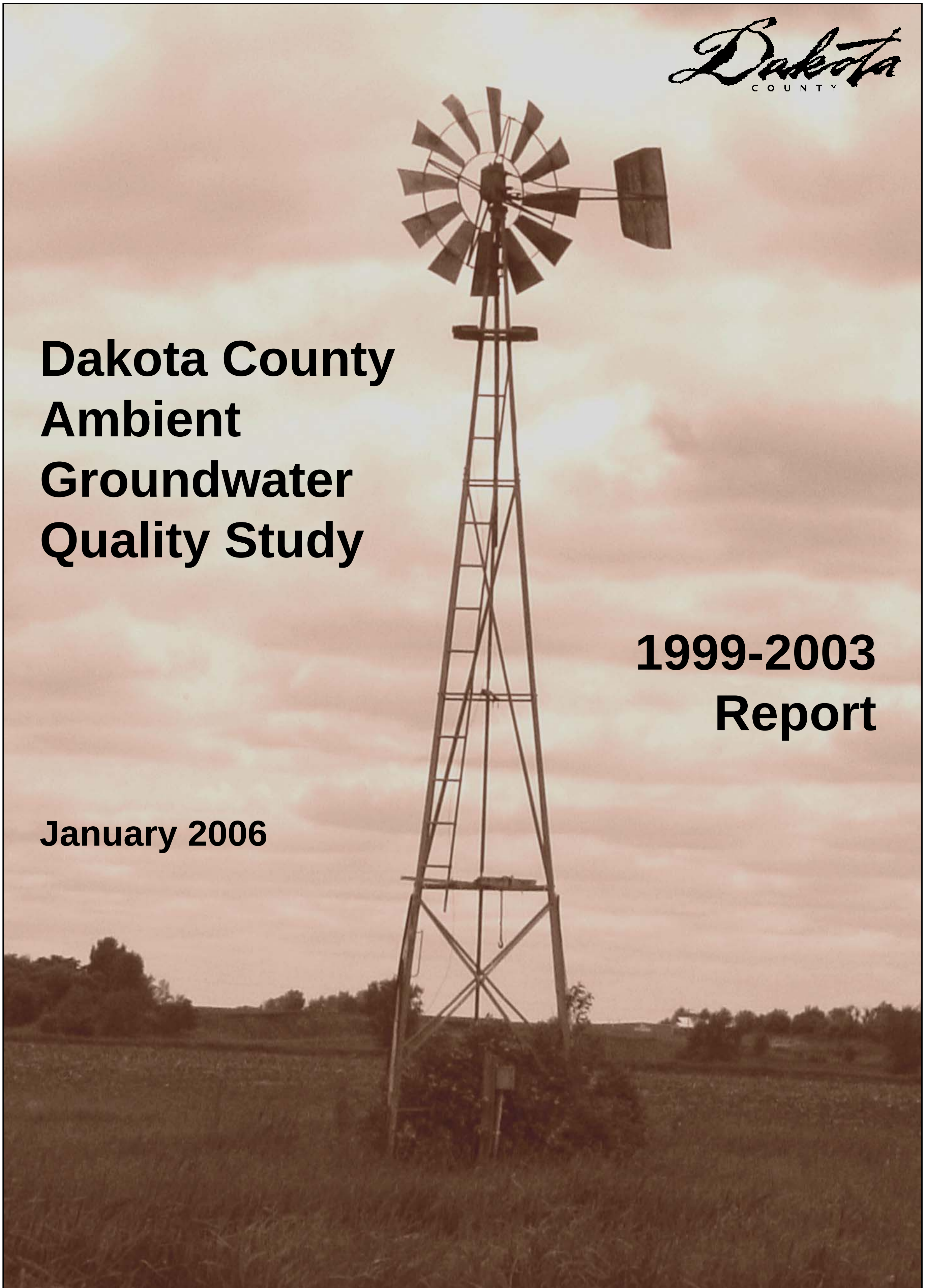


Dakota County Ambient Groundwater Quality Study

1999-2003 Report

January 2006

DAKOTA COUNTY AMBIENT GROUNDWATER QUALITY STUDY

ACKNOWLEDGEMENTS

The Dakota County Ambient Groundwater Quality Study has been made possible by the private well owners who have allowed their drinking water wells to be sampled each year as part of the study. Without the voluntary cooperation of so many Dakota County residents, this study would not have been possible.

Dakota County is very grateful to the many state and local agency staff people who helped with this project. Vanessa Demuth designed the project and David Swenson provided oversight from beginning to end. Barry Schade, Director of Environmental Management for Dakota County, supported the project throughout. Demuth and Jill V. Trescott served as co-managers of the project: Demuth managed sampling logistics and well owner relations and Trescott managed data analysis and reporting. Swenson, Demuth, and Trescott jointly provided annual strategic analysis and continuous process improvement.

The United States Geological Survey provided invaluable assistance on pesticide and pesticide degradates analysis through its Organic Geochemistry Research Group in Lawrence, Kansas, and its Minnesota Water Sciences Center in Mounds View, Minnesota. Dakota County has also been very fortunate to benefit from the technical and professional assistance of staff from the Minnesota Department of Agriculture and the Minnesota Department of Health.

Dakota County Ambient Groundwater Quality Study:
1999-2003 Results and Discussion

Contents

Tables, Charts, and Figures

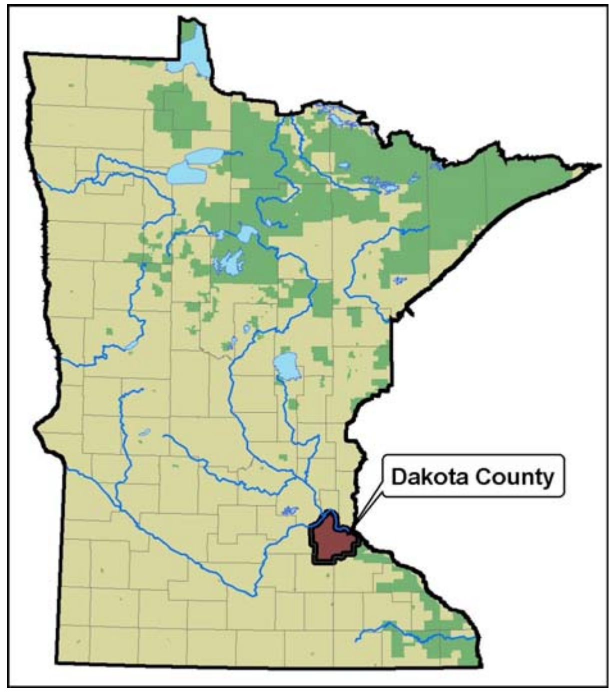
Tables

Charts

Figures

Appendices

INTRODUCTION



In 1999, Dakota County's Environmental Management Department initiated the Ambient Groundwater Quality Study (AGQS), an ongoing, multi-year study of the County's major drinking water aquifers. The goal of the study is to establish a baseline of data to which future water quality data can be compared. This information will help the County track changes in groundwater quality, identify trends of concern, and protect the future of this valuable resource. The study concept is to sample the same set of privately-owned drinking water wells, located throughout the County, once each year in order to study changes in the water over time and space.

Groundwater Basics

Groundwater is widely used throughout the United States to supply drinking water. Groundwater is one of the most basic and important natural and economic resources, and it is vulnerable to both pollution and depletion. Therefore, its protection is an important function of government.

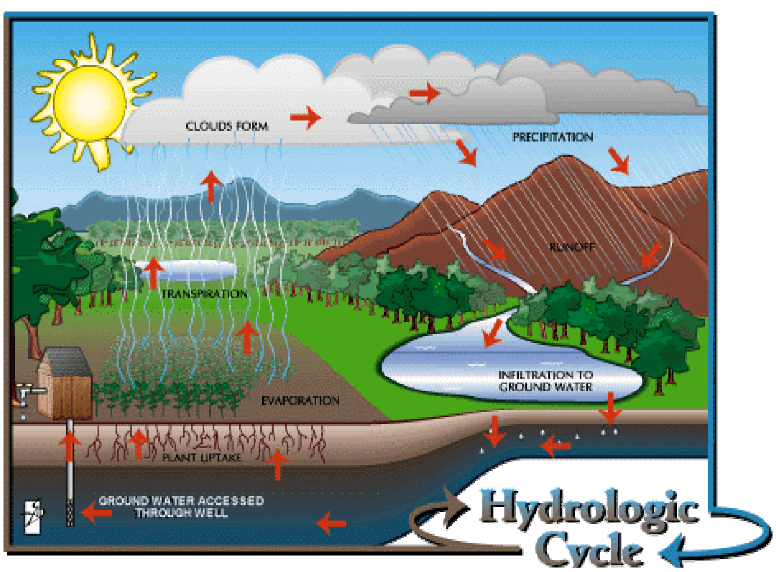


Figure 1: Hydrologic Cycle (Ground Water Primer EPA Region 5 & Purdue University)

Groundwater is an integral component of the hydrologic (water) cycle, illustrated in Figure 1. The cycle begins with precipitation falling to the ground. Rain or melt water from snow runs off the land into surface water bodies or soaks into the soil. Some of this soil water is taken up by plants and transpired back into the air. The rest, called recharge, percolates downward to the "water table," or top of the groundwater.

In the saturated zone below the water table, water moves from high to low head pressure; head pressure is often thought of in terms of elevation. In general, groundwater moves from a recharge area at higher elevation to a lower elevation where it discharges into a lake, stream, or ocean, becoming surface water. Surface water evaporates into the atmosphere where it forms clouds and becomes precipitation to begin the cycle again.

The subsurface reservoirs that store and transmit water are called aquifers. Aquifers are not free-flowing underground rivers or lakes; instead, water collects in pore spaces and cracks in various depths of soil and bedrock. Wells are drilled to the water-bearing layers underground and water is pumped from below to homes and businesses, for human consumption and use.

Approximately 91% of Dakota County residents obtain their drinking water from groundwater (instead of surface water) from either private or municipal wells. The two most heavily used aquifers in the County are the Prairie du Chien Dolomite (Opdc) and the Jordan Sandstone (Cjdn). While many of the state's hydrogeologists consider these formations as a single aquifer system, Dakota County staff has found that they behave as separate aquifers in most of the County; the geologic layer that is thought to separate the two aquifers is the Oneota, which is the bottom of the Opdc.

Purpose and Scope

The purpose of the AGQS is to determine the chemical components in the groundwater of Dakota County. All water in nature contains far more than just hydrogen and oxygen; it picks up small traces of the conditions through which it has passed as it moves from cloud to ground to subsurface. These traces, such as minerals or dissolved gases, may be naturally occurring or anthropogenic (caused by humans). Most natural impurities, such as calcium or magnesium, pose no health risk to humans; some, such as iron or sulfur, may affect drinking water's taste or smell; others, such as arsenic, may pose serious health risks. In contrast, nearly all anthropogenic components of groundwater pose some danger to human health, depending on concentration.

By establishing a baseline for water quality, Dakota County will have a reference to define when changes occur and to make decisions about environmental factors that may affect groundwater. Developing a baseline is a very important strategy to protect the environment and human health. The suitability of groundwater for drinking water use is critical to providing a safe place to live and work for County residents.

Dakota County is one of the fastest growing counties in Minnesota; the County grew 83% from 1980 to 2000. Increasing population pressure on resources, along with changes in land use, accentuates the need for ways to measure the impacts on groundwater.

In addition to identifying environmental factors influencing groundwater, the AGQS will allow for characterization of the water chemistry for each aquifer. The study may also identify sensitive areas and better define zones of groundwater recharge and discharge.

The AGQS is limited to Dakota County. The County boundaries define the study area. The wells selected for sampling represent the County's geologic and geographic conditions. The parameters for which the water samples are analyzed may vary with each sampling event. The results are used to evaluate the variations in water quality over a range of geologic zones, aquifer conditions, and seasonality.

Land and Climate

Dakota County is a temperate region, dominated by various species of trees and grasses. Historically, various species of pine, fir, birch, maple, and other deciduous varieties covered the area. Natural prairie has all but disappeared from the area due to human impact. Much of the County is agricultural, predominantly corn and soybean crops, with minor cattle grazing and dairy production.

Land use in the County is relatively stable, with an average annual change of agricultural land to residential of 1%. Land use in the County is shown on Figure 3. In general, agricultural land occupies 63% of the acreage, with residential 18%, exempt (parks, schools, churches, etc.) 12%, commercial 3.5%, and industrial 3.5%.

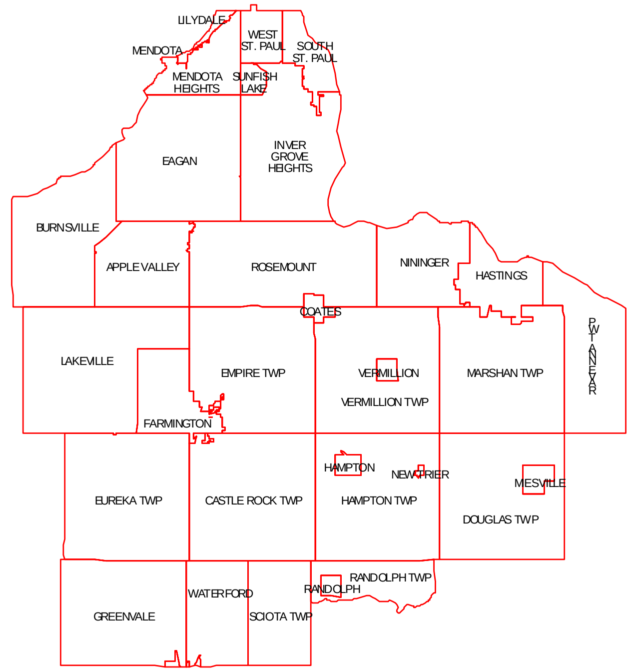
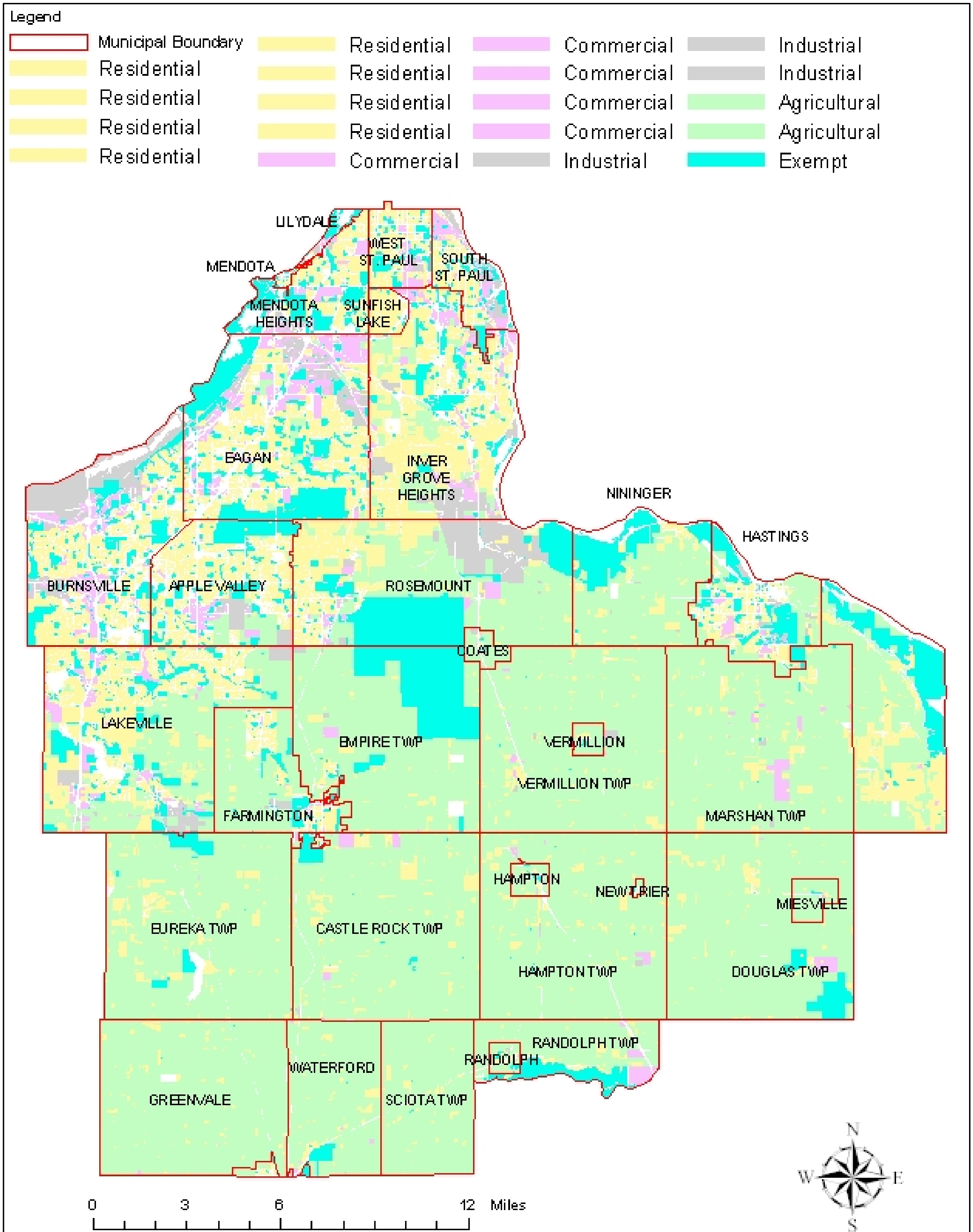


Figure 2: Municipal Boundaries

Average annual rainfall in the region ranges between 29 and 32 inches. Average monthly temperature ranges from around 10°F in January to around 70°F in July. Most rainfall occurs during the months from May to September. Snow usually accumulates and covers much of the ground during the months from December to March.

The quantity of groundwater available in an area is determined by the quantity of water that seeps from the surface down into the underlying aquifers, or recharge. Recharge cannot be measured directly. Recharge varies in accordance with rainfall and a wide array of other complex factors. As a result, professional estimates of regional recharge can vary widely. A recent report by the U.S. Geological Survey described a number of estimation methods used in the Twin Cities area. On of the study's focal areas was the Vermillion River watershed, which includes most of central Dakota County. Based on this report (Ruhl et al, 2002), recharge in Dakota County ranges from three inches to 13 inches per year, depending on precipitation. County staff conservatively estimates that the County's aquifers receive five inches per year on average.

Water levels in surface or near surface aquifers generally drop quickly during dry periods and rebound quickly when water is available for recharge. Water levels in deeper bedrock aquifers are also impacted during periods of drought. Unlike surface or near surface aquifers, deeper bedrock aquifers may take a much longer time to recharge to pre-drought conditions. The impact of drought is compounded because of increased water demand. During the drought of 1987-1989, annual water use by irrigation, municipal, and other high capacity wells was more than double the annual water use in 1986.



Land Use

AGQS Figure 3

Population and Water Use

Dakota County is the third most populous county in Minnesota, with 355,904 people in 2000. (Hennepin County, which includes Minneapolis, has the largest population in the state; Ramsey County, which includes St. Paul, is second.) Between 1990 and 2000, the County added 81,000 people, a 29% increase. Such growth increases the reliance on resources.

The City of St. Paul supplies surface water to Lilydale, Mendota, Mendota Heights, and West St. Paul. These municipalities account for approximately 9% of the County's population. The remaining 91% of the County's residents rely on groundwater for their water supply.

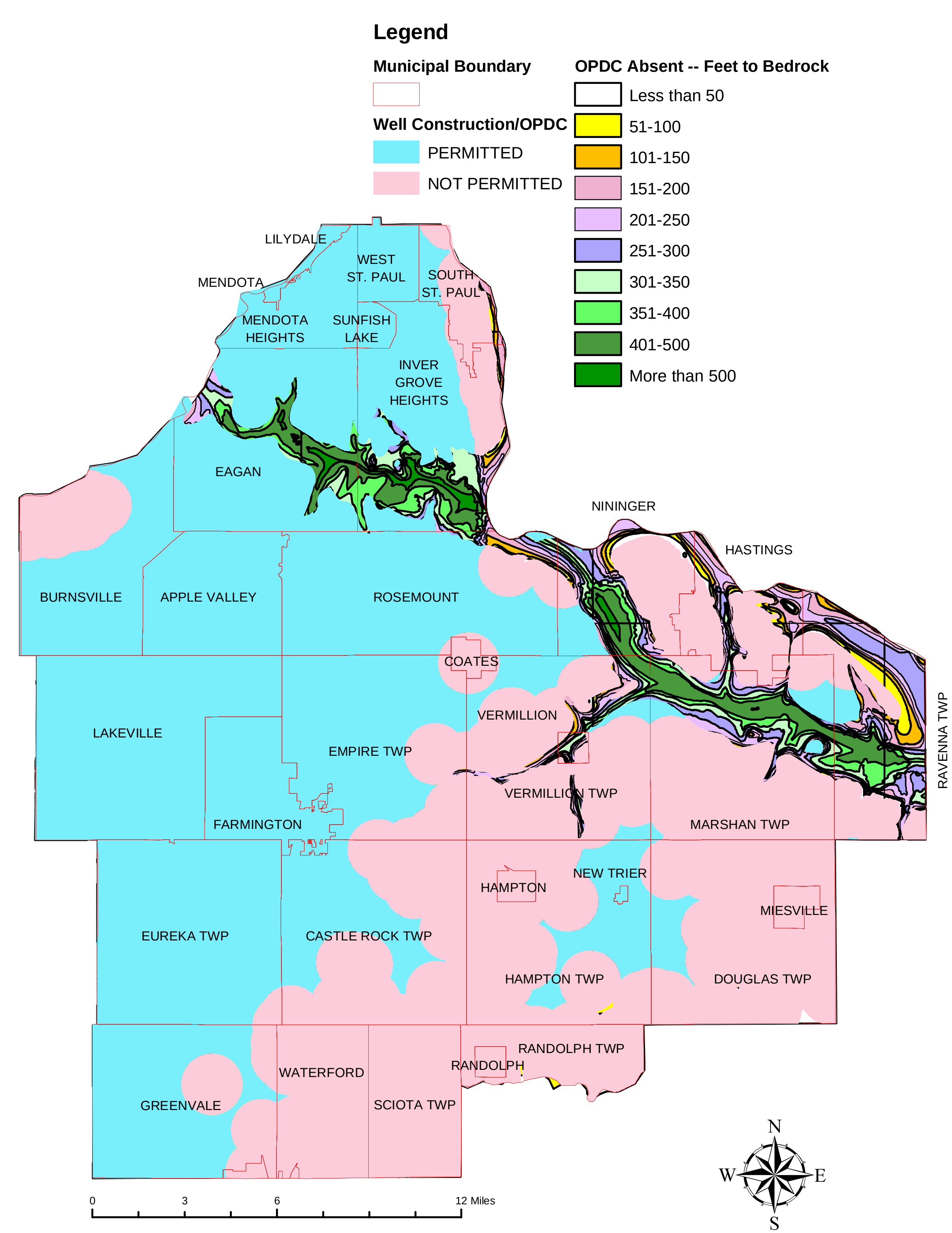
Over the next 20 years, the County's population will grow by an estimated 110,000 people and, if current land use trends continue, approximately 50,000 acres of farmland and natural areas will be converted to residential, commercial, or industrial uses. As the population grows and the County becomes more developed, more pressure will be put on the County's environment and natural resources. Further, the potential risk of sickness or injury from drinking or contact with contaminated surface or groundwater will increase as the population increases.

Between 20 and 30 percent of the County's available and viable groundwater resources are unsafe for human consumption. Most of the contaminated groundwater is located in surface sand and gravel aquifers. However, in the southern and southeastern portions of the County, new wells may not be drilled in the Prairie du Chien bedrock because of that aquifer's susceptibility to contamination in that part of the County (Figure 4).

City or Township	Total
Apple Valley	45,527
Burnsville	60,220
Castle Rock Township	1,495
Coates	163
Douglas Township	760
Eagan	63,557
Empire Township	1,638
Eureka Township	1,490
Farmington	12,365
Greenvale Township	684
Hampton	434
Hampton Township	986
Hastings	18,201
Inver Grove Heights	29,751
Lakeville	43,128
Lilydale	552
Marshan Township	1,263
Mendota	197
Mendota Heights	11,434
Miesville	135
New Trier	116
Nininger Township	865
Northfield	557
Randolph	318
Randolph Township	536
Ravenna Township	2,355
Rosemount	14,619
Sciota Township	285
South St. Paul	20,167
Sunfish Lake	504
Vermillion	437
Vermillion Township	1,243
Waterford Township	517
West St. Paul	19,405
County Total	355,904

Table 1: Dakota County Population (2000)

Source: U.S. Bureau of the Census



Dakota COUNTY

Well Drilling Advisory Areas

AGQS Figure 4

Dakota County groundwater use is shown in Table 2, below. As the population grows, this demand will increase. Groundwater supplies may not be adequate in some areas of the County to meet this demand. In addition, groundwater levels may not remain high enough to support surface water features such as trout streams and fens (rare wetlands) that depend on groundwater. Since contaminated water cannot be used for human consumption without treatment, the availability of drinking water may be further decreased unless adequate measures to protect groundwater quality are initiated.

	1999	2000	2001	2002	2003
Municipal and Community Water Supplies	12,636	13,697	14,142	12,570	14,191
Crop Irrigation	4,639	4,896	6,443	4,083	8,189
Industrial	3,041	3,334	3,297	3,030	3,118
Non-Crop Irrigation	369	604	644	357	668
Other	1,123	1,170	1,133	1,015	1,649
Total	21,808	23,700	25,659	21,056	27,815

Table 2: Groundwater Appropriations (millions of gallons per year) (Source: Department of Natural Resources)

Landforms

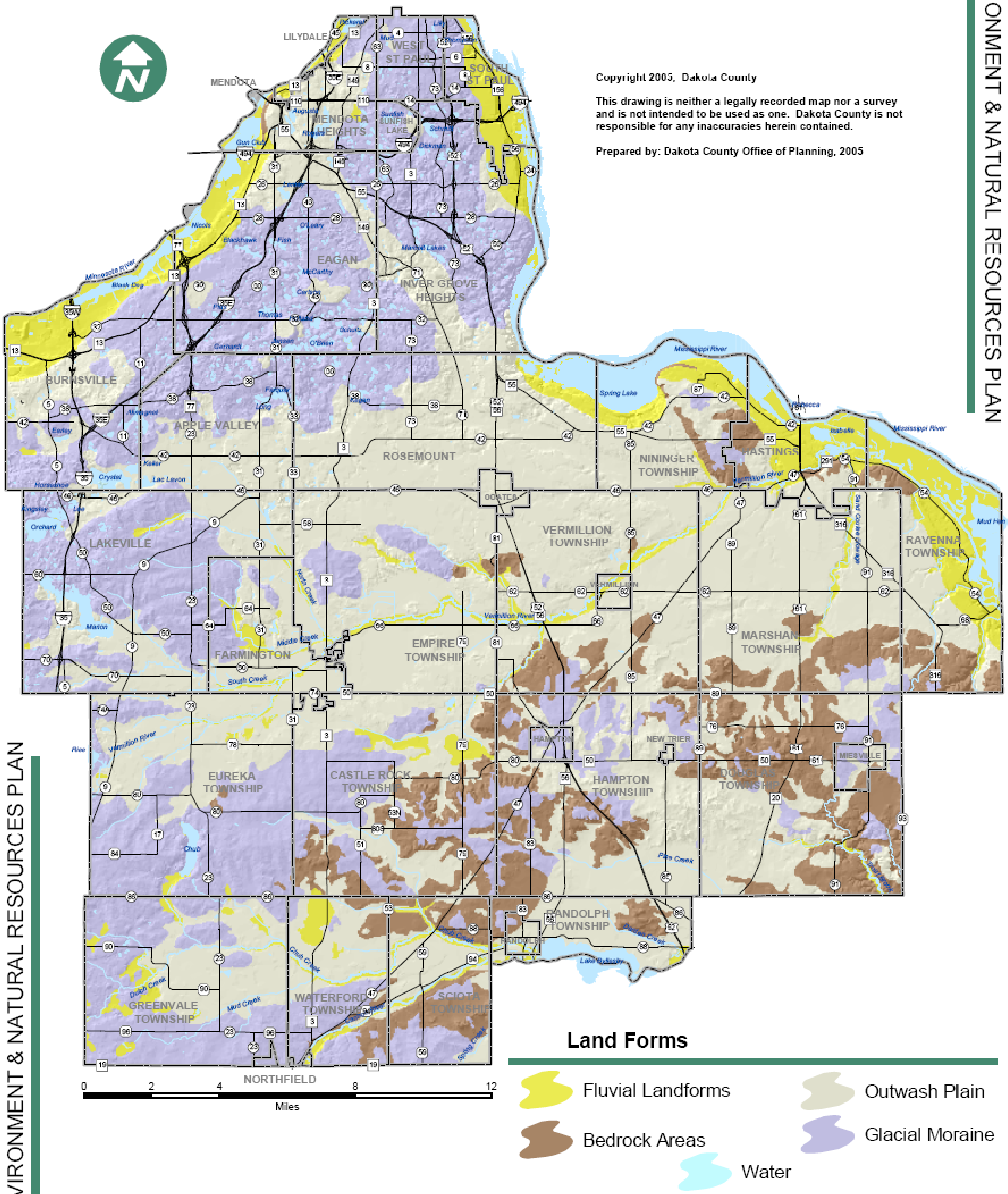
The shape and composition of the region's landforms are key factors in shallow groundwater flow patterns and susceptibility to contamination from the surface. Landforms in Dakota County (Figure 5) can be divided into four generalized categories:

- Glacial moraines,
- Outwash plains,
- Bedrock areas, and
- Fluvial landforms.

Glacial Moraine in Rosemount

In the last two million years, Dakota County has been covered several times by continental glaciation. The most recent glaciation took place approximately 12,000 years ago during the Pleistocene Epoch of the Quaternary Era. These glaciers originated in northern and northeastern Canada. As the glaciers moved across the continent, they cut and moved large amounts of material, in some cases carrying this material hundreds of miles. As the glaciers retreated, this material, known as glacial drift, was left behind and reworked by the resulting meltwater.

ENVIRONMENT & NATURAL RESOURCES PLAN



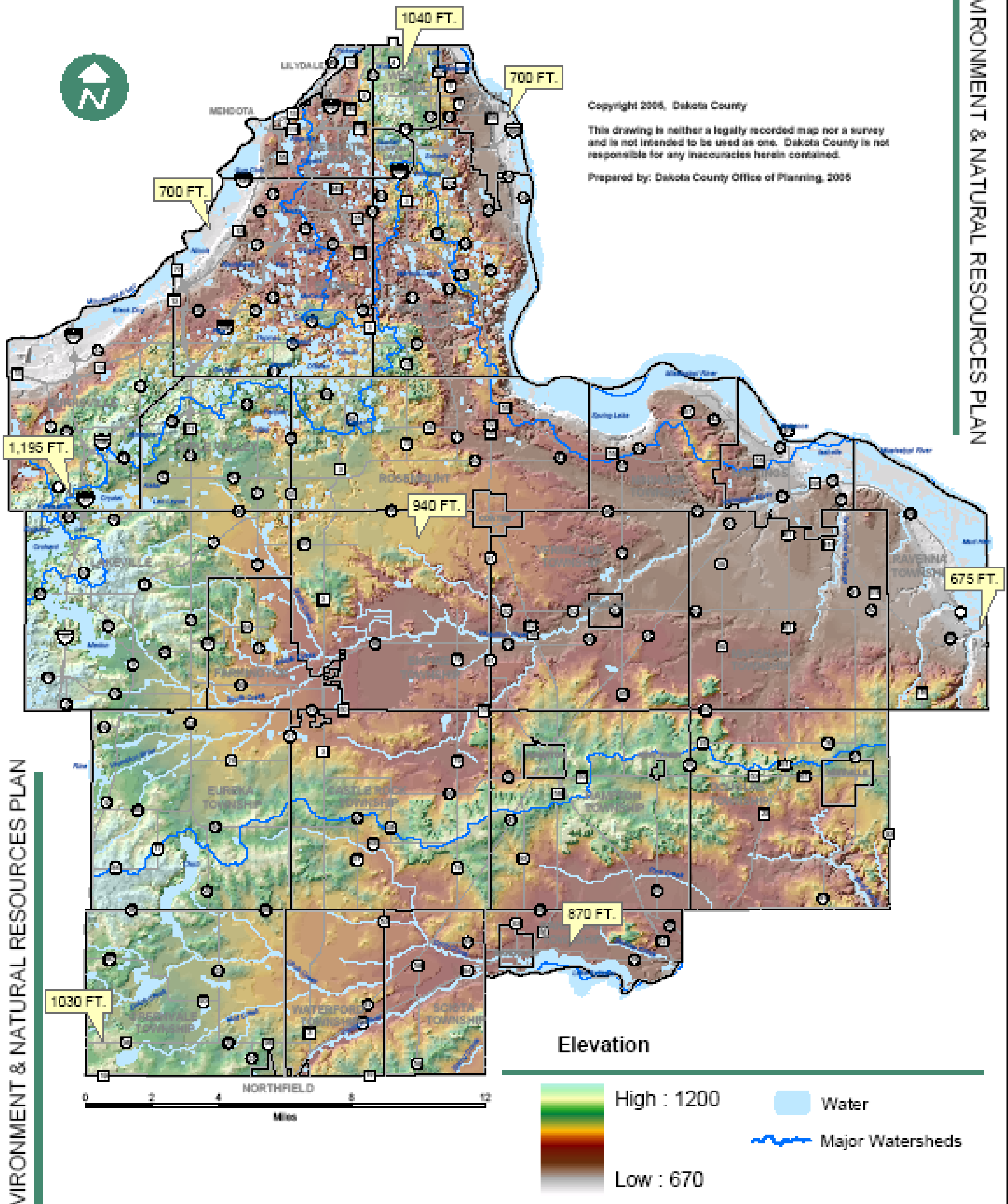
ENVIRONMENT & NATURAL RESOURCES PLAN

Dakota COUNTY

Land Forms

(Dakota County Environment & Natural Resources Plan, 2005)

AGQS Figure 5



ENVIRONMENT & NATURAL RESOURCES PLAN

Dakota COUNTY

Topography

(Dakota County Environment & Natural Resources Plan, 2005)

AGQS Figure 6

The topography of Dakota County (Figure 6) is largely a result of these various glacial advances and retreats. The hilly areas in the northern and western parts of the County are glacial moraines, that is, they indicate the terminus of a glacial advance. The flat, sandy portions in the central and south central areas of the County are outwash plains. These areas were created as water from the melting glaciers reworked the debris carried by these glaciers. The deep valleys and terraces of the Minnesota and Mississippi Rivers appear to be the result of flooding associated with the release of water from the Glacial Lake Agassiz. Soils, lakes, and most other surface features in the County can be also attributed to these glacial advances.

Mississippi River Valley facing East from Rosemount

The highest elevations in the County are located on the moraines in the northern and western areas. The highest point in the County is Buck Hill with an elevation of over 1,195 feet and the lowest point is approximately 675 feet where the Mississippi leaves the County. Although there are abrupt and frequent elevation changes along the Mississippi and Minnesota River Valley, the overall slope of the County is towards the southeast with an average elevation change of approximately 200 feet.

<u>Glacial Moraines</u>

The most recent glacial advance, the Wisconsin Glaciation, consisted of several lobes of ice that ebbed and flowed across the County beginning approximately 75,000 years ago and ending approximately 12,000 years ago. The glacial moraines found in the northern and western parts of Dakota County mark the furthest advance of the two most recent lobes to advance across the County, the Superior Lobe and the Des Moines Lobe. An earlier glacial advance, possibly the Wadena Lobe created the moraine found in Hampton and Douglas Townships in the south-central portion of the County.

The topography of the moraine areas in the County is hilly and irregular and includes many deep, poorly drained depressions. As a result, most of the palustrine wetlands (non-river or lake-wetlands) and natural lakes in the County are found in these areas. Because glacial moraines consist of a heterogeneous mixture of sand, gravel, boulders, and clay, perched water tables are also found in these areas. The relief of the glacial moraines ranges from five to 200 feet from hill base to hilltop. The range of slopes varies a great deal from 1-6% in gently rolling areas, to 12-18%, or more, in parts of the cities of Eagan, Apple Valley, Burnsville, and Inver Grove Heights, and Hampton and Douglas Townships.

The rolling topography and the presence of surface water features within the moraine areas create desirable locations for residential development. Conversely, the rolling topography, poorer soils, presence of wetlands, and poor soils make these areas less desirable for cropland. As a result these areas are under increasing development pressure.

Chimney Rock in Marshan Township

Outwash Plains

Outwash plains are located adjacent to most of the moraine areas in the County. Outwash plains were formed by the deposition of materials from glacial meltwater created as glaciers from the Wisconsin glaciation retreated. These areas are found throughout most of the central portion of the County and contain some of the richest gravel deposits in the metropolitan area. Most of the soils in the outwash plains tend to be droughty. However, with irrigation these soils can become some of the most productive cropland in the state.

Bedrock Areas

In the south central and southeastern parts of the County, bedrock outcrops are interspersed among the glacial deposits, colluvium, and other surface deposits. Where bedrock is visible at the surface it is generally part of the St. Peter Sandstone or Platteville Formation. The Prairie du Chien Formation is generally covered by a thin layer of overburden (overlying material). However, the Prairie du Chien is visible in some ravines and road cuts. Chimney Rock near Hastings and Castle Rock, in Castle Rock Township, are erosional remnants of the St. Peter Sandstone. Karst features in the County are found in the bedrock areas. Karst topography includes features such as sinkholes, disappearing streams, and underground drainage. Karst areas provide conduits that directly connect surface water to the groundwater and, as such, are particularly susceptible to groundwater contamination.

The predominant land use in the bedrock areas of the County is agriculture. Although soils in these areas are not considered "prime agricultural," appropriate farming practices have produced good crops and pastureland.

Fluvial Landforms

As rivers and streams flow they mold their geologic settings into discernable landforms. Floodplains are the most common fluvial landform and are found in all river valleys in the County. The Mississippi and Minnesota rivers contain the most extensive floodplains in the County. These floodplains contain a complex network of lakes, wetlands, sandbars, chutes, and sloughs. Smaller floodplains are located along the Cannon and Vermillion Rivers. Although some riverine wetlands are found along these rivers, their floodplains consist mostly of floodplain forests, shrubland, cropland, or pastureland. Floodplain material consists mostly of channel fill deposits, such as fine silts and clays. However, some large peat deposits are located within the Minnesota River floodplain. Other than for crop and pastureland, most floodplains exist in a natural state or a somewhat altered natural state. In the past, some development was allowed to occur within floodplains; current state law and local ordinances prohibit any new development.

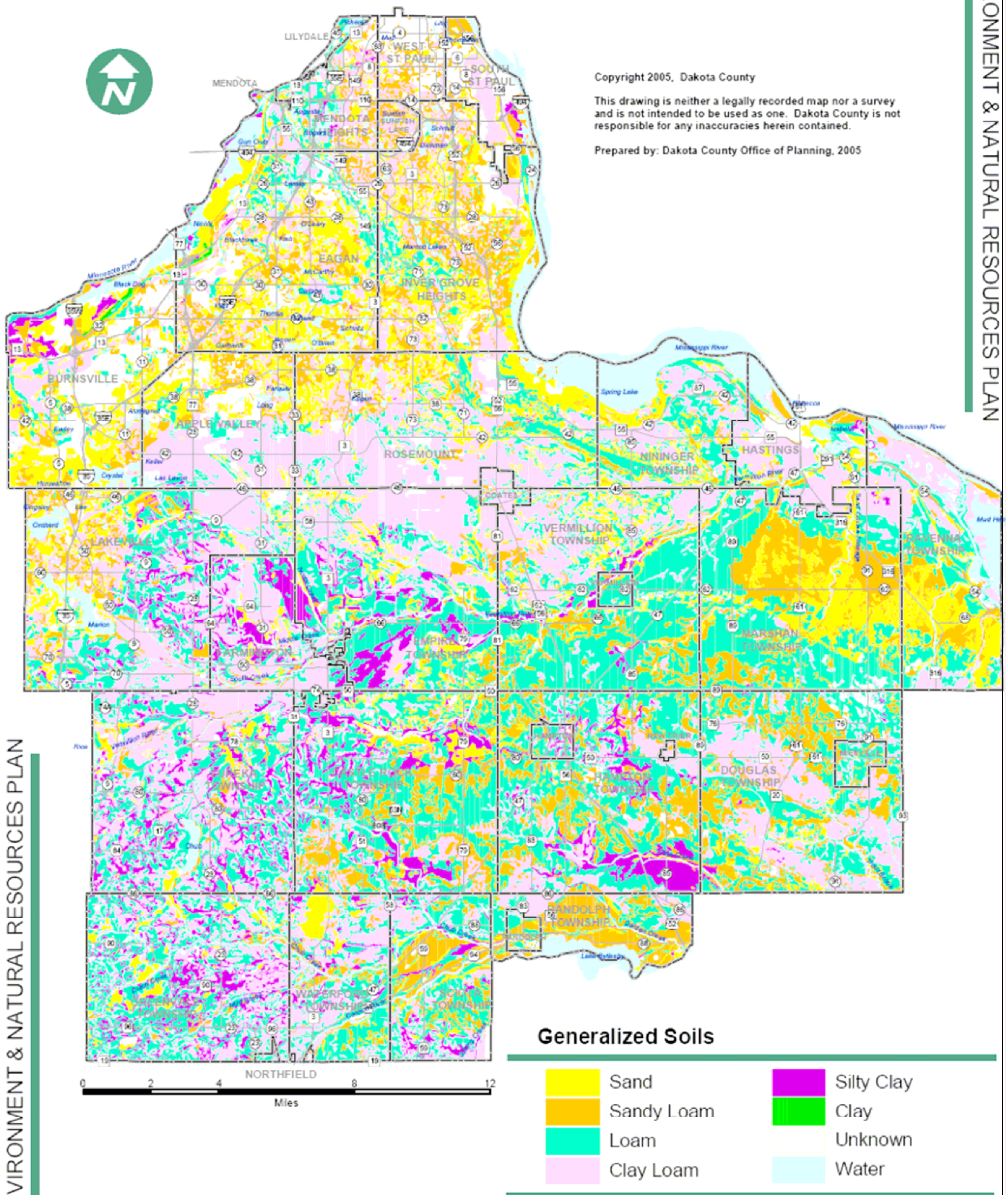
Well-developed terraces are located along the sides of the Minnesota and Mississippi River valleys in Dakota County. Terraces are abandoned floodplains that were formed when a river flowed at a higher level than the present. They represent periods of stability separated by periods of down cutting by a river that carved the valley now occupied by the Minnesota and Mississippi Rivers. In many places, terrace materials overlay outwash and the boundary is not well defined. However, there are three distinct terraces along the Mississippi River valleys, an upper, middle and lower terrace. Of the three, the middle terrace is the most extensive and the best defined. Terraces support a wide range of land uses. All or large parts of the cities of Burnsville, Eagan, Hastings, Mendota, Mendota Heights, and South St. Paul, as well as portions of Nininger and Ravenna Townships are located on river terraces.

Soils

Soil characteristics influence the underlying groundwater quality by affecting how quickly water and potential contamination seep from the ground surface to the water table. Figure 7 shows a generalized soil map for Dakota County. The soils of the County have been described and mapped in detail by the U.S. Department of Agriculture's Natural Resource Conservation Service (NRCS) and are published in the "Soil Survey of Dakota County." This information is also available in digital form from the Dakota County Office of Planning.

The characteristics of a particular soil is a function of the physical and mineralogical composition of its parent material, the climate under which the soil accumulated and existed since accumulation, the plant and animal life on the soil, local topography, and time. In Dakota County, most soils were formed from glacial till, glacial outwash, loess, river sediments, and bedrock materials. Soils formed in glacial till tend to be fine-to-coarse-textured silty to sandy loams; soils formed in glacial outwash commonly have moderate-to-coarse textures and have a sandy to gravelly substratum; soils formed in loess deposits are fine textured silty loams; soil formed in river deposits range in particle size from clays and silts to sands and cobbles; and soils from bedrock tend to be thin, loamy to sandy loams.

Clays, loams, organic soils, and fine textured soils tend to hold water and help slow the rate that contaminants can enter the groundwater. As soils become more coarse, they hold less water and contaminants travel through them faster. Soils along the Mississippi and Minnesota Rivers and in floodplains along the Vermillion River and Chub and Pine Creeks tend to be loamy, silty, and clayey. These soils are fairly level and are poorly drained. Soils in the remainder of the County are well drained to excessively well drained and occur on gentle to steep slopes. Soils tend to become more shallow to the east and southeast of the County.



ENVIRONMENT & NATURAL RESOURCES PLAN

Dakota COUNTY

Soils

(Dakota County Environment & Natural Resources Plan, 2005)

AGQS Figure 7

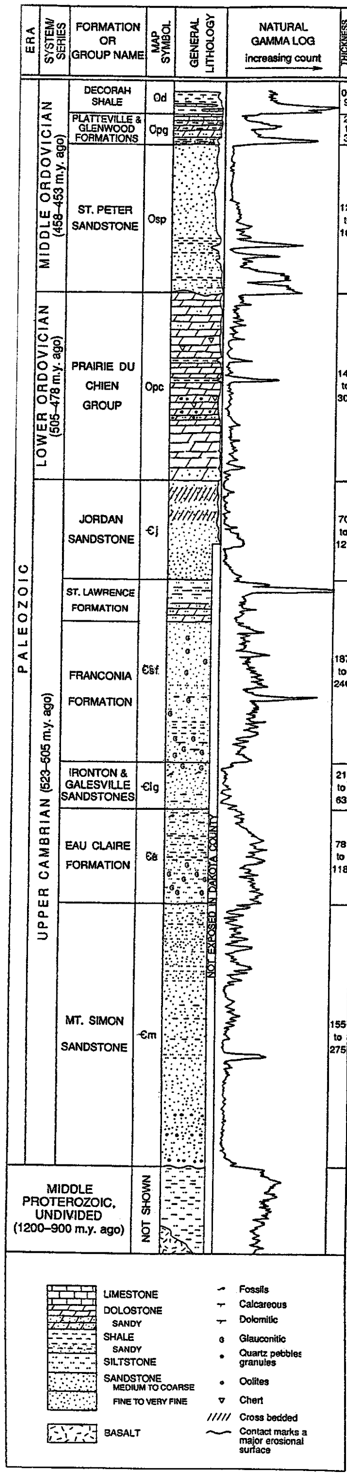


Figure 8: Geologic Column of Dakota County (1991, Dakota County Geologic Atlas).

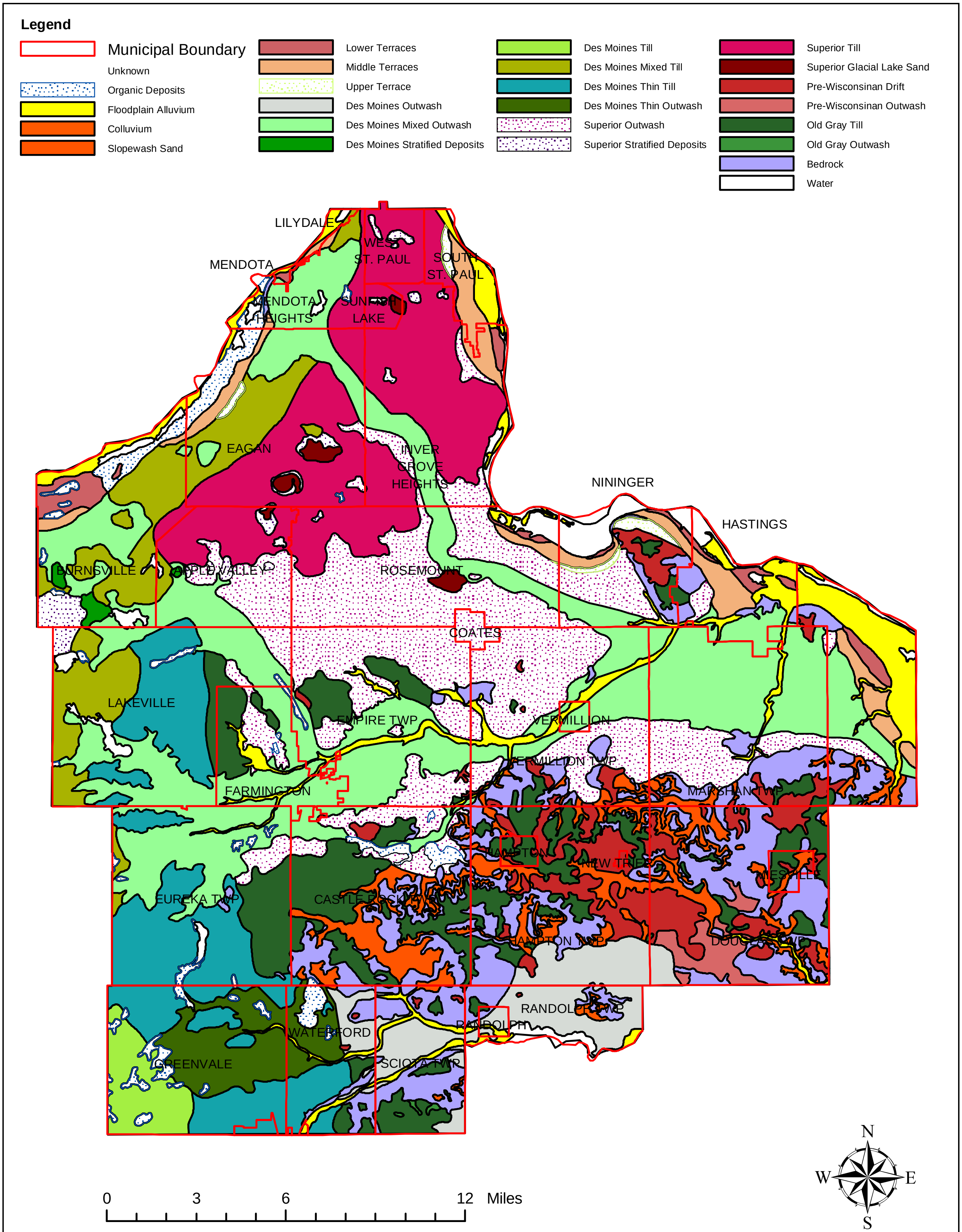
Geology

The geology of Dakota County can be described by three major units: Quaternary or surface geology, Paleozoic or bedrock geology, and Proterozoic or basement geology (Figure 8). Quaternary geology, in this discussion, will include all those deposits above the bedrock formations. These Quaternary deposits are primarily glacial tills and outwash, alluvium (river deposits), and lacustrine (lake) deposits. Bedrock geology in the County consists of several layers of limestone, dolomite, sandstone, and shales associated with regressions and advances of ancient seas. Basement geology in the County is made up of basalts and crystalline igneous rocks. These rocks have little impact on land use and are relatively unimportant resources in the County.

Quaternary (Surface) Geology

Quaternary geology in Dakota County consists of surface and near surface materials that have been deposited within the last two million years. Quaternary deposits consist of glacially derived or reworked materials and non-glacial deposits. The non-glacial deposits include floodplain alluvium, colluvium, and organic deposits. Since much of the geologic record was erased during the last major glaciation, most of the Quaternary deposits in Dakota County were laid down less than 75,000 years ago. Figure 9 shows the surficial geology of Dakota County.

Glacial deposits in Dakota County consist of sands and gravels, till, and loess. Sand and gravel deposits are generally associated with glacial outwash. Glacial outwash refers to materials deposited beyond the terminal margin of the ice. Outwash is usually well sorted and normally consists of rounded sand and gravels carried and reworked by streams and channels formed from glacial melt water. Finer silts and clays generally settle out in glacial lakes or are carried completely out of the system. The well-sorted gravel deposits mined in the County are, for the most part, found in glacial outwash deposits. The coarse texture of these deposits allows for the formation of surface aquifers. Where the outwash is close to the surface, these aquifers are particularity susceptible to contamination.



Dakota County

Surficial Geology

AGQS Figure 9

The glaciers caused other changes, not visible on the land surface. For example, a large buried river valley that cuts deeply into the bedrock, transverses the County in a path from the Minneapolis - St. Paul Airport to Ravenna Township. This valley was filled with fine sands during early periods of glaciation and is of special concern because the buried valley creates a hydrologic connection between the surface and all of the bedrock aquifers used for drinking water supplies in the County.

Other deposits associated with glaciation include loess and terrace deposits. Loess is usually classified as homogeneous, fine wind blown silt winnowed from glacial outwash and laid down in blanket-like deposits. Loess is generally highly porous and contains significant amounts of sand (5-10 percent) and clay (5-30 percent). Loess deposits are found in portions of Lakeville, Farmington and much of Douglas Township.

The non-glacial surface deposits found in the County are floodplain alluvium, colluvium, and organic deposits that are associated with events that occurred in the relatively recent geologic history (less than 12,000 years ago). In many cases the physical processes that created these deposits continue to work today.

Floodplain alluvium are generally poorly bedded, moderately well sorted sediments deposited by modern streams during flood stage. This consists mostly of sand in the valleys of the Mississippi, Vermillion, and Cannon Rivers and clayey silt in the Minnesota River Valley. The thickest deposits of alluvium are associated with the Minnesota and Mississippi Rivers. Minor deposits of well-sorted sands have also been recorded in the Miesville Ravine along Trout Brook.

Organic deposits, mostly peat and mucky soils are found along the Minnesota River and in parts of Castle Rock Township. Peat and muck have a high capacity to absorb and hold water. Where they have not been ditched or tiled, wetlands are usually found in these areas.

Colluvium is found in small deposits scattered throughout the south central and southeastern parts of the County. Colluvium deposits are poorly sorted localized deposits derived from eroding hill slopes. In the County, these deposits generally consist of native rock topped with loess.

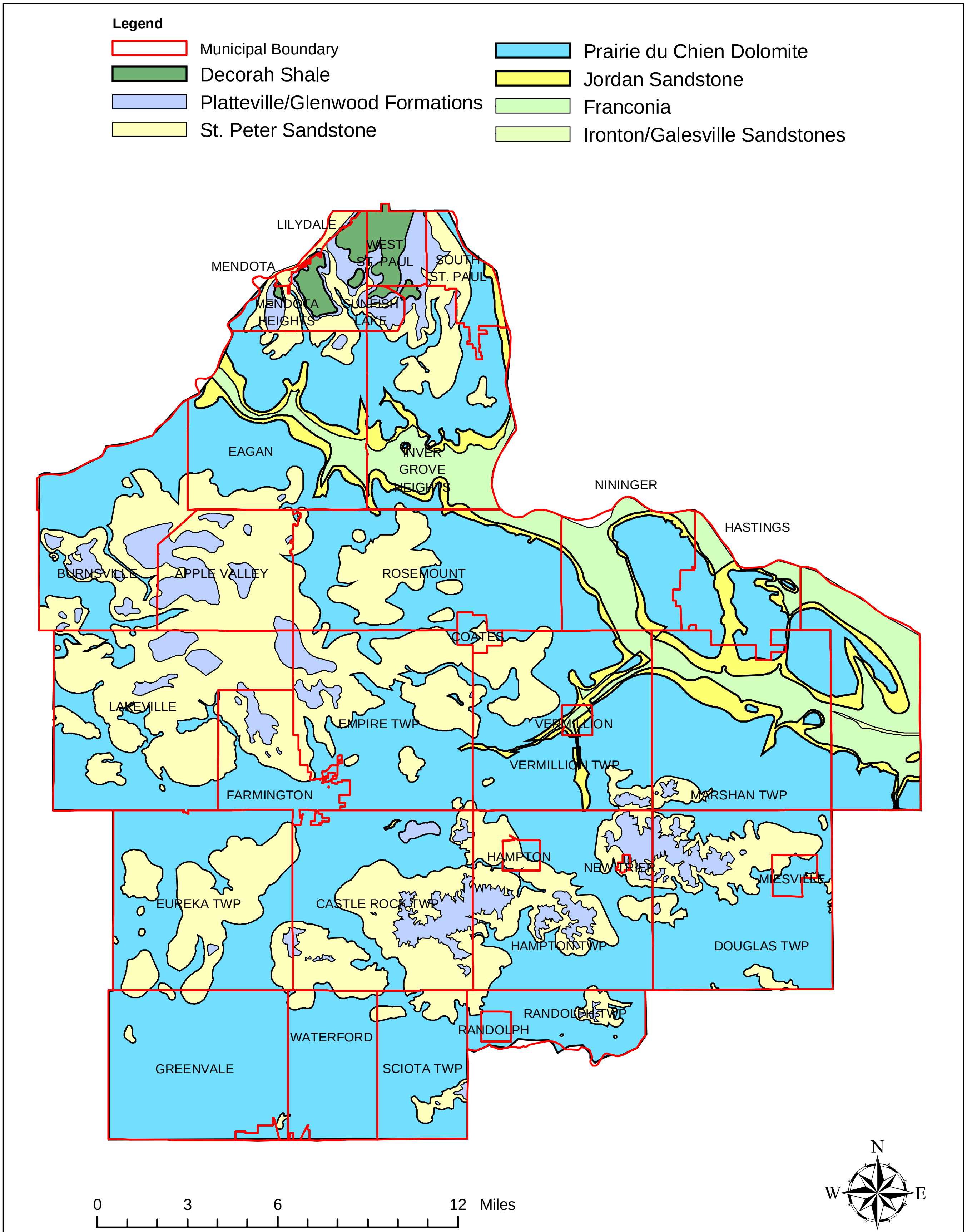
Vermillion River in Farmington

Paleozoic (Bedrock) Geology

The bedrock below Dakota County is part of the Twin Cities Basin formed during the Paleozoic Era (225-600 million years ago). Bedrock formations in Dakota County (Figure 10) are marine sedimentary rock consisting of dolomite, limestone, sandstone, and shales associated with the regression and transgression of ancient seas in the area. Sand accumulated in near-shore bars, on beaches, and in sand dunes; silt and clay formed mud flats or settled out in quiet waters farther from shore; and carbonate derived from remains of invertebrate shells and algae accumulated in small banks and reefs and as tabulate layers on the sea floor. Over time, these sediments were compressed and hardened to form the sandstone, shale, and dolomitic limestone of today.

After these formations were laid down, tectonic forces acted upon them creating a series of small folds and faults. Individually, these folds and faults have displacements of approximately 100 feet for folds and between 50 and 150 feet for faults. The Empire Fault and the Vermillion Anticline (an upward fold) are the two largest structures know to occur in the County. (In Figure 10, the location of the Empire Fault can be seen running through the town of Vermillion) Several other smaller structures known to exist in the bedrock formations occur in the eastern part of Dakota County.

- The youngest and uppermost bedrock Formation found in Dakota County is the Decorah Shale, which occurs in the extreme northern portions of the County and underlies portions of Mendota, Mendota Heights, and West St. Paul. Outcrops can be seen along the Minnesota River bluffs below Mendota Heights. The Decorah Shale ranges up to 90 feet in thickness and is a green, calcareous shale interbedded with thin beds of limestone.
- The Platteville and Glenwood Formations are located below the Decorah Shale and are distributed throughout much of Dakota County. The Platteville Formation varies in thickness between 18 to 28 feet and is made up of a fine-grained dolomite and limestone. The Glenwood Formation varies between 2.5 to 10 feet thick and consists of a green, sandy shale. Many of the flat-topped mesas in the southeastern part of the County are capped with the relatively resilient Platteville Formation.
- The St. Peter Sandstone is a widely distributed formation located below the Glenwood Formation. The upper half to two-thirds of this formation is a poorly cemented homogenous quartzose sandstone. The lower parts of this formation contain multicolored beds of sandstone, siltstone, and shale interbedded with coarse-grained sandstone. This formation varies in thickness from approximately 160 feet in the north to approximately 128 feet in the southern part of the County.
- The Prairie du Chien Group is a geologic unit made up of the Shakopee Dolomite, New Richmond Sandstone, and the Oneota Dolomite. The dolomite of the Shakopee Formation forms the upper half to two-thirds of this unit. It is commonly thin-bedded and sandy or oolitic (rounded pebbles generally with a nucleus of sand created in near-shore environments) and contains thin beds of sandstone and chert. The lower part of this unit, the Oneota Dolomite is commonly massive to thick-bedded and is generally not oolitic or sandy, except in the transition zone between just above the Jordan Sandstone. Dolomite in both formations is karst. The upper part, where the overlying formation may have been eroded, is rubbly.



Dakota County

Bedrock Geology

AGQS Figure 10

The Prairie du Chien Group underlies almost all of Dakota County and ranges in thickness from 160 feet in the north to 128 feet in the south. Formations in this unit outcrop along the Vermillion River in and near Hastings and in low bluffs, road cuts, and ravines by the Mississippi River from near Nininger to west of Sedil and from Inver Grove Heights and south. Numerous small outcrops occur in the southeastern part of the County.

Rolling Hills in Castle Rock

- The Jordan Sandstone occurs below the Prairie du Chien Group. This formation is a poorly cemented, cross-bedded, quartzose sandstone that ranges in thickness from 70 to 125 feet.
- The underlying St. Lawrence and Franconia Formations are between 187 to 240 feet thick and consist of dolomitic shale and sandstone, respectively. The St. Lawrence Formation is the oldest formation that outcrops in Dakota County.
- The Ironton and Galesville Sandstones are poorly sorted, silty to coarse-grained, fossiliferous sandstone. These formations are between 21 to 63 feet thick and grade into the Eau Claire Formation. The Eau Claire Formation is between 78 to 188 feet thick and is made up of siltstone, fine sandstone, and shale.
- The Mt. Simon Formation is chiefly a fine to coarse-grained quartzose sandstone ranging in thickness between 155 to 275 feet. The upper third of this formation consists of well-defined layers of very fine-grained sandstone and siltstone and is quite fossiliferous. The lower two-thirds consists mostly of medium to coarse-grained sandstone.

After the deposition of the Prairie du Chien Group (478 million years before present (B.P) the marine waters withdrew from the area long enough for dry land to form and significant erosion to occur. There are no bedrock formations younger than the Decorah Shale (458 million years B.P.) in the County.

Groundwater

In Dakota County, groundwater comes from two major sources, aquifers in the glacial drift or “Quaternary aquifers” and aquifers in the underlying formations or “bedrock aquifers.”

Quaternary Aquifers

Quaternary deposits may behave as aquifers or as confining layers. Confining layers serve to separate aquifers from each other and may offer some protection to aquifers from surface infiltration. Most glacial drift aquifers are highly variable in composition. Many contain significant fractions of gravel or coarse sand, and are of particular concern where contamination occurs because they transmit water and contaminants quickly.

Glacial drift aquifers that are in physical contact with bedrock aquifers may be hydrologically connected and behave as a single aquifer unit. Where glacial drift aquifers have filled ancient valleys cut deeply into the bedrock, they provide vertical connection between bedrock aquifers that are otherwise separated from each other by bedrock confining layers. In these cases, contaminated water from the drift aquifer or from another aquifer can enter lower bedrock aquifers.

Quaternary aquifers provide a source of water for domestic supplies and a few irrigation wells in Dakota County. The highest yielding Quaternary deposits are generally located in buried bedrock valleys. Many private drinking water wells have been constructed in Quaternary aquifers, especially those constructed prior to the first state Well Code in 1974. Because of their susceptibility to pollution they are not used for municipal or public water supply wells. In part, this is because the deeper, higher yielding Quaternary deposits were located outside of developing areas when municipal systems were established. Even though more recent development is situated where it can take advantage of these deposits, it is unlikely that they will be used for municipal supplies. Concerns about contamination, impact from drought, and siltation have rendered these aquifers unreliable and unusable.

Bedrock Aquifers

There are six regional bedrock aquifers in Dakota County: Platteville (Opg), St. Peter (Osp), Prairie du Chien (Opdc) and Jordan (Cjdn), Franconia (Csf), Ironton-Galesville (Cig), and the Mt. Simon-Hinckley (Cm).

The *Platteville aquifer* is a limestone aquifer used for some domestic supplies in Mendota Heights, South St. Paul, and Inver Grove Heights. Most of the wells completed in this area were drilled before well records were required so little is known about the hydrologic properties of this aquifer. The static water level in this aquifer is about 985 feet in elevation near the northern border of the County in West St. Paul and is 855 feet north of Sunfish Lake in Mendota Heights. The generalized direction of flow is southerly; however, localized flow conditions may be in almost any direction.

The *St. Peter aquifer* consists of a poorly cemented sandstone aquifer used for domestic water supplies in the northern part of the County. The Minnesota Geological Survey reports that water from this aquifer is also used in combination with water from the Prairie du Chien aquifer in some older municipal wells and other high capacity wells.

The St. Peter Formation occurs discontinuously throughout most of the County. Where it is not overlain by the Platteville and Glenwood Formations, the St. Peter lies directly below surface deposits. In parts of Randolph and Castle Rock Townships the water table is in the St. Peter Formation. Local recharge to this formation is greatest where it is lays below sandy surface deposits and not covered by the Glenwood formation or thick layers of glacial till. Lakes overlying the St. Peter may also serve to recharge this aquifer. Flow direction is closely related to that of the Prairie du Chien.

Castle Rock: St. Peter Sandstone Formation in Castle Rock Township

The Prairie du Chien-Jordan aquifer is continuous throughout the County except where it is interrupted by deep buried bedrock valleys. The Prairie du Chien - Jordan aquifer consists of four geologic units: the Shakopee Dolomite, the New Richmond Sandstone, Oneota Dolomite, and the Jordan Sandstone. In other parts of Minnesota, the Prairie du Chien and the Jordan are treated as a single aquifer, however, in Dakota County the two are hydrologically separated and act as independent aquifers.

The potential yield of the Prairie du Chien - Jordan aquifer indicates that yields of greater than 2,500 gallons per minute are found throughout most of the County (10 gallons per minute is the minimum required for domestic wells). Lowest yields in the formation occur where the aquifer thins along the flanks of buried bedrock valleys. Conversely, in these areas the potential yields of the glacial drift deposits found in the buried valleys are the greatest.

The *Franconia aquifer* is located directly below the Jordan Sandstone. This aquifer is believed to extend throughout the entire County, except at the east end of the buried bedrock valley in Ravenna and Marshan Townships. The Franconia aquifer is used primarily for domestic supplies; however, the Minnesota Geological Survey reports that some multi-aquifer wells use this aquifer to supplement flow from the overlying Prairie du Chien or underlying Ironton-Galesville Formations. This aquifer is used primarily in the southeast portion of the County although some multi-aquifer wells may be located elsewhere in the County. Yield in this aquifer is low to moderate and varies from less than 50 gpm to less than 200 gpm.

The *Ironton-Galesville aquifer* is a relatively thin (50 foot) sandstone aquifer that lies directly below the Franconia aquifer. It is likely the two aquifers are hydrologically connected, but the degree of this connection is not known. The Minnesota Geological Survey's County Well Index contains no record of wells being completed in this aquifer, however, data indicate that this aquifer is used to supplement flow in some high capacity wells.

The *Mt. Simon-Hinckley aquifer* is the deepest, high-yielding aquifer in Dakota County. The Minnesota Geological Survey has calculated yields of between 650 and 1,800 gallons per minute from this aquifer. It occurs throughout the entire County with a saturated thickness varying from 215 feet in South St. Paul to about 255 feet in Burnsville.

The static water level is about 650 feet in elevation in Eagan and about 708 feet in Vermillion. Generalized flow in this aquifer is to the north and northwest.

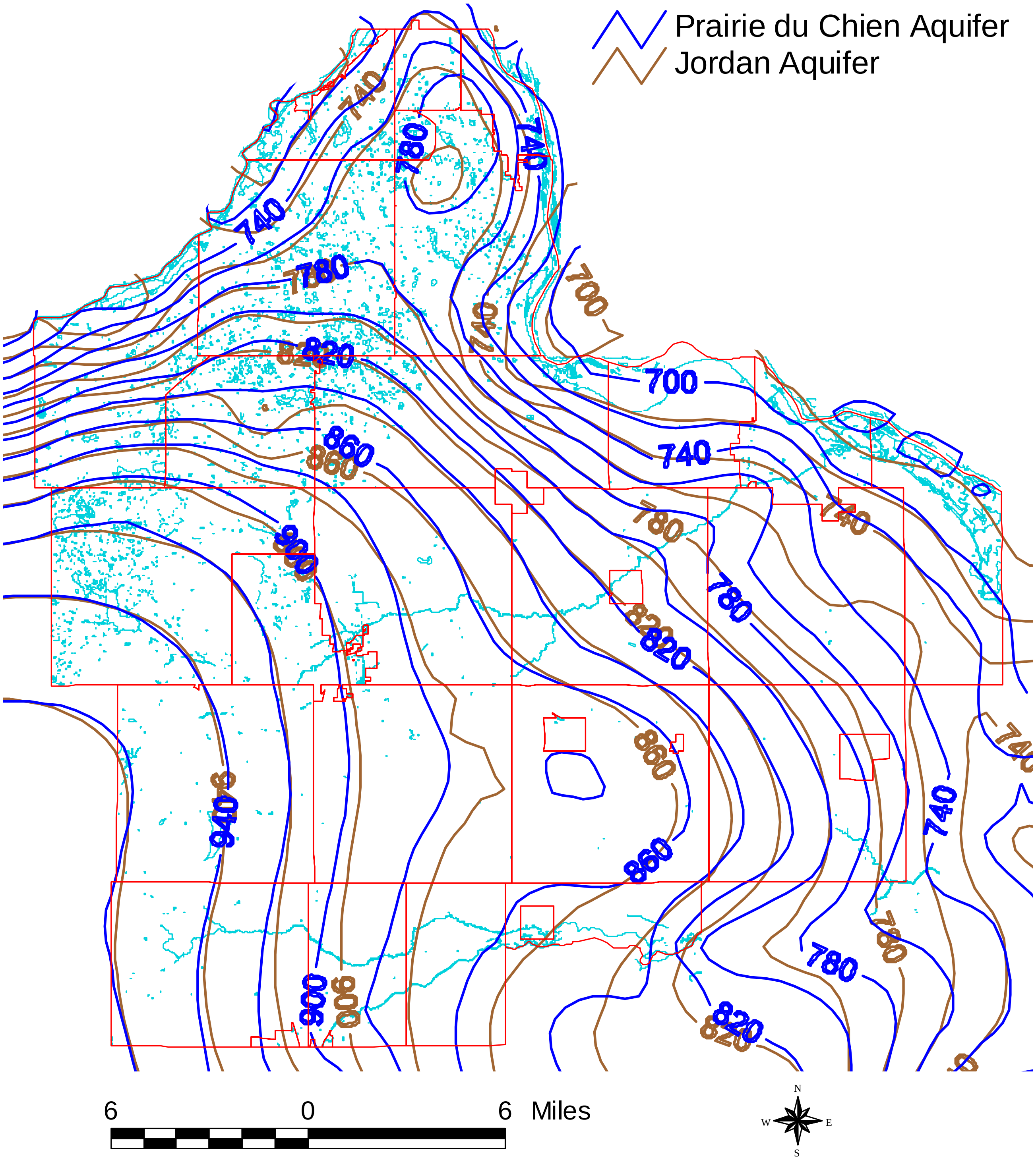
Because of its depth and the availability of water from other aquifers the Mt. Simon - Hinckley aquifer is not used for domestic supplies. High capacity industrial, municipal, and multi-aquifer wells have been reported as completed into this aquifer; however, the Department of Natural Resources now prohibits any new wells from being drilled into this aquifer unless no other feasible or practical alternatives exist.

Hydrogeologic Setting

Groundwater is affected by a number of factors as it falls to the ground as rain, infiltrates through the surface and soil, and is transported through an aquifer. Thus, air quality, soil composition, and aquifer properties have a major impact on the water yielded by wells. Air quality is relatively good in Dakota County. The EPA has determined the Minneapolis/St. Paul metropolitan area is minimally impacted by air pollution. In general, the average precipitation has a pH between 6 and 7, or, slightly acidic.

As water enters the aquifer from the soil, it seeps through pore spaces and voids in the geologic material. The level below which the geologic material is saturated is the water table. Below the water table, water moves from high to low head pressure; head pressure is often thought of in terms of elevation. In general, groundwater moves from a recharge area at higher elevation to a lower elevation.

The overriding drainage system of the County is from west to east. Figure 11 shows contours of head in the Prairie du Chien and Jordan Aquifers, as calculated by the Dakota County Groundwater Model. The heads in the Prairie du Chien and Jordan Aquifers are similar. The direction of water movement is always from higher to lower head; the figure shows that groundwater flows from the center of the County toward the Minnesota and Mississippi Rivers to the north, and the Cannon River to the south. The Vermillion River bisects the County from southwest to northeast; however, it is a minor tributary to the Mississippi and has less effect on groundwater flow than the Minnesota or the Cannon. The rate and direction of flow is controlled by recharge (primarily rainfall), discharge (primarily into rivers), and by the characteristics of the aquifers. The deeper aquifers receive their water from the shallower aquifers through downward movement, and they give up their water to wells or to shallower aquifers through upward movement. In Dakota County, most downward movement occurs in the central and southeastern regions, while upward movement is typical where the groundwater discharges into the major river systems.



Dakota COUNTY

Opdc and Cjdn Head Levels

(feet above sea level)

AGQS Figure 11

SAMPLING DESIGN

Well Selection

Wells for the AGQS were selected to represent the geography of the County, the Opdc or Cjdn aquifers, and one of four hydrogeological zones. Dakota County maintains information on well locations and construction details in its proprietary version of the County Well Index, the Well & Water Supply Management Database (Wellman). The County has an estimated 8,000 households that rely on private drinking water wells. Of these, approximately one-third are screened in the Quaternary aquifer, one-third are completed in the Opdc, and one-third are completed in the Cjdn.

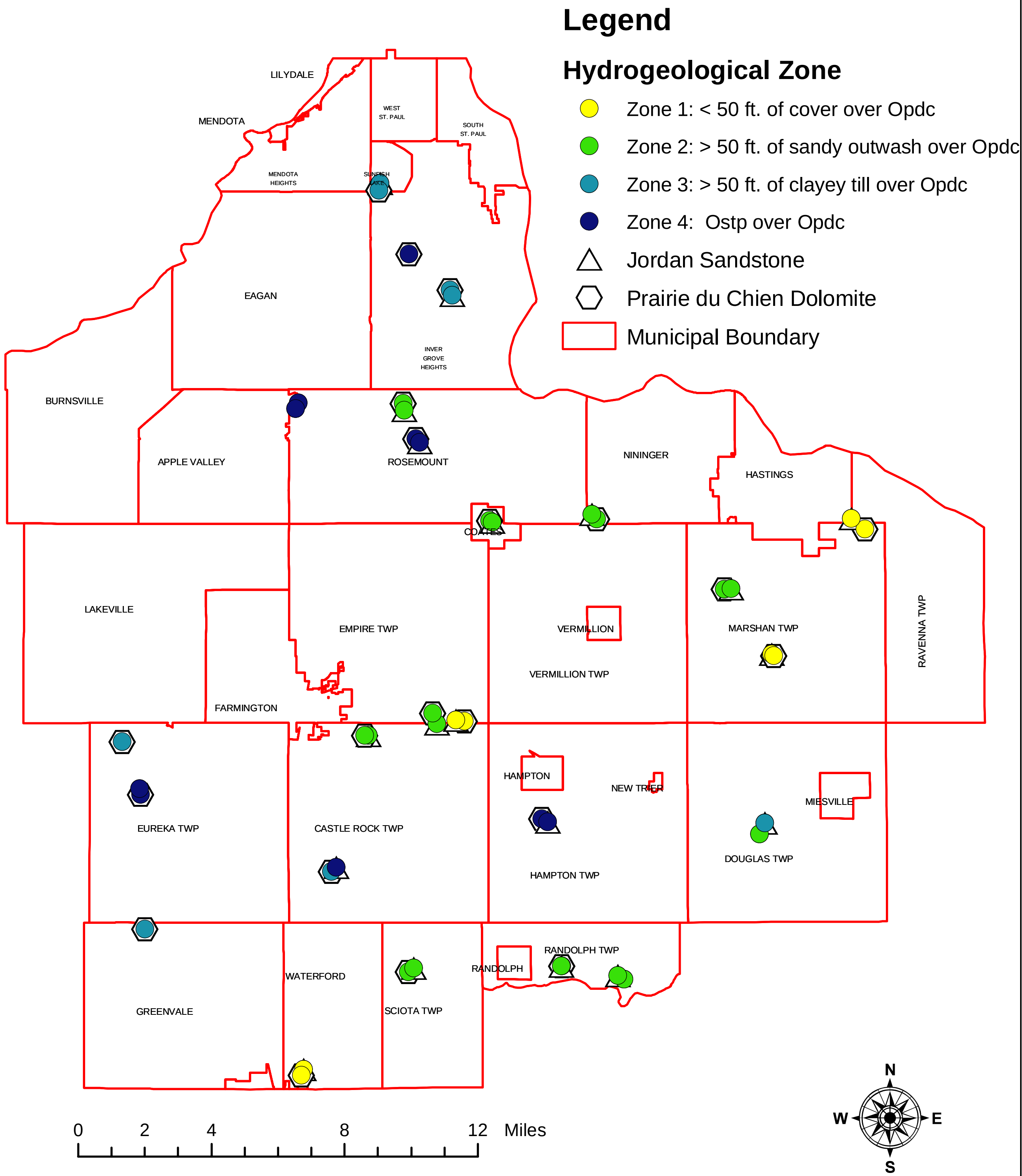
Domestic Well

Staff used Wellman and a geographic information system (ArcView 3.2) to select wells throughout the County. The GIS was used to overlay geologic, soils, and hydrogeologic maps on the well location base map. A well selected for sampling had to be completed in either the Opdc or the Cjdn aquifer, but not both. A balanced geographical distribution was taken into consideration. Where possible, wells were paired up; i.e., wells were selected that were within 1,500 feet of each other horizontally but completed in different aquifers.

Wells with construction records, which document how the well was constructed, were preferred. Well contractors were not required by the Minnesota Department of Health to submit well construction records until 1974. Several of the wells sampled do not have a well record; an exception was made to include these wells, based on proximity to another well to create a pair, one in each aquifer. Each well is accurately located with sub-meter accuracy based on Global Positioning System (GPS) technology.

The wells were chosen from four hydrogeological settings in which the Opdc occurs, based upon the overlying material. These zones are based on the factors used by the Department of Natural Resources to identify areas where the groundwater is sensitive to contamination. Zone 1 has less than 50 feet of cover material over the Opdc. Zone 2 has over 50 feet of glacial outwash, mostly sands overlying the Opdc. Zone 3 has over 50 feet of glacial till with a characteristic amount of clay that overlies the Opdc. Zone 4 has the St. Peter Sandstone overlying the Opdc. Well locations with their hydrogeological zone are shown in Figure 12.

The County contacted well owners by letter to obtain their permission to sample their wells. Participation in the AGQS is voluntary for the well owners, and the results of individual wells are not publicized. A follow-up letter is sent to each owner each year to explain the results from their well for that year.



Dakota County

AGQS Wells: Hydrogeological Zones

AGQS Figure 12

Well Sampling and Sample Analysis

An independent sampling contractor samples the wells with oversight by Dakota County staff. The main goal is to sample "aquifer water," not the delivery system, which includes the pressure tank and pipes. To avoid misrepresentation of certain water quality parameters, samples are taken after running the water for approximately 15 to 30 minutes. This is required to flush the delivery system and produce a representative sample. During the collection process, water is tested for a number of field parameters, including pH, temperature, conductivity, dissolved oxygen, and oxidation/reduction potential.

Samples are collected in appropriate containers for major cations and anions, volatile organic compounds (VOCs), total organic carbon (TOC), nitrate, nitrite, pesticide and pesticide degradates. The parameters may vary each sampling event; please refer to the discussion of each sampling event for a list of parameters sampled.

The samples are immediately placed in a cooler of ice and cooled to four degrees Celsius until transported to an independent laboratory.

Physical Properties

Physical parameters are identified as those that can be measured on the site of sample collection. They are typically measurements made with probes and other mechanical devices, as opposed to chemical analysis. Examples include temperature, pH, or specific conductivity.

Temperature for groundwater is generally very stable, between 35 and 40 degrees Fahrenheit, depending upon depth. Knowing this, changes in groundwater temperature can have significant implications. It can mean thermal pollution or high amounts of exothermic reactions in the water from contaminant pollution. Higher temperatures can also create a setting in which harmful bacteria can flourish, since bacteria are typically more active in a warmer environment. Temperature is also important in the ecosystem where groundwater flows into streams; trout and other cold-water fish require a steady supply of cold groundwater to breed and grow.

The pH is the measure of acidity or alkalinity of water. A value of 7 is neutral with lower numbers representing acidic values and higher numbers representing alkaline, or basic. A normal range for pH is between 6 and 8. Slightly basic water is preferred for drinking water purposes. Levels lower than 6 and higher than 8.5 can present health risks. The further the pH is from 7.0, the greater the health risks.

Specific conductivity is the ability of water to transmit an electrical current. It is related to the concentration and charge of ions present in the water. There is no innate danger for any level of conductivity.

Dissolved gases are present in both surface water and groundwater. The major gases of concern are oxygen and carbon dioxide. Nitrogen, which is more or less inert, is also present. Minor gases of concern include hydrogen sulfide and methane. Hydrogen sulfide is toxic and imparts a bad odor, but it is not present in water that contains dissolved oxygen. Dissolved oxygen levels are an indicator of possible serious problems. If organic matter, such as untreated human or animal waste, is present in water, dissolved oxygen levels diminish as microorganisms grow, using the organic matter as an energy source and consuming oxygen in the process. If dissolved oxygen levels are low, it could mean that there are serious contaminants in the water. Concentrations greater than 1 mg/L indicate an aerobic environment. Nitrate, if it is present, will not degrade in an oxygenated environment.

While alkalinity is a chemical property, rather than physical, it can be measured in the field. Alkalinity is the amount of carbonate ions present in the water. It is one of the factors that contribute to hardness. Alkalinity is controlled primarily by the mineralogy of the aquifer. In Dakota County, limestone and dolomite stratigraphic units contribute carbonate to the groundwater. Limestone is a form of calcium carbonate. Dolomite is a variation of carbonate rock similar to limestone, but with varying amounts of magnesium replacing calcium.

Eh is a measure of the oxidation potential of an aqueous solution. For a chemical reaction in which electrons are transferred from one ion to another, a "redox" or oxidation-reduction reaction occurs. The ability for a solution of water containing dissolved ions to allow this electron transfer is the oxidation potential. The actual transfer of electrons produces an electrical current, measurable in the field with an Eh meter. Eh is an indicator of the number of ions in solution, as well as the reactivity within that solution. Eh is measured in volts, around zero, whereby further digression from zero means more extreme reducing or oxidizing conditions. Negative values represent reducing conditions while positive values represent oxidizing conditions. If Eh and pH of a water sample are known, it is possible to determine a number of characteristics of the aquifer, including the stability of the minerals in contact with the water.

Turbidity is a measure of the cloudiness of water. The cloudiness in surface water is typically caused by soil runoff when sediment is suspended in the water column. The more serious concern with turbidity is if it is found in groundwater. Drinking water with high levels of turbidity is often associated with higher levels of disease-causing microorganisms. These organisms may include viruses, bacteria, or parasites that might cause problems with human or animal digestive processes.

Chemical Properties

Chemical properties include the parameters classified as major ions, nutrients, total organic carbon, volatile organic carbons, and pesticides and their metabolites. Each chemical property measured represents a compound that, in some concentration, poses health risks. "Coliform bacteria" is an additional parameter that is included in the chemical property category, because it is analyzed for at the laboratory.

The “major ions” are calcium, magnesium, sodium, potassium, chloride, sulfate, fluoride, and bromide. Ions are electrically charged atoms or molecules that dissolve in water. The polarity of water allows charged particles to remain dissolved.

Nutrients are compounds that contain nitrogen, phosphorus, or potassium and are necessary for the growth of plants and animals. They are found readily in nature in varying concentrations. Concern arises when these compounds increase in concentration in drinking water due to human activity.

Total organic carbon is a classification of compounds that contain carbon atoms in their structure. These compounds encompass any compound that is derived from living organisms. TOC is a summation of these compounds. Some of the substances that are included in TOC are VOCs, alcohols, caffeine, and many others. TOC does not pose health risks on its own, but the organics that are included in the total may be dangerous. High levels of TOC require more extensive analysis to deduce the nature of the organics.

Volatile organic compounds are typically thought of as those associated with petroleum products, petroleum processing, and numerous industrial processes. The term volatile refers to a compounds ability to vaporize, or change from a liquid to a vapor, under atmospheric conditions. VOCs, by nature, are difficult to measure, yet they pose some of the most serious health risks associated with groundwater contamination. VOCs are created during the processing of other organic compounds. They are almost entirely anthropogenic.

The term pesticide is defined as “a chemical substance used to kill pests.” Pesticides can be generally divided into three categories: insecticides, herbicides, and fungicides. Herbicides are developed to kill or inhibit *plant* pests, such as weeds. Fungicides are developed to kill or inhibit fungi, such as molds or mushrooms. In Dakota County, the primary use of pesticides is for protection for agricultural crops. Residential areas also use significant amounts of pesticides for lawns and gardens. Even the County and municipalities use significant amounts of pesticides to control overgrowth along roads and highways.

Along with pesticides, fertilizers are applied to many acres of the County. Fertilizers contain nutrients used to increase the fertility of soil to aid the growth of plants. While not innately harmful to organisms, the presence of fertilizers and their metabolites in the groundwater can cause health concerns.

Of all potential groundwater contaminants, nitrate is one of the most prevalent. Nitrate is a metabolite of natural organic matter, natural fertilizer (manure), and synthetic fertilizers. Nitrate, while not dangerous at natural levels, can pose severe health risks at elevated levels. With the increased use in fertilizers, especially in geologically sensitive areas, nitrate levels are becoming an increasing problem in groundwater. Nitrate replaces oxygen in the blood stream and can cause serious health problems, especially in young children. In children under six months, nitrate replacement of oxygen can cause "blue baby syndrome." This condition can lead to severe brain damage. The Minnesota Department of Health's drinking water standard for nitrate is 10 milligrams per liter (mg/L). Dakota County implements a policy of notification at 3 mg/L and makes recommendations for treatment at 5 mg/L.

Drinking Water Standards

Many of the chemical parameters for which the samples were analyzed have drinking water standards established by the Environmental Protection Agency or the Minnesota Department of Health. All of the results were compared to these allowable levels. There are two systems of criteria that Dakota County uses for analyte comparison, HRLs and MCLs. HRLs, or Health Risk Limits, are established by the Minnesota Department of Health. A HRL is the concentration of a groundwater contaminant, or mixture of contaminants, that can be safely consumed daily for a lifetime. The EPA establishes MCLs, or Maximum Contaminant Levels. The EPA publishes a list of groundwater components and contaminants and their MCLs, along with the sources and possible health effects of exposure. MCLs make up a more comprehensive list than HRLs, however, they are often less restrictive than the limits that individual states allow. HRLs are used to evaluate domestic wells. MCLs are used to evaluate municipal and non-community wells. When there is no HRL for a parameter the MCL is utilized. The AGQS sample results were also compared to the National Secondary Maximum Contaminant Levels (SMCLs), which are EPA guidelines for aesthetic effects in drinking water, such as taste, odor, and color.

Participating well owners receive a copy of the test results for their well and a letter that explains any parameter that exceeds drinking water standards. The letter includes suggestions for mitigation.

How to Use this Report

A summary of the first five years of sampling (1999-2003) follows, and an annual report will be added as an appendix each year. A description of the wells sampled, parameters analyzed, and results will be included. The number of wells, parameters analyzed, and data analysis may vary with each sampling event. You may request an annual report by contacting:

Dakota County
Environmental Management Department
14955 Galaxie Ave
Apple Valley, MN 55124
(952) 891-7010

Or email a request to: environ@co.dakota.mn.us

REFERENCES

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1999-2003 RESULTS AND DISCUSSION

Statistical Analysis

Dakota County AGQS samples were collected in December 1999, September 2000, June 2001, September 2002, and September 2003. In 1999, Spectrum Labs collected and analyzed the samples. In 2000 and 2001, Minnesota Valley Testing Laboratory (MVTL) collected and analyzed the samples. In 2001, as explained below, the United States Geological Survey's (USGS) Organic Geochemistry Research Group in Lawrence, Kansas, analyzed some of the samples for pesticides and pesticide degradates. In 2002 and 2003, MVTL collected the samples and analyzed them for general water chemistry, iron, and nutrients, while the USGS lab analyzed them for pesticides and degradates.

Nonparametric statistical analysis was completed on the field data and laboratory results using Statistix v. 7 (Analytical Software). Spearman's rank correlation (Spearman's rho) was used to compare ordinal (numerical) data such as nitrate associated with well depth, and multiway factorial analysis of variance (Kruskal-Wallis H) was used to compare nominal (categorical) data, such as nitrate versus associated with aquifer (Zar, 1984).

Aquifer Characteristics

All water in nature contains far more than just hydrogen and oxygen; it picks up small traces of the conditions through which it has passed as it moves from cloud to ground to subsurface. These traces, such as minerals or dissolved gases, may be naturally occurring or anthropogenic (caused by humans). Most natural impurities, such as calcium or magnesium, pose no health risk to humans; some, such as iron or sulfur, may affect drinking water's taste or smell; others, such as arsenic, may pose serious health risks. In contrast, nearly all anthropogenic components of groundwater pose some danger to human health, depending on concentration.

Water from different aquifers will probably have different natural chemical compositions, for two primary reasons. The mineral compositions of the aquifer rocks will be different, creating differences in the minerals that leach into the groundwater. Also, the different relative positions of the aquifers (i.e., one above the other) mean that when the water reaches the lower aquifer it usually will have passed through the upper aquifer, picking up some chemicals from the upper aquifer as it flows and leaving some chemicals from the surface behind.

Physical Properties

Appendix I shows the physical parameters that are statistically different and those that are not in the Opdc and Cjdn aquifer results. In most cases, the results did not vary significantly by year. When the results did show statistically significant differences from year to year, they are reported by year; otherwise, the results are combined. "Well Characteristics" shows the differences in well construction – well depth, casing depth, depth to water, elevation, and elevation of water table -- between the two aquifers in the sample set. Because the wells were selected to pair an Opdc well with a nearby Cjdn well, the average elevations of the wells and the water table are the same for the two aquifers. Total well depth and casing depth vary significantly between the two aquifers, with a median well depth of 183 feet for Opdc wells and 350 feet for Cjdn wells.

"Physical Parameters" include water temperature, pH, specific conductance, dissolved oxygen, alkalinity, and redox potential. Temperature, alkalinity, and redox potential are not different in the two aquifers. Dissolved oxygen and specific conductance are higher and pH is lower in the Opdc than in the Cjdn. The difference between dissolved oxygen levels in the two aquifers (4.88 mg/L vs. 1.93 mg/L) is discussed further, below, in relation to nitrate and pesticide contamination.

Chemical Properties

"Major ions" include calcium, magnesium, sodium, potassium, chloride, sulfate, fluoride, and bromide. Calcium, magnesium, sodium, chloride, and sulfate are significantly higher in the Opdc than in the Cjdn. Calcium and magnesium are naturally occurring minerals that do not have drinking water criteria; there are health benefits associated with their presence rather than concerns. However, they are the minerals that account for most hardness in water and can cause scaling of pipes and water heaters (MPCA, 1999). Generally, concentrations of calcium plus magnesium greater than 100 mg/L are considered "hard" (MPCA, 1999). The combined median levels in the Opdc (100.1 mg/L) are higher than the Cjdn (92.5 mg/L). The ratio of calcium to magnesium is very similar in the two aquifers: 2.7 to 1 in the Opdc and 2.6 to 1 in the Cjdn.

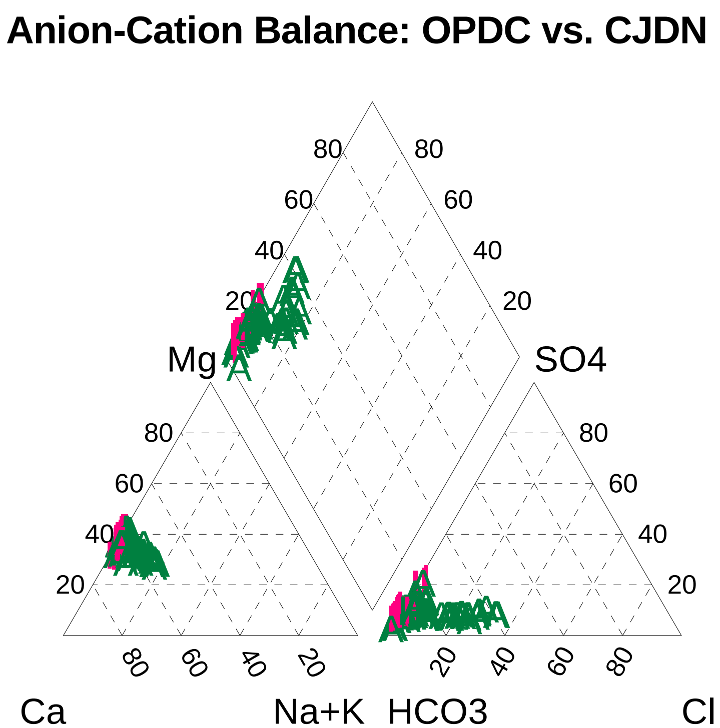
Sodium and chloride occur naturally, but also come from anthropogenic sources such as road salt. Both sodium and chloride are significantly higher in the shallower Opdc aquifer than in the Cjdn aquifer. Conditions in the aquifers do not generally show significant changes over the years of the AGQS (1999 through 2003), but chloride is one exception (from median levels of 0.0 mg/L to 3.8 mg/L in the Cjdn from 1999 to 2003). Chloride is a parameter that will bear investigating in Quaternary water supplies; a 1998 USGS study in the northwest part of Minnesota's Twin Cities Metropolitan Area found chloride concentrations from 4.6 to 330 mg/L, with a median concentration of 46 mg/L in 30 wells completed in unconfined sand and gravel aquifers just below the water table (Andrews et al, 1998). (Sand and gravel wells are generally shallow and more susceptible to contamination, so their chloride levels could be expected to be higher than in bedrock Opdc or Cjdn wells.) Neither sodium nor chloride has a health-based drinking water standard. Chloride has a standard for taste (secondary maximum contaminant level, or SMCL) of 250 mg/L. The highest chloride level detected in the AGQS was 110 mg/L. Sodium in drinking water does not have a numerical standard, but sodium intake from either food or water may lead to hypertension and be a concern for people with heart conditions (MPCA, 1999).

Sulfate occurs naturally, but is also introduced to the environment by anthropogenic sources, such as industrial processes, fertilizers, or pesticides. Gypsum in the soil above an aquifer or in the aquifer minerals themselves can be the source of high levels of sulfate. In addition, combustion of fossil fuels releases large quantities of sulfur to the atmosphere. Sulfur in the atmosphere is oxidized to sulfate and eventually deposited with precipitation. Sulfate has a MCL of 500 mg/L because it can have a laxative effect and imparts an unpleasant taste to water. Aquifers with high concentrations of hydrogen sulfide have a bad odor. The Minnesota Department of Health recommends a limit of 400 mg/L for water used in infant formula. Sulfate levels were higher in the Opdc than in the Jordan, but all detections were well below the suggested standards. The highest detection was 64.0 mg/L.

Fluoride in drinking water is desirable up to a point. The optimum concentration of fluoride for dental health is 0.7 to 1.2 mg/L. Many wells in the AGQS did not have detectable levels of fluoride; the overall median fluoride concentration was 0.10 mg/L. Most adults receive adequate fluoride from sources outside the home or from toothpastes with fluoride, but parents of small children who use well water should consult with their dentist regarding supplemental fluoride treatment. Fluoride has a maximum contaminant level of 4 mg/L based on potential mottling of teeth. (MPCA, 1999)

The anion-cation balance of major ions is plotted in the Piper Diagram on page 33. (Figure 13: The green triangles represent the Opdc and the pink marks represent the Cjdn.) Measured relative levels of calcium (Ca+), magnesium (Mg+), sodium (Na+), potassium (K+), sulfate (SO4-) and chloride (Cl-), as well as estimated levels of carbonate (HCO3-), are plotted. Calcium, magnesium, sodium, chloride, and sulfate are all significantly higher in the Opdc than in the Cjdn; potassium is not different in the two aquifers. In addition, the Piper Diagram shows that the variability of the major ions is much greater in the Opdc than in the Cjdn.

Figure 13: Piper Diagram



The trace metal included in the AGQS is iron. Iron does not have a health-based drinking water standard, but does have a SMCL of 0.30 mg/L. Above that level, iron stains plumbing fixtures and clothing and has an unpleasant taste. Much of Dakota County's drinking water is high in iron: 51% of the wells in the AGQS exceeded the SMCL. Cjdn water is significantly higher in iron than Opdc water; 67% of the Cjdn wells exceeded the drinking water standard, and the Cjdn median result was 0.63 mg/L, twice the standard. A total of 37.5% of the Opdc wells exceeded the standard, but the Opdc median result was 0.07 mg/L. Iron is discussed more below in relation to nitrate contamination.

The final section of Appendix I includes nutrients and total organic carbon. Nitrate, nitrite-nitrogen, and ammonia-nitrogen are significantly different by aquifer. Nitrate is discussed at length in the "Groundwater Contamination" section on page 35.

Hydrogeological Zone Characteristics

Wells sampled for the AGQS were classified by hydrogeological zones that represent the relative amount of protection against groundwater contamination provided by the depth and type of geological cover material over the Opdc (even if the well was completed in the Cjdn). Zone 1 has less than 50 feet of cover over the Opdc, the least protection against contamination. Zone 2 has more than 50 feet of sandy outwash over the Opdc. Zone 3 has more than 50 feet of clayey glacial till over Opdc; clayey materials provide greater protection against contamination than do sandy materials. Zone 4 has St. Peter Sandstone over the Opdc, the greatest level of geological protection against contamination in the County.

Figure 12 in the introduction shows the locations of the AGQS wells and their hydrogeological zones. Appendix II shows the sampling results by zone, as discussed below.

Physical Properties

The elevations of the water table did not show significant differences between Zones. Specific conductance (conductivity), dissolved oxygen (DO), and alkalinity showed significant differences between Zones. Zone 1 had the highest conductivity, highest DO, and lowest alkalinity. Zone 3 had the lowest conductivity and DO, while Zone 4 had the highest alkalinity. Water temperature, pH, and Eh were not significantly different between Zones.

Chemical Properties

Calcium, magnesium, sodium, potassium, chloride, sulfate, fluoride, and iron showed significant differences by Zone.

- Zone 1 had the highest median levels of calcium (73.85 mg/L), magnesium (29.15 mg/L), and chloride (13.05 mg/L), and the lowest levels of fluoride (0.0 mg/L, along with Zone 2) and iron (0.02 mg/L). The higher levels of chloride probably indicated human influences.
- Zone 2 had the highest levels of sulfate (26.50 mg/L) and the lowest levels of calcium (66.3 mg/L), magnesium (24.5 mg/L), potassium (1.30 mg/L), chloride (3.60 mg/L), and fluoride (0.0 mg/L).
- Zone 3 had the highest levels of sodium (4.48 mg/L), fluoride (0.14 mg/L), and iron (1.20 mg/L) and the lowest levels of sulfate (19.40 mg/L).
- Zone 4 has the highest level of potassium (1.64 mg/L) and the lowest level of sodium (2.72 mg/L).

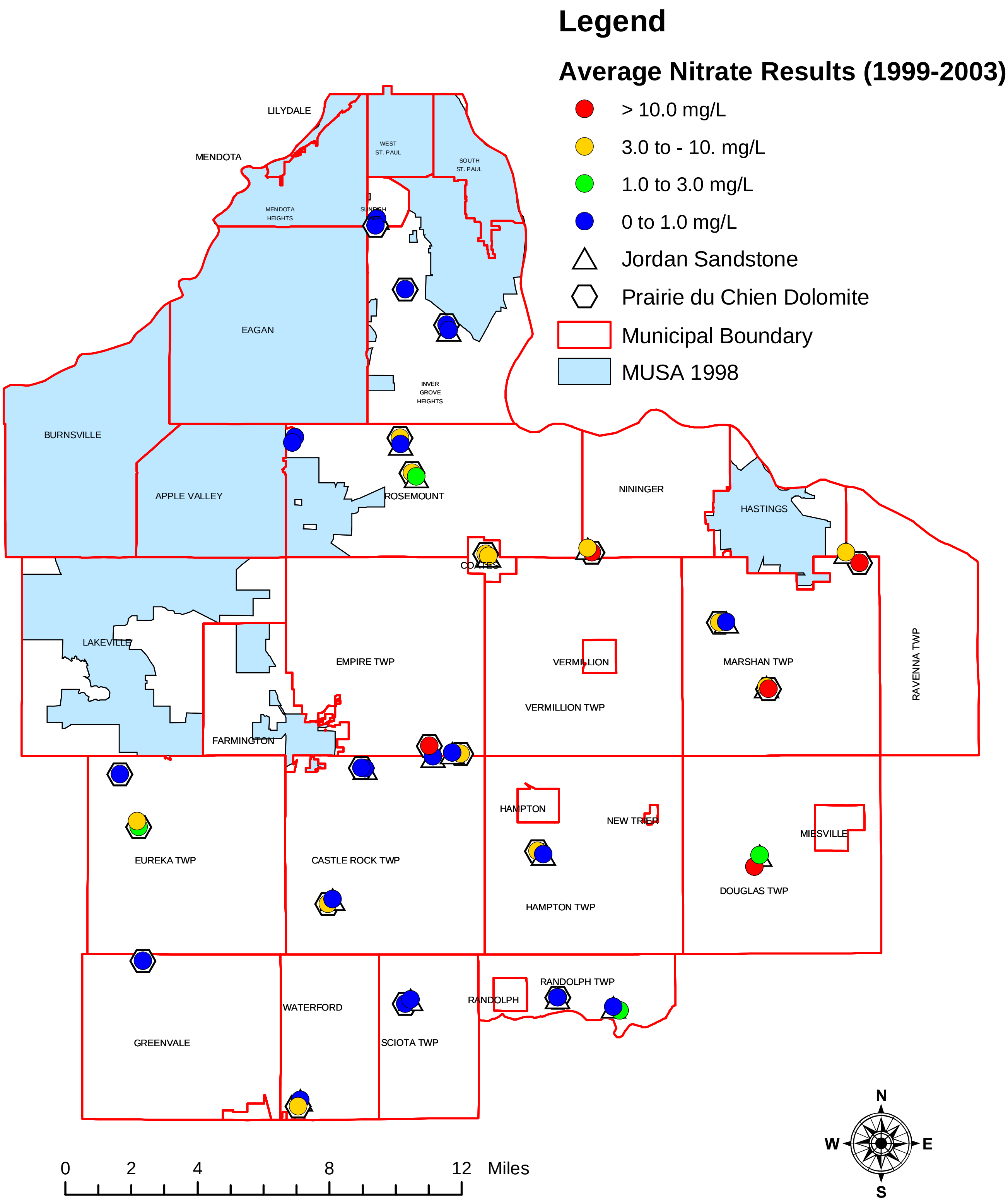
Groundwater Contamination

Nitrate

Nitrate is the main contaminant of concern in Dakota County, as in the rest of Minnesota. In the AGQS from 1999 through 2003, when wells in the AGQS did not meet drinking water standards, it was due to elevated nitrate. Figure 14 shows the average nitrate results per well for 1999 through 2003. Nitrate is a metabolite of natural organic matter, natural fertilizer (manure), and synthetic fertilizers. Nitrate, while not dangerous at natural levels, can pose severe health risks. With the increased use in fertilizers, especially in geologically sensitive areas, nitrate levels are becoming an increasing problem in groundwater. Nitrate replaces oxygen in the blood stream and can cause serious health problems, especially in young children. In children younger than six months, nitrate replacement of oxygen can cause “blue baby syndrome.” This condition can lead to severe brain damage. The Minnesota Department of Health’s drinking water standard for nitrate is 10 milligrams per liter (mg/L). Dakota County implements a policy of notification at 3 mg/L and makes recommendations for treatment at 5 mg/L.

Overall, 10% of the wells in the AGQS have nitrate levels that exceed the drinking water standard. Through 2003, the AGQS only included Prairie du Chien and Jordan bedrock wells; many private wells in the County are wells completed in unconfined sand and gravel aquifers (Quaternary wells) with even less geological protection from contamination than the bedrock wells. Therefore, the actual percentage of private wells in the County that exceed the drinking water standard for nitrate is probably in the 18-26% range, based on results from the County’s nitrate clinics and the Hastings Area Nitrate Study (HANS). The County has approximately 8,000 households with private drinking water supplies, suggesting that the County has 1440 to 2080 households whose water supplies do not meet drinking water standards.

Prairie du Chien wells have significantly higher risk of nitrate contamination than do Jordan wells. In the AGQS, 59% of Prairie du Chien wells had detectable levels of nitrate, while 41% of Jordan wells had detectable nitrate. All the wells that exceeded the drinking water standard for nitrate were Prairie du Chien wells; none of the Jordan wells exceeded the drinking water standard. The wells in the AGQS did not show significant changes in nitrate levels from 1999 through 2003.



Dakota COUNTY

Average Nitrate Levels (1999-2003)

AGQS Figure 14

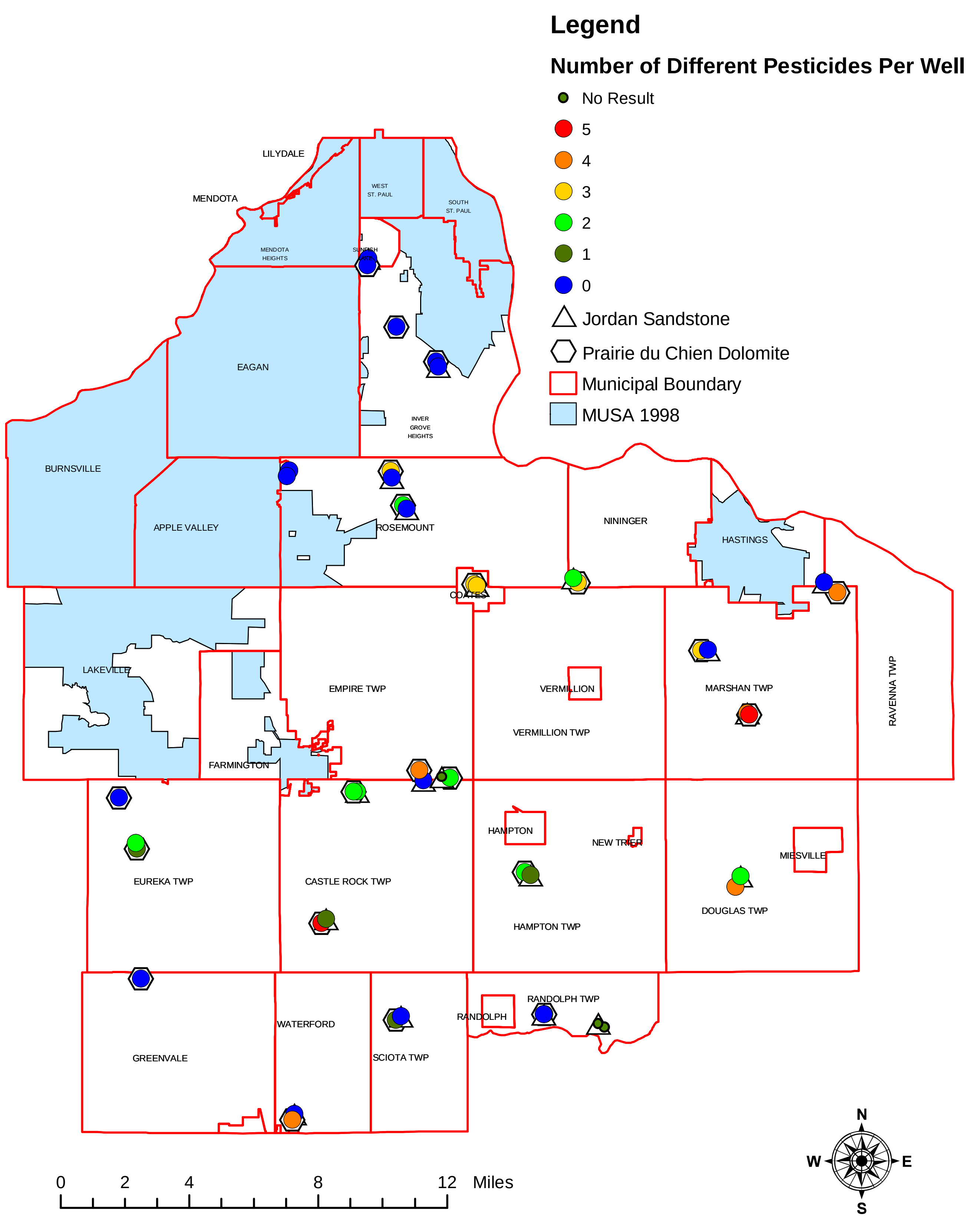
Pesticides

In 1999, 2000, and 2001, the AGQS samples were analyzed for the Minnesota Department of Agriculture's List 1 of agricultural pesticides commonly used in corn and soybean farming (analytes and reporting limits are listed in Appendix III). Using this analysis, in 1999, s-ethyl dipropylthiocarbamate (EPTC) was the only pesticide detected; it was found in two wells at 0.28 μg/L and 0.26 μg/L, respectively. The Health Risk Limit (HRL) for EPTC is 200 μg/L. No pesticides were detected in 2000. In 2001, Minnesota Valley Testing Service (MVTL) analysis found atrazine and its breakdown products in 12 Opdc wells. MVTL detected deethylatrazine from 0.2 to 0.3 μg/L in 12 wells; eight of the same wells contained atrazine from 0.2 to 0.3 μg/L, and one of the same wells contained deisopropylatrazine at 0.3 μg/L.

Pesticide analysis performed by the U.S. Geological Survey (USGS) Organic Geochemistry Research Group was added to the AGQS's analytical suite in 2001 because of the high frequency of pesticide detections in the HANS wells. (Analytes and reporting limits are listed in Appendix IV). In 2001, samples from 19 AGQS wells that had previously shown nitrate above 1.0 mg/L were analyzed by the USGS; in 2002 and 2003, samples from all wells were analyzed by the USGS. The results from these two sets of wells were significantly different, so they are reported as "First Sample Set" and "Remaining Samples" in Appendix V.

Since Dakota County began using the USGS laboratory analysis, pesticides (and pesticide breakdown products) associated with corn and soybean farming have been the most widely detected contaminants in the AGQS. (No pesticides exceeded drinking water standards.) 61% of the wells in the AGQS showed detectable levels of pesticides or pesticide breakdown products; 48% showed detectable levels of nitrate. (Note: the detection limits for the pesticides were much lower than the detection limits for nitrate.) The number of different pesticides detected per well is shown in Chart 1 and Figure 15.

The Minnesota Department of Health has performed cumulative risk assessments on the AGQS wells that contained detectable levels of pesticides (Appendix VI). No hazard index calculated in the MDH risk assessment was equal to or greater than one. In other words, the chemicals and concentrations in the AGQS wells are below the MDH policy risk level of 1 in 100,000 incidences of cancer or noncancer health effects. However, the MDH expressed concern over the detection of multiple pesticides in the AGQS wells: half of the wells (52%) contained multiple pesticide contaminants (a pesticide and/or its degradates). In order of frequency, the pesticide contaminants detected were Alachlor (62% of wells in 2002 and 2003), Metolachlor (52%), Atrazine (36%), Acetochlor (21%), Cyanazine (4%), and Dimethenamid (1%).



Pesticides Per Well (2001-2003)

AGQS Figure 15

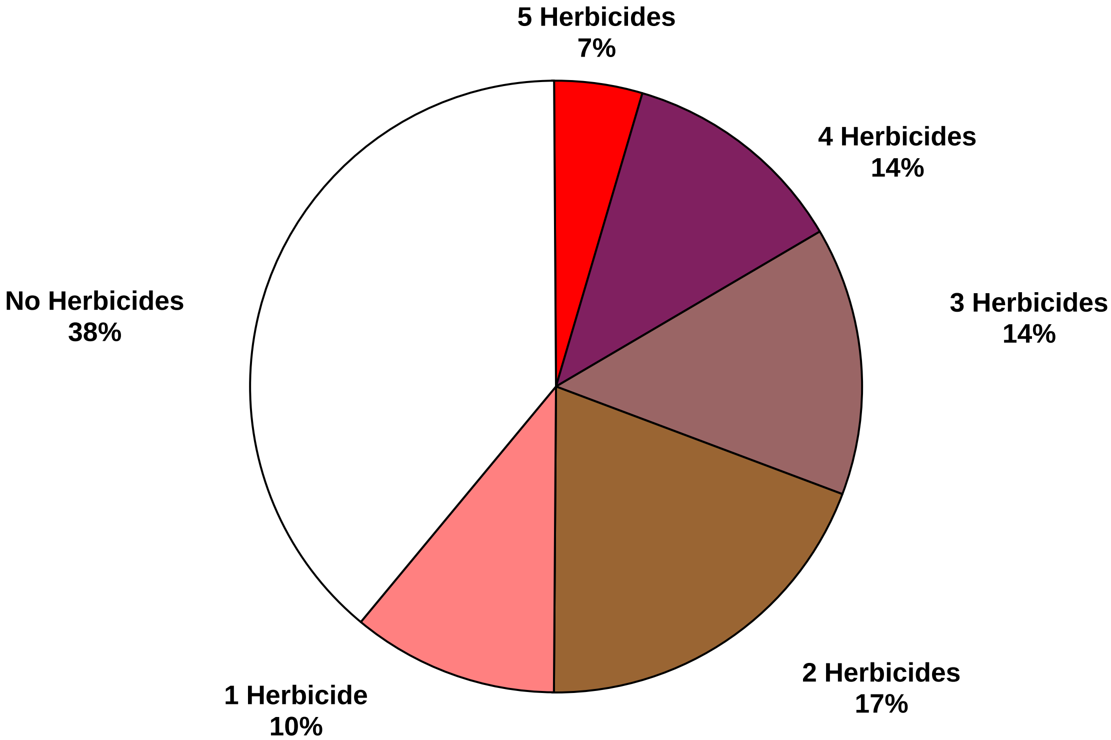


Chart 1: Pesticides per Well

In the 2002-2003 AGQS results:

- When 1 pesticide contaminant was detected, it was Alachlor;
- When 2 were detected, they were Alachlor and Metolachlor;
- When 3 were detected, they were Alachlor, Metolachlor, and Atrazine;
- When 4 were detected, they were Alachlor, Metolachlor, Atrazine, and Acetochlor.

There was a nearly one-to-one correlation between the number of active ingredients in a sample and the total pesticide concentration in the sample (Spearman's rho = 0.9625, p = 0.0000). In other words, when the total pesticide concentration goes up, it does so because the variety of pesticides is increasing, not because the concentration of an individual pesticide is increasing. The wells in the HANS that were tested for pesticides showed a similar relationship between the number of active ingredients and the total pesticide concentration.

Pesticide Leaching into Groundwater

Leaching of pesticides or pesticide degradates into groundwater is determined by a variety of factors: chemical characteristics of the specific pesticide (water solubility, adsorbtivity, and half-life), physical and chemical characteristics of the soil to which the pesticide is applied (clay content, organic material, permeability, pH), and local conditions such as irrigation, precipitation, and temperature.

A pesticide's tendency to be adsorbed by soil is expressed by its adsorption coefficient: K(oc). The lower the K(oc) value, the more available the pesticide is to plants (Hartzler, 2002), but the greater the potential for leaching into groundwater. Adsorption coefficients less than 500 indicate considerable potential for loss through leaching (van Es, 1990). The pesticides detected in the AGQS all have low K(oc) values: Alachlor (170), Metolachlor (200), Atrazine (100), Acetochlor (200), Cyanazine (190), and Dimethenamid (155).

Pesticide Use, Current Detections in Groundwater, and Anticipated Trends

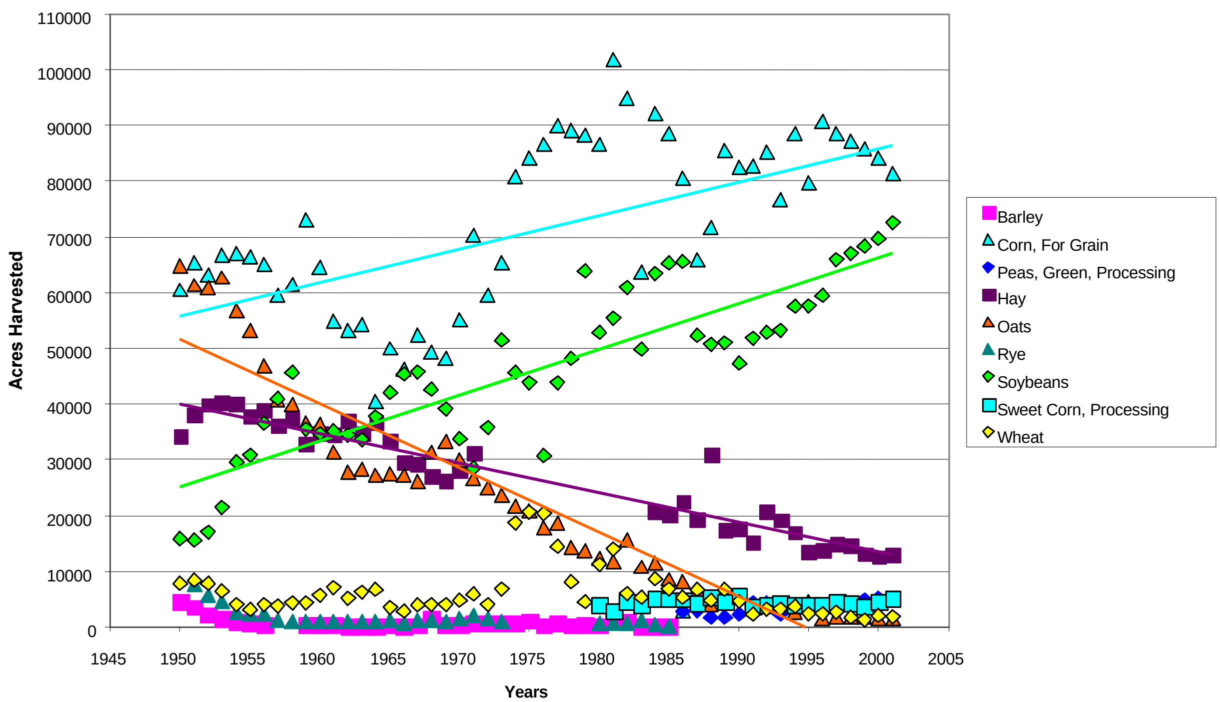
Over time, the obvious most important factor determining what is detected in groundwater is what is being used at the surface. Appendix VIII shows the agricultural pesticides used in southeastern Minnesota (including Dakota County) in 2001, from the highest to the lowest; whether that compound was analyzed in the AGQS, and the maximum concentration of the pesticide, if found.

In Dakota County, like the rest of the United States, the most widely used agricultural pesticides (and also the most widely detected in groundwater and surface water), are those associated with corn and soybean farming. In the past 50 years, due to federal farm policy and other socioeconomic factors, the number of acres planted in corn and soybeans has increased dramatically, at the expense of acreage planted in pasture, hay, or small grains such as oats, barley, or rye. Table 3 and Chart 2, pages 42 and 43, show the changes in crop production trends in Dakota County from the 1950s to the present (NASS, 2004).

Table 3: Average Annual Agricultural Acreage in Dakota County: Major Crops

Average Annual Acres Harvested	**1950s**	**% Of Major Crop Acreage**	**1990s**	**% Of Major Crop Acreage**
Barley	1,813	1%	NASS stopped collecting data on barley acreage in Minnesota in 1985	
Hay	37,540	19%	15,980	9%
Oats	52,350	27%	3,130	2%
Rye	3,480	2%	NASS stopped collecting data on rye acreage in Minnesota in 1985	
Wheat	5,447	3%	2,780	2%
Sweet corn (for processing)	NASS started measuring sweet corn acreage in 1980		4,200	2%
Corn (for grain)	64,820	33%	84,760	50%
Soybeans	28,920	15%	58,100	34%
Average Annual Acreage – Major Crops	194,370		168,950	

Chart 2: Annual Agricultural Acreage in Dakota County: Major Crops



In the 2002-2003 AGQS data, the most commonly detected pesticide was a breakdown product of Alachlor. The overall mean concentration of Alachlor plus its degradates was 0.89 μg/L; the maximum concentration was 6.74 μg/L (of which 6.14 μg/L was Alachlor ESA). (The HRL for Alachlor is 4 μg/L; the Health Based Value – HBV -- for Alachlor ESA, the most commonly detected degradate, is 100 μg/L.) Alachlor is being removed from the market and reported 2001 usage in this area was too low to merit reporting. (Acetochlor was introduced as a substitute for Alachlor.) As a result, based on the age-dating results discussed below, Alachlor and its degradates may attenuate out of Dakota County groundwater in 10 to 20 years.

The second most commonly detected pesticide was Metolachlor and its breakdown products. The overall mean concentration of Metolachlor plus its degradates was 0.58 μg/L; the maximum concentration was 5.94 μg/L. (The HRL for Metolachlor is 100 μg/L.) This compound is now available in two formulations: "old" Metolachlor and s-Metolachlor. S-Metolachlor is considered a lower risk for water resource impacts than the old formulation and is being presented as such in the Minnesota Department of Agriculture's (MDA) new pesticide Best Management Practices. On the one hand, "Old" Metolachlor and s-Metolachlor are currently the most widely used pesticides in southeastern Minnesota; on the other hand, new application rates should reduce the amount of the compound and its degradates reaching the groundwater. These opposing current trends make future groundwater trends difficult to estimate.

Atrazine was the third most detected active ingredient. Nationally, Atrazine is the most commonly used herbicide and the most frequently detected in groundwater and surface water. The overall mean concentration of Atrazine plus its degradates was 0.11 μg/L; the maximum concentration was 1.00 μg/L. (The HRL for Atrazine is 20 μg/L.) In southeastern Minnesota, Atrazine use ranks below Metolachlor/s-Metolachlor and Acetochlor. Atrazine use in Minnesota and the rest of the Midwest appears to be on the rise (USDA, 2002), due to the increased number of acres being used for corn production in recent years. Also, atrazine has been added as a weed control "kicker" to many other products, resulting in pre-packed mixes (or custom "tank mixes") that contain acetochlor + atrazine or metolachlor + atrazine. This practice results in atrazine being used on more acres but in smaller applications per acre. (Zachmann, personal communication, 2004).

Acetochlor was the fourth most detected active ingredient. The overall mean concentration of Acetochlor plus its degradates was 0.05 μg/L; the maximum detection was 0.75 μg/L. (The HBV for Acetochlor is 10 μg/L.) Acetochlor was approved for registration by the USEPA in 1994 for use on corn. The agency stipulated that its continued registration depended on a five-year cumulative reduction in the use of other corn herbicides, including alachlor, atrazine, butylate, EPTC, metolachlor, and 2,4-D. The 1999 adjusted usage of the other herbicides was about 70 million pounds less than in 1992, exceeding the target reduction by about four million pounds of active ingredient (USEPA, 2003).

Cyanazine was only detected in one well, but this detection was of great concern to both MDH and MDA because of how high it was relative to its Health Based Value (0.12 ug/L detection, compared to an HBV of 0.40 ug/L). Cyanazine is no longer licensed and has not been legal for use since December 2002.

Glyphosate (Round-Up) has not been included in AGQS analysis to date. Glyphosate usage on soybeans has increased dramatically with the introduction of "Round-Up Ready" soybeans. Although Glyphosate is probably replacing other herbicides on soybeans, total usage of herbicides such as atrazine and metolachlor are increasing because of the general increase in corn acreage.

State Regulatory Process (Joe Zachmann, MDA)

The primary statutes regulating pesticides in Minnesota waters are:

- MN Groundwater Protection Act (MN Stat. Chap. 103H)
- MN Pesticide Control Law (MN Stat Chap 18B)
- MN Fertilizer Control Law (MN Stat Chap 18C)
- U.S. Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA)
- Other state and federal rules and statutes.

Under the Pesticide Control Law, pesticides may not cause "unreasonable adverse effects on the environment." MDA is the lead agency for pesticides and is responsible for monitoring pesticide impacts on the environment and for developing a Pesticide Management Plan.

Under the Groundwater Protection Act, it is the goal of the state that groundwater be maintained in its natural condition, free from any degradation caused by human activities. It is recognized that for some human activities, this degradation prevention goal cannot be practicably achieved. However, where prevention is practicable, it is intended that it be achieved.

MDA must evaluate monitoring results for agricultural chemicals and determine if agricultural chemicals are "commonly detected." The MDA has shallow monitoring wells in selected agricultural areas of the state that are susceptible to groundwater contamination, such as the state's central sand plains and karst areas of the southeast.

The Commissioner of Agriculture ultimately decides "common detection" determinations. The statute defines "common detection" as the detection of a pollutant that is not due to misuse or unusual or unique circumstances, but is likely to be the result of normal use of a product or practice. However, the statute does not define either "common" or "detection." Industry has taken the position that "common" should be interpreted as "more than half the samples" and "detection" should be interpreted as a specific percentage of Health Risk Limits (HRLs). MDA has interpreted the statute to be more inclusive.

MDA must develop Best Management Practices (BMPs) for commonly detected chemicals. MDA must educate on and promote the BMPs, then evaluate the adoption and effectiveness of BMPs. If the implementation of BMPs proves ineffective, then MDA may develop rules, called "water resource protection requirements" (WRPRs). WRPRs must be designed to "prevent and minimize pollution to the extent practicable," prevent pollution from exceeding HRLs, and must be based on the use and effectiveness of BMPs, product use and practices causing pollution, economic factors, and availability, technical feasibility, implementability, and effectiveness. WRPRs must be submitted to the legislature.

In 2002, the Commissioner of Agriculture declared Metolachlor, Atrazine, and Metribuzin in "common detection." Acetochlor was not declared in common detection because the absence of a state HRL for Acetochlor precludes a legal determination of common detection; the MDA has requested a HRL for Acetochlor from MDH. Despite the lack of a "common detection" declaration for Acetochlor, MDA is developing and promoting BMPs for Acetochlor. Alachlor was also not declared in common detection because, in the data considered by MDA, Alachlor breakdown products were detected rather than Alachlor per se. One of the herbicides in common detection, Metribuzin, has not been detected in Dakota County's samples.

MDA has used Dakota County's HANS pesticide data in the "common detection" policy discussions, along with their own data and data from Department of Natural Resources (DNR), Minnesota Pollution Control Agency (MPCA), and the USGS. They will be using the AGQS results, as well. Dakota County's data is the only data developed by a local government unit to be used by MDA in this way.

The 319 grant (HANS II) that Dakota County will be receiving to implement the recommendations of HANS I includes funding for an Extension Service employee to perform one-on-one outreach to farmers, promoting BMPs for water quality, including nutrient management, integrated pest management, and surface water protection. This person will promote the MDA's new Pesticide BMPs, not only helping farmers to develop their Nutrient Management and Pest Management Plans, but identifying for them the available state and federal funding programs and assisting them in the application process.

Age-Dating

In 2003, samples were taken from those AGQS wells constructed after 1985 and analyzed by the University of Rochester (New York) for helium and tritium isotopes. This isotope analysis found water ages ranging from more than 100 years to less than one year, with a median age of 20.3 years. Chart 3 shows the strong relationship between the age of the water and the casing depth of a well; Charts 4 and 5 show the relationships between the age of the water vs. nitrate concentrations and the age of the water vs. pesticide concentrations, respectively. Appendix VII contains details of the age-dating results and pesticide detections. Nitrate and pesticides were not detected in wells with water older than 21 years.

Chart 3: He-H3 Age-Dating Results and Well Casing Depth

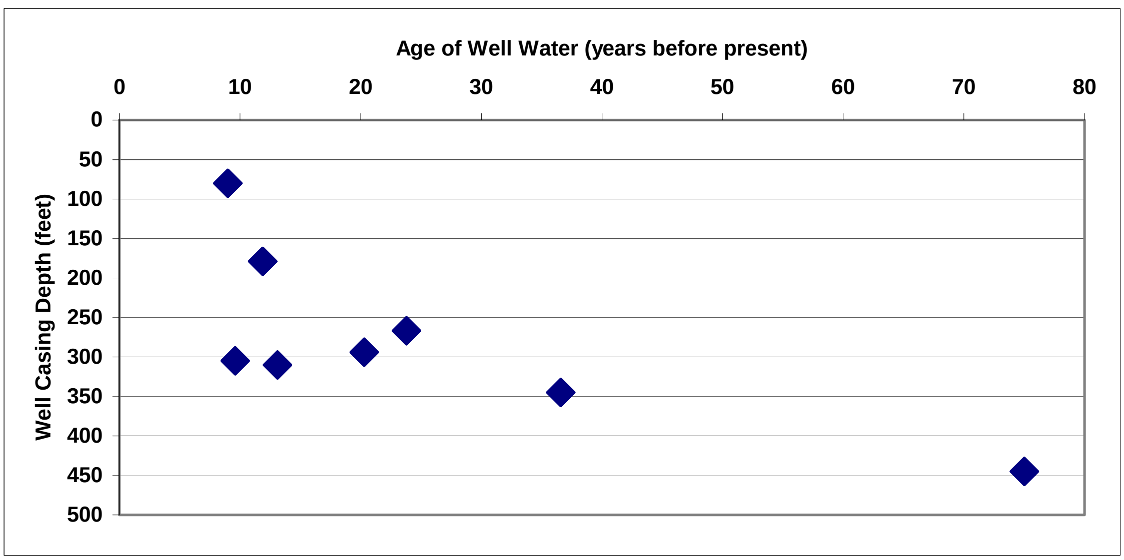


Chart 4: He-H3 Age-Dating Results and Nitrate Concentrations

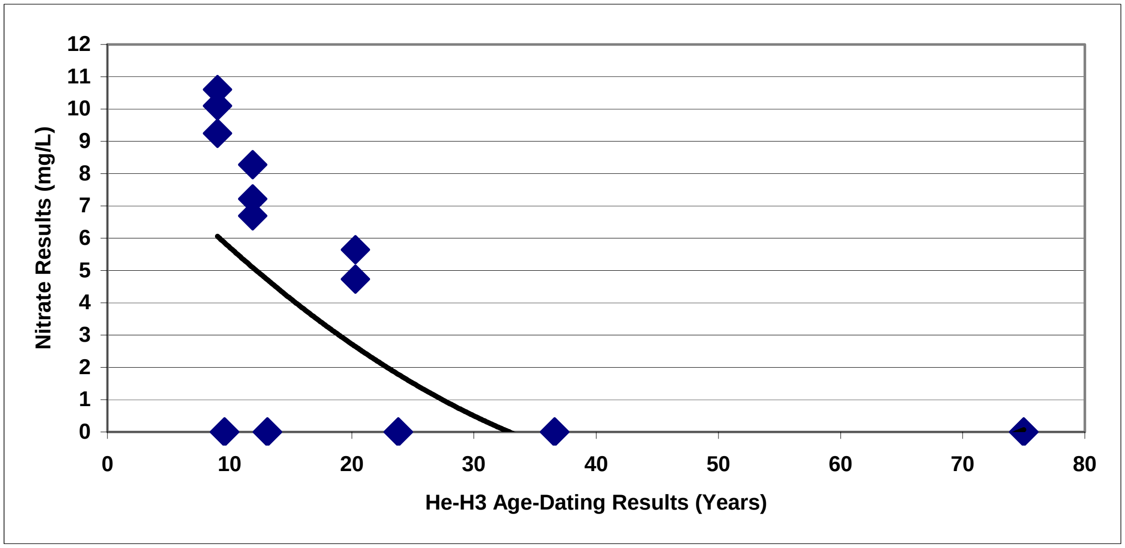
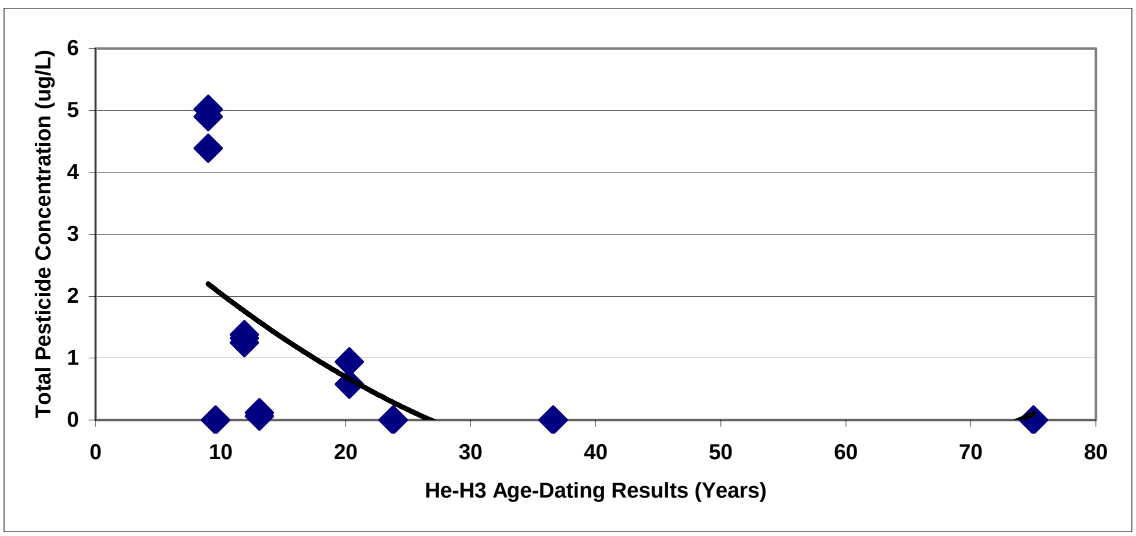


Chart 5: He-H3 Age-Dating Results and Total Pesticide Concentrations



The age-dating results show how quickly water moves from the surface to the groundwater in Dakota County, which can also be seen from the pesticides detected: Acetochlor was introduced to the market in 1994; in 2002, it was detected in groundwater that had an estimated age of nine years. (In 2001, in the HANS, Acetochlor was detected in about a quarter of the wells tested for pesticides.) Dimethenamid, which was introduced in 1993, was detected in 2003 in the AGQS and in 2001 in the HANS.

Nitrate, Pesticides, and Hydrogeological Zone

As discussed above, each well sampled for the AGQS was assigned to a hydrogeological zone.

Zone 1: Less than 50 feet of cover over the Prairie du Chien (Opdc)

Zone 2: More than 50 feet of sandy outwash over Opdc

Zone 3: More than 50 feet of clayey till over Opdc

Zone 4: St. Peter Sandstone over Opdc

In the AGQS wells, the hydrogeological zone was not correlated to the total depth of the well (Kruskal-Wallis H = 3.8447, p = 0.2787) or the depth of the well casing (Kruskal-Wallis H = 2.3818, p = 0.4970).

Nitrate levels were significantly correlated to the hydrogeological zone (Kruskal-Wallis H = 22.5664, p = 0.0000), as shown below.

Table 4: Hydrogeological Zone and Nitrate Results

Zone	# Of Samples	Median Nitrate Results (mg/L)	Samples with Detections	Samples > 10 mg/L
1 (Less than 50 ft. of cover over Opdc)	35	5.00	28 (80%)	9 (26%)
2 (More than 50 ft. of sandy outwash over Opdc)	78	0.00	34 (44%)	9 (12%)
3 (More than 50 ft. of clayey glacial till over Opdc)	38	0.00	9 (24%)	2 (5%)
4 (St. Peter Sandstone over Opdc)	48	0.24	25 (53%)	0 (0%)

Pesticide levels were also significantly correlated to the hydrogeological zone (Kruskal-Wallis H = 8.1384, p = 0.0432).

Table 5: Hydrogeological Zone and Pesticide Results

Zone	# Of Samples	Median Pesticide Results (ug/L)	Samples with Detections	Median Number of Active Ingredients
1 (Less than 50 ft. of cover over Opdc)	14	2.33	10 (71.4%)	3.5
2 (More than 50 ft. of sandy outwash over Opdc)	34	0.83	24 (70.6%)	2
3 (More than 50 ft. of clayey glacial till over Opdc)	16	0.00	5 (31.3%)	0
4 (St. Peter Sandstone over Opdc)	20	0.12	12 (60.0%)	1

Tools for Evaluating Groundwater Sensitivity to Non-Point Source Pollution

The AGQS provided the opportunity for County staff to review several approaches to evaluating the sensitivity of an aquifer or well to non-point source pollution. Based on this review, geochemical sensitivity can be used to estimate aquifer susceptibility to nitrate and pesticide contamination when groundwater chemistry data is available. The depth of the well and the hydrogeological zone in which it was constructed can be used to estimate susceptibility to contamination when well construction records are available.

In Dakota County, both the AGQS and HANS found that most variables correlated with groundwater contaminants such as nitrate or pesticides – aquifer, age of the well, age of the water -- are also correlated with well depth. A number of processes work to reduce the concentration of any contaminant with well depth: outgassing, plant uptake, dilution, or adsorption to soil or aquifer materials. It would be useful to identify factors that were associated with contaminant (such as nitrate or pesticide) levels, but which were not correlated to well depth. As discussed below, geochemical sensitivity is correlated with well depth but the hydrogeological zone is not.

Geochemical Sensitivity

Trojan, et al of the MPCA (2002) estimated aquifer sensitivity to nitrate contamination in Minnesota using the geochemical parameters dissolved oxygen, total iron, reduced iron, and Eh. Dakota County staff modified this classification slightly because reduced iron was not measured in the AGQS and the Eh values fluctuated from year to year.

Table 6: Geochemical Sensitivity Classification

Sensitivity	**Dissolved Oxygen**	**Total Iron**
High	> 1.0 mg/L	< 0.7 mg/L
Low	< 1.0 mg/L	> 0.7 mg/L
Variable	Other combinations than above	

Staff then analyzed the results to see which was the better estimator of nitrate and pesticide contamination: geochemical sensitivity, aquifer, zone, or well depth. (Differences between categories were analyzed using the Kruskal-Wallis test for nonparametric analysis of variance; numerical relationships were analyzed using the Spearman rank correlation.) All four factors were very significantly correlated with nitrate levels, so any of the four could be used as an indicator.

Table 7: Comparison of Estimators of Nitrate Contamination

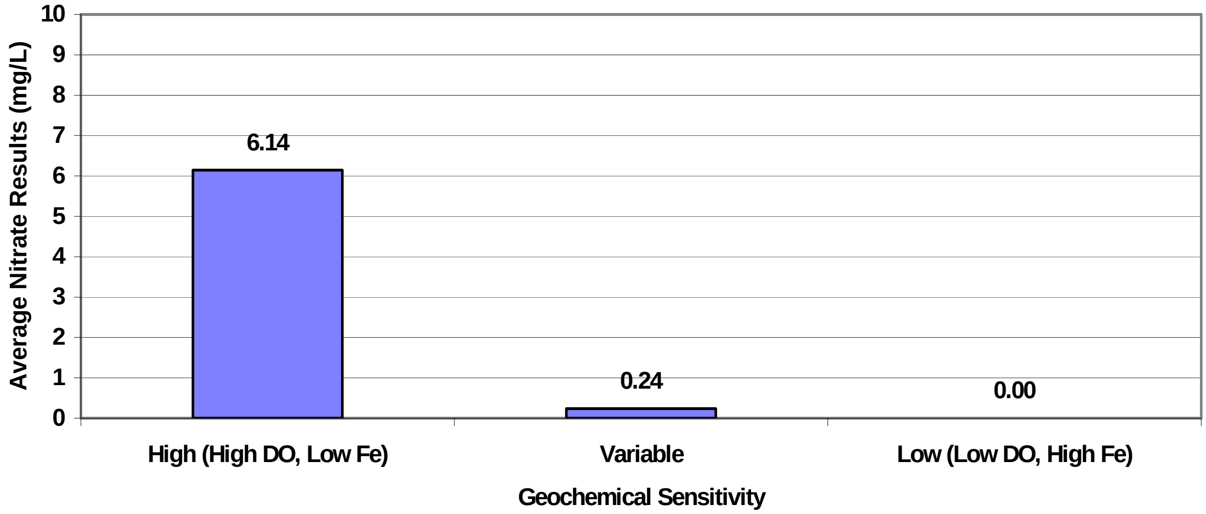
Estimator	**Data Type**	**Correlation to Nitrate Results**
Geochemical Sensitivity	Nominal (categorical)	Kruskal Wallis H = 67.0075, p = 0.0000
Aquifer	Nominal (categorical)	Kruskal Wallis H = 26.5109, p = 0.0000
Zone	Nominal (categorical)	Kruskal Wallis H = 21.3253, p = 0.0001
Total Well Depth	Ordinal (numerical)	Spearman's rho = -0.7601, p = 0.0000

The larger the Kruskal Wallis statistic, the stronger the correlation, so geochemical sensitivity was the best of the categorical estimators of nitrate levels in the AGQS.

Table 8: Geochemical Sensitivity and Nitrate Results

Geochemical Sensitivity	# Of Wells	Wells w/ no NO3 detected (annual average)	Wells w/ NO3 detected (annual average)	Wells w/ NO3 > 10 mg/L (annual average)	Average NO3 level (mg/L)
High	27	5 (18.5%)	22 (81.5%)	5 (18.5%)	6.14
Variable	6	5 (83%)	1 (17%)	0 (0%)	0.24
Low	12	12 (100%)	0 (0%)	0 (0%)	0.00
Total	45	22 (49%)	23 (51%)	5 (11%)	3.71

Chart 6: Geochemical Sensitivity and Nitrate Results



These four factors (geochemical sensitivity, aquifer, zone, and total well depth) were also significantly correlated with total pesticide concentrations (2002 and 2003 data only).

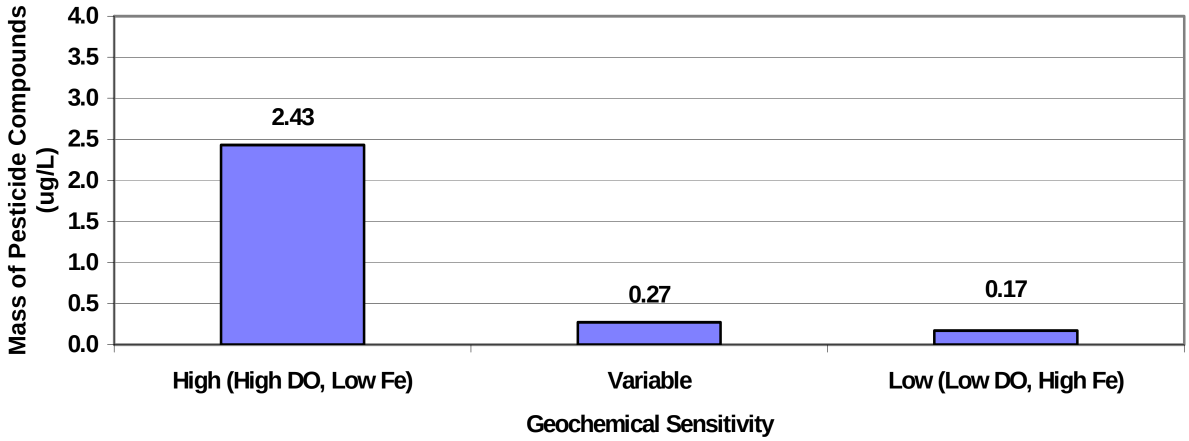
Table 9: Comparison of Estimators of Pesticide Contamination

Estimator	Data Type	Correlation to Total Pesticide Concentrations
Geochemical Sensitivity	Nominal (categorical)	Kruskal Wallis H = 25.9796, p = 0.0000
Aquifer	Nominal (categorical)	Kruskal Wallis H = 13.2457, p = 0.0003
Zone	Nominal (categorical)	Kruskal Wallis H = 8.2774, p = 0.0406
Total Well Depth	Ordinal (numerical)	Spearman's rho = -0.4928, p = 0.0000

Table 10: Geochemical Sensitivity and Pesticide Results

Geochemical Sensitivity	# Of Wells	Wells w/ no pesticide compounds detected (annual average)	Wells w/ pesticide compounds detected (annual average)	Average mass of pesticides (ug/L)
High	27	5 (18.5%)	22 (81.5%)	2.43
Variable	5	4 (80%)	1 (20%)	0.27
Low	10	7 (70%)	3 (30%)	0.17
Total	43	22 (49%)	23 (51%)	1.63

Chart 7: Geochemical Sensitivity and Pesticide Results



Opdc wells have significantly less iron than do Cjdn wells (Kruskal-Wallis H = 14.8813, p = 0.0001); as a result, Opdc wells are more likely to have geochemically sensitive conditions.

Table 11: Aquifer and Geochemical Sensitivity to Nitrate and Pesticide Contamination

Aquifer	**Overall**	**High Sensitivity**	**Variable Sensitivity**	**Low Sensitivity**
Prairie du Chien (Average DO = 4.84 mg/L, average Fe = 0.49 mg/L – High Sensitivity)				
# Of Wells	24	17 (71%)	4 (17%)	3 (12%)
Average Nitrate Results (mg/L)	5.77	8.07	0.00	0.00
Average Mass of Pesticides (ug/L)	2.38	3.10	0.46	0.26
Jordan (Average DO = 3.64 mg/L, average Fe = 1.44 mg/L – Variable Sensitivity)				
# Of Wells	21	10 (48%)	2 (10%)	9 (43%)
Average Nitrate Results (mg/L)	1.75	2.85	0.00	0.00
Average Mass of Pesticides (ug/L)	0.73	1.29	0.73	0.13

Chart 8: Aquifer and Geochemical Sensitivity to Nitrate Contamination

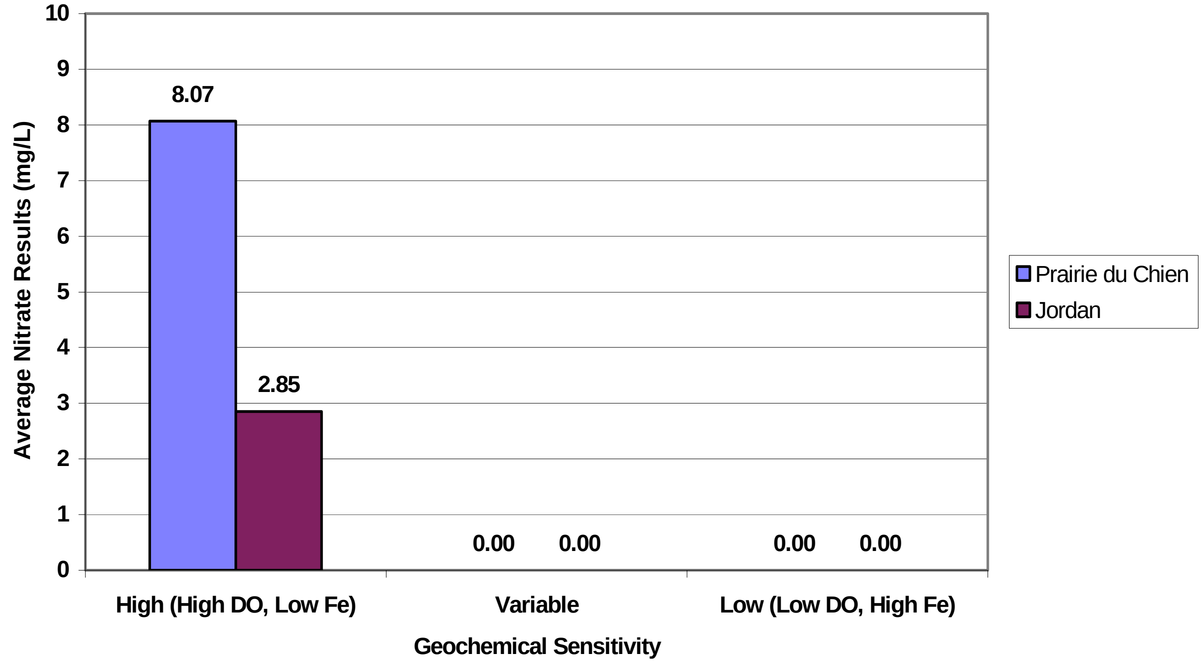
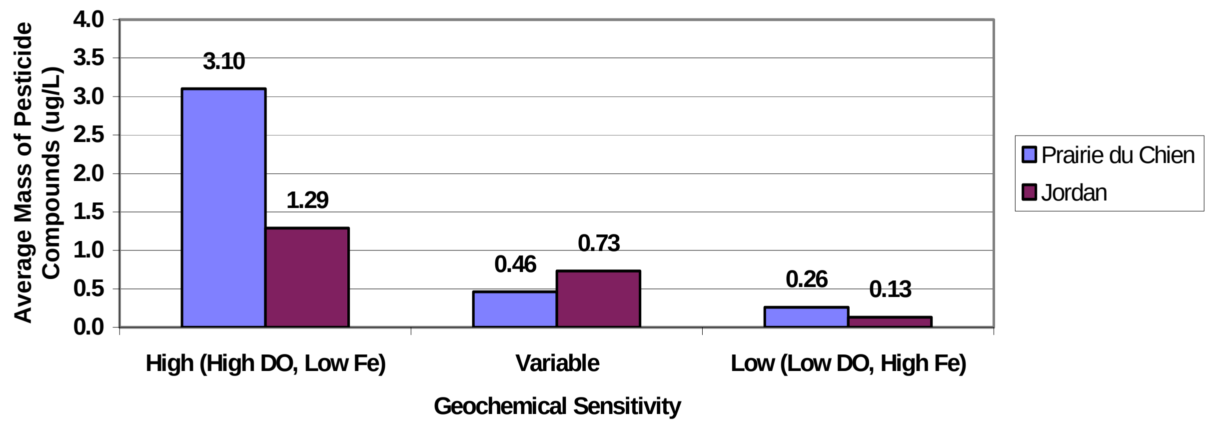


Chart 9: Aquifer and Geochemical Sensitivity to Pesticide Contamination



To determine if geochemical sensitivity was independent of well depth, County staff developed a numerical ranking of geochemical sensitivity for the AGQS samples by assigning each sample one rank based on its dissolved oxygen concentration (high to low), a second rank based on iron levels (low to high), and adding the two. Thus, the highest ranked samples had the lowest geochemical sensitivity. This ranking was then compared to the total depth of the well, which turned out to be significantly correlated (Spearman's rho = 0.6464, p = 0.0061). As a result, although geochemical sensitivity is useful in understanding nitrate contamination, in the AGQS it cannot be separated from the effects of depth.

As mentioned above, in the AGQS wells, the hydrogeological zone was not correlated to the total depth of the well (Kruskal-Wallis H = 3.8447, p = 0.2787) or the depth of the well casing (Kruskal-Wallis H = 2.3818, p = 0.4970). Table 12 and Chart

10, below, show average nitrate results by well depth interval and hydrogeological zone. Unfortunately, as can be seen from this table, in Dakota County bedrock wells there is no magic combination of well depth and hydrogeological zone in which nitrate will be completely undetected. Nonetheless, in Zone 3, nitrate is typically low below 120 feet; in Zone 4, nitrate is low below 200 feet; in Zone 1, nitrate is low below 320 feet; and in Zone 2, nitrate is low below 320 feet.

Chart 10: Well Depth, Zone, and Average Nitrate Results

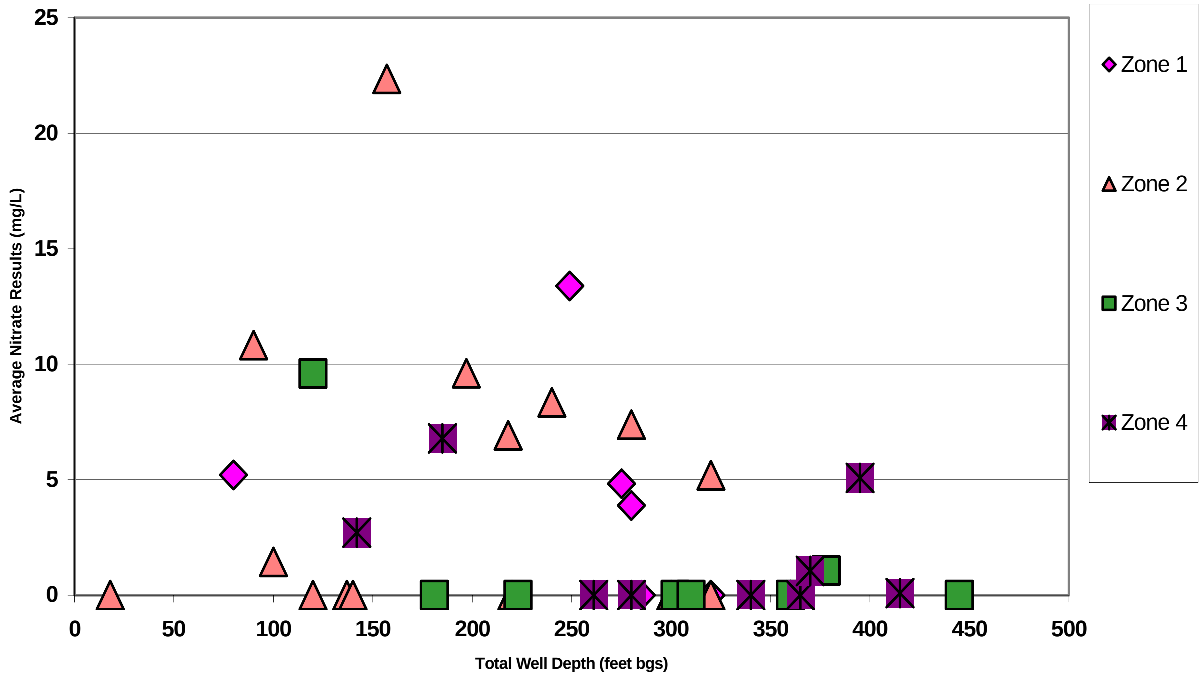


Table 12: Well Depth Intervals (40-foot), Zone, and Average Nitrate Results

Depth Interval (40 ft)	Zone	# Of wells	Average Nitrate per zone	# Of Wells > 10 mg/L
40-120 (feet bgs)	1	1	5.21	0
	2	3	4.09	1
	3	1	9.59	0
	4	0	N/A	N/A
121-160	1	0	N/A	N/A
	2	3	7.45	1
	3	0	N/A	N/A
	4	1	2.7	0
161-200	1	0	N/A	N/A
	2	1	9.6	0
	3	1	0	0
	4	1	6.79	0
201-240	1	0	N/A	N/A
	2	3	5.08	0
	3	1	0	0
	4	0	N/A	N/A
241-280	1	3	7.36	1
	2	1	7.38	0
	3	0	N/A	N/A
	4	2	0	0
281-320	1	2	0	0
	2	4	1.30	0
	3	2	0	0
	4	0	N/A	N/A
321-360	1	0	N/A	N/A
	2	2	0	0
	3	1	0	0
	4	1	0	0
361-400	1	0	N/A	N/A
	2	0	N/A	N/A
	3	1	0	0
	4	3	2.04	0
400-480	1	0	N/A	N/A
	2	1	0	0
	3	1	0	0
	4	1	0.09	0

Changes to List of Parameters Analyzed

Volatile Organic Compounds (VOCs)

In 1999 and 2000, the AGQS samples were analyzed for volatile organic compounds, a complete list of which is included in Appendix IX. Since none were detected, this analysis was discontinued.

Arsenic

In 2001, the AGQS samples were analyzed for arsenic. Arsenic occurs naturally in the environment and can work its way into groundwater from aquifer minerals or soils. Groundwater in west-central or northwestern Minnesota tends to have higher levels of arsenic than other parts of the state, but it can be found anywhere in the state. Long-term exposure to elevated levels of arsenic can increase the risk of skin damage, circulatory system problems, or cancer. For many years, the MCL for arsenic was 50 μg/L, but the EPA lowered the standard to 10 μg/L, effective in 2006 (MDH, 2004). The 2001 AGQS samples contained two arsenic detections in Opdc wells, one at 6.2 μg/L and the other at 3.1 μg/L. Arsenic analysis has been discontinued.

1999-2003 Conclusions and Next Steps

- Nitrate is the principal contaminant of concern. 10% of the bedrock wells exceeded the drinking water standard of 10 mg/L.
- The numerous detections of pesticides and pesticide degradates are also a concern.
- Nitrate and pesticide levels are very highly correlated, indicating that row-crop agricultural is the primary source for both.
- Nitrate and pesticide levels are strongly associated with the geochemical sensitivity (high dissolved oxygen and low iron) of the source water, the depth of the well, and the age of the well.
- Depth and geochemistry make Prairie du Chien wells more prone to contamination than Jordan wells.
- Water chemistry and contaminant levels do not show significant changes from year to year.
- No volatile organic compounds were detected in AGQS wells.
- Screened (Quaternary) wells were added to the AGQS sample set in 2004.
- Pesticide parameters were modified in 2004, with lower detection limits and more pesticide degradates.

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Appendix I

Dakota County Ambient Groundwater Quality Study
Appendix I: Aquifer Characteristics

AQUIFER CHARACTERISTICS												
		Prairie du Chien Wells					Jordan Wells					
Well Characteristics	Units	# of Wells	Range	Median	Mean	Standard deviation	# of Wells	Range	Median	Mean	Standard deviation	**Significant difference between aquifers?**
Well Depth	Feet below ground surface	20	79-310	183	186.55	71.37	22	220-480	350	343.77	61.492	**Yes (Kruskal-Wallis H = 25.1475, p = 0.0000)**
Casing Depth	Feet below ground surface	20	55-267	135	148.65	67.546	22	190-445	307.5	314.91	59.037	**Yes (Kruskal-Wallis H = 26.9281, p = 0.0000)**
Depth to water (1)	Feet below ground surface	20	6-190	82.5	80.85	55.138	21	1-185	70	75.905	61.16	No (Kruskal-Wallis H = 0.2210, p = 0.6383)
Elevation (2)	Feet above mean sea level	20	830-1068	909	928.25	63.368	21	820-1018	910	918.57	50.649	No (Kruskal-Wallis H = 0.0615, p = 0.8041)
Elevation of water table (3)	Feet above mean sea level	19	745-965	838	844.21	75.015	20	695-970	859.5	834.9	70.719	No (Kruskal-Wallis H = 0.0071, p = 0.9328)

(1) SWL measured at the time of well construction, not at the time of sampling.
(2) Estimated.
(3) Calculated from Elevation and SWL.

Dakota County Ambient Groundwater Quality Study
Appendix I: Aquifer Characteristics

AQUIFER CHARACTERISTICS

		Prairie du Chien Wells					Jordan Wells					
Physical Parameters	Units	# of Wells and Samples	Range	Median	Mean	Standard deviation	# of Wells and Samples	Range	Median	Mean	Standard deviation	**Significant difference between aquifers?**
Water Temperature	Degrees Celsius	2 Wells X 2 21 Wells X 4 1 Well X 5 "= 93 Samples"	9.5-15.0	10.6	10.91	1.01	3 Wells X 2 18 Wells X 4 "= 78 Samples"	9.3-14.4	10.55	10.68	1.06	No (Kruskal-Wallis H = 2.3692, p = 0.1238). No difference between years, 1999 excluded (Spearman's rho = -0.0823, p =0.2842)
pH	pH Units	1999 (n=17)	7.22-7.74	7.59	7.52	0.17	1999 (n=13)	7.30-7.95	7.64	7.61	0.18	**Yes, significant difference between aquifers (Kruskal-Wallis H = 4.03058, p = 0.0447) and between years (Spearman's rho = 0.3423, p = 0.0000).**
		2000 (n=23)	6.53-7.48	7.25	7.21	0.22	2000 (n=20)	6.82-7.63	7.24	7.24	0.23	
		2001 (n=23)	6.60-8.17	7.50	7.46	0.39	2001 (n=20)	6.82-7.84	7.61	7.50	0.32	
		2002 (n=23)	5.75-7.82	7.44	7.30	0.49	2002 (n=19)	6.71-7.90	7.58	7.53	0.31	
		2003 (n=24)	7.30-8.17	7.67	7.66	0.19	2003 (n=19)	7.30-8.13	7.73	7.75	0.16	
		Overall (n=110)	5.75-8.17	7.48	7.43	0.36	Overall (n=91)	6.71-8.13	7.61	7.52	0.30	
Specific Conductance	umhos/cm	2 Wells X 2 21 Wells X 4 1 Well X 5 "= 93 Samples"	192-978	557	581.3	148.68	3 Wells X 2 18 Wells X 4 "= 78 Samples"	197-714	499.00	490.31	96.40	**Yes (Kruskal-Wallis H = 19.8062, p = 0.0000).** No significant difference between years, 1999 excluded (Spearman's rho = 0.0695, p = 0.3660).
Dissolved Oxygen	mg/L	1Well X 1 2 Wells X 2 5 Wells X 4 16 Wells X 5 "= 110 Samples"	0.08-14.10	4.875	5.3611	4.418	3 Wells X 2 5 Wells X 4 13 Wells X 5 "= 91 Samples"	0.08-12.20	1.93	3.31	3.54	**Yes (Kruskal-Wallis H = 9.3924, p = 0.0022).** No significant difference between years (Spearman's rho = 0.0536, p = 0.4492).

AQUIFER CHARACTERISTICS												
		Prairie du Chien Wells					Jordan Wells					
Physical Parameters	Units	# of Wells and Samples	Range	Median	Mean	Standard deviation	# of Wells and Samples	Range	Median	Mean	Standard deviation	**Significant difference between aquifers?**
Alkalinity	mg/L as CaCO3	1Well X 1 2 Wells X 2 5 Wells X 4 16 Wells X 5 "= 110 Samples"	100-356	255.5	249.33	55.02	3 Wells X 2 5 Wells X 4 13 Wells X 5 "= 91 Samples"	104-371	245	241.76	54	No (Kruskal-Wallis H = 1.0899, p = 0.2965) No significant difference between years (Spearman's rho = 1.0899, p = 0.2965).
Eh (Redox Potential) Negative values indicate reducing conditions; positive values indicate oxidizing conditions.	Eh Units	2 Wells X 2 1 Well X 3 21 Wells X 4 "= 91 Samples"	"-72.50-46.50"	-34.90	-30.97	22.22	3 Wells X 2 18 Wells X 4 "= 78 Samples"	"79.50-29.30"	-36.2	-33.26	23.54	No (Kruskal-Wallis H = 0.8832, p = 0.3473). Significant difference between years, 1999 excluded (Spearman's rho = -0.7688, p = 0.0000)

AQUIFER CHARACTERISTICS

		Prairie du Chien Wells					Jordan Wells					
Major Ions	Units	# of Wells and Samples	Range	Median	Mean	Standard deviation	# of Wells and Samples	Range	Median	Mean	Standard deviation	**Significant difference between aquifers?**
Calcium	mg/L	1Well X 1 2 Wells X 2 5 Wells X 4 16 Wells X 5 "= 110 Samples"	0.0-122.0	73.05	74.08	19.57	3 Wells X 2 5 Wells X 4 13 Wells X 5 "= 91 Samples"	37.0-99.0	66.8	65.24	13.74	**Yes (Kruskal-Wallis H = 16.7807, p = 0.0000).** No significant difference between years (Spearman's rho = 0.0262, p = 0.7119).
Magnesium	mg/L	1Well X 1 2 Wells X 2 5 Wells X 4 16 Wells X 5 "= 110 Samples"	0.0-48.0	27.05	27.09	6.91	3 Wells X 2 5 Wells X 4 13 Wells X 5 "= 91 Samples"	14.7-45.0	25.7	25.32	5.82	**Yes (Kruskal-Wallis H = 6.7071, p = 0.0096).** No significant difference between years (Spearman's rho = -0.0769, p = 0.2830).
Sodium	mg/L	1Well X 1 2 Wells X 2 5 Wells X 4 16 Wells X 5 "= 110 Samples"	1.07-149.0	4.35	10.97	20.07	3 Wells X 2 5 Wells X 4 13 Wells X 5 "= 91 Samples"	0.556-8.50	2.9	3.13	1.45	**Yes (Kruskal-Wallis H = 30.8381, p = 0.0000).** No significant difference between years (Spearman's rho = -0.0164, p = 0.8171).
Potassium	mg/L	1Well X 1 2 Wells X 2 5 Wells X 4 16 Wells X 5 "= 110 Samples"	0.0-12.20	1.53	1.75	1.59	3 Wells X 2 5 Wells X 4 13 Wells X 5 "= 91 Samples"	0.0-3.9	1.37	1.43	0.68	No (Kruskal-Wallis H = 2.2564, p = 0.1331). Significant difference between years (Spearman's rho = -0.2151, p = 0.0022).
Chloride	mg/L	1999 (n=17)	0.0-93.0	11.00	21.96	30.91	1999 (n=13)	0.0-15.0	0.00	2.39	4.98	**Yes (Kruskal-Wallis H = 52.7229, p = 0.0000). No significant difference between years (Spearman's rho = 0.0664, p = 0.4899) in OPDC, but significant difference between years in CJDN (Spearman's rho = 0.2876, p = 0.0059).**
		2000 (n=23)	0.0-84.5	10.70	20.82	29.42	2000 (n=20)	0.0-12.8	0.00	1.80	4.01	
		2001 (n=23)	0.0-79.5	10.90	16.20	21.25	2001 (n=20)	0.0-11.3	0.00	2.61	4.14	
		2002 (n=23)	0.0-107.0	11.30	21.40	28.14	2002 (n=19)	0.0-11.0	3.00	3.38	4.00	
		2003 (n=24)	0.0-110.0	11.25	21.17	28.07	2003 (n=19)	0.0-13.40	3.80	4.02	3.96	
		Overall (n=110)	0.0-110.0	11.00	20.23	27.14	Overall (n=91)	0.0-15.0	0.00	2.86	4.16	

AQUIFER CHARACTERISTICS

		Prairie du Chien Wells					Jordan Wells					
Major Ions, continued	Units	# of Wells and Samples	Range	Median	Mean	Standard deviation	# of Wells and Samples	Range	Median	Mean	Standard deviation	**Significant difference between aquifers?**
Sulfate	mg/L	1Well X 1 2 Wells X 2 5 Wells X 4 16 Wells X 5 "= 110 Samples"	5.6-52.50	25.25	25.49	8.55	3 Wells X 2 5 Wells X 4 13 Wells X 5 "= 91 Samples"	8.6-64.0	21.2	24.11	11.71	**Yes (Kruskal-Wallis H = 5.4363, p = 0.0000).** No significant difference between years (Spearman's rho = 0.0984, p = 0.1646).
Fluoride *Optimum range of fluoride concentration in drinking water for dental health is 0.7 to 1.2 mg/L. Most wells in this study did not have detectable levels of fluoride. Overall median fluoride concentration is 0.10 mg/L*	mg/L	1Well X 1 2 Wells X 2 5 Wells X 4 16 Wells X 5 "= 110 Samples"	0.0-0.94	0.00	0.08	0.13	3 Wells X 2 5 Wells X 4 13 Wells X 5 "= 91 Samples"	0-0.25	0.11	0.08	0.08	No (Kruskal-Wallis H = 3.3769, p = 0.0661). Significant difference between years (Spearman's rho = 0.4289, p = 0.0000).
Bromide	mg/L	1Well X 1 2 Wells X 2 5 Wells X 4 16 Wells X 5 "= 110 Samples"	0.0-0.87	0.00	0.13	0.18	3 Wells X 2 5 Wells X 4 13 Wells X 5 "= 91 Samples"	0.0-0.82	0	0.16	0.22	No (Kruskal-Wallis H = 0.4005, p = 0.5268). No significant difference between 2000 and 2001, the years with detections in all wells (Spearman's rho = -0.0573, p = 0.6001).
Trace Metals	Units	# of Wells and Samples	Range	Median	Mean	Standard deviation	# of Wells and Samples	Range	Median	Mean	Standard deviation	**Significant difference between aquifers?**
Iron	mg/L	1Well X 1 2 Wells X 2 5 Wells X 4 16 Wells X 5 "= 110 Samples"	0.0-9.87	0.07	0.58	1.26	3 Wells X 2 5 Wells X 4 13 Wells X 5 "= 91 Samples"	0.0-7.10	0.63	1.23	1.47	**Yes (Kruskal-Wallis H = 14.8813, p = 0.0001).** No significant difference between years (Spearman's rho = 0.1193, p = 0.0.0917).

AQUIFER CHARACTERISTICS

		Prairie du Chien Wells					Jordan Wells					
Nutrients and Total Organic Carbon	Units	# of Wells and Samples	Range	Median	Mean	Standard deviation	# of Wells and Samples	Range	Median	Mean	Standard deviation	**Significant difference between aquifers?**
Nitrite-Nitrogen	mg/L	1Well X 1 2 Wells X 2 5 Wells X 4 16 Wells X 5 "= 110 Samples"	0.0-0.007	0.00	0.00	0.01	3 Wells X 2 5 Wells X 4 13 Wells X 5 "= 91 Samples"	0.0-0.204	0.00	0.009	0.03	**Yes (Kruskal-Wallis H = 8.6434, p = 0.0033).** No significant difference between years (Spearman's rho = 0.0359, p = 0.6126).
Ammonia-Nitrogen	mg/L	1Well X 1 2 Wells X 2 5 Wells X 4 16 Wells X 5 "= 110 Samples"	0.0-0.33	0.00	0.02	0.06	3 Wells X 2 5 Wells X 4 13 Wells X 5 "= 91 Samples"	0.0-0.40	0.00	0.03	0.08	**Yes (Kruskal-Wallis H = 4.9396, p = 0.0262).** No significant difference between years (Spearman's rho = -0.1200, p = 0.0898).
Nitrate-Nitrogen	mg/L	2 Wells X 2 7 Wells X 4 14 Wells X 5 1 Well X 6 "= 108 Samples"	0.0-22.60	5.10	5.31	5.55	3 Wells X 2 5 Wells X 4 13 Wells X 5 "= 91 Samples"	0.0-8.02	0.00	1.33	2.3176	**Yes (Kruskal-Wallis H = 26.5109, p = 0.0000).** No significant difference between years (Spearman's rho = -0.0738, p = 0.3001).
Ortho Phosphate	mg/L	17	0.0-0.055	0.014	0.015	0.01	13	0.0-0.049	0.01	0.0121	0.0149	No (Kruskal-Wallis H = 0.7852, p = 0.3756). Detections only in 1999 and one detection in 2001.
Total Organic Carbon	mg/L	2 Wells X 2 21 Wells X 4 1 Well X 5 "= 93 Samples"	0.0-2.60	0.60	0.57	0.54	3 Wells X 2 18 Wells X 4 "= 78 Samples"	0.0-1.3	0.50	0.44	0.45	No (Kruskal-Wallis H = 2.4286, p = 0.1191). Significant difference between years (Spearman's rho = 0.2356, p = 0.0020).

Appendix II

Dakota County Ambient Groundwater Quality Study
Appendix II: Hydrogeological Zone Characteristics

ZONE CHARACTERISTICS

Zone 1 has less than 50 feet of cover over Prairie du Chien Dolomite.

Zone 2 has more than 50 feet of sandy outwash over Prairie du Chien Dolomite.

Zone 3 has more than 50 feet of clayey glacial till over Prairie du Chien Dolomite.

Zone 4 has St. Peter Sandstone over Prairie du Chien Dolomite.

Well Characteristics	Units	Zone	# of Wells	Range	Median	Mean	Standard deviation	**Significant difference between zones?**
Well Depth	Feet below ground surface	All	42	79-480	280	269	103.02	No (Kruskal-Wallis H = 4.8795, p = 0.1808)
Casing Depth	Feet below ground surface	All	42	55-445	910	923	56.693	No (Kruskal-Wallis H = 3.2992, p = 0.3477)
Depth to water (1)	Feet below ground surface	1	6	15-163	77.5	79.83	68.17	**Yes (Kruskal-Wallis H = 9.2107, p = 0.0266)**
		2	18	1-130	50	53.94	44.06	
		3	8	20-190	125	128.63	58.33	
		4	9	20-170	95	81.33	58.33	
		All	41	1.0-190.0	80	78.32	57.63	
Elevation (2)	Feet above mean sea level	1	7	858-920	885	889	23.07	**Yes (Kruskal-Wallis H = 20.1523, p = 0.0002)**
		2	17	820-974	900	892	36.37	
		3	8	892-1068	948	969	64.45	
		4	9	886-1018	985	969	42.23	
		All	41	820-1068	910	923	56.69	
Elevation of water table (3)	Feet above mean sea level	All	39	695-970	850	839	72.03	No (Kruskal-Wallis H = 2.9549, p = 0.3986)

(1) SWL measured at the time of well construction, not at the time of sampling.
(2) Estimated.
(3) Calculated from Elevation and SWL.

Dakota County Ambient Groundwater Quality Study
Appendix II: Hydrogeological Zone Characteristics

			ZONE CHARACTERISTICS					
Physical Parameters	Units	Zone	# of Wells and Samples	Range	Median	Mean	Standard deviation	**Significant difference between zones?**
Water Temperature	Degrees Celsius	All	171	9.3-15.0	10.6	10.81	0.963	No (Kruskal-Wallis H = 2.8944, p = 0.4082). No difference between years, 1999 excluded (Spearman's
pH	pH Units	All	1999 (n=30)	7.22-7.95	7.61	7.56	0.18	No (Kruskal-Wallis H = 2.5165, p = 0.4723). Significant difference between years (Spearman's rho = 0.3423, p = 0.0000).
			2000 (n=43)	6.53-7.63	7.24	7.23	0.22	
			2001 (n=43)	6.60-8.17	7.57	7.48	0.36	
			2002 (n=42)	5.75-7.90	7.55	7.41	0.43	
			2003 (n=43)	7.30-8.17	7.69	7.70	0.18	
			Overall (n=201)	5.75-8.17	7.56	7.47	0.33	
Specific Conductance	umhos/cm	1	30	326-978	609	632.33	160.57	**Yes (Kruskal-Wallis H = 21.7297, p = 0.0001).** No significant difference between years, 1999 excluded (Spearman's rho = 0.0695, p = 0.3660).
		2	68	312-915	509	521.68	121.86	
		3	32	192-645	508	485.22	101.25	
		4	41	193-923	550	544.73	128.89	
		All (1999 excluded)	177	192-978	531	539.8	135	
Dissolved Oxygen	mg/L	1	36	0.14-14.10	6.92	5.87	4.54	**Yes (Kruskal-Wallis H = 9.7854, p = 0.0205).** No significant difference between years (Spearman's rho = 0.0536, p = 0.4492).
		2	79	0.10-12.90	4.02	4.78	4.22	
		3	38	0.08-11.50	1.91	2.94	3.16	
		4	48	0.08-14.00	2.39	3.98	4.13	
		All	201	0.08-14.10	3.01	4.43	4.16	
Alkalinity	mg/L as CaCO3	1	36	100-371	226.5	250.89	72.22	**Yes (Kruskal-Wallis H = 27.0163, p = 0.9999)** No significant difference between years (Spearman's rho = 0.0006, p = 0.9935).
		2	79	160-294	230	227.46	35.57	
		3	38	146-356	280	263.24	60.55	
		4	47	104-346	365	261.53	49.84	
		All	201	100-371	252	245.9	54.56	

			ZONE CHARACTERISTICS					
Physical Parameters, continued	Units		# of Wells and Samples	Range	Median	Mean	Standard deviation	**Significant difference between zones?**
Eh (Redox Potential)	Eh Units	2000	43	"-36.70 to +46.50"	-11.20	-9.34	16.20	No (Kruskal-Wallis H = 2.8448, p = 0.4162) Significant difference between years (Spearman's rho = -0.7688, p = 0.0000)
		2001	43	"-55.30 to +26.60"	-34.50	-26.90	20.22	
		2002	41	"-68.20 to +16.40"	-42.60	-38.36	15.22	
		2003	42	"-79.50 to -28.30"	-54.32	-54.32	9.97	
		All	169	"-79.50 - 46.50"	-35.70	-32.03	22.80	

Dakota County Ambient Groundwater Quality Study
Appendix II: Hydrogeological Zone Characteristics

			ZONE CHARACTERISTICS					
Major Ions	Units		# of Wells and Samples	Range	Median	Mean	Standard deviation	**Significant difference between zones?**
Calcium	mg/L	1	36	43-115	73.85	77.58	118.31	**Yes (Kruskal-Wallis H = 15.0227, p = 0.0018).** No significant difference between years (Spearman's rho = 0.0262, p = 0.7119).
		2	79	0-101	66.3	64.92	16.34	
		3	38	41-110	68.8	71.28	15.53	
		4	48	0-122	69.9	71.98	18.92	
		All	201	0-122	69.5	70.08	17.697	
Magnesium	mg/L	1	36	15.5-38.30	29.15	28.417	5.4465	**Yes (Kruskal-Wallis H = 35.0680, p = 0.0000).** No significant difference between years (Spearman's rho = -0.0769, p = 0.2830).
		2	79	0.06-36.0	24.5	23.9	5.2905	
		3	38	15.1-48.0	26.4	26.43	6.8809	
		4	48	0.0-43.0	28.55	28.52	7.4173	
		All	201	0.0-48.0	26.6	26.29	6.4861	
Sodium	mg/L	1	36	0.56-42.0	4.22	10.94	13.16	**Yes (Kruskal-Wallis H = 16.4760, p = 0.0009).** No significant difference between years (Spearman's rho = -0.0164, p = 0.8171).
		2	79	1.03-149.0	3.23	6.92	17.24	
		3	38	1.07-14.40	4.48	5.48	3.47	
		4	48	1.07-129.00	2.72	7.15	18.92	
		All	201	0.56-149.0	3.52	7.42	15.35	
Potassium	mg/L	1	36	0.0-3.90	1.54	1.67	0.81	**Yes (Kruskal-Wallis H = 15.9572, p = 0.0012)**. Significant difference between years (Spearman's rho = -0.2151, p = 0.0022).
		2	79	0.0-12.20	1.30	1.59	1.84	
		3	38	0.0-3.9	1.53	1.61	0.73	
		4	48	0.0-2.85	1.64	1.59	0.59	
		All	201	0.0-12.20	1.46	1.61	1.27	

			ZONE CHARACTERISTICS					
Major Ions, continued	Units		# of Wells and Samples	Range	Median	Mean	Standard deviation	**Significant difference between zones?**
Chloride	mg/L	1	36	0.0-93.0	13.05	25.11	30.44	**Yes (Kruskal-Wallis H = 9.4894, p = 0.0234). Significant difference between years (Spearman's rho = 0.1422, p = 0.0442).**
		2	79	0.0-84.5	3.60	9.79	16.81	
		3	38	0.0-19.50	3.85	5.16	5.62	
		4	48	0.0-110.0	3.95	12.75	26.75	
		All	201	0.0-110.0	4.30	12.36	22.01	
Sulfate	mg/L	1	36	8.6-64.0	24.60	28.43	15.61	**Yes (Kruskal-Wallis H = 18.3123, p = 0.0004).** No significant difference between years (Spearman's rho = 0.0984, p = 0.1646).
		2	79	10.9-40.20	26.50	25.47	6.17	
		3	38	5.6-39.10	19.40	19.40	8.14	
		4	48	10.2-52.50	25.50	25.67	10.03	
		All	201	5.6-64.0	24.50	24.86	10.10	
Fluoride *Optimum range of fluoride concentration in drinking water for dental health is 0.7 to 1.2 mg/L. Most wells in this study did not have detectable levels of*		1	36	0.0-0.18	0.00	0.05	0.06	**Yes (Kruskal-Wallis H = 15.7661, p = 0.0013).** Significant difference between years (Spearman's rho = 0.4289, p = 0.0000).
		2	79	0-0.25	0.00	0.07	0.08	
		3	38	0-0.60	0.14	0.13	0.14	
		4	48	0-0.94	0.11	0.11	0.15	
		All	201	0.0-0.94.0	0.10	0.09	0.11	
Bromide	mg/L	All	201	0.0-0.87	0.00	0.14	0.20	No (Kruskal-Wallis H = 0.4475, p = 0.9303). No significant difference between 2000 and 2001, the years with detections in all wells
Trace Metals								
Iron	mg/L	1	36	0.0-2.43	0.02	0.35	0.71	**Yes (Kruskal-Wallis H = 22.7629, p = 0.0000).** No significant difference between years (Spearman's rho = 0.1193, p = 0.0.0917).
		2	79	0.0-3.94	0.30	0.76	0.99	
		3	38	0.0-7.10	1.20	1.37	1.38	
		4	48	0.0-9.87	0.10	1.09	2.06	
		All	201	0.0-9.87	0.16	0.88	1.39	

Dakota County Ambient Groundwater Quality Study
Appendix II: Hydrogeological Zone Characteristics

			ZONE CHARACTERISTICS					
Nutrients and Total Organic Carbon	Units		# of Wells and Samples	Range	Median	Mean	Standard deviation	**Significant difference between zones?**
Nitrate-Nitrogen	mg/L	1	35	0.0-15.2	5.00	6.12	4.79	**Yes (Kruskal-Wallis H = 22.5664, p = 0.0000).** No significant difference between years (Spearman's rho = -0.0738, p = 0.3001).
		2	78	0.0-22.60	0.00	4.11	5.60	
		3	38	0.0-10.6	0.00	1.37	3.27	
		4	48	0.0-9.74	0.24	2.24	3.13	
		All	201	0.0-22.60	0.00	3.49	4.80	
Ammonia-Nitrogen	mg/L	1	36	0.0-0.16	0.00	0.01	0.03	**Yes (Kruskal-Wallis H = 29.3174, p = 0.0000).** No significant difference between years (Spearman's rho = -0.1200, p = 0.0898).
		2	79	0.0-0.06	0.00	0.01	0.01	
		3	38	0.0-0.40	0.02	0.10	0.13	
		4	48	0.0-0.14	0.00	0.01	0.03	
		All	201	0.0-0.40	0.00	0.02	0.07	
Nitrite-Nitrogen	mg/L	1	36	0.0-0.2	0.00	0.02	0.05	**Yes (Kruskal-Wallis H = 5.2240, p = 0.1561).** No significant difference between years (Spearman's rho = 0.0359, p = 0.6126).
		2	79	0.0-0.04	0.00	0.00	0.00	
		3	38	0.0-0.07	0.00	0.00	0.01	
		4	48	0.0-0.02	0.00	0.00	0.01	
		All	201	0.0-0.2	0.00	0.00	0.02	
Ortho Phosphate	mg/L		201	0.0-0.37	0.000	0.004	0.03	**Yes (Kruskal-Wallis H = 9.8759, p = 0.0197).** Detections only in 1999 and one detection in 2001.
Total Organic Carbon	mg/L	1	30	0.0-1.5	0.60	0.55	0.51	**Yes (Kruskal-Wallis H = 10.0659, p = 0.0180). Significant difference between years (1999 excluded because of**
		2	68	0.0-2.6	0.50	0.41	0.47	
		3	32	0.0-1.9	0.80	0.74	0.57	
		4	41	0.0-1.3	0.60	0.47	0.45	
		All	171	0.0-2.6	0.60	0.51	0.50	

Appendix III

Dakota County Ambient Groundwater Quality Study
Appendix III: Pesticides --- Analytes and Reporting Limits

1999: Spectrum Labs, St. Paul, MN	
Minnesota Department of Agriculture List I: 8141A	
Pesticides	**Practical Quantification Limit (PQL)(ug/L)**
Acetochlor	0.40
Alachlor (Lasso)	0.40
Atrazine (Aatrex)	0.20
Chlorpyrifos (Lorsban)	0.20
Cyanazine (Bladex)	0.20
Deethylatrazine	0.40
Deisopropylatrazine	0.40
Dimethenamid (Frontier)	0.40
EPTC (Eradicane)	0.20
Ethalfluralin (Sonolan)	0.40
Fonofos (Dyphonate)	0.20
Metolachlor (Dual)	0.40
Metribuzin (Sencor, Lexone)	0.40
Pendimethalin (Prowl)	0.20
Phorate (Thimet)	0.20
Prometon (Pramitol)	0.40
Propachlor (Ramrod)	0.40
Propazine (Milogard)	0.20
Simazine (Princep)	0.20
Terbufos (Counter)	0.20
Tri-Allate (Far-Go)	0.20
Trifluralin (Treflan)	0.40

Dakota County Ambient Groundwater Quality Study
Appendix III: Pesticides --- Analytes and Reporting Limits

2000: Minnesota Valley Testing Laboratory, New Ulm, MN		
Minnesota Department of Agriculture List I: 3510, 8081, 8141A		
Pesticides	**Reporting Limit (RL) (ug/L)**	
Acetochlor	0.50	
Alachlor (Lasso)	0.50	
Atrazine (Aatrex)	0.50	
Chlorpyrifos (Lorsban)	0.50	
Cyanazine (Bladex)	0.20	
Deethylatrazine	0.50	
Deisopropylatrazine	0.50	
Dimethenamid (Frontier)	0.50	
EPTC (Eradicane)	0.50	
Ethalfluralin (Sonolan)	0.50	
Fonofos (Dyphonate)	0.50	
Metolachlor (Dual)	0.50	
Metribuzin (Sencor, Lexone)	0.50	
Pendimethalin (Prowl)	0.50	
Phorate (Thimet)	0.30	
Prometon (Pramitol)	0.50	
Propachlor (Ramrod)	0.50	
Propazine (Milogard)	0.50	
Simazine (Princep)	0.50	
Terbufos (Counter)	0.20	
Tri-Allate (Far-Go)	0.50	

Dakota County Ambient Groundwater Quality Study
Appendix III: Pesticides --- Analytes and Reporting Limits

2001: Minnesota Valley Testing Laboratory, New Ulm, MN	
Minnesota Department of Agriculture List I: 3510, 8270 Modified	
Pesticides	**Reporting Limit (RL) (ug/L)**
Acetochlor	0.10
Alachlor (Lasso)	0.10
Atrazine (Aatrex)	0.10
Chlorpyrifos (Lorsban)	0.10
Cyanazine (Bladex)	0.10
Deethylatrazine	0.10
Deisopropylatrazine	0.10
Dimethenamid (Frontier)	0.10
EPTC (Eradicane)	0.10
Ethalfluralin (Sonolan)	0.10
Fonofos (Dyphonate)	0.10
Metolachlor (Dual)	0.10
Metribuzin (Sencor, Lexone)	0.10
Pendimethalin (Prowl)	0.10
Phorate (Thimet)	0.10
Prometon (Pramitol)	0.10
Propachlor (Ramrod)	0.10
Propazine (Milogard)	0.10
Simazine (Princep)	0.10
Terbufos (Counter)	0.10
Tri-Allate (Far-Go)	0.10
Trifluralin (Treflan)	0.10

Appendix IV

Dakota County Ambient Groundwater Quality Study
Appendix IV: Pesticides
U.S.G.S. Organic Geochemistry Research Group Analyses

Liquid Chromatography/Mass Spectrometry (LCPD)	
Pesticides (Parent Compounds in Bold)	**Reporting Limit (ug/L)**
Acetochlor	0.02
Acetochlor ESA	0.02
Acetochlor OXA	0.02
Acetochlor SAA	0.02
Alachlor (Lasso)	0.02
Alachlor ESA	0.02
Alachlor ESA -- 2nd Amide	0.02
Alachlor OXA	0.02
Alachlor SAA	0.02
Dimethenamid (Frontier)	0.02
Dimethenamid ESA	0.02
Dimethenamid OXA	0.02
Flufenacet	0.02
Flufenacet ESA	0.02
Flufenacet OXA	0.02
Metolachlor (Dual)	0.02
Metolachlor ESA	0.02
Metolachlor OXA	0.02
Metolachlor/Acetochlor ESA - 2nd Amide	0.02
Propachlor (Ramrod)	0.02
Propachlor ESA	0.05
Propachlor OXA	0.02

Dakota County Ambient Groundwater Quality Study
Appendix IV: Pesticides
U.S.G.S. Organic Geochemistry Research Group Analyses

Gas Chromatography/Mass Spectrometry (GCS)	
Pesticides (Parent Compounds in Bold)	**Reporting Limit (ug/L)**
Acetochlor	0.05
Alachlor (Lasso)	0.05
Ametryn	0.05
Atrazine (Aatrex)	0.05
Cyanazine (Bladex)	0.05
Cyanazine amide (CAM)	0.05
Deethylatrazine (DEA)	0.05
Deisopropylatrazine (DIA)	0.05
Dimethenamid (Frontier)	0.05
Flufenacet	0.05
Metolachlor (Dual)	0.05
Metribuzin (Sencor, Lexone)	0.05
Pendimethalin (Prowl)	0.05
Prometon (Pramitol)	0.05
Prometryn	0.05
Propachlor (Ramrod)	0.05
Propazine (Milogard)	0.05
Simazine (Princep)	0.05
Terbutryn	0.05

Appnedix V

Dakota County Ambient Groundwater Quality Study
Appendix V: U.S.G.S. Pesticide Results
Nitrate above background levels vs. Nitrate below background levels

		First Sample Set: Wells w/ Nitrate above 1.0 mg/L (n = 18)				Wells w/ Nitrate below 1.0 mg/L (n = 24)				
Compounds	**Sample Year**	**Number of Detections**	**Median Sum of Parent and Degradates (µg/L)**	**Maximum Sum of Parent and Degradates (µg/L)**	**Significant Difference Between Years?**	**Number of Detections**	**Median Sum of Parent and Degradates (µg/L)**	**Maximum Sum of Parent and Degradates (µg/L)**	**Significant Difference Between Years?**	**Significant Difference Between High Nitrate Wells and Other Samples?**
Acetochlor and/or Degradates (HBV = 10 ug/L)	2001	2 (11%)	0.00	0.12	**Yes (Spearman's rho = 0.2824, p = 0.0388)**	Samples analyzed for MDA List I herbicides by MVTL, none detected in these wells.			No (Spearman's rho = -0.2085, p = 0.1546)	**Yes (Kruskal Wallis H = 9.4682, p = 0.0021)**
	2002	5 (28%)	0.00	0.75		2 (8%)	0.00	0.13		
	2003	7 (39%)	0.00	0.63		0	0.00	0.00		
Alachlor and/or Degradates (Alachlor HRL = 4 ug/L; Alachlor ESA HBV = 100 ug/L)	2001	15 (83%)	1.48	3.98	No (Spearman's rho = -0.1472, p = 0.2871)	Samples analyzed for MDA List I herbicides by MVTL, none detected in these wells.			No (Spearman's rho = -0.0067, p = 0.9639)	**Yes (Kruskal Wallis H = 34.1697, p = 0.0000)**
	2002	16 (89%)	1.43	3.93		10 (42%)	0.00	6.74		
	2003	15 (83%)	0.97	3.06		10 (42%)	0.00	4.75		
Atrazine and/or Degradates (HRL = 20 ug/L)	2001	11 (61%)	0.12	0.78	No (Spearman's rho = -0.0351, p = 0.8006)	Samples analyzed for MDA List I herbicides by MVTL, none detected in these wells.			No (Spearman's rho = -0.0860, p = 0.5596)	**Yes (Kruskal Wallis H = 29.2510, p = 0.0000)**
	2002	12 (67%)	0.11	1.00		2 (8%)	0.00	0.89		
	2003	11 (61%)	0.07	0.70		1 (4%)	0	0.66		
Cyanazine and/or Degradates (HBV = 0.40 ug/L)	2001	3 (17%)	0.00	0.08	No (Spearman's rho = -0.1592, p = 0.0607)	Samples analyzed for MDA List I herbicides by MVTL, none detected in these wells.			No (Spearman's rho = -0.1459, p = 0.3214)	No (Kruskal Wallis H = 2.2878, p = 0.1304)
	2002	1 (6%)	0.00	0.12		1 (4%)	0.00	0.08		
	2003	1 (6%)	0.00	0.05		0	0.00	0.00		

Dakota County Ambient Groundwater Quality Study
Appendix V: U.S.G.S. Pesticide Results
Nitrate above background levels vs. Nitrate below background levels

		First Sample Set: Wells w/ Nitrate above 1.0 mg/L (n = 18)				Wells w/ Nitrate below 1.0 mg/L (n = 24)				
Compounds	Sample Year	Number of Detections	Median Sum of Parent and Degradates (μg/L)	Maximum Sum of Parent and Degradates (μg/L)	Significant Difference Between Years?	Number of Detections	Median Sum of Parent and Degradates (μg/L)	Maximum Sum of Parent and Degradates (μg/L)	Significant Difference Between Years?	Significant Difference Between High Nitrate Wells and Other Samples?

Dakota County Ambient Groundwater Quality Study
Appendix V: U.S.G.S. Pesticide Results
Nitrate above background levels vs. Nitrate below background levels

		First Sample Set: Wells w/ Nitrate above 1.0 mg/L (n = 18)				Wells w/ Nitrate below 1.0 mg/L (n = 24)				
Compounds	**Sample Year**	**Number of Detections**	**Median Sum of Parent and Degradates (μg/L)**	**Maximum Sum of Parent and Degradates (μg/L)**	**Significant Difference Between Years?**	**Number of Detections**	**Median Sum of Parent and Degradates (μg/L)**	**Maximum Sum of Parent and Degradates (μg/L)**	**Significant Difference Between Years?**	**Significant Difference Between High Nitrate Wells and Other Samples?**
Dimethenamid and/or Degradates (HBV = 40 ug/L)	2001	0	0.00	0.00	No (Spearman's rho = 0.1682, p = 0.2232)	Samples analyzed for MDA List I herbicides by MVTL, none detected in these wells.			N/A	No (Kruskal Wallis H = 0.8889, p = 0.3458)
	2002	0	0.00	0.00		0	0.00	0.00		
	2003	1 (6%)	0.00	0.02		0	0.00	0.00		
Metolachlor and/or Degradates (HRL = 100 ug/L)	2001	15 (83%)	0.56	2.54	No (Spearman's rho = 0.0576, p = 0.6779)	Samples analyzed for MDA List I herbicides by MVTL, none detected in these wells.			No (Spearman's rho = 0.0368, p = 0.8034)	**Yes (Kruskal Wallis H = 33.5511, p = 0.0000)**
	2002	16 (89%)	0.44	3.08		5 (21%)	0.00	5.94		
	2003	15 (83%)	0.47	3.45		6 (25%)	0.00	5.29		
Prometon (HRL = 100 ug/L)	2001	1 (6%)	0.00	0.06	No (Spearman's rho = -0.1682, p = 02232)	Samples analyzed for MDA List I herbicides by MVTL, none detected in these wells.			N/A	No (Kruskal Wallis H = 0.8889, p = 0.3458)
	2002	0	0.00	0.00		0	0.00	0.00		
	2003	0	0.00	0.00		0	0.00	0.00		

Dakota County Ambient Groundwater Quality Study
Appendix V: U.S.G.S. Pesticide Results
By Pesticide Contaminant

First Sample Set: Wells w/ Nitrate above 1.0 mg/L (n = 18)	# of Wells w/ No Detections	# of Wells w/ Detections	# of Wells w/ Multiple Pesticide Contaminants detected	Median # of parent compounds in wells w/ detections	Maximum # of parent compounds in wells w/ detections	Median # of degradates in wells w/ detections
2001	3 (17%)	15 (83%)	15 (83%)	1	2	4
2002	2 (11%)	16 (89%)	16 (89%)	1	1	4
2003	3 (17%)	15 (83%)	15 (83%)	1	2	6

Wells w/Nitrate below 1.0 mg/L (n = 24)	# of Wells w/ No Detections	# of Wells w/ Detections	# of Wells w/ Multiple Pesticide Contaminants detected	Median # of parent compounds in wells w/ detections	Maximum # of parent compounds in wells w/ detections	Median # of degradates in wells w/ detections
2002	14 (58%)	10 (42%)	5 (21%)	0	3	2
2003	14 (58%)	10 (42%)	6 (25%)	0	3	3

Dakota County Ambient Groundwater Quality Study
Appendix V: U.S.G.S. Pesticide Results
By Pesticide Contaminant

First Sample Set: Wells w/ Nitrate above 1.0 mg/L (n = 18)	Maximum # of degradates in wells w/ detections	Median # of pesticide contaminantsi n wells w/ detections	Maximum # of pesticide contaminants in wells w/ detections	Median Sum of Pesticide Concentrations (µg/L)	Maximum Sum of Pesticide Concentrations (µg/L)	Significant Difference Between Years?
2001	8	3	5	2.20	6.43	No (Spearman's rho = -0.0394, p = 0.7769
2002	8	3	5	2.41	7.52	
2003	10	3	5	2.13	6.82	

Wells w/Nitrate below 1.0 mg/L (n = 24)	Maximum # of degradates in wells w/ detections	Median # of pesticide contaminantsi n wells w/ detections	Maximum # of pesticide contaminants in wells w/ detections	Median Sum of Pesticide Concentrations	Maximum Sum of Pesticide Concentrations	Significant Difference Between Years?
2002	8	2	5	0.00	13.77	No (Spearman's rho = 0.0168, p = 0.9096)
2003	6	2	3	0.00	10.70	

Dakota County Ambient Groundwater Quality Study
Appendix V: U.S.G.S. Pesticide Results
By Pesticide Contaminant

All Wells (n = 42)	# of Wells w/ No Detections	# of Wells w/ Detections	# of Wells w/ Multiple Pesticide Contaminants detected	Median # of parent compounds in wells w/ detections	Maximum # of parent compounds in wells w/ detections	Median # of degradates in wells w/ detections
2002	16 (38%)	26 (62%)	21 (50%)	0	3	3
2003	17 (40%)	25 (60%)	21 (50%)	0	3	4
All (84)	33 (39%)	51 (61%)	42 (50%)		3	

Hastings Area Nitrate Study (n = 32)	# of Wells w/ No Detections	# of Wells w/ Detections	# of Wells w/ Multiple Pesticide Contaminants detected	Median # of parent compounds in wells w/ detections	Maximum # of parent compounds in wells w/ detections	Median # of degradates in wells w/ detections
2001	10 (31%)	22 (69%)	18 (56%)	0	3	3

Dakota County Ambient Groundwater Quality Study
Appendix V: U.S.G.S. Pesticide Results
By Pesticide Contaminant

All Wells (n = 42)	Maximum # of degradates in wells w/ detections	Median # of pesticide contaminantsin wells w/ detections	Maximum # of pesticide contaminants in wells w/ detections	Median Sum of Pesticide Concentrations	Maximum Sum of Pesticide Concentrations	Significant Difference Between Years?
2002	8	3	5	0.78	13.77	No (Spearman's rho = -0.0334, p = 0.7623
2003	10	2	5	0.72	10.70	
All (84)	10		5		13.77	

Hastings Area Nitrate Study (n = 32)	Maximum # of degradates in wells w/ detections	Median # of pesticide contaminantsin wells w/ detections	Maximum # of pesticide contaminants in wells w/ detections	Median Sum of Pesticide Concentrations	Maximum Sum of Pesticide Concentrations
2001	7	3	5	1.50	17.89

Appendix VI

MINNESOTA
MDH
DEPARTMENT OF HEALTH

Protecting, maintaining and improving the health of all Minnesotans

April 27, 2004

Vanessa DeMuth
Dakota County Environmental Management
Groundwater Protection Section
14955 Galaxie Avenue
Apple Valley, Minnesota 55124

Dear Ms. DeMuth:

At the request of Dakota County Environmental Management, the Health Risk Assessment Unit of the Minnesota Department of Health (MDH) has performed cumulative risk assessments for 22 wells in Dakota County. The cumulative risk assessment was conducted using guidance set forth in the Statement of Need and Reasonableness for the 1993 Health Risk Limits Rule (HRL) and in memos sent by MDH to the Minnesota Department of Agriculture on November 8, 1999 and February 15, 2002.

No hazard index calculated in this risk assessment was equal to or greater than one. Therefore, the chemicals and concentrations in this well are not expected to pose risk of a noncancer health effect and the risk of cancer is below the policy risk level of 1 in 100,000. The attached spreadsheet (Attachment A) shows the results of the cumulative risk assessment for each well. The spreadsheet lists the hazard index for each relevant endpoint.

In performing this risk assessment, MDH utilized HRLs from the 1993/1994 promulgations and HBVs developed as guidance since that time. MDH is in the process of revising the HRLs. The revision is expected to replace the adult-based intake rates currently used in the HRL algorithm with child-based intake rates. Absent other factors affecting the toxicological evaluation of a chemical, this would result in lowering the applicable value. MDH performed a tentative cumulative risk assessment using values from the draft revised rule. Hazard indices calculated for those chemicals for which the review process is complete did not exceed one.

According to the cumulative risk assessment based on the 1993/1994 HRLs, the well of greatest concern is that at site id 426379. The cumulative excess cancer risk calculated for this well is 0.1475/100,000, or 1.475/1,000,000. This approaches the policy risk level. The majority of this risk can be attributed to cyanazine amide. Risk attributed to cyanazine amide is based on the toxicity of its parent, cyanazine. Although using a parent compound as a surrogate for its degradates is generally expected to yield conservative estimates of risk, this is not always the case. MDH has been unable to locate toxicity information specific to cyanazine amide.

Although MDH's cumulative risk assessments indicate that the pesticides and degradates present do not pose an immediate risk to health, MDH is concerned about the number of pesticides and degradates found in these wells. MDH recommends that well owners be notified of the results of the testing. Attachment B contains an example of text that might be included in letters sent to well owners. MDH also recommends continued monitoring of this well by the county or the well owner.

The results of your analyses indicate the presence of multiple pesticides and pesticide degradates in drinking water wells in Dakota County. MDH recommends that Dakota County staff work with the Department of Agriculture to determine why so many pesticides are reaching groundwater and to attempt to mitigate the factors leading to this condition. If the results from any well indicate a problem with well construction, Dakota County staff, in consultation with the MDH well management section, should work to identify other wells that may have similar problems and take steps to correct problems allowing contaminants to enter these wells.

Please call me if you have any questions at 651-215-0854.

Sincerely,

Anne Kukowski
Health Risk Assessment Unit

AK:rlk
cc: Patricia Bloomgren, MDH
Greg Buzicky, MDA
Mike Convery, MDH
Larry Gust, MDH
Michael Meyer, USGS, 4821 Quail Crest Place, Lawrence Kansas 66049
Dan Wilson, MDH
Joseph Zachmann, MDA

Attachment B

Dakota County Environmental Management, in conjunction with the U.S. Geological Survey (USGS), has been conducting an investigation of contamination of drinking water wells by pesticides and pesticide degradates in vulnerable wells in your area. In September of 2003, a water sample was collected from the well serving your residence. Chemical analysis by USGS laboratories revealed the presence of several pesticides and/or degradates in the water.

Dakota County Environmental Management compared the results of the chemical analyses to concentrations that may be consumed in water on a daily basis for a lifetime with no health risk or only negligible health risk. These exposure limits are developed by the Minnesota Department of Health (MDH) using a conservative approach to ensure the protection of health. Water containing a chemical in excess of its exposure limit is considered to pose a possible health risk. At the request of Dakota County Environmental Management, the Minnesota Department of Health also evaluated whether as a group the combination of all pesticides and/or degradates found in water from your well pose a risk to health.

Concentrations of the individual pesticides and/or degradates found in your well were below applicable exposure limits. The pesticides and/or degradates found in your well were also below cumulative exposure limits.

Even though concentrations of pesticides and/or degradates in your water do not reach exposure limits, you may wish to take steps to limit your exposure. Point-of-use treatment devices such as an activated carbon filter or reverse-osmosis can be effective in removing pesticides. However, in order for any treatment unit to be effective, it must be properly maintained and any filters must be replaced in a timely manner. For information on treatment devices, please call Vanessa DeMuth, at Dakota County Environmental Services, 952-891-7010.

Appendix VII

Dakota County Ambient Groundwater Quality Study
Appendix VII: Age-Dating, Nitrate, and Pesticide Results

Well Identification	Water Quality Sample Collection Date	Age derived from Helium-Tritium Isotopes (years before present)	Well Casing Depth (feet bgs)	Nitrate (mg/L)	Mass of Pesticides (ug/L)	Chemical Families	Total Alachlor (ug/L)	Total Metolachlor (ug/L)	Total Atrazine (ug/L)	Total Acetochlor (ug/L)	Total Cyanazine (ug/L)
							Introduced 1969, being replaced by Acetochlor.	Introduced 1976; s-Metolachlor replacing Metolachlor.	Introduced 1956	Introduced 1994	No longer in use.
AGQS - 1	10/9/2002	75	445	0	0	0	0	0	0	0	0
AGQS - 1	9/30/2003	75	445	0	0	0	0	0	0	0	0
AGQS - 2	10/9/2002	36.6	345	0	0	0	0	0	0	0	0
AGQS - 2	9/30/2003	36.6	345	0	0	0	0	0	0	0	0
AGQS - 3	10/9/2002	23.8	267	0	0	0	0	0	0	0	0
AGQS - 3	9/30/2003	23.8	267	0	0	0	0	0	0	0	0
AGQS - 4	10/9/2002	20.3	294	4.73	0.58	1	0.58	0	0	0	0
AGQS - 4	9/30/2003	20.3	294	5.64	0.94	2	0.9	0.04	0	0	0
AGQS - 5	10/8/2002	13.1	310	0	0.06	1	0.06	0	0	0	0
AGQS - 5	9/29/2003	13.1	310	0	0.12	1	0.12	0	0	0	0
AGQS - 6	6/18/2001	11.9	179	6.69	1.38	2	0.96	0.42	0	0	0
AGQS - 6	10/9/2002	11.9	179	7.22	1.32	3	0.85	0.41	0.06	0	0
AGQS - 6	9/30/2003	11.9	179	8.28	1.25	3	0.71	0.46	0.08	0	0
AGQS - 7	10/8/2002	9.6	305	0	0	0	0	0	0	0	0
AGQS - 7	9/29/2003	9.6	305	0	0	0	0	0	0	0	0
AGQS - 8	6/19/2001	9	80	9.25	4.9	4	3.98	0.06	0.78	0	0.08
AGQS - 8	10/8/2002	9	80	10.6	5.02	5	3.44	0.14	1	0.32	0.12
AGQS - 8	9/29/2003	9	80	10.1	4.39	5	3.06	0.05	0.61	0.62	0.05

Appendix VIII

Dakota County Ambient Groundwater Quality Study
Appendix VIII: 2001 Pesticide Use in Southeast Minnesota and 2001-2003 Ambient Study Detections

Rank (by 2001 use)	Agricultural Chemical Used in MASS Reporting District 90 (Southeast)(1)	Total Applied in District 90 in 2001 (1,000 lbs)	Sample Trade Name (2)	Pesticide Type (2)	Drinking Water Standard (ug/L) (2)	Ambient Groundwater Study: 2001-2003 Results	
						Analyzed & Detected -- Maximum Detection	Analyzed & Not Detected
1	Metolachlor	686.1	Dual	Herbicide	100 (HRL)	0.07	
	Metolachlor ESA					3.70	
	Metolachlor OXA					2.17	
	Metolachlor/Acetochlor ESA -- 2nd amide					0.33	
4	s-Metolachlor	207.2	Dual	Herbicide		No analysis separate from Metolachlor & degradates	
2	Acetochlor	632.3	Surpass, Harness	Herbicide	10 (HBV)	ND	Yes
	Acetochlor ESA					0.63	
	Acetochlor OXA					0.12	
	Acetochlor SAA					ND	Yes
3	Atrazine	579.4	Atrazine, Aatrex	Herbicide	20 (HRL)	0.43	
	Deethylatrazine					0.40	
	Deisopropylatrazine					0.42	
5	Glyphosate	148.6				Not Analyzed	
6	Clopyralid	92.8	Loncid	Herbicide		Not Analyzed	
7	Dimethenamid	90.6	Frontier	Herbicide	40 (HBV)	ND	Yes
	Dimethenamid ESA					0.02	
	Dimethenamid OXA					ND	Yes
8	Dicamba, Potassium salt	40.8				Not Analyzed	
9	Flumetsulam	34.3				Not Analyzed	
10	Dicamba	22.9	Banvel, Marksman	Herbicide	200 (HRL)	Not Analyzed	
11	Terbufos	18.2	Counter	Herbicide	0.2 (HBV)	Not Analyzed	
12	Tefluthrin	17.3				Not Analyzed	
13	Glufosinate-ammonium	10.9				Not Analyzed	
14	Nicosulfuron	5.6				Not Analyzed	

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						Analyzed & Detected -- Maximum Detection	Analyzed & Not Detected
15	Tebupirimphos	4.4				Not Analyzed	
16	Rimsulfuron	0.7				Not Analyzed	
17	Primisulfuron	0.5				Not Analyzed	
18	Cyfluthrin	0.2				Not Analyzed	
	Alachlor	Insufficient data to publish	Lasso	Herbicide	4 (HRL)	0.27	
	Alachlor ESA				100 (HBV)	6.14	
	Alachlor ESA -- 2nd. Amide					0.08	
	Alachlor OXA					0.60	
	Alachlor SAA					ND	Yes
	Ametryn (not reported used in 2001)					ND	Yes
	Bifenthrin	Insufficient data				Not Analyzed	
	Bromoxynil	Insufficient data				Not Analyzed	
	Carbofuran	Insufficient data				Not Analyzed	
	Carfentrazone-ethyl	Insufficient data				Not Analyzed	
	Chlorpyrifos	Insufficient data	Lorsban	Insecticide	20 (HBV)	Not Analyzed	
	Cyanazine (not legal after 12/31/02)	Insufficient data	Bladex	Herbicide	0.4 (HBV)	ND	Yes
	Cyanazine amide					0.12	
	Dicamba, Dimethylamine salt	Insufficient data				Not Analyzed	
	Diflufenzopyr-sodium	Insufficient data				Not Analyzed	
	EPTC	Insufficient data	Eradicane	Herbicide	200 (HRL)	Not Analyzed	
	Fipronil	Insufficient data				Not Analyzed	
	Flufenacet (not reported used in 2001)					ND	Yes
	Flufenacet ESA					ND	Yes
	Flufenacet OXA					ND	Yes

Dakota County Ambient Groundwater Quality Study
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						Analyzed & Detected -- Maximum Detection	Analyzed & Not Detected
	Imazapyr	Insufficient data				Not Analyzed	
	Imazethapyr	Insufficient data				Not Analyzed	
	Mesotrione	Insufficient data				Not Analyzed	
	Metribuzin (not reported used in 2001)					ND	Yes
	Pendimethalin	Insufficient data	Prowl	Herbicide	90 (HBV)	ND	Yes
	Permethrin	Insufficient data				Not Analyzed	
	Prometon (not reported used in 2001)					0.06	
	Prometryn (not reported used in 2001)					Not Analyzed	Yes
	Propachlor (not reported used in 2001)					Not Analyzed	Yes
	Propachlor ESA					Not Analyzed	Yes
	Propachlor OXA					Not Analyzed	Yes
	Propazine (not reported used in 2001)					Not Analyzed	Yes
	Simazine (not reported used in 2001)					Not Analyzed	Yes
	Terbutryn (not reported used in 2001)					Not Analyzed	Yes
	(1) Minnesota Department of Agriculture, "Expanded Minnesota Agricultural Statistics Pesticide Use Data," August 2003	(2) Minnesota Department of Agriculture, "Pesticide Monitoring in Water Resources: Annual Data Report," May 2004.					

Appendix IX

Dakota County Ambient Groundwater Quality Study
Appendix IX: Volatile Organic Compounds --- Year 2000 Analysis

EPA SW-846	
Volatile Organics	**Reporting Limit (ug/L)**
Chloroethane	0.7
Chloromethane	1.0
Bromomethane	0.7
Dichlorodifluoromethane	0.6
Vinyl Chloride	0.5
Methylene Chloride	0.6
Trichlorofluoromethane	0.6
1,1-Dichloroethene	0.5
1,1-Dichloroethane	0.6
trans-1,2-Dichloroethene	0.5
Chloroform	0.7
1,2-Dichloroethane	0.5
1,1,1-Trichloroethane	0.7
Carbon Tetrachloride	0.5
Bromodichloromethane	0.5
1,2-Dichloropropane	0.8
trans-1,3-Dichcloropropene	0.5
Trichloroethene	0.7
Chlorodibromomethane	0.5
1,1,2-Trichloroethane	0.5
cis-1,3-Dichloropropene	0.5
Bromoform	1.0
1,1,2,2-Tetrachloroethane	0.5
Tetrachloroethene	0.9
Chlorobenzene	0.5
Benzene	0.5
Toluene	0.6
Ethyl Benzene	0.9
1,2-Dichlorobenzene	1.0
1,3-Dichlorobenzene	0.6
1,4-Dichlorobenzene	0.5
cis-1,2-Dichloroethene	0.5
1,3-Dichloropropane	0.6
1,2,3-Trichloropropane	0.6
Allyl Chloride	0.7
1,2-Dibromoethane	0.6
Methyl Ethyl Ketone	5.0
Methyl Isobutyl Ketone	1.6
Tetrahydrofuran	5.0
m-Xylene and p-Xylene	0.7
o-Xylene	0.3
Cumene	0.6
1,1,1,2-Tetrachloroethane	0.5
1,1-Dichloropropene	0.5
Dichlorofluoromethane	0.5
Trichlorotrifluoroethane	0.8
Ethyl Ether	0.7

Dakota County Ambient Groundwater Quality Study
Appendix IX: Volatile Organic Compounds --- Year 2000 Analysis

EPA SW-846	
Volatile Organics	**Reporting Limit (ug/L)**
Acetone	10.0
Dibromomethane	1.0
2,2-Dichloropropane	1.0
Bromochloromethane	0.8
Methyl tert-butyl Ether	0.6
Styrene	1.0
n-Propylbenzene	0.6
Bromobenzene	0.9
2-Chlorotoluene	0.5
1,3,5-Trimethylbenzene	0.9
4-Chlorotoluene	0.5
t-Butylbenzene	0.6
1,2,4-Trimethylbenzene	0.6
sec-Butylbenzene	0.5
p-Isopropyltoluene	0.5
n-Butylbenzene	0.6
1,2-Dibromo-3-chloropropane	1.0
1,2,4-Trichlorobenzene	1.0
Hexachlorobutadiene	1.0
Naphthalene	0.7
1,2,3-Trichlorobenzene	1.0