water Treatment	7,500	7,500	Wa.Co.VBWD
Project Budget Totals	$125,000	$125,000	

<u>5.0 PARTNERSHIPS:</u> Washington County, five Watershed Districts, one Watershed Management Organization one municipality, and one non-profit organization are partnering in this project. The intent is to pool financial and political resources together to achieve a common goal- ***Integrate groundwater and surface water components to manage the entire hydrologic system and associated resources.*** Table 5.0 summarizes the project partners, their stake in the project and the individual goals they are hoping to achieve:

Table 5.0 North Washington County Integrated Groundwater-Surface Water Assessment Summary of Project Partners

Participant	Partner Stake/Goals
Washington County	Committing $ 40,000/Provide leadership in Groundwater, Improve Water Management. The project will also bring additional groundwater information into the Landlocked Basin Pilot Study currently being funded through another BWSR challenge grant.
Brown's Creek WD	Committing $ 20,000/Develop strategies and policies to manage ground and surface water.
Carnelian-Marine WD	Committing $ 10,000/Develop strategies and policies to manage ground and surface water. CMWD has conducted some assessment of groundwater resources on targeted water bodies.
Comfort/Forest Lake WD	Support Project/Seeking assistance in managing groundwater/surface water.
Rice Creek WD	Committing $ 20,000/Develop strategies and policies to manage ground and surface
Valley Branch WD	Committing $ 20,000/Developing innovative strategies to manage high water/flooding issues in the Sunnybrook Lake subwatershed area.
Marine on St. Croix WMO	Committing $ /Developing water management strategies and stewardship goals.
City of Stillwater	Committing $ 10,000/Conducting assessments to evaluate urban impacts, develop infiltration strategies, and monitor groundwater in Brown's Creek watershed.

6.0A: Funding History: This project is new and has no funding history in Washington County.

6.0-B: Target Water Resources: Picking benefitting target resources is a challenge because **all** water resources will benefit from this project. A major void in water management will be filled when this project is complete.

Lakes

There are over 125 lakes in the study area. Because infiltration practices will be maximized and groundwater input maintained, virtually all lakes in the study area will benefit due to protection of water quality and quantity. Lakes with the highest component of groundwater input will benefit the most. The project will serve to identify lakes with a high component of groundwater input as well as lakes that are important groundwater recharge areas. Priority Lakes that will benefit from the project are: Bone Lake, Big Marine Lake, Sand Lake, Forest Lake, Clear Lake, Rice, Oneka, Terrapin, Square, Big Carnelian, Little Carnelian, Goggins, School Section, Silver, Twin, Masterman, White Bear.

Streams

Approximately 22 small spring creeks flow into the St. Croix River in the study area. Many of these streams contain populations of naturally reproducing brook trout These spring creeks and their delicate ecosystems are entirely dependent on a healthy groundwater. Two larger trout streams are Brown's Creek and Mill Stream. Both streams will benefit from this project. The St. Croix River will also benefit.

Wetlands

Wetlands function as critical groundwater recharge and discharge areas. Groundwater recharge wetlands will benefit through added protective measures. Groundwater discharge or seepage wetlands are numerous in the north part of Washington County. Many of these spring seepage wetlands contain high quality natural communities. In northwest Washington County, wetlands are subject to water level fluctuations from changing groundwater levels. Development in those areas may impact wetland quality if groundwater factors are not taken into consideration.

Water Supply Resources

Groundwater provides 100% of the drinking water in the study area. The identification of recharge areas and development of policies to protect those areas will serve to maintain water quality and quantity.

Downstream Receptors

The project will minimize the draining of landlocked basins and other flood susceptible regions and therefor will minimize water quality and quantity impacts to downstream receptors.

Appendix B
BWSR Challenge Grant Work Plan

Integrating Groundwater and Surface Water Management – Northern Washington County

WORKPLAN

Education and Information (E&I)

E&I-1. Pre-project meetings

Objective: Inform watershed districts and local units of government about the project. Get feedback on issues of concern before developing the final workplan.
Tasks: Make presentations at watershed meetings for Rice Creek, Carnelian-Marine, Brown's Creek, and Valley Branch Watershed Districts and others as needed. Cities and Washington County will be invited to attend.
Deliverables: Five presentations at Watershed District meetings. Letter of invitation sent to city administrators.
Participants: EOR staff, Washington County staff.
Schedule: April – May 2002.

E&I-2. Post-project meetings

Objective: Inform watershed districts and local units of government about the results of the project. Disseminate information and policies developed during the study. Discuss issues related to integrating groundwater and surface water management.
Tasks: Make presentations at watershed meetings for Rice Creek, Carnelian-Marine, Brown's Creek, and Valley Branch Watershed Districts and others as needed. Cities and Washington County will be invited to attend.
Participate in a statewide workshop on "Integrating Groundwater and Surface Water Management" to be held in conjunction with the "St. Croix River Spring Creeks Stewardship Plan".
Deliverables: Five presentations at Watershed District meetings. Letter of invitation sent to city administrators. Participation in the statewide workshop.
Participants: EOR staff, Washington County staff.
Schedule: June - July 2003.

Inventory, Rank, and Compile (IR&C)

IR&C – 1. Compile existing surface water, groundwater, and climatic data.

A. Compile existing data

Objective: Compile existing data for later analysis.

a. Groundwater data

Tasks:	Obtain data on geology from published maps and other available unpublished sources. Obtain data bases on groundwater quality and elevation (CWI). Obtain pumping rates for large wells.
Deliverables:	Collected reports and data bases. GIS will be used where feasible.
Participants:	U of M/MGS – Retrieve studies from CMWD, unpublished data, groundwater models EOR – Obtain published studies, CWI data, groundwater models WC PHE – Retrieve water quality data SWCD – Obtain readings from past SWCD fieldwork (if any)
Schedule:	April – June 2002

b. Surface water data

Tasks:	Obtain data on stream discharges. Compile 1996 and 2000 aerial photographs and 2000 topography and inventory surface water features and elevations
Deliverables:	Collected reports and data bases. GIS will be used where feasible.
Participants:	EOR – Obtain published studies, surface water models WC PHE – Obtain aerial photography and 2 ft elevation contours. SWCD – Obtain readings from past SWCD fieldwork U of M/MGS – Obtain data from CMWD study SMM – Obtain published and unpublished reports and studies
Schedule:	April – June 2002

c. Precipitation and climatic data

Tasks:	Obtain precipitation and evapotranspiration data
Deliverables:	Collected reports and data bases. GIS will be used where feasible.
Participants:	EOR – Obtain data available from internet databases WC PHE – Obtain county records (if any) SWCD – Obtain readings from past SWCD fieldwork SMM – Obtain data from SMM weather station U of M/MGS – Obtain data from CMWD study (if any)
Schedule:	April – June 2002

d. Natural resources and land use

Tasks:	Develop a GIS project showing natural resources and land use. Much of the study area has had detailed natural resources mapping, primarily by EOR. In other areas, the best available existing data will be used.
Deliverables:	GIS project showing natural resources and land use.

Participants: EOR – Develop GIS project from existing coverages
WC PHE – Obtain county records (if any)
SWCD – Obtain agricultural data including crop types, fertilizer usage, and feedlot operations
Schedule: April – June 2002

B. Determine additional data needs/gaps
Objective: Determine the need for additional data gathering.
Tasks: Review existing data. Work with the TAC to determine additional data needs/gaps.
Deliverables: None
Participants: EOR – Review data and work with the TAC to identify additional data needs.
Schedule: May - June 2002

IR&C – 2. Inventory and rank surface water bodies and their groundwater function (recharge, discharge).

A. Determine surface water body function – recharge/discharge
Objective: Determine how specific surface water bodies interact with groundwater and whether they are recharge areas, discharge areas, or both.
Tasks: Determine minimum size water body for initial analysis (*TAC*). Review aerial photographs for evidence of recharge or discharge characteristics. Map 1996 and 2000 groundwater levels from CWI and new data collected in MON-1 and 1996 and 2000 surface water levels. Based on existing information, develop a methodology to determine the groundwater function. Develop a GIS project identifying recharge and discharge function of surface water features.
Deliverables: Report, data, and GIS project
Participants: EOR – Analysis and report writing
U of M/MGS – Review and refine methodology
Schedule: June 2002 – March 2003

B. Rank surface water bodies as recharge and discharge areas
Objective: Rank surface water bodies in terms of their relative importance and contribution to groundwater recharge and discharge.
Tasks: Develop ranking scheme based on hydrology, biology, chemistry, and geology

- Hydrology – key factors to consider include subwatershed size, existing outlet and inlet controls, groundwater levels
- Biology – key factors include rare, unique, or sensitive resources
- Chemistry – key factors include current water quality, potential changes in water quality due to change in landuse
- Geology – key factors include contributing or accepting aquifer, bedrock characteristics

Rank surface water features based on above criteria
Deliverables: Report, data, and GIS project

Participants: EOR – Analysis and report writing
PHE, TAC – Review results
Schedule: September 2002 – April 2003

IR&C-3. Inventory and rank groundwater recharge and discharge areas and infiltration potential.

A. Determine and inventory groundwater recharge areas.
Objective: Identify areas other than surface water bodies that contribute to groundwater recharge
Tasks: Map recharge/infiltration potential for the study area based on TAC approved methodology. Determine recharge and discharge functions. Map recharge and discharge areas based on recharge/infiltration potential and land cover.
Deliverables: Report, data, and GIS project
Participants: EOR – Analysis and report writing
PHE, TAC – Review results
Schedule: October 2002 – May 2003

B. Inventory groundwater discharge points/areas
Objective: Identify groundwater discharge points along the St. Croix River
Tasks: AW Research will create low-altitude aerial images along 17 miles of the St. Croix River shoreline. Images will include optical, infra-red, and other sensors. Using available data and methodologies identify groundwater discharge areas throughout the study area.
Deliverables: Data and images from the aerial imaging, map of groundwater discharge areas
Participants: EOR (subcontract with AW Research)
PHE, TAC – Review results
Schedule: March – April 2002 (St. Croix River discharge points)
October 2002 – May 2003

C. Rank recharge and discharge areas
Objective: Rank areas other than surface water bodies that contribute to groundwater recharge in terms of their relative importance. Identify discharge areas.
Tasks: Develop ranking scheme based on hydrology, biology, chemistry, and geology:

- Hydrology – key factors to consider include subwatershed size, existing outlet and inlet controls, groundwater levels, potential changes in hydrology from development
- Biology – key factors include rare, unique, or sensitive resources, landcover
- Chemistry – key factors include current water quality, potential changes in water quality due to change in landuse

- Geology – key factors include contributing or accepting aquifer, infiltration potential

Rank recharge and discharge areas based on above criteria

Deliverables: GIS map of infiltration potential for Northern Washington County, GIS map of ranked groundwater and recharge areas

Participants: EOR – Analysis and report writing
PHE, TAC – Review results

Schedule: October 2002 – May 2003

IR&C-4. Inventory and rank groundwater dependant resources.

A. Groundwater dependant resource inventory

Objective: Coordinate with the St. Croix River Spring Creeks Stewardship Plan (SCRSCSP) to identify groundwater dependant resources

Tasks:

a. Review existing data
   1. Wetland inventories, NWI
   2. Natural resource inventories
   3. Landforms and topography
   4. Water table elevations
b. Determine large scale groundwater dependant areas
   1. Utilize infiltration potential map, landform data, and groundwater elevations
   2. Map areas with common characteristics
   3. Identify those areas that appear to be groundwater dependent based on interaction with groundwater
c. Identify areas subject to groundwater interaction
   1. Use stereoscope to identify type of resource communities
   2. Map potential groundwater dependent resources in GIS
d. Conduct field inventory to spot check and verify locations and types of resources

Deliverables: GIS map of groundwater dependent resources

Participants: EOR – Analysis and report writing
PHE, TAC – Review results

Schedule: December 2002 – May 2003

B. Rank groundwater dependent resources

Objective: Identify where to focus future efforts related to groundwater dependent resources

Tasks: Develop a ranking system to classify groundwater dependant resources (in conjunction with SCRSCSP) based on:

- Hydrology – key factors to consider include groundwatersheds, flow, potential changes in hydrology from development
- Biology – key factors include rare, unique, or sensitive resources, land cover
- Chemistry – key factors include current water quality, potential changes in water quality due to change in landuse

- Geology – key factors include contributing aquifer(s), elevation of discharge/recharge points

Deliverables: GIS map of ranked groundwater dependant resources in Northern Washington County.

Participants: EOR – Analysis and report writing
PHE, TAC – Review results

Schedule: December 2002 – May 2003

Monitoring (Mon)

Note: This task to be completed prior to IR&C-2, 3, and 4.

Mon-1. Develop a project wide monitoring network based on additional needs identified in IR&C-1.

Objective: Obtain additional groundwater, surface water, discharge, geology, and natural resources data needed for use in IR&C 2, 3, and 4.

Tasks: Obtain additional groundwater level data utilizing private and public wells including MGS network. Obtain accurate locations and monthly elevation readings. Obtain additional surface water level data utilizing existing DNR Lake Level MN Program to obtain additional volunteers to monitor surface water. Obtain additional surface water levels using two-foot contour data and GPS. Obtain additional discharge data (groundwater/stream) at identified points. Obtain additional natural resource inventory and land cover mapping data. Obtain additional geology/geomorphology data including geologic units and elevations associated with groundwater discharge and recharge points. Obtain additional information from low level aerial photography.

Deliverables: Summary of collected data for incorporation into chapter entitled "Comprehensive Hydrologic Monitoring Plan"

Participants: EOR – land cover mapping, natural resource inventories and analysis, report writing
SWCD – surface water, groundwater, and stream discharge data collection and analysis
U of M/MGS – geologic data collection and interpretation, monitoring well network participants
WC PHE – Surface water and groundwater elevations, GPS unit, review results

Schedule: June 2002 – September 2002

Mon-2. Monitor surface and groundwater chemistry to develop data for assessing groundwater recharge function.

A. <u>Surface water chemistry</u>

Objective: Obtain additional data on surface water quality that will aid in identifying groundwater functions.

Tasks: Utilize methodologies developed for the St. Croix River Spring Creeks Stewardship Plan to obtain surface water quality and chemistry data as needed. Using lake, wetland, and stream locations identified in IR&C-1 and Mon-1, sample surface water for analytes useful in determining connectivity with groundwater system.

Deliverables: Summary of surface water chemistry data for incorporation into chapter entitled "Comprehensive Hydrologic Monitoring Plan"

Participants: EOR – coordinate and assist in data collection
SWCD – data collection and analysis
SMM – surface water chemistry analysis

Schedule: June 2002 – September 2002

B. <u>Groundwater chemistry</u>

Objective: Obtain additional data on groundwater quality that will aid in identifying groundwater functions.

Tasks: Using wells identified during IR&C-1 and Mon-1, sample groundwater to obtain representative analytes for determination of groundwater function.

Deliverables: Summary of groundwater chemistry data for incorporation into chapter entitled "Comprehensive Hydrologic Monitoring Plan"

Participants: EOR – coordinate and assist in data collection
SWCD – data collection and analysis
U of M/MGS – groundwater chemistry analysis

Schedule: June 2002 – September 2002

Mon-3. Monitor precipitation.

Objective: Develop a precipitation monitoring program as identified in IR&C-1 and develop relationships between precipitation and water tables and surface water features present in the study area.

Tasks: Collect additional precipitation data. Summarize trends in precipitation and groundwater/surface water levels when corresponding data is available.

Deliverables: Summary of trends in precipitation and water table levels for incorporation into the Chapter entitled "Comprehensive Hydrologic Monitoring Plan"

Participants: EOR – review of results and report writing
SWCD – data collection and analysis
SMM – interpretation of results, review of results

Schedule: June 2002 – September 2002

Mon-4. Monitor overall performance of technologies and policies developed from this project.

A. Monitor performance of practices implemented in P&EC-4.

Objective: Determine effectiveness and long-term performance of implemented practices identified in P&EC-4.
Tasks: Establish a monitoring program for at least one of the implemented practices. Monitor surface and groundwater levels, surface and groundwater quality, and inflows/outflows including precipitation. Publish a project report summarizing the effectiveness and performance of the implemented practice.
Deliverables: Chapter entitled "Performance Evaluation-Hydrologic Management"
Participants: EOR – develop, implement monitoring plan
PHE – Review plan, continue beyond the end of the project
Schedule: January 2003 – July 2003

B. Determine monitoring methodology to meet performance based standards set forth in model management policies.

Objective: Develop model monitoring methodology for incorporation at the local government level.
Tasks: Compile existing monitoring programs in Northern Washington County. Develop model monitoring methodology. Obtain approval of methodology by TAC and select local units of government.
Deliverables: Chapter entitled "Performance Evaluation-Hydrologic Management"
Participants: EOR – develop methodology and report writing
SWCD – develop methodology
TAC – review methodology
Schedule: January 2003 – July 2003

Land and Water Treatment (L&WT)

L&WT – 1. Sunnybrook Lake subwatershed analysis

Objective: Address flooding issues in the Sunnybrook Lake area.
Tasks: Investigate and provide alternatives for retention and infiltration of water in the upper watershed.
Deliverables: Report entitled "Feasibility Study for Managing Excess Surface Water – Sunnybrook Basin"
Participants: Barr Engineering
Schedule: March 2002 – July 2002

Planning and Environmental Control (P&EC)

P&EC-1. Develop model management policies

Objective: Provide local governmental units with guidance and policies on how to protect and manage groundwater dependant resources.
Tasks: Develop a Policy Advisory Committee (PAC) consisting of watershed organizations, municipalities, agencies, and others. Research existing ordinances, rules, and other management policies . Develop model management policies for protection and management of groundwater recharge and discharge areas, areas susceptible to high water levels , and groundwater -surface water interactions. Hold three PAC meetings to gain input on draft policies.
Deliverables: Model management policies for incorporation into Final report.
Participants: EOR, WC PHE
Schedule: January 2003 – July 2003

P&EC-2. Develop GIS maps and overlay districts for groundwater management

Objective: Define management overlay districts
Tasks: Compile new datasets on groundwater function, recharge and discharge areas, infiltration potential, groundwater dependant resources, and rankings. Develop overlay districts for management purposes (PAC) based on data and rankings.
Deliverables: GIS maps of management overlay districts
Participants: EOR, WC PHE
Schedule: March – July 2003

P&EC-3. Develop policies related to landuse in areas susceptible to high groundwater levels

Objective: Working with local governmental units, develop specific management policies for areas with high groundwater levels
Tasks: Coordinate with the Washington County project entitled "Landlocked Basin Pilot Study" to identify and map areas with high water tables. Map areas susceptible to high water table and verify with field and anecdotal evidence. Develop policies to manage areas susceptible to high water table including recommended landuses, minimum first floor elevations, minimum septic system elevations, and landlocked basin outlet design and considerations.
Deliverables: Meetings with managers and administrators, high water table maps, draft policies for use in P&EC-1.
Final Report Chapter: *Strategies, Policies, and Rules-Integrating Groundwater and Surface Water Management*
Participants: EOR, PHE
Watershed Districts, other LGUs – Policy and Rule development support
Schedule: March – July 2003

P&EC-4. Incorporate Infiltration Management Strategies

Objective: Assist with planning and monitoring of Infiltration Management Strategies identified in L&WT.

Tasks: Identify sites suitable for infiltration of surface water (stormwater, lake water, etc.)
Assist Watershed Districts or other LGUs with planning infiltration projects.
Monitor performance of projects and report results.

Deliverables: Project descriptions and monitoring results in the Final Report

Participants: EOR, WC PHE

Schedule: June 2002 – July 2003

Appendix C
Existing Watershed District Groundwater Policies

(Washington County Water Consortium, 2003)

Comparison of Groundwater Management Standards.

BCWD	CMWD	SWWD	RWMWD	VBWD	RCWD
POLICY STATEMENT - GENERAL					
No specific language addressing this issue.	The District shall work with local government units to modify land use and Zoning Plans to protect groundwater and groundwater recharge areas. *(WMP Sect. IV Subd. E.3)* The District shall not allow mining within three feet of the highest indicated groundwater table. *(WMP Sect. IV Subd. E.3)*	Encourage land use practices that consider the groundwater, surface water, and associated natural resources in the decision-making process. *(WMP Sect. III)*	Participate in an intergovernmental committee, including Washington County, to evaluate and guide groundwater management activities. *(WMP Sect. IV)* Develop a shared GIS database including data on District water wells, water use and contamination sources and collaborate on geographic and attribute data management and updating. *(WMP Sect. IV)*	To manage the water resources of the District, the Managers require that the effect of the proposed appropriation of ground and/or surface waters. The Managers require that the effect of the proposed appropriation be defined before approval is granted." *(Rule Sect. VII. Subd.1)*	No specific language addressing this issue.
POLICY STATEMENT - WELLHEAD PROTECTION					
No specific language addressing this issue.	No specific language addressing this issue.	Work with all communities and non-community public water supplies systems as they develop and implement their Wellhead Protection plans. *(WMP Sect III Subd. B)*	Assist with development and implementation of the North St. Paul Wellhead Protection Project. *(WMP Sect. IV)*	No specific language addressing this issue.	No specific language addressing this issue.

Comparison of Groundwater Management Standards.

BCWD	CMWD	SWWD	RWMWD	VBWD	RCWD
POLICY STATEMENT - GROUNDWATER RECHARGE AND SURFACE WATER INTERACTIONS					
Identify groundwater recharge and discharge areas by linking surface water and groundwater studies results. *(WMP Sect III-8)* It is the policy of the District to: - Promote on-site infiltration of stormwater *(Rule 2.1)*	The District shall require natural infiltration of runoff where practical. *(WMP Sect. IV.E.7.b(4))* Identify, map, and prioritize, and protect groundwater recharge areas within the District boundaries. *(WMP Sect. IV Subd. E.3)* Requires that all development and improvement which result in one-half acre of impervious surfaces to implement groundwater recharge and infiltration BMPs. *(WMP Sect. IV Subd. E.3)* All water resource management plans adopted by each local government are required to include land use development guidelines for natural groundwater recharge through infiltration of	Identity and provide a high level of protection for wetlands and other landscape features that serve as important groundwater recharge areas. *(WMP Sect III Subd. B)* Utilize infiltration to filter stormwater and replenish groundwater to the extent possible without compromising groundwater quality. *(WMP Sect III Subd. B)*	Promote increased open spaces and reduction of impervious surfaces to potentially increase groundwater recharge. *(WMP Sect. IV)* Cooperate with other agencies in completion of studies evaluating of how surface water management activities affect groundwater resources. *(WMP Sect. IV)*	No specific language addressing this issue.	Restrict impervious areas within the floodplain in the recharge area of the Prairie du Chien-Jordan aquifer or surficial aquifers. *(WMP Sect 4)* Enhance the floodplains' water resource values. Water resource values are defined as those characteristics which promote the natural moderation of floods, maintain the streams' water quality, and provide groundwater recharge. *(Rule E)* To manage stormwater and snowmelt runoff and promote natural infiltration: - Maximize infiltration and control runoff volume increase.

Comparison of Groundwater Management Standards.

BCWD	CMWD	SWWD	RWMWD	VBWD	RCWD
	rain. *(WMP Sect. IV Subd. E.3)* Review and permit all development and improvements within 1000 feet of an identified groundwater recharge area that is listed by the District as a sensitive or high priority recharge area. *(WMP Sect. IV Subd. E.3)*				
POLICY STATEMENT - GROUNDWATER CONTAMINATION					
It is the policy of the District to: ▪ Require management of stormwater flow to limit sediment, nutrient and metals concentrations conveyed to ground and surface waters and promote water quality *(Rule 2.1)*	No specific language addressing this issue.	Identify and ensure effective management of areas where groundwater contamination potential is high or where groundwater contamination has already occurred. *(WMP Sect III Subd. B)*	Promote efficient and effective administration of groundwater pollution regulations. *(WMP Sect. IV)*	No specific language addressing this issue.	Protect recharge areas from future sources of contamination. *(WMP Sect 4)*
POLICY STATEMENT - GROUNDWATER PROGRAMS AND PROJECTS					
Participate in the development of a groundwater monitoring plan and subsequent	Groundwater recharge area identification. *(WMP Sect IV Subd.D.2c)*	Complete an inventory of unused, unsealed wells; feed lots; drywells;	Create a Phase II groundwater management strategy and implementation	No specific language addressing this issue.	The District supports the sealing of abandoned wells and will cooperate with

Comparison of Groundwater Management Standards.

BCWD	CMWD	SWWD	RWMWD	VBWD	RCWD
monitoring program. *(WMP Sect III-8)*		injection wells; old solid waste disposal areas; storage tanks; and permitted discharge points using the Potential Contaminant Source Inventory. *(WMP Sect VI Subd. C.3)* Periodically review status of known contamination sites remediation systems. *(WMP Sect VI Subd. C.3)* Establish a monitoring network of existing wells to sample semi-annually. *(WMP Sect VI Subd. C.3)* Identify surface water bodies that are connected to the water table system. *(WMP Sect VI Subd. C.3)* Evaluate the effects of stormwater infiltration on groundwater flow system. *(WMP Sect VI Subd.*	programs. *(WMP Sect. IV)* Collaborate on the development of an education/information program to promote awareness about groundwater resources and groundwater protection. *(WMP Sect. IV)* Continue to operate the District's abandoned well sealing program. *(WMP Sect. IV)* Develop a groundwater flow model for the entire District. *(WMP Sect. IV)* Evaluate need and resources for a permanent groundwater quality monitoring program. *(WMP Sect. IV)* When possible and appropriate, cost-share with cities and other jurisdictional entities or obtain grant funds to implement a		other governmental units identifying priority wells for sealing. *(WMP Subd 5 Sect. 11)* The District will seek to promote water conservation by urging municipalities to adopt permanent water conservation rules. *(WMP Subd 5 Sect 11)*

Comparison of Groundwater Management Standards.

BCWD	CMWD	SWWD	RWMWD	VBWD	RCWD
		C.3) Inventory sensitive groundwater and surface water resources and establish guidelines to prevent degradation of the resources that might financially impact individual citizens of the watershed in the future. *(WMP Sect III Subd. B)*	consistent cost-effective district-wide groundwater strategy that is consistent with the Ramsey and Washington County groundwater management plans and programs. *(WMP Sect. IV)*		
ACTIVITIES REGULATED					
Proposed land-altering activity will not: ▪ Increase stormwater flow volume from the site for a 24-hour precipitation event with a return frequency of 1.5 years, excepting the increased flow resulting from impervious cover on five percent of the site possessing average site permeability. *(Rule 2.4)*	Requires all septic tanks and drain fields that outlet directly or indirectly into the District waters to be constructed and maintained in accordance with the rules and recommendations of the State Board of Health and PCA. *(Rule Sect.5.H.)* The volume of discharge shall be limited to the pre-development	Review and provide approval for water appropriations. *(Rules Sect VIII, Subd. 2)* The following Interim Infiltration Standards will apply to landlocked and semi-landlocked subwatersheds outside of the Metropolitan Urban Service Area that is adopted as of February 9, 1999 until an infiltration or volume control policy	No septic tank or other waste disposal facility shall outlet directly or indirectly into any lake, watercourse, or public or private drain. *(Rule Sect.V.Subd.1.(1).)*	To manage the water resources of the District, the Managers require that the effect of the proposed appropriation of ground and/or surface waters. The Managers require that the effect of the proposed appropriation be defined before approval is granted." *(Rule Sect. VII. Subd.1)*	Review and comment on groundwater appropriations. *(WMP Subd 5 Sect 11)* Soil absorption systems not allowed in: ▪ Low swampy areas or areas subject to recurring flooding ▪ Areas where highest known ground water table, bedrock or

Comparison of Groundwater Management Standards.

BCWD	CMWD	SWWD	RWMWD	VBWD	RCWD
	discharge volumes for the 2-year and 10-year storm events. *(WMP Sect. IV.F.1.(d))*	is developed and adopted. ▪ Maintain the quality and quantity of runoff to pre-development levels; ▪ Stormwater quantity must be limited to pre-development volumes only to be adjusted by the watershed where pre-existing land-use zoning makes minor increases necessary. In all cases, infiltration management techniques shall be used to maximize infiltration. *(Rule Sect. IX Subd. 3.D)*			impervious soil conditions are within 4' of bottom of system ▪ Where ground slope creates a danger of the seepage of the effluent on the surface *(Rule H.3.)* Construction of impervious areas within flood plain areas will not be allowed within the designated groundwater recharge areas for the Prairie du Chien-Jordan formation except for road construction, trails, and other recreational improvements. *(Rule E.3)* Volume control rules include a 2-Step Process ▪ Minimize imperviousness; ▪ Address the use of BMPs designed to

Comparison of Groundwater Management Standards.

BCWD	CMWD	SWWD	RWMWD	VBWD	RCWD
					infiltrate the impervious surface runoff from the Mpls-St. Paul median storm (0.34 inches) in seventy-two hours. *(Rule C.3.k)*
POLICY STATEMENT -ISTS					
		Ensure cities adopt state standards (MN Rules Ch 7080) for septic system construction and maintenance. Assist local and state officials in notifying septic system owners and service providers of the April 1, 1996 requirements for all systems to be inspected by a licensed or qualified inspector. *(WMP Sect. VI.C.3)*		No specific language addressing this issue.	No new Individual Sewage Treatment Systems (ISTS) will be allowed in sewered areas including replacement of existing ISTS unless a severe hardship is demonstrated and sewer connections are not practical. Administration and enforcement of these standards is to be conducted by the LGU in accordance with MN Rules Ch. 7080. *(WMP Sect. 5.5)* The RCWD promotes the local adoption of the MPCA individual wastewater treatment

BCWD	CMWD	SWWD	RWMWD	VBWD	RCWD
					system regulations. *(WMP Sect 4)*
WATERSHED DISTRICT ROLE IN ISTS					
No specific language addressing this issue.	No specific language addressing this issue.	No specific language addressing this issue.	Ensure local enforcement of existing local septic system or ordinances that are in conformance with Minnesota Pollution Control Agency (MPCA) 7080 Rules and Metropolitan Council requirements. *(WMP Sect. 4)*	No specific language addressing this issue.	Through the water quality monitoring program, the District will advise the LGU on water quality problems that may be associated with the improper design, location, installation, use and maintenance of ISTS. Enforcement or compliance with the ISTS standards shall be the responsibility of the LGU. LGU's will be responsible for the assurance that inspection and maintenance of ISTS are carried out. *(WMP Sect. 5.5)*

Comparison of Groundwater Management Standards.

BCWD	CMWD	SWWD	RWMWD	VBWD	RCWD
REFERENCE TO WASHINGTON COUNTY GROUNDWATER PLAN					
Follow the lead of Washington County on matters concerning the management and regulation of groundwater. *(WMP Sect III-8)*	The District acknowledges the Washington County Groundwater Management Plan, as amended. *(WMP Sect. IV Subd. E.3)*	The SWWD intends to follow the general recommendations given in the draft Washington County Groundwater Management Plan. *(WMP Sect VI Subd. C)*	Work with cities where possible to implement a cost-effective district-wide groundwater strategy that is consistent with the Ramsey and Washington County groundwater management plans and programs. *(WMP Sect. IV)*	No specific language addressing this issue.	No specific language addressing this issue.

Appendix D
Excerpts from *Minnesota's Native Vegetation: A Key to Natural Communities*, *Version 1.5 (DNR, 1993)*

Excerpted from: *Minnesota's Native Vegetation: A Key to Natural Communities, Version 1.5*. Minnesota Natural Heritage Program, 1993. Biological Report 20, Minnesota Department of Natural Resources. 110 pp.

Black Ash Swamp

Black ash swamp is dominated by black ash trees, which occur either in almost pure stands or in mixed stands with other hardwoods. In Washington and Chisago counties, very local, small stands of black ash swamp occur in seepage zones at the bases of river terrace slopes; these stands are classified as seepage subtypes of black ash swamp.

White Cedar Swamp

White cedar swamp occurs primarily in the conifer-hardwood forest zone, with scattered stands in the deciduous forest-woodland zone. White cedars dominate the tree canopy, either forming pure, dense, even-aged stands or mixed, uneven-aged stands with various amounts of black spruces, balsam firs, white spruces, balsam poplars, or black ashes. White cedar swamp occurs on wet mineral soils or well-decomposed peat soils on level to gently sloping (<3%) terrain along the margins of peatlands, along drainage courses, and in shallow depressions. There is one subtype of white cedar swamp, a seepage subtype, which occurs in groundwater seepage areas.

Black Spruce Swamp

Black spruce swamp occurs primarily in the conifer-hardwood forest zone, with scattered outlying stands in the deciduous forest-woodland zone. The canopy is dominated by black spruces, often growing in pure stands or in association with tamaracks or white cedars. Black spruce swamp occurs on shallow to deep, moderately acidic peat. Nutrient levels in the community vary with the depth and degree of decomposition of the peat. Under certain conditions, Black spruce swamps will succeed to black spruce bogs, as the surface waters in the community become acidified and there is an increase in the abundance of peat-forming sphagnum mosses. Black spruce swamp differs from black spruce bog by containing species that grow in minerotrophic environments. Black spruce is long-lived in swamps or bogs, and may form mature and old-growth stands.

Mixed Hardwood Swamp

Mixed hardwood swamp is present in the deciduous forest-woodland and conifer-hardwood forest zones. The community has a mixed canopy of hardwoods, including paper birches, yellow birches, American elms, black ashes, red maples, quaking aspens, and green ashes. Black ashes, although commonly present, never form more than 50% of the canopy cover in the community. Mixed hardwood swamp occurs most commonly on muck and shallow peat on lake plains and floodplains. A seepage subtype of mixed hardwood swamp occurs in groundwater seepage areas at the bases of terrace slopes near the St. Croix River in Washington, Chisago, and Pine counties.

Tamarack Swamp

Tamarack swamp is present throughout the deciduous forest-woodland and conifer-hardwood forest zones. It occurs on minerotrophic muck and shallow peat along rivers and in shallow lake basins, and on nutrient-poor, mildly-acidic to acidic peat in ice-block basins or large peatland systems. Tamarack is either the only canopy species or is mixed with black spruce, paper birch, yellow birch, white pine, black ash, American elm, or red maple. There are three subtypes of tamarack swamp, a minerotrophic subtype, a sphagnum subtype, and a seepage subtype. The seepage subtype is local and rare. At present, it is documented only along the St. Croix River and along the Sauk River in Stearns County, where it occurs in groundwater seepage areas at the bases of river terrace slopes.

Shrub Swamp

Shrub swamps are minerotrophic, tall-shrub communities, most often present on mucks and shallow peat in the deciduous forest-woodland and conifer-hardwood forest zones. The major shrub species in these communities are speckled alder, willows (especially pussy willow, slender willow, and Bebb's willow), and red-osier dogwood. Shrub swamps are considered mid-successional communities, between wet meadow/fen communities and conifer or hardwood swamp forests. However, shrub swamp communities are relatively stable in areas where water table fluctuations are small, as the loss or gain of woody vegetation in many wetland areas is linked to particularly dry or wet cycles that affect seedling establishment, flooding, windthrow, and fire frequency. Before European settlement, extensive areas of shrub swamp existed in shallow wetlands on outwash plains and in glacial lake basins. Where fires occurred relatively frequently in wetland areas, the wetland communities probably were open, mainly lacking shrubs or trees. Occasional fires or prolonged flooding (such as from beaver ponds) in conifer swamp or hardwood swamp may have been important in maintaining patches of shrub swamp in areas that are predominantly swamp forest. Artificially drained meadows or fens rapidly succeed to shrubby wet meadow or fen, to shrub swamp, or to forested swamps.

Alder Swamp

Alder swamp is a minerotrophic wetland with a canopy of tall shrubs dominated by speckled alder, often mixed with other shrub species such as willows, bog birch, poison sumac, or alder buckthorn.

Wet Prairie

Wet prairie occurs mainly in the southern and western parts of the prairie zone, with scattered occurrences in the deciduous forest-woodland zone. Typically, wet prairie is dominated by grasses, but sedges are also important in the community. Forbs are abundant in wet prairies, but on the whole fewer forb species occur in wet prairie than in mesic prairie. Wet prairie occurs in low areas (such as depressions and drainageways) where the water table remains within the plant rooting zone for several weeks during the growing season, but where inundation occurs only infrequently and briefly. In some wet prairies groundwater seepage causes soils to be very moist or wet. Occurrences of the seepage subtype almost always have significant shrub cover (especially by bog birch).

Wet Brush-Prairie

Wet brush-prairie is an open wetland community of the northern part of the deciduous forest-woodland zone. It is composed of clumps or thickets of low brush in a herbaceous matrix dominated by grasses characteristic of wet prairie. There is one subtype of wet brush-prairie, a seepage subtype.

Rich Fen

Rich fen occurs in the conifer-hardwood forest and deciduous forest-woodland zones. The groundlayer is dominated by wiregrass sedge (Carex lasiocarpa), brown sedge (Carex buxbaumii), livid sedge (Carex livida), Calamagrostis neglecta, or bog reed-grass (Calamagrostis inexpansa). Surface waters within the community are slightly acidic to circumneutral (pH 5.8 - 7.8) with moderate nutrient levels ($[Ca^{2+}]$ = 10-32 mg/1). Rich fen grades into poor fen but is distinguishable from poor fen by its higher species diversity and by the more frequent occurrence and greater abundance of minerotrophic indicator species.

Poor Fen

Poor fen is most common in the conifer-hardwood forest zone, with scattered occurrences in the deciduous forest-woodland zone. The ground cover of the community is dominated by wiregrass sedge *(Carex lasiocarpa*) or few-seeded sedge *(C. oligosperma*). Poor fens have at least 50% cover by sphagnum mosses and up to 70% cover by shrubs and small trees, most commonly bog birches and stunted tamaracks.

Poor fen occurs on deep peat (>1.0m) that receives minimal nutrient-rich run-off from surrounding uplands. In Minnesota's large patterned peatlands, poor fen often is present on sites with water infiltration from adjacent raised bogs. Less frequently, poor fen occurs in the interiors of small basins that are relatively isolated from run-off. The surface water of poor fen is slightly acidic (pH 4.1 - 5.9) and nutrient poor ($[Ca^{2+}]$ <13 mg/l). Poor fen is transitional between rich fen and open bog and commonly grades into these communities on the landscape.

There are three subtypes of poor fen, a sedge subtype, a shrub subtype, and a scrub tamarack subtype.

Calcareous Seepage Fen

Calcareous seepage fen is an open sedge and rush community that occurs throughout Minnesota. The groundlayer is usually dominated by wiregrass sedge *(Carex lasiocarpa*), *Carex sterilis*, beaked-sedge *(Rhynchospora capillacea*), spike-rush *(Eleocharis rostellata*), and *Scirpus cespitosus*. Shrubs, including bog birch, sage-leaved willow, and shrubby cinquefoil, are common in the community. Mosses range in cover from abundant to scarce. Calcareous seepage fens occur on shallow or deep peaty soils in areas of calcareous groundwater discharge.

Wet Meadow

Wet meadow is present throughout Minnesota. The groundlayer of the community is composed of dense, closed stands of predominately wide-leaved sedges. Forb cover and diversity usually are high. Shrub cover in wet meadows ranges from 0 to 70% and is composed of Bebb's willows and pussy willows. Wet meadow occurs on wet mineral soil, muck, or shallow peat (>0.5m). Standing water (generally stagnant) is present in the spring and after heavy rains, but the water table is generally below the soil surface for most of the growing season. Occurrences of wet meadow along stream courses or adjacent to lakes often have fairly constant water levels relative to wet meadows in depressions or basins. On these sites siltation may be important in maintaining high nutrient levels.

Seepage Meadow

Seepage meadow is best documented in the St. Croix valley. Seepage meadows develop around spring heads and in broader areas of groundwater discharge, most commonly in deep glacial meltwater-cut river valleys, at the bases of slopes separating stream terraces. The upwelling groundwater is cold and flows year-round. Peat is present in some seepage areas, sometimes in layers greater than one meter thick. Other seepage areas have little organic material, with the groundwater welling up through carbonate encrusted gravel.

Talus Slope

Talus slope communities occur in northeastern and southeastern Minnesota in the deciduous forest-woodland and conifer-hardwood forest zones. They are accumulations of coarse rock and soil at the bases of cliffs and steep slopes. They range in habitat type from shady and moist to exposed and dry. There is one subtype, the algific subtype.

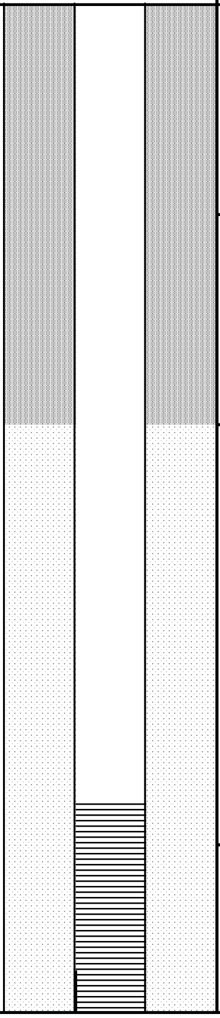
The algific subtype occurs only on the Paleozoic Plateau in southeastern Minnesota, at the bases of steep, north-facing dolomite talus slopes. Continuous cold air drainage from fissures and ice caves in the talus creates a cool, moist microclimate in which summer temperatures rarely exceed 16°C. These talus slopes may be small (one square meter), or narrow linear complexes up to 1.5 km long.

Moist or Maderate Cliff

Moist cliff communities occur on north- to northeast-facing, vertical or nearly vertical exposures of bedrock or unconsolidated material. They also occur on well-shaded overhangs and sometimes on the lower portions of south- to west-facing cliffs, where these are shaded by a forest canopy. Most of the rock surface in the community is kept moist by seepage or condensation. The cool, moist microhabitat in the community supports several rare plant species. Moist cliff communities often occur upslope from talus slope communities and grade into talus slope communities. There are two sections of moist cliff, the southeast section and the northeast section. These sections occur on different rock types and harbor different plant species. The southeast section includes one subtype, the maderate subtype.

Most occurrences in the southeast section are on the Paleozoic Plateau of southeastern Minnesota, with others along the St. Croix Valley in east-central Minnesota. The rock cliffs are formed primarily of limestone or sandstone, and the community usually occurs on these cliffs below forested slopes along major streams and rivers. The maderate subtype of the southeast section of moist cliff occurs on rock faces with actively dripping cold water systems that create a cool microhabitat. The maderate subtype is often associated with the algific subtype of talus slope.

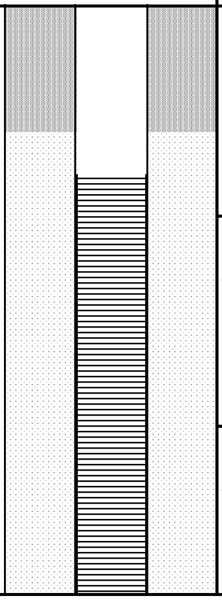
Appendix E
Hardwood Creek Monitoring Well Logs



Depth (ft)	Well Construction	Boring Log	Sample Type	Sample no., type, interval	Blow counts	Sample recovery [ft]
		light brown clay loam, with sand moist				4
5	Bentonite grout seal	dark brown clay loam, with sand wet/moist				
10	#30 Red flint sand pack	dark brown almost black peat wet, with sand				
15		same				
		same, lighter				19
20	PVC well screen, 5'	fine grey sand, wet				
25						

No. MW-1	Sheet 1 of 1	**Soil Boring Log & Well Log**
Unique # 689955		
Elev.: Surf	T.O.C.	
Drill type Hollow Stem Auger	Contractor MDNR	Site name/Location Hardwood Creek 157th Street Hugo Township, MN
Driller Mike & Tom	Logged by MDR	
Landowner City of Hugo	File	

EMMONS & OLIVIER RESOURCES



Depth (ft)	Well Construction	Boring Log	Sample Type	Sample no., type, interval	Blow counts	Sample recovery [ft]
	Bentonite grout seal	light brown clay loam, with sand moist				
5	#30 Red flint sand pack	dark brown clay loam, with sand wet/moist				
10	PVC well screen, 10'	dark brown almost black peat wet, with sand				
15						
20						
25						

No. MW-2

Sheet 1 of 1

Unique # 689954

Elev.: Surf

T.O.C.

Drill type Hollow Stem Auger

Contractor MDNR

Driller Mike & Tom

Logged by MDR

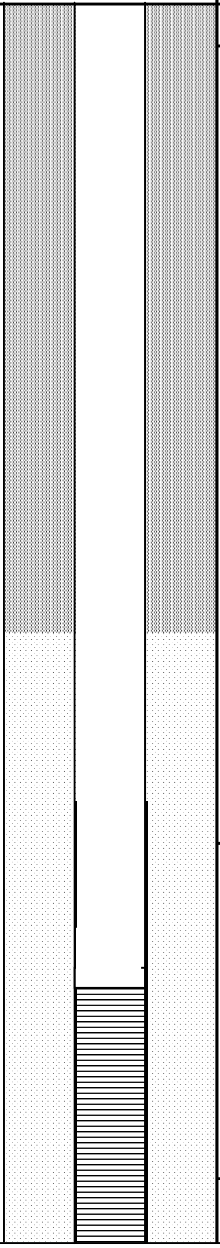
Landowner City of Hugo

File

EMMONS & OLIVIER RESOURCES

Soil Boring Log & Well Log

Site name/Location
Hardwood Creek 157th Street
Hugo Township, MN

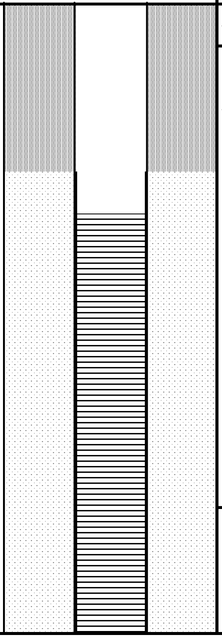


Depth (ft)	Well Construction	Boring Log	Sample Type	Sample no., type, interval	Blow counts	Sample recovery [ft]
		light grey clay loam sand (road fill?)				1
		dark brown/black clay loam wet/moist				
5	Bentonite grout seal					
10						
15						
	#30 Red flint sand pack					
20		coarse grey sand, wet				
25	PVC well screen, 5'					
		grey sandy clay, wet				

No.	MW-3	Sheet 1 of 1	
Unique #	689953		
Elev.: Surf		T.O.C.	
Drill type	Hollow Stem Auger	Contractor	MDNR
Driller	Mike & Tom	Logged by	MDR
Landowner	City of Hugo	File	

Soil Boring Log & Well Log

Site name/Location
Hardwood Creek 165th Street
Hugo Township, MN



Depth (ft)	Well Construction	Boring Log	Sample Type	Sample no., type, interval	Blow counts	Sample recovery [ft]
	Bentonite grout seal	wet grey clay loam sand dark brown clay loam, with sand wet/moist				
5	#30 Red flint sand pack	numerous shells and shell fragments				
10	PVC well screen, 10'	fine grey sand				
15						
20						
25						

No. MW-4

Sheet 1 of 1

Unique # 689952

Elev.: Surf

T.O.C.

Drill type Hollow Stem Auger

Contractor MDNR

Driller Mike & Tom

Logged by MDR

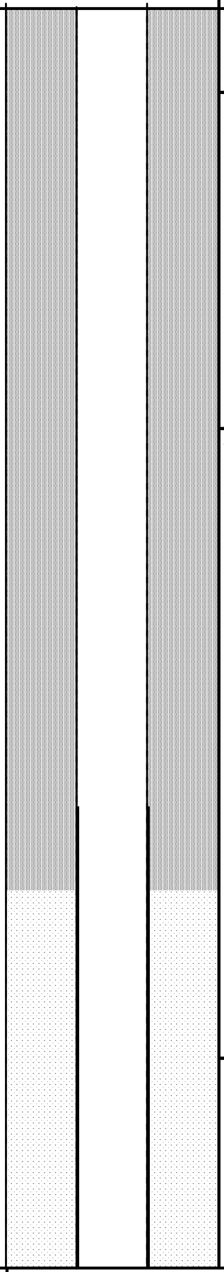
Landowner City of Hugo

File

Soil Boring Log & Well Log

Site name/Location
Hardwood Creek 165th Street
Hugo Township, MN

Depth (ft)	Well Construction	Boring Log	Sample Type	Sample no., type, interval	Blow counts	Sample recovery [ft]
		dark brown medium sand, moist				1
		grey medium to coarse sand, moist				
5	Bentonite grout seal					
10		black loamy medium sand moist				
	#30 Red flint sand pack					
15		same, grey				
20		same, wet, more loam less sand				
25		gravel , sand, clay, grey, wet				

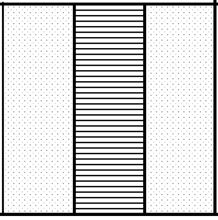


No.	MW-5	Sheet 1 of 2	
Unique #	689951		
Elev.: Surf		T.O.C.	
Drill type	Hollow Stem Auger	Contractor	MDNR
Driller	Mike & Tom	Logged by	MDR
Landowner	Washington County	File	

EMMONS & OLIVIER RESOURCES

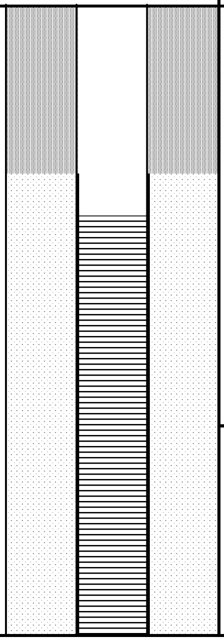
Soil Boring Log & Well Log

Site name/Location
Hardwood Creek 170th Street
Hugo Township, MN

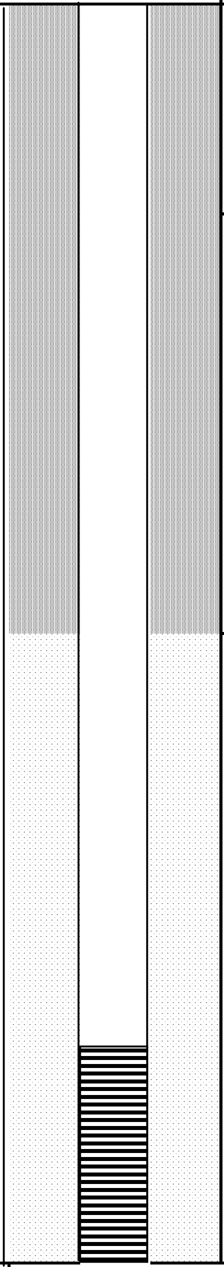
Depth (ft)	Well Construction	Boring Log	Sample Type	Sample no., type, interval	Blow counts	Sample recovery [in]
	#30 Red flint sand pack PVC well screen, 5" 	grey sandy clay, wet				
35						
40						
45						
50						
55						

No. MW-5	Sheet 2 of 2	**Soil Boring Log & Well Log**
Unique # 689951		
Elev.: Surf	T.O.C.	
Drill type Hollow Stem Auger	Contractor MDNR	Site name/Location Hardwood Creek 170th Street Hugo Township, MN
Driller Mike & Tom	Logged by MDR	
Landowner Washington County	File	

Depth (ft)	Well Construction	Boring Log	Sample Type	Sample no., type, interval	Blow counts	Sample recovery [ft]
	Bentonite grout seal	dark brown almost black peat moist				
5	#30 Red flint sand pack					
10	PVC well screen, 10'	grey sandy till				
15						
20						
25						



No. MW-6	Sheet 1 of 1	**Soil Boring Log & Well Log**	
Unique # 623100			
Elev.: Surf	T.O.C.		
Drill type Hollow Stem Auger	Contractor MDNR	Site name/Location Hardwood Creek 170th Street Hugo Township, MN	
Driller Mike & Tom	Logged by MDR		
Landowner Washington County	File		



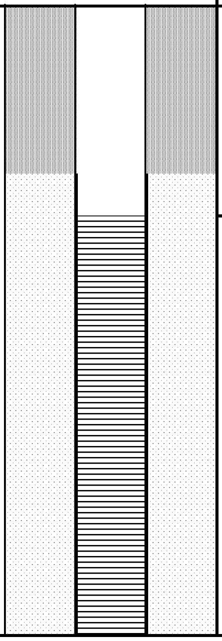
Depth (ft)	Well Construction	Boring Log	Sample Type	Sample no., type, interval	Blow counts	Sample recovery [ft]
		dark brown/black clay loam, with sand				1
5	Bentonite grout seal	grey fine sand and clay silt till				
10		same with coarse sand and more clay				
15		light brown medium sand and silty clay, moist				
	#30 Red flint sand pack					
20		water at 19'				20
		same				
25	PVC well screen, 5'					

Soil Boring Log & Well Log

No.	MW-7	Sheet 1 of 1	
Unique #	689956		
Elev.: Surf		T.O.C.	
Drill type	Hollow Stem Auger	Contractor	MDNR
Driller	Mike & Tom	Logged by	MDR
Landowner	DNR	File	

Site name/Location
Hardwood Creek WMA Jeffries Ave.
Forest Lake Township, MN

Depth (ft)	Well Construction	Boring Log	Sample Type	Sample no., type, interval	Blow counts	Sample recovery [ft]
	Bentonite grout seal	dark brown/black clay loam, with sand				
5	#30 Red flint sand pack	grey fine sand and clay silt till				
10	PVC well screen, 10'	same with coarse sand and more clay				
15						
20						
25						

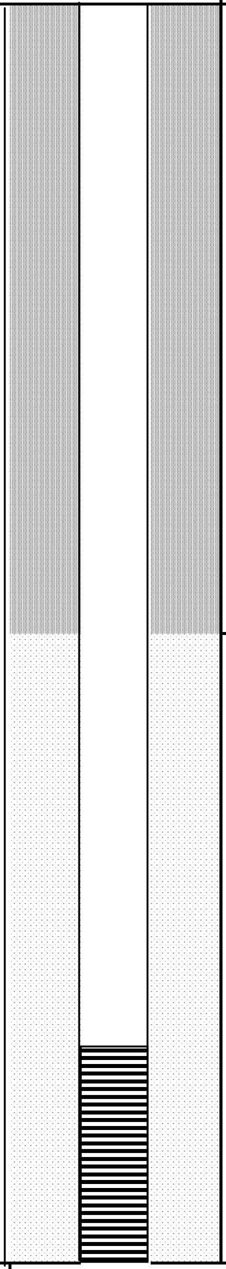


Soil Boring Log & Well Log

No.	MW-8	Sheet 1 of 1	
Unique #	689957		
Elev.: Surf		T.O.C.	
Drill type	Hollow Stem Auger	Contractor	MDNR
Driller	Mike & Tom	Logged by	MDR
Landowner	DNR	File	

Site name/Location
Hardwood Creek WMA Jeffries Ave.
Forest Lake Township, MN

Depth (ft)	Well Construction	Boring Log	Sample Type	Sample no., type, interval	Blow counts	Sample recovery [ft]
		dark brown/black clay loam, with sand				
5	Bentonite grout seal					
10						
15		grey fine sand and clay silt till				
	#30 Red flint sand pack					
20						
25	PVC well screen, 5'					

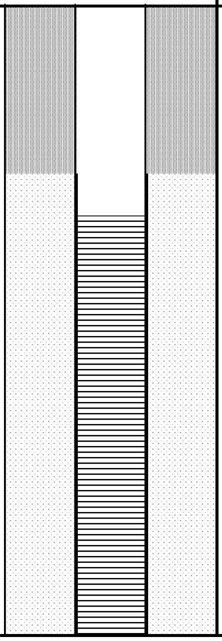


No. MW-9	Sheet 1 of 1
Unique # 623099	
Elev.: Surf	T.O.C.
Drill type Hollow Stem Auger	Contractor MDNR
Driller Mike & Tom	Logged by MDR
Landowner DNR	File

Soil Boring Log & Well Log

Site name/Location
Hardwood Creek Harrow Avenue
Forest Lake Township, MN

Depth (ft)	Well Construction	Boring Log	Sample Type	Sample no., type, interval	Blow counts	Sample recovery [ft]
	Bentonite grout seal	dark brown/black clay loam, with sand				
5	#30 Red flint sand pack					
10	PVC well screen, 10'					
15						
20						
25						



No. MW-10

Sheet 1 of 1

Unique # 623098

Elev.: Surf

T.O.C.

Drill type Hollow Stem Auger

Contractor MDNR

Driller Mike & Tom

Logged by MDR

Landowner DNR

File

EMMONS & OLIVIER RESOURCES

Soil Boring Log & Well Log

Site name/Location
Hardwood Creek Harrow Avenue
Forest Lake Township, MN

Appendix F
Model Ordinance for Groundwater Protection

Draft Washington County Groundwater Protection Model Ordinance

Adopted by the (County, City, Township, Watershed) of __________, on _____, 200_.

I. STATEMENT OF NEED

The broad acceptance of an ordinance is usually dependent upon general acceptance of the need for a change. The first section of the model ordinance should provide the statement of need that leads to the adoption of this regulatory step.

The _______ of _______ recognizes that all of its current and future residents rely on groundwater for their safe drinking water supply, that businesses and institutions also rely on this source of water, and that certain land uses and certain activities can contaminate groundwater. ______ also recognizes that increased urbanization introduces impervious surfaces that decrease the recharge (replenishment) of aquifer-sustaining water, thus limiting the quantity of groundwater available for current and future use by its citizens. Finally, _______ recognizes the need to maintain the interaction between groundwater and surface water, and the role this interaction plays in supporting surface water features, such as wetlands, lakes, rivers and streams.

To ensure the protection of these drinking water supplies, this ordinance establishes a (zoning, planning) overlay district within _______to be known as the (Groundwater Protection) Overlay District. This approach recognizes the need to approach groundwater protection in a comprehensive land use manner by controlling land uses which include the use, handling, production, storage or disposal of potentially contaminating substances, as well as controlling the total acreage of pervious recharge areas.

The purpose of the (Groundwater Protection) Overlay District is to protect public health and safety by minimizing contamination of aquifers, preserving and protecting existing and potential sources of drinking water supplies, and ensuring protection of significant natural resources reliant on groundwater. It is the intent to accomplish this through both public education and public cooperation, as well as by creating appropriate land use regulations that may be imposed ,in addition to those currently imposed by existing zoning districts or other county or local regulations.

The (Groundwater Protection) Overlay District is superimposed on current zoning districts and shall apply to all new construction, reconstruction, or expansion of existing buildings and new or expanded uses. Applicable activities/uses allowed in a portion of one of the underlying zoning districts which fall within the (Groundwater Protection) Overlay District must additionally comply with the requirements of this district. Uses prohibited in the underlying zoning districts shall not be permitted in the (Groundwater Protection) Overlay District.

II. REASONS FOR ORDINANCE

This optional section is a follow-up to Section I. It specifies the reasons for adoption of an ordinance. Adopting entities might want to structure this section to their particular needs, adding new protection elements or deleting those for which they have little concern.

The _______ of _______ deems it necessary to adopt this ordinance to:

- Provide protection for its sole source of water supply;
- Maintain an adequate volume of groundwater supply by assuring continued recharge;
- Provide separation between buildings and ISTSs ("individual sewage treatment systems", commonly called septic systems) and the local water table;
- Assure continued interaction between groundwater and surface water resources; and
- Encourage land use and activity that can appropriately and safely be located in groundwater protection areas.

III. DEFINITIONS

This section fulfills the need to define the terms within the ordinance that are not commonly used by the general public. A rule-of-thumb for the adopting entity should be "when in doubt, include a definition". The following list is merely a compilation of some terms that other adopting entities have used. This can be expanded or contracted depending upon local need.

For the purposes of this ordinance, the following terms are defined below:

Aquifer. A geological formation, group of formations or part of a formation composed of rock, sand or gravel capable of storing and yielding significant amounts of groundwater to wells and springs.

Best Management Practices (BMPs): A practice or combination of practices determined to be the most effective practicable (including technological, economic, and institutional considerations) means of preventing or reducing the amount of pollution to a level compatible with water, soil, and air quality goals.

Bulk Storage: Storage equal to or exceeding _______ gallons of liquid or _______ tons of solids in a single above-ground container

Closure: The cessation of operation of a facility, or any portion thereof, and the act of securing such facility or portion thereof to ensure protection of groundwater in accordance with the appropriate State, Federal, regional and local regulations.

Contamination: An impairment of water quality by chemicals, radionuclides, biologic organisms, or other extraneous matter, whether or not it affects the potential or intended beneficial use of water.

Development: The carrying out of any construction, reconstruction, external repair, land disturbing activity, grading, road building, pipe laying, alteration of surface or structure, or other activity resulting in a change in the physical character of any parcel or land.

Discharge: Includes, but shall not be limited to, spilling, leaking, seeping, pouring, injecting, emitting, emptying, disposing, releasing, or dumping regulated substances, hazardous waste or petroleum products to the soils, air, groundwater, or surface waters of _______. Discharge does not include the use of a regulated substance in accordance with the appropriate use intended or specified by the manufacturer of the substances, provided that such use is not prohibited by Federal, State, regional or local regulations. Discharge shall not include discharges specifically authorized by Federal or State permits.

Disposal: The deposition, injection, dumping, spilling, leaking, incineration, or placing of any regulated substances into or on any land or water so that such substances, or any constituent thereof, may enter the environment or be emitted into the air or discharged into any waters, including groundwater.

Drinking Water Source: A drinking water well supplying water which has been permitted or intended for consumptive use.

Facility: Something that is built, installed, or established for a particular purpose.

Groundwater: Any water drawn from the ground.

Groundwater Divide: A line on a water table on each side of which the water table slopes downward in a direction away from the line. A line that divides groundwatersheds.

Hazardous Material: A material which is defined in one or more of the following categories:

> Ignitable: A gas, liquid or solid which may cause fires through friction, absorption of moisture, or which has low flash points. Examples: white phosphorous and gasoline.
>
> Carcinogenic: A gas, liquid, or solid which is normally considered to be cancer causing or mutagenic. Examples: PCB's in some waste oils.
>
> Explosive: A reactive gas, liquid or solid which will vigorously and energetically react uncontrollably if exposed to heat, shock, pressure or combinations thereof. Examples: dynamite, organic peroxides and ammonium nitrate.
>
> Highly Toxic: A gas, liquid, or solid so dangerous to man as to afford an unusual hazard to life. Example: chlorine gas.

Moderately Toxic: A gas, liquid or solid which through repeated exposure or in a single large dose can be hazardous to man.

Corrosive: Any material, whether acid or alkaline, which will cause severe damage to human tissue, or in case of leakage might damage or destroy other containers of hazardous materials and cause the release of their contents. Examples: battery acid and phosphoric acid.

Other: Any substance or mixture of physical, chemical, or infectious characteristics posing a significant, actual, or potential hazard to water supplies or other hazards to human health if such substance or mixture were discharged to land or water, including all substances regulated by local, county, state and federal law.

Impervious Surface: Material or structure on, above, or below the ground that does not allow precipitation or surface water to penetrate directly into the soil.

Infiltration: The downward movement of water through the surface of the ground.

ISTS: Individual sewage treatment system, or commonly called a septic system.

Overlay District: The zoning district defined to overlay other zoning districts in the (jurisdiction) of ____. This district may include specifically designated recharge areas that collect precipitation or surface water and carry it to aquifers. An area within which best management practices are required for restricted uses, or certain uses are prohibited, in order to protect groundwater flowing to public drinking water sources.

Petroleum Product: Fuels (gasoline, diesel fuel, kerosene, and mixtures of these products), lubricating oils, motor oils (new and used), hydraulic fluids, and other similar petroleum-based products.

Pollution: The presence of any substance or condition in water which tends to degrade its quality so as to constitute a hazard or impair the usefulness of the water.

Potentiometric Surface: The elevation to which water will rise in a tightly cased well.

Primary Containment Facility: A tank, pit, container, pipe or vessel of first containment of a liquid or chemical.

Recharge: The movement of infiltrating or flowing water into an aquifer.

Recharge Areas: Areas that collect precipitation or surface water, and carry it to aquifers through infiltration and subsequent downward or lateral flow.

Regulated Substance: Any substance, including petroleum or derivatives thereof, or combination of substances which because of their quantity, concentration, physical, chemical, infectious, flammable, combustible, radioactive, or toxic characteristics, may cause or significantly contribute to a present or potential risk to human health, safety, welfare, to groundwater resources or to the natural environment. Regulated Substances include those materials subject to the following regulations which meet the requirements of this definition:

- Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA), 42 U.S.C. §§ 9601-9675;
- Clean Water Act (Federal Water Pollution Control Act), 33 U.S.C. §§ 1251-1387;
- Federal Insecticide, Fungicide and Rodenticide Act (FIFRA), 7 U.S.C. §§ 136-136Y;
- Emergency Planning and Community Right-to-Know Act of 1986 (EPCRTKA), 42 U.S.C. §§ 11001-11050;
- Hazardous Materials Transportation Act (HMTA), 49 App. (U.S.C.) §§ 1801-1819;
- Hazardous and Solid Waste Amendments of 1984 (HSWA), Pub.L. 98-616, Nov. 8, 1984, Stat. 3221;
- Solid Waste Disposal Act and Resource Conservation and Recovery Act (RCRA), 42 U.S.C. §§ 6901-6992K;
- Superfund Amendments and Reauthorization Act (SARA), Pub. L. 99-499, as amended by Pub. L. 99-563, Pub. L. 100-102, and Pub. L. 101-144;
- Toxic Substances Control Act (TSCA), 15 U.S.C. §§ 2601-2654; and
- All applicable local and state laws, rules and regulations.

Release: Any unplanned or improper discharge, leak, or spill of a potential contaminant, including a hazardous material.

Secondary Containment Facility: A second tank, catchment pit, pipe, or vessel that limits and contains liquid or chemical leaking or leaching from a primary containment area; any system that is used to provide release detection and release prevention, such as trays under containers, floor curbing or other systems designed to hold materials or liquids that may discharge from containers holding regulated substances, petroleum products or hazardous waste. Examples include a double-walled tank, a double-walled integral piping system, or a single-walled tank or integral piping system that is protected by an enclosed concrete vault, liner, or an impervious containment area.

Septage: The liquid, solid, and semi-solid contents of sewage waste receptacles.

Septic Holding Tank: A watertight receptacle, used to contain septic waste, the contents of which are removed and disposed of at a waste disposal facility.

Septic Tank System: A generally watertight receptacle connected to a drain field that allows liquid from the tank to enter the soil. The system is constructed to promote separation of solid and liquid components of domestic wastewater, to provide decomposition of organic matter, to store solids, and to allow clarified liquid to discharge for further treatment and disposal in a soil absorption system. See also ISTS.

Shallow/Surficial Aquifer: An aquifer of glacially deposited, unconsolidated material consisting of variably permeable sand, silt, clay, gravel and rocks, starting at the land surface or immediately below the soil profile and extending downward to the first consolidated bedrock unit.

Sludge or Biosolids: The solids separated from wastewater during the wastewater treatment process.

Source Water Protection: Any effort that is intended to prevent harm or to maintain the viability of a drinking water supply source, such as a groundwater aquifer.

Spill: The un-permitted release or escape of a Regulated Substance directly or indirectly to soils, surface waters, or groundwater.

Spill Response Plans: Detailed plans for control, re-containment, recovery, and clean up of hazardous or polluting material releases, such as during accidents, fires or equipment failures.

Stormwater Treatment Practices: Measures, either structural or nonstructural, that are determined to be the most effective, practical means of preventing or reducing point source or nonpoint source pollution inputs to stormwater runoff and water bodies. Often also called Best Management Practices or BMPs.

Time-of-Travel Distance: The distance that groundwater will travel in a specified time. This distance is generally a function of the permeability and slope of the aquifer.

Unconfined Aquifer: An aquifer which has the water table as its upper boundary and a confining unit as a lower boundary. It is also an aquifer under atmospheric conditions at the water table.

Watershed: Any area defined by the topographic basin draining to a particular spot on the land surface. A **Groundwatershed** is defined as the surficial expression of the water draining underground to a particular spot; note that the watershed and groundwatershed could be substantially different for any point on the land surface.

Well: Any excavation that is drilled, cored, bored, washed, driven, dug, jetted, or otherwise constructed for which the intended use of such excavation is the location, acquisition, development, or artificial recharge of groundwater.

Wellfield: An area of land which contains one or more drinking water supply wells.

Wellhead Protection Areas (WHPA): Legally defined zones delineated around wells and/or wellfields within which land uses are regulated to protect the quality of the groundwater resource. Regulated through the Minnesota Department of Health Wellhead Protection Program.

Zones: Geographical protection zones within the Overlay District within which certain protections apply. For example, to parallel the proposed County system, Zone 1 could be a “Critical Impact Zone”, Zone 2 a “Potential Impact Zone” and Zone 3 a “General Protection

Zone". Various levels of protection can be imposed within each Zone reflective of the potential for impact.

IV. APPLICABILITY

> *This chapter defines the areas covered by the ordinance. They can be either mapped and defined areas (1), or areas that fall into coverage because of unique conditions (2).*

This ordinance establishes certain standards and restrictions intended to prevent contamination or depletion of the groundwater system as a result of pollution or overuse/recharge reduction. It shall be the responsibility of any person owning real property and/or owning or operating a business within the protective zones or recharge areas established pursuant to this Chapter to conform and comply with the applicable provisions contained herein. Ignorance of this Chapter shall not excuse any violations of the provisions hereof.

The provisions established in this ordinance shall apply to the following areas:

> (1) Any potentially polluting activity occurring within an area designated on the _______ Overlay District map, dated _______, and made a part of this chapter by reference. (Potential Overlay Districts include major recharge zones, areas of groundwater/surface water interaction, high water table, shallow soil depth, soils unsuitable for ISTSs, and _______).
>
> (2) Such other areas as may be determined by the (zoning administrator) through drainage, groundwater and soils analyses conducted by the (Department) of _______ to be essential to protection of groundwater.

The requirements established under this ordinance constitute the rules of the _______ Overlay District and shall be superimposed over other zoning districts of the _______. The provisions herein shall apply in addition to all other applicable ordinances and regulations. In the event of a conflict between any provision herein and any other ordinance or regulation, the one more protective of the groundwater resource shall apply.

V. LIMITED USES/REGULATIONS/RULES

> *This chapter addresses what the ordinance regulates. The information presented is given largely as an example of the type of areal coverage that could apply, as well as activities that are allowed and not allowed. Many potentially polluting activities can be done in a protected area, as long as they are properly managed and carefully conducted. The adopting entity should look closely at what kinds of activities they truly do not want in the protection area, and those they could tolerate, if done carefully. As an additional note, some of the pollution impacts are likely to be regulated through the MDH Wellhead Protection Program and Well Code. This ordinance can be either an integral part of the adopted mitigation plan, or an interim protective measure put in place until the local wellhead protection program is formally adopted.*

Groundwater Protection Overlay District

A Groundwater Protection Overlay District has been adopted by _______ to assure the continued protection of the _______'s water supply and groundwater dependent surface water features. This District is a compilation of three distinct zones within which variable levels of protection are sought.

As a general statement, no person shall discharge, or permit the discharge of any regulated substance, hazardous or biological waste, or petroleum product, whether treated or untreated, to soils, air, groundwater, or surface water in any recharge area or water quality protection zone, that may have a deleterious effect upon the groundwater, unless the discharge is in compliance with Federal, State, and local regulations. Similarly, the movement of infiltrating water into the groundwater system shall not be reduced as the result of development or redevelopment.

The uses regulated within this District have been identified as risks for groundwater contamination or as actions that limit groundwater/surface water interaction. This method of regulation is employed to provide the greatest assurance that inadvertent discharge of pollutants into the groundwater supply will not occur, since groundwater cleanup is often prohibitively expensive, and liability for such cleanup is often difficult or impossible to establish. It also assures that recharge and groundwater/surface water interaction will continue so that both a viable water supply and viable surface water features are maintained.

The uses prohibited within this District represent the state of present knowledge and most common description of such uses. As other polluting uses are discovered, or other terms of description become necessary, it is the intention to add them to the list of uses prohibited by this District. To screen for such other uses or terms for uses, no use shall be permitted in this District without first submitting its building, site and operational plans for _______ review and approval.

The uses prohibited by this District are prohibited based upon the combined pollution experience of the technology class. As the technology of identified use classes change to non-risk materials or methods, upon petition from such a use, and after conferring with expert geological and other opinion, it is the intention to delete from the prohibited list, or allow conditionally, uses that demonstrate convincingly that they no longer pose a pollution hazard.

In dealing with uses or classes of uses that attempt to become permissible, under the terms of this District, by continuing to use pollutant materials but altering their methods of storage or handling, for example transferring materials storage from leak-prone but explosion-resistant underground tanks, to leak-resistant but explosion-vulnerable aboveground vessels, it is not the intention to accept such alternate hazards as the basis for making a use permissible. It is the intention to continue the ban on such uses until the technology of the class of uses removes reliance upon the pollutant materials or processes.

Unless otherwise specified, the provisions of this Section apply to new development, changes or expansion of use, and/or handling, movement, and storage of hazardous waste, petroleum products and regulated substances.

Zone 1: Critical Groundwater Quality Impact Zone .

Zone 1 is defined as the area within the District where severe damage to the groundwater or groundwater dependent resources would occur if certain polluting activities introduced contamination to the ground or infiltration is limited. This zone is defined as the most rapidly infiltrating, fastest movement to water table area in the County, and can be sub-divided according to any mix of geologic, soil, land use/cover, and time-of-travel criteria. Within Zone 1, particular attention is devoted to eliminating the threat of contaminating material from entering the soil, bedrock or any potential route to groundwater, including such things as wells, holes, pits and mines. Also within this area, the method of maintaining infiltration will be scrutinized to assure the continued movement of high quality water infiltrating into the ground.

a. **Encouraged Uses**. The following uses are encouraged within Zone 1 provided they meet the appropriate performance standards outlined in section e and are designed to prevent any groundwater contamination.

- Parks, greenways, or publicly-owned recreational areas such as foot, bicycle and/or horse paths, and bridges;
- Necessary public utilities/facilities including the construction, maintenance, repair, and enlargement of drinking water supply related facilities such as, but not limited to, wells, pipelines, aqueducts, and tunnels;
- Conservation efforts for soil, water, plants, and wildlife; and
- Low density residential uses with an educational program for chemical use.

b. **Special Exceptions**. The following uses are permitted only under the terms of a special exception and must conform to provisions of the underlying zoning district and meet the performance standards outlined in section e (below):

- Expansion of existing nonconforming uses to the extent allowed by the underlying district. The applicant should consult the local zoning plan to confirm nonconforming uses. The (zoning authority) reserves the right to review all applications and shall not grant approval unless it finds such expansion does not pose greater potential contamination of groundwater than the existing use.

c. **Regulated and Prohibited Uses**. The following uses, unless granted a special exception, are regulated or prohibited (*as noted by regulating authority*) within Zone 1;

NOTE > this is a fairly comprehensive list collected from several regulating entities. The zoning authority should carefully scrutinize the list to see which uses fall into the regulated versus prohibited category.

- Automobile body/repair shop
- Gas station
- Fleet/trucking/bus terminal
- Cemetery
- Dry cleaner
- Electrical/electronic manufacturing facility
- Machine shop
- Metal plating/finishing/fabricating facility
- Chemical processing/storage facility
- Fertilizer manufacturing/large-scale storage
- Wood preserving/treating facility
- Junk/scrap/salvage yard
- Landfill or open dump
- Mines/gravel pit
- Irrigated nursery/greenhouse stock
- Concentrated animal feeding operations
- Land divisions resulting in high density (>1 unit/acre) septic systems
- Disposal of collected septage or septic sludge
- Equipment maintenance/fueling areas
- Uncovered storage of de-icing salt and salt/sand mix areas, or loading areas
- Injection wells/dry wells/sumps, except for single-family residences directing gutter downspouts to a drywell
- Underground storage tanks, (except those with spill, overfill, and corrosion protection requirements in place)
- All other facilities involving the collection, handling, manufacture, use, storage, transfer or disposal of any solid or liquid material or waste having potentially harmful impact on groundwater quality
- All uses not permitted in the underlying zone district
- All uses not permitted under federal, state or local law or program

d. **Exclusions**. The following substances are not subject to the provisions of this Section provided that these substances are handled, stored, and disposed of in a manner that does not result in an unauthorized release or cause contamination of the groundwater.

- Regulated substances stored at residences that do not exceed ten (10) pounds (dry) or five (5) gallons (liquid) and are used for personal, family, or household purposes.
- Fertilizers, pesticides, herbicides, erosion control products, and soil amendment, in quantities normally available at retail outlets, when stored, handled and applied in

accordance with the manufacturer's instructions, label directions, and nationally recognized standards.

- Commercial products limited to use at a commercial or industrial site solely for office or janitorial purposes when stored in total quantities of less than fifty (50) pounds for dry products, or fifty five (55) gallons for liquids.
- Prepackaged consumer products available through retail sale to individuals for personal, family, or household use, that are properly stored.
- Water-based latex paint, or oil-based finishes, in quantities normally available at retail outlets, when stored, handled and applied in accordance with the manufacturer's instructions, label directions, and nationally recognized standards.
- Compressed gases.
- Substances or mixtures which may pose a hazard but are labeled pursuant to the Federal Food, Drug, and Cosmetic Act.
- Substances which, in the judgment of the _______ pose no hazard to groundwater.
- The transportation of any regulated substance(s), hazardous waste or petroleum products through any protection zone or recharge area shall be allowed provided that the transporting vehicle is in continuous transit.

e. **Performance Standards**: The following standards shall apply to uses in Zone 1 of the Groundwater Protection Overlay District:

The volume of water infiltrating into the surface of the ground must be maintained locally or in a regional infiltration facility at levels existing before development or redevelopment.

Any facility involving the collection, handling, manufacture, use, storage, transfer or disposal of any solid or liquid material or wastes, unless granted a special exception either through permit or another ordinance, must have a secondary containment system which is easily inspected and whose purpose is to intercept any leak or release from the primary containment vessel or structure. Underground tanks or buried pipes carrying such materials must have double walls and inspectable sumps.

Storage of petroleum products in quantities exceeding (_) gallons at one locality in one tank or series of tanks must be in elevated tanks; such tanks must have a secondary containment system where it is deemed necessary by _______________.

All permitted facilities must adhere to appropriate federal and state standards for storage, handling and disposal of any hazardous materials and hazardous waste.

An acceptable contingency plan for all permitted facilities must be prepared for preventing hazardous materials and hazardous waste from contaminating the shallow/surficial aquifer should floods, fire, or other natural catastrophes, equipment failure, or releases occur:

(a) For flood control, all underground facilities shall include but not be limited to a monitoring system and secondary standpipe above the 100 year flood control level, for monitoring and recovery. For above ground facilities, an impervious dike, above the 100 year flood level and capable of containing 100 percent of the largest volume of storage, will be provided with an overflow recovery catchment area (sump).

(b) For fire control, plans shall include but not be limited to a safe fire fighting procedure, a fire retarding system, effective containment of any liquid runoff, and provide for dealing safely with any other health and technical hazards that may be encountered by disaster control personnel in combating fire. Hazards to be considered are pipes, liquids, chemicals, or open flames in the immediate vicinity.

(c) For equipment failures, plans shall include but not be limited to:

For below ground storage systems, removal and replacement of leaking parts, a leak detection system with monitoring, and an overfill protection system.

For above ground storage systems, liquid level and leak monitoring of primary containment systems, the replacement or repair of leaking tanks, and cleanup and/or repair of the impervious surface.

(d) For any other release occurring, the owner and/or operator shall report all incidents involving liquid or chemical material to the Minnesota Duty Officer and the groundwater protection coordinator designated by the (local government authority).

Since it is known that improperly abandoned wells can become a direct conduit for contamination of groundwater by surface water, all abandoned wells should be properly sealed according to local and state regulations.

Zone 2: Groundwater Quality Impact Zone.

Zone 2 is established in the Groundwater Protection Overlay District as zone within which significant recharge occurs and there is a substantial connection between groundwater and surface water resources. Protection is also deemed necessary to ensure adequate protection of public drinking water supplies. This zone can also be defined according to any mix of geologic, soil, land use/cover, and time-of-travel criteria. Zone 2 must meet all of the County requirements on maintenance of infiltration but will have less stringent management practices requirements.

a. **Permitted Uses**: All uses permitted in the underlying zoning districts of (the zoning authority) provided that they can meet the Performance Standards as outlined for the Groundwater Protection Overlay District.

b. **Special Exceptions**: All special exceptions allowed in underlying districts (of the zoning authority) may be approved provided they can meet Performance Standards outlined for the Groundwater Protection Overlay District.

c. **Regulated Uses:** All of the prohibited uses listed for Zone 1 are considered regulated uses for Zone 2. These uses will be reviewed by (the zoning authority) to assure that there are no threats to groundwater presented.

d. **Performance Standards**: The performance standards listed in the previous section (Zone 1) apply to uses in Zone 2 of the Groundwater Protection Overlay District.

Zone 3: General Groundwater Quality Protection Zone

Zone 3 is established in the Groundwater Protection Overlay District as a zone within which general recharge occurs and/or there is substantial connection between groundwater and surface water features. Zone 3 must meet all of the County requirements on maintenance of infiltration, but will have less stringent management practices requirements.

a. **Permitted Uses**: All uses permitted in the underlying zoning districts (of the zoning authority) provided that they can meet the Performance Standards as outlined in section b.

b. **Performance Standards**: The following standards shall apply to uses in Zone 3 of the Groundwater Protection Overlay District:

Any facility, building or roadway construction, landscaping, or activity associated with these actions must not alter the net movement or quality of groundwater moving either downward or upward within the normal flow system. Any alteration to this system must be off-set by management techniques that restore the lost function.

Infiltration management practices will be an essential element used to off-set lost areas of perviousness.

VI. LIABILITY

Nothing in this ordinance shall be construed to imply that the (local government authority) ___________ has accepted any of an owner/developer's liability if a permitted facility or use contaminates groundwater in any aquifer.

VII. ADDITIONAL CLAUSES

This chapter is added to provide a location for any adopting entity to put in additional legal requirements. A list of potential items to consider is suggested based on elements suggested by sample ordinances.

a) **Boundary Disputes**

b) **Enforcement and Penalties**

c) **Additional Study Requirements to Define Applicability of the Ordinance**

d) **Procedures for Issuance of a Permit and Appealing Decision**

e) **Severability**

f) **Fees**

g) **Inspections**

h) **Reporting Requirements**

i) **Effective Date**

j) **Possible Contaminating Activities**

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