Appendix A:

Yellow Medicine County

Water Plan Scoping Document

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Priority Concerns Scoping Document

For

Yellow Medicine County
Local Water Management Plan

December 2003

History:

The Yellow Medicine County Local Water Management planning process of addressing priorities has included the following actions:

- **November 20, 2002**: The Water Plan Coordinator sent a request to various local and state agencies to submit priority concerns that they would like to see addressed in the Water Plan. Comments were received from the Department of Agriculture, Redwood-Cottonwood Rivers Control Area, Minnesota Pollution Control Agency, Minnesota Department of Health, Department of Natural Resources, US Fish and Wildlife Service, Board of Water and Soil Resources, Yellow Medicine River Watershed, Yellow Medicine Soil and Water Conservation District, City of Clarkfield, Yellow Medicine County Ditch Inspector and the University of Minnesota Extension Service.

- **December 4, 2002:** A letter was sent to all cities and townships within the county, adjacent counties, rural water systems, watershed districts, county highway department, RCRCA, UMVRDC, Area II, BWSR, SWCD and the Yellow Medicine County Ditch Inspector. The letter informed them of Yellow Medicine County's intent to update the local water plan and requested a copy of existing plans and a list of priority concerns that they would like to see included in the Plan.

- **December 2002:** A survey was included in the December issue of the Water Quality/Quantity newsletter. This newsletter/survey was sent to every resident in Yellow Medicine County. Residents were instructed to identify their top ten environmental concerns. Fifteen responses were received.

- **January 29, 2003:** An issues identification meeting was held in Marshall, MN. The meeting was attended by representatives from the Minnesota Department of Health, Department of Natural Resources, US Fish and Wildlife Services, Board of Water and Soil Resources, Natural Resources Conservation Service, Lincoln Pipestone Rural Water, Soil and Water Conservation Districts and Lincoln County and Yellow Medicine County staff. Comments received were discussed and new issues were identified.

- **February 25, 2003:** The Yellow Medicine County Water Task Force held a public hearing to receive input from the general public, cities, townships and local government agencies. There were three members of the public in attendance.

- **April 30, 2003:** The Yellow Medicine County Water Task Force convened to review and discuss the issues identified at the various meetings that had been held and correspondence that had been received. At this meeting the priority concerns were drafted.

RESULTS:

Written responses to the November 20, 2002 and December 4, 2002 request for priority concerns include the following comments:

- **Minnesota Pollution Control Agency (MPCA)** - Feedlots, TMDL's, ISTS, Unsewered Areas and Storm Water
- **Minnesota Department of Health (MDH)** - Wellhead protection
- **Minnesota Department of Natural Resources (DNR) - Wildlife-** Wetland Restoration
- **US Fish and Wildlife Service (USFWS)- Morris Wetland Management District** - Wetland and Prairie Restoration, Protect existing wetland and native prairie habitats, Flood control and water quality improvement
- **Minnesota Department of Natural Resources (DNR) - Waters -** Water quality, drainage, groundwater quality and availability, stream/river stability and restoration
- **Board of Water and Soil Resources (BWSR) -** Integrate plans, address run-off volume, protect groundwater resources.
- **Minnesota Department of Agriculture (MDA)** - Feedlots, manure management, erosion control
- **Yellow Medicine Soil and Water Conservation District (SWCD) -** Promote and enhance surface water quality by reducing the amount of sedimentation and pollutants entering the County's lakes, streams, rivers and wetlands; protect surface and groundwater supplies from contamination caused by point and nonpoint pollution; preserve existing wetlands and restore legally drained wetlands having potential for flood damage reduction, wildlife, recreational, and groundwater recharge benefits.
- **Yellow Medicine River Watershed District (YMRWD) -** Nutrient management, protect and improve existing surface and ground water quality, river bank restoration, erosion control
- **City of Clarkfield -** Well sealing, groundwater and surface water protection, wellhead protection
- **Yellow Medicine County Ditch Inspector -** Prevent soil erosion
- **Yellow Medicine County Extension Service -** Environmental education
- **Fortier Township -** no concerns

The comments and concerns listed above were discussed at the issues identification meeting held on January 29, 2003, in Marshall, MN. Additional discussion also took place and in summary, the concerns were categorized into the following:

- Restorable Wetlands Inventory
- Reduce priority pollutants with Best Management Practice (BMPs) emphasis
- Drainage
- Education
- Intergovernmental Cooperation
- Recreation, Tourism, Fisheries & Wildlife
- Groundwater Protection

A survey was placed in the December 2002 Water Quality/Quantity newsletter. The newsletter was sent to every household in the County. The survey consisted of a list of concerns and issues related to water. There was also an opportunity for respondents to offer their own suggestions or concerns. The following are the results of the survey, in order of importance, as rated by those who responded.

- Protect ground water supplies from contamination
- Protect surface water from contamination
- Reduce the amount of sedimentation entering the County's lakes, streams and rivers
- Promote the use of BMP's
- Promote the proper use of household hazardous waste, pesticides, etc.
- Preserve existing wetlands
- Bring feedlots into compliance
- Identify sensitive geologic areas which may cause groundwater contamination
- Restore drained wetlands that have flood damage reduction or wildlife and recreational benefits
- Improve flood control efforts
- Increase and enhance the recreational use of waters of Yellow Medicine County
- Work with landowners to test their private wells
- Properly seal abandoned wells
- Address illegal dumping of solid waste and demolition debris
- Clean up unpermitted junk yards
- Identify and remove underground storage tanks
- Bring non-conforming individual sewage treatment systems into compliance
- Provide municipalities with assistance in developing a wellhead protection plan
- Reduce the amount of wind erosion on severely erodible acres
- Assist in the construction of flood damage reduction structures
- Limit/remove/reduce development of agricultural uses in flood prone areas
- Expand surface and ground water monitoring
- Increase the number of acres of native prairie in the County
- Provide support for the development of nutrient/manure management plans for feedlots

Issues identified at the public hearing include tree removal from the waterways in the County, septic systems, feedlots and best management practices.

Setting the Priority Concerns for Yellow Medicine County:

The Yellow Medicine County Water Task Force determined from the above concerns that the focus for the next five years would be the following:

1. Groundwater Protection: aiding public water suppliers with the development of wellhead protection plans and by providing assistance to help manage vulnerable areas from potential contamination sources.

2. Erosion and Sediment Control on agricultural lands located in the Yellow Medicine and Lac qui Parle Watersheds.

3. Reduce priority pollutants, nutrients and bacteria, related to feedlots and non-conforming individual sewage treatment systems.

4. Manage flooding and its' effects minimizing losses associated with the flooding of agricultural lands.

5. Surface water and drainage management by addressing runoff volume and water quality deterioration due to excessive runoff.

These five issues will be the focus in the creation of the goals, objectives and an implementation plan.

The following issue will not be addressed within the scope of the Local Water Management Plan are:

- Integrate County land use plans with the water plan and develop one implementation strategy.
  The Yellow Medicine County Comprehensive Land Use Management Plan is outdated, however, because of budget concerns the County does not plan to update this document in the near future. The Water Task Force has chosen to keep the documents separate but will utilize the existing document any way possible and will work closely with the Yellow Medicine County Zoning Office in the development and implementation of the Local Water Plan.

- Identify and remove underground storage tanks.

  This will not be addressed due to lack of funding.

- Address illegal dumping of solid waste and demolition debris and the clean up of unpermitted junk yards.

  These issues will be handled by the Environmental Office and the Zoning Office.

Appendix B:

Regional Hydrogeologic Maps Cropped to Yellow Medicine County

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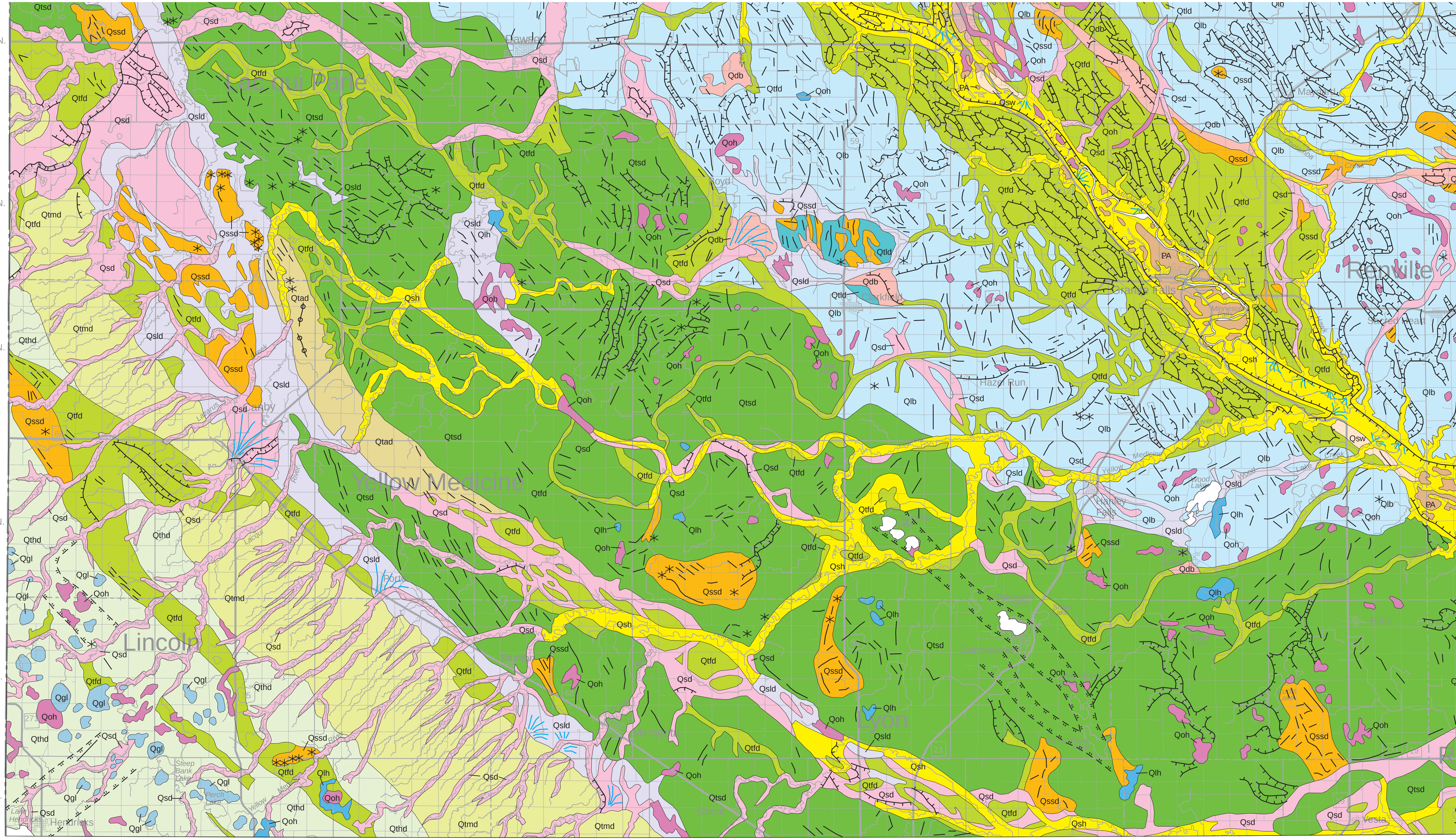


Digital base modified from 1990 Census TIGER/Line Files of U.S. Bureau of the Census (source scale 1:100,000); county border files modified from Minnesota Department of Transportation files; digital base annotation by Minnesota Geological Survey

Universal Transverse Mercator Projection, grid zone 15
1927 North American Datum

SCALE 1:200 000

5 0 5 10 MILES

5 0 5 10 15 KILOMETERS

Yellow Medicine County
Regional Hydrogeologic Assessment
Plate 1

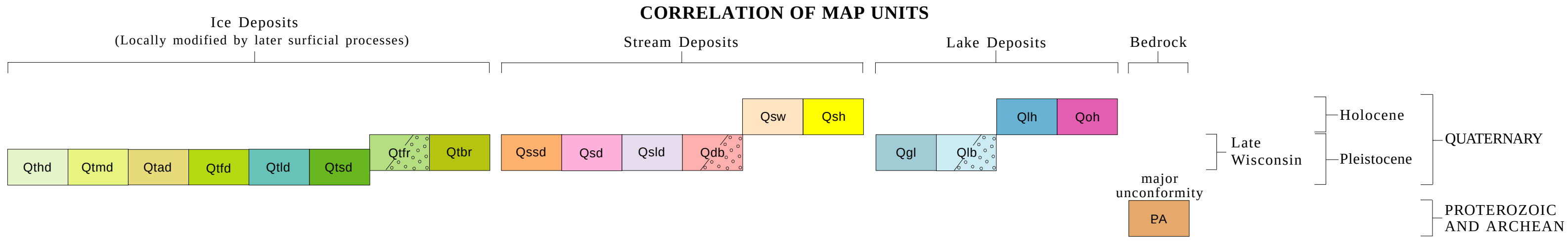
SURFICIAL GEOLOGY

By

Carrie J. Patterson, Alan R. Knaeble, Sara E. Gran, and Stephanie J. Phippen

1999

CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

HOLOCENE AND LATE PLEISTOCENE

Qoh **Organic deposits**—Peat and sediment deposited in marshes and shallow lakes. Typically found in depressions interpreted to have formed through melting of buried glacial ice and along former glacial stream channels. Some deposits have been drained.

Qlh **Lake sediment**—Clay, silt, marl, and some organic material. The basins are commonly shallow (less than 10 feet deep), and the sediment may be thin; some basins have been drained.

Qsh **Stream sediment**—Stratified layers of silt, clay, and sand; some organic material. The sediment is coarser in the Minnesota River channel. Commonly located along glacial stream channels, where it may bury and incorporate coarser glacial stream sediment. The unit is not shown in narrow channels, although it is present to some extent wherever a modern stream flows. The unit includes the steep side slopes of channels, especially along the Minnesota River, where very little stream sediment is preserved. Rather, older units are exposed in bluffs, and colluvial sediment covers less steep slopes.

Qsw **Stream sediment of Glacial River Warren**—Stratified sand and gravel; commonly forms bars that protrude above Holocene stream sediment (map unit Qsh) in the River Warren gorge (Fig. 2). The unit is predominantly found where the river reworked existing deposits of sand and gravel. Glacial River Warren was mostly an erosive stream and created erosional (strath) terraces that have boulder lags at the surface.

PLEISTOCENE

DEPOSITS OF THE BIG STONE PHASE OF THE RED RIVER LOBE (LATE WISCONSIN)

Qtbr **Till of the Big Stone moraine**—Till that contains lenses of sorted sediment and blocks of incorporated clayey lake sediment. Till texture and lithology are highly variable. Texture of the till matrix is loam to clay; yellow-brown where oxidized, gray where unoxidized. Clast rock types include carbonate, crystalline rock, shale (from none to 50 percent of the coarse sand fraction), and some lignite.

The unit is a complex of tills that were deposited along ice fronts that advanced into glacial Lake Benson (Figs. 1b and 2). The first advance to this position was probably of the Des Moines lobe, but the later advances were of the Red River lobe. Although the Red River lobe followed a path similar to that of the Des Moines lobe, its clast content and pattern of retreat indicate it originated in a different part of the ice sheet (directly north rather than north–northwest of the study area; Figs. 1a and 1b). The unit includes areas where lobate bodies of till, interpreted as flow tills, extend from the position of the former ice front (along the Big Stone moraine) into glacial Lake Benson (shown on map by fan symbol). Arcuate ridge crests mark the eastern extent of the moraine (crest line of moraine symbol; see Description of Map Symbols); they may be small push moraines. Elsewhere, the moraine has an irregular, extremely pitted surface, and the till contains many boulders. Pits are interpreted to have formed by burial and subsequent melting of small blocks of ice, possibly lake ice. Boulders are interpreted to have been incorporated locally from nearby granite outcrops. Linear depressions trending south and southeast through the moraine are interpreted to represent collapsed drainageways that eroded through or beneath debris-laden ice.

Qtfr **Till with stream-modified surface**—Till modified by flowing water; fluvially eroded and streamlined in places. Till texture, lithology, and color are as above (till of the Big Stone moraine; map unit Qtbr). Locally overlain by thin lag of sand and gravel or covered by silt and clay. Channel scars are common; channels may localize organic deposits (map unit Qoh), lakes, and modern streams and flood waters. Stipple indicates areas that collapsed after stream modification, probably from meltout of buried ice; the resulting topography is irregular.

DEPOSITS OF THE ALTAMONT, MARSHALL, GARY, ANTELOPE AND YOUNGER PHASES OF THE DES MOINES LOBE (LATE WISCONSIN)

Qlb **Lake sediment of glacial Lake Benson**—Silt, clay, and some fine sand; rhythmically laminated in places. Upper part of unit is commonly a massive silt. The thickest, most continuous lake sediment is found in the northeastern quadrant of the former lake, where the lake may have survived longer after the southern part of the basin was drained. A discontinuous distribution of lake sediment in lake margins, ice-supported inlets and outlets, and a lack of clear shoreline features indicate that the lake was confined by stagnant ice. Minor linear ridges and small channels in the basin are interpreted to have formed beneath stagnating ice. Stipple indicates areas of collapsed lake sediment, which is interpreted as originating from meltout of buried ice; the resulting topography is irregular.

Qdb **Delta sediment of glacial Lake Benson**—Sand, gravel, and silt deposited by streams entering glacial Lake Benson. The largest deltas formed at the mouths of the Pomme de Terre and Chippewa Rivers. Minor deltas are located (1) on the northeastern side of the basin where the East Branch Chippewa River entered it (Swift Falls delta; Fig. 2); (2) at a higher elevation south of the East Branch Chippewa River where some small streams entered during a higher stage of the lake (within the Kerkhoven washed-till plain; Fig. 2); and (3) where Tenmile Creek entered the southwest part of the basin (Boyd delta; Fig. 2). Stipple indicates collapsed delta sediment, areas where a delta apparently formed on a buried glacier and possibly on lake ice; the resulting topography is irregular.

Qtsd **Subglacial till**—Dense, homogeneous till of the Marshall, Antelope, and younger phases of the Des Moines lobe. Texture of till matrix is loam to clay loam. Clast rock types include carbonate, crystalline rock, shale (average proportion for Marshall phase, 20–30 percent, for Antelope phase, 30–50 percent), and some lignite. Till surface has low relief. Locally overlain by thin (about 10–20-feet thick), discontinuous, supraglacial and englacial sorted sediment and till that typically form linear ridges. The sediment is interpreted to have been localized by crevasses in stagnant ice.

Qtld **Till with lake-modified surface**—Till that has at its surface a discontinuous, silty, clayey cap or a coarser, near-shore sediment. Till of all phases of the Des Moines lobe and the Big Stone phase of the Red River lobe, and, possibly, older glacial sediment are affected. Till texture, color, and clast lithology are similar to surrounding unit. The till surface has low relief. Erosion may have removed fine sediment, leaving a lag of clasts at the surface. Shorelines are locally marked by very low escarpments, beach ridges, or deltas (sediment of map unit Qdb).

Qtfd **Till with stream-modified surface**—Till modified by flowing water; fluvially eroded and streamlined in places. Till of all phases of the Des Moines lobe and, locally, older glacial sediment are included in this unit. Matrix texture, color, and clast lithology are similar to the original till unit before erosion. Locally overlain by a thin lag of sand and gravel or covered with silt and clay. Channel scars are common. Channels may localize organic deposits (map unit Qoh), lakes, and modern streams and flood waters. After stream modification, channels may have collapsed from meltout of buried ice.

Qtad **Till of the Antelope moraine**—Till that forms a low, broad ridge. Matrix texture is loam to clay loam; yellow brown where oxidized, gray where unoxidized. Clast rock types include carbonate, crystalline rock, a moderate to large proportion of shale (30–50 percent), and some lignite. The Antelope-phase ice margin is otherwise indicated by deposits of ice-marginal and ice-supported streams (Antelope Hills and Big Tom hills ice-supported-stream ridges; map unit Qssd; see also Fig. 2).

Qtmd **Till modified by slope processes**—Till along the slope of the Coteau des Prairies (a glacial erosional scarp); modified by slope wash, mass movement, and ice-marginal streams. Matrix texture is loam to clay loam; yellow-brown where oxidized, gray where unoxidized. Clast rock types include carbonate, crystalline rock, a low to moderate proportion of shale (10–20 percent), and some lignite. In the map area, this part of the Coteau slope was exposed after the Gary phase of the Des Moines lobe, but older units, including pre–Late Wisconsin units, may be exposed locally.

Qthd **Hummocky till**—Till that has an irregular surface expression and contains discontinuous lenses of clay, silt, sand, and gravel. Clast rock types include carbonate, crystalline rock, a low to moderate proportion of shale (10–20 percent), and some lignite. Unit is interpreted to have been deposited during the Altamont and Gary phases of the Des Moines lobe on and beneath stagnant, wasting ice, and it may have been subject to repeated mass movement during deposition. Unit includes small areas of supraglacial lake and stream sediment. Much of the relief is inherited in the northeast corner of the map area: the till there buries an older moraine of an ice advance from the northeast, and the till texture reflects the more sandy till of the underlying Alexandria moraine (Alexandria highlands; Fig. 2).

Qsd **Stream sediment**—Sand and gravel deposited by meltwater issuing from stagnating or receding ice of the Altamont and younger phases of the Des Moines lobe. Includes sediment of contemporaneous nonglacial streams, as well as younger and finer glacial and postglacial stream sediment. Broadly arcuate streams delimit former ice-margin positions (Marshall phase, Antelope phase, and possibly younger phases).

Qssd **Stream sediment formerly supported by ice**—Ridges of sand and gravel deposited by streams; some glacial sediment was deposited by gravity flow into channels. Interpreted to have been deposited in channels that were walled, supported, or enclosed by ice (eskers in the broadest definition of the term). Melting of ice may have led to local disruption of bedding. A significant amount of unsorted, glacial sediment may overlie the sorted sediment. Areas of this unit too small to delineate at the map scale are indicated by a line symbol (minor linear ridges; see Description of Map Symbols).

Qsld **Stream sediment overlain by lake sediment**—Similar to stream sediment (map unit Qsd) but buried by thin layers (generally less than 10 feet thick) of clay, silt, fine sand, and organic deposits. Streams flowing down the Coteau des Prairies slope deposited fans (for example, Canby fan; Fig. 2) that blocked streams flowing southeast between the base of the slope and the ice margin. The unit is also present where glacial streams backed up owing to some other type of constriction.

Qgl **Sediment of ice-walled glacial lakes**—Lake sediment in a high topographic position. Deposited in pools in stagnant ice. Fine sediment (clay and silt) may be rhythmically bedded near former lake centers; minor amounts of sand and gravel are present along former lake rims. Unit commonly contains thick, till-like, debris-flow deposits. Forms flat-topped circular uplands within hummocky till terrain in the southwest and northeast corners of map area.

PROTEROZOIC AND ARCHEAN

PA **Gneiss and granite, undivided—**Archean quartzofeldspathic gneiss; granitoid intrusions and low-grade greenstone belts. Exposed mostly along the bottom of the Glacial River Warren channel (present-day Minnesota River Valley), where overlying glacial sediment and weathered rock (saprolith) have been eroded. Saprolith is still preserved in some protected locations. The smoothly undulating rock surface is interpreted to have formed through chemical weathering while the rock was buried by thick regolith. Glacial and fluvial erosion selectively stripped away the regolith but has made only the minor modifications to the rock surface of striae, crescentic fractures, polish, and potholes.

DESCRIPTION OF MAP SYMBOLS

Geologic contact—Approximately located; established from aerial photographs, geomorphology, and examination of surficial material and soil maps.

Scarp—Ticks point down scarp; established from aerial photographs and topographic maps. Where paired, interpreted as former drainageway. Not indicated where scarp coincides with stream-related unit. In places, drainageways contain organic material, lake sediment, and stream sediment; the deposits are commonly too small in area, too thin, or too discontinuous to map. Former drainageways may locally control the direction of present-day surface and near-surface water flow, especially flood waters. Scarps shown on the Kerkhoven washed-till plain (Fig. 2) are interpreted as having been lake cut and therefore represent former shorelines.

Deep, broad, irregular trough—Interpreted as collapsed subglacial channel (tunnel valley) or buried valley. Some troughs now contain long narrow lakes, such as Lake Hendricks in the extreme southwest corner of the map area.

Fan-shaped sloping hill at mouth of channel—Interpreted to be an alluvial fan (for example, Canby fan; Fig. 2) or a delta into a lake (Boyd delta; Fig. 2) composed of sand, gravel, and silt. Where shown on till of the Big Stone moraine (map unit Qtbr), the symbol indicates a fan-shaped lobe of till (not sorted sediment) that flowed into the lake basin.

Crest line of moraine.

Minor linear ridges—Discontinuous ridges that are generally less than 15 feet high. Visible in areas of thin supraglacial debris. Texture varies from till that is slightly coarser than is found in surrounding area to sand and gravel. Chaotic and collapsed deposits. Interpreted to be sediment localized by low areas, such as crevasses and supraglacial stream channels, in the disintegrating glacier and along the ice margin.

Steep-sided mound of sorted sediment (kame)—Stream sediment deposited on, beneath, or along wasting ice that subsequently collapsed as the ice melted.

Circular depression—Small, generally circular pit that may contain water, lake sediment, or peat, depending on the local water-table elevation. Interpreted to have formed through melting of buried chunks of ice. Very common in certain parts of the Big Stone moraine.

ACKNOWLEDGMENTS

Field work was conducted by Carrie J. Patterson, Alan R. Knaeble, Sara E. Gran, and Stephanie J. Phippen; additional assistance in the field was provided by Thomas Hooyer, Tammy Rittenour, and Heather Anderson. Terrence J. Boerboom mapped bedrock outcrops. The data base was compiled by Barbara A. Lusardi and Emily J. Bauer; wells were located in the field by Tammy Rittenour, Angela Whitney, Heather Anderson, Eric Olsen, and Stacy Foss. Canoe support was provided by Philip Heywood. Special thanks are owed to the staff at the Upper Sioux Agency State Park (especially Terri Dinesen) and Lac qui Parle State Park for their friendly assistance. The staff at the Minnesota Department of Natural Resources fisheries office in Ortonville provided access to the outcrops on Big Stone Lake. Retired soil scientist Raymond Diedrick shared unpublished information on glacial Lake Benson. David Craigmile, local resident and amateur geologist, contributed observations, interest, and encouragement. J.F.A. Cotter, A.C.R. Campos, H.E. Wright, Jr., and C.L. Matsch provided valuable comments in the field.

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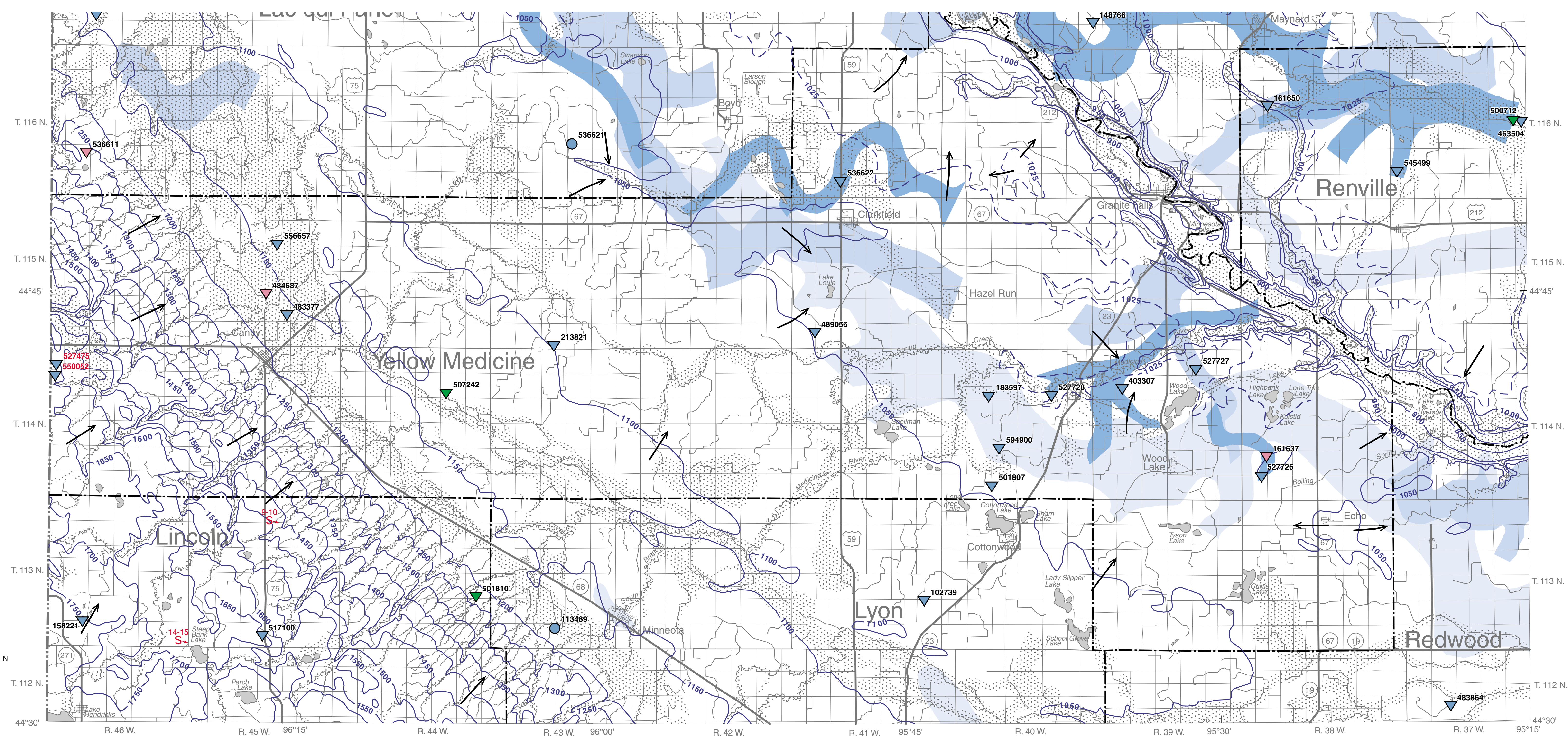


SCALE 1:200 000

5 0 5 10 Miles

5 0 5 10 Kilometers

Contour Interval 50 Feet

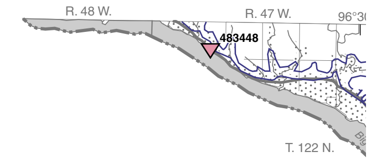
Supplementary Contours Shown in Selected Areas

Digital base map composite:
Roads and county boundaries - Minnesota Department of Transportation GIS Statewide Base Map (source scale 1:24,000)
Hydrologic features - U.S. Geological Survey Digital Line Graphs (source scale 1:100,000)
Digital base map annotation - Minnesota Geological Survey.

Project data compiled from 1997 to 1999 at the scale of 1:200,000. Universal Transverse Mercator projection, grid zone 15, 1983 North American datum. Vertical datum is mean sea level.

GIS and cartography by Randy McGregor. Edited by Nick Kroska. Digital assembly by Nordic Press.

GIS data and metadata available through the Ground Water Mapping Program website:
http://www.dnr.state.mn.us/waters/programs/gw_section/cgarha/index.html



SURFICIAL HYDROGEOLOGY

By
Randy Bradt and James A. Berg
2000

INTRODUCTION

The Upper Minnesota River Basin Regional Hydrogeologic Assessment focuses on ground-water occurrence, movement, and chemistry on a regional scale. The study area spans a large portion of the Minnesota River headwaters. The Minnesota River bisects the study area from northwest to southeast. The aquifers within and beneath the fine-grained sediments provide most domestic water supplies. The significant fraction of readily soluble minerals in these sediments helps to explain the high dissolved mineral content in ground water for most of the aquifers in the area. Data collected from 84 wells included general water chemistry; radioactive isotopes of hydrogen and carbon; and stable isotopes of sulfur, hydrogen, and oxygen.

GROUND-WATER OCCURRENCE AND MOVEMENT

Water Table

Water infiltrating the land surface moves generally downward through unsaturated soil and geologic materials. This water eventually reaches the water table, which is the surface that separates saturated sediments from overlying unsaturated sediments. The water table is commonly referred to as an unconfined surface; this means the pressure exerted on this surface is equal to atmospheric pressure. Most wells in the region, however, are completed in buried aquifers that generally have water that is under greater than atmospheric pressure. These buried aquifers are referred to as confined aquifers.

Contour lines on the map provide a regional depiction of the water-table surface. Delineation of the water-table contours relied on information available in the County Well Index (CWI) data base maintained by the Minnesota Geological Survey, including depth to water measurements taken when wells were drilled. Since only 6 percent of the wells listed in the data base for this study area are screened in a water-table aquifer, and these few wells are geographically limited, additional information was needed to determine depth to the water table. Water-table elevations were inferred where the water table is expressed at some lakes, streams, and wetlands. The water elevations for these features were obtained from U.S. Geological Survey (USGS) 1:24,000-scale topographic maps. Depth to water table was also determined using seismic refraction, which measures differences in the physical properties of saturated and unsaturated geologic materials to locate the water-table surface. Results obtained from eight locations show areas with low-relief topography generally have a shallow (less than 20 feet below land surface) water table, while high-relief areas have deeper water tables, sometimes more than 50 feet below land surface. In most of the study area, the water table approximates a subdued surface topography. Contours of surface elevations generated from the USGS 1:24,000-scale Digital Elevation Model (DEM) were used to guide placement of the water-table contours.

Flow arrows on the water-table map illustrate the regional ground-water flow directions in the near-surface geologic sediments. The rate of ground-water flow depends on the ability of these sediments to transmit water (hydraulic conductivity) and the slope of the water-table surface (hydraulic gradient). The mapped geologic materials shown on Plate 1, Part A, can be subdivided into two general categories: the more permeable sand and gravel stream deposits (speckled pattern on the map) and less permeable loam to clay tills or lake deposits. The actual rate of ground-water flow through geologic materials in the two permeability categories is determined by the hydraulic gradient, which is reflected in the spacing of the water-table contours. More closely spaced contours indicate a steeper hydraulic gradient and faster ground-water movement.

Aquifers

Aquifers are porous and permeable geologic materials that yield sufficient quantities of water to wells for the intended use. Most wells in the study area are completed in Quaternary sand and gravel deposits. Locally important aquifers include Cretaceous sandstones and fractured Precambrian bedrock. Precambrian igneous and metamorphic rocks underlie the entire study area. Few wells are completed in Precambrian rocks because the yields are generally poor. They are used only when overlying Quaternary or Cretaceous aquifers are either absent or do not yield sufficient water for the intended use. The supply potential for Precambrian aquifers generally ranges from a few gallons per minute (gpm) to several tens of gpm. Wells are often drilled deeply into the Precambrian rocks in order to intersect as many fractures as possible and to provide storage space for water between pumping intervals. Less than 2 percent of the wells listed in CWI are completed in Precambrian rocks, and most of these wells are found along the Minnesota River in the southeastern part of the study area.

Cretaceous sediments overlie Precambrian rocks in approximately half the study area (see Figure 3 on Plate 2, Part A) and are generally found southwest of the Minnesota River. Cretaceous sediments consist of interbedded shale, siltstone, and sandstone and have thicknesses mapped by Setterholm (1990) exceeding 600 feet southwest of the City of Canby in Yellow Medicine County. Approximately 12 percent of the wells in CWI are screened in Cretaceous sandstones; these wells range in depth from less than 50 feet to more than 400 feet below land surface. Wells completed in Cretaceous aquifers are common in areas where the overlying Quaternary aquifers are absent or lack sufficient yield. Woodward and Anderson (1986) reported that yields for Cretaceous aquifers are generally from a few gpm to several tens of gpm.

During the past 800,000 years, several glacial advances have deposited a complex series of glacial sediments that are more than 600 feet thick in northern Lincoln County and eastern Swift County. In the rest of the study area, the sediments are generally less than 300 feet thick. Most of these deposits are glacial tills, which are unsorted mixtures of clay, silt, sand, and gravel. Other important sediments include lake deposits, which primarily consist of clays, silts, and a few fine sands. Some of the most extensive lake deposits are associated with glacial Lake Benson. Rittenour, Geiger, and Cotter (1998) interpreted glacial Lake Benson to have a maximum depth of 60 feet; therefore, the lake sediments are less than 60 feet thick. During each glacial retreat, meltwater streams from the glaciers deposited sands and gravels, generally referred to as outwash. Some of these deposits formed networks of long, narrow meltwater channels, while others were more widespread such as the delta deposits. Subsequent glacial events buried these potential aquifers beneath confining materials, including tills and lake sediments.

Thicknesses of the outwash deposits vary from a few feet to more than 100 feet in some locations. A median thickness of approximately 8 feet was determined using CWI well log information for both surficial and buried outwash deposits. In plan view, outwash deposits commonly occur in dendritic patterns that reflect their deposition by streams. In cross-section, outwash deposits appear as lenticular, thin, and discontinuous, but they commonly yield enough water for domestic water needs. Most of the wells listed in CWI are completed in buried outwash deposits. Buried aquifers are indicated on this map where they are at least 20 feet thick and information is sufficient to determine their areal extent. These aquifers are color-coded according to stratigraphic position to match the aquifer classifications in Figures 3, 4, and 5 on Plate 2, Part A. The last glacial retreat deposited surficial sand and gravel mapped as either stream or delta sediment on Plate 1, Part A. Approximately 25 percent of the study area is mapped as having sand and gravel at or near the land surface (speckled pattern on the map). Few wells are completed in these deposits because most of the sediments are too thin to provide a useable water supply. In addition, the sediments are commonly associated with floodplains, which have building and well construction limitations. Some of the thickest deposits, sometimes exceeding 50 feet, are located near the City of Appleton and along the Pomme de Terre River. Most of the irrigation wells in the study area are completed in deposits at these locations. Yields of wells completed in Quaternary deposits are extremely variable primarily because of variations in aquifer thickness and areal extent and hydraulic properties of aquifer materials. Quaternary aquifers will generally yield less than 100 gpm (Kanivetsky, 1978). However, numerous wells, especially near the City of Appleton, have yields from several hundred gpm to more than a thousand gpm.

Recharge and Discharge

Recharge to the water table occurs throughout the study area by infiltration of precipitation, surface runoff from areas of lower to higher infiltration, and subsurface ground-water movement from adjacent areas. Sources of recharge include some lakes and wetlands and short reaches along stream segments. Water-table elevations fluctuate in response to seasonal variations in recharge to and discharge from the ground-water system. Spring rain and snowmelt are major sources of recharge to surficial aquifers and cause water levels to rise significantly. During the summer, evapotranspiration uses most of the available precipitation and recharge to the water table is negligible. When recharge does occur in the summer, it likely coincides with significant rainfall events. Recharge can also occur in the fall, depending on rainfall, runoff, and evapotranspiration rates. Water levels decline in the winter, when precipitation is stored on the land surface as snow, and typically reach a low point before spring thaw.

Recharge amounts to the water table in surficial sand and gravel aquifers in Swift County were estimated by Delin (1986) using hydrographs from 12 observation wells. Annual average recharge estimates ranged from 1.2 inches to 15.1 inches and averaged 6.0 inches. This average is consistent with the findings by Larson (1976) that showed recharge estimates for the same region of 8.4 inches and 5.0 inches for 1972 and 1973, respectively. The recharge amounts to buried aquifers are much less. Exponential increases in ground-water age with well depth observed in this study support this conclusion. For example, if the average annual recharge amount of 6 inches were applied to buried aquifers, the residence time of water in these aquifers would be only a few decades to a few hundred years old. In fact, however, several samples from buried aquifers were age-dated to several thousands of years. Factors determining the amount of recharge to buried aquifers are the vertical hydraulic gradient, which is the head difference between the water table and the water level in the buried aquifer; the thickness of overlying geologic materials; and the geologic materials' hydraulic conductivity.

The amount of water that recharges ground water through wetlands has likely been reduced since the advent of ditching and tiling. Presettlement wet mineral soils and peatlands covered approximately 35 percent of the study area (Minnesota Department of Natural Resources, 1997). The mapped locations of these features are likely areas where wetlands existed prior to the advent of tiling and ditching. Today only 5.5 percent of the area is wetlands and lakes according to the National Wetlands Inventory. Some of the potential recharge to ground water is now redirected by agricultural tiling and ditching (Magner and Alexander, 1994). Drainage tiles intercept infiltrating water, discharging it directly to river systems via ditches.

Ground-water discharge occurs both naturally and artificially. Regionally, natural discharge occurs as ground water flows from topographically high areas toward the Minnesota River. Locally, ground water discharges toward topographically low areas, wetlands, streams, and lakes. The contribution of ground water to wetlands and streams, for example, is evident during drought when streams continue to flow and wetlands do not dry up. Artificial discharge is represented by pumping from wells, which accounts for an increasing proportion of ground-water discharge. Artificial ground-water discharge could significantly reduce the amount of water available to wetlands, streams, and other surface water bodies.

WATER CHEMISTRY

The chemical evolution of ground water begins as surface water and precipitation infiltrate below the land surface. The chemistry of the water changes as it percolates through soil and geologic material. Factors affecting ground-water chemistry include land use, initial water chemistry, length of flow path, chemical reactions, and residence time.

Water samples were collected for chemical analysis in 84 wells from autumn 1997 to autumn 1998. Seventy-eight of these samples were collected from wells completed in Quaternary deposits (only two of these samples represent water-table wells), and six samples were from wells completed in Cretaceous deposits. Sampling locations are indicated on the map, and the chemistry results are summarized in Table 1 according to aquifer type. The chemistry results were used to characterize water resources and to evaluate ground-water recharge processes.

Water Quality Indicators

As water infiltrates into the subsurface, it accumulates additional carbon dioxide (CO_2) gas from decaying organic material. Dissolution of carbonate minerals in sediments is limited by the amount of dissolved carbon dioxide, which in turn controls the amount of dissolved calcium, magnesium, and bicarbonate. Water hardness is the sum of dissolved calcium and magnesium. Ground water from most sampled wells was very hard.

Another measure of water quality is the total dissolved mineral concentration in water samples. The 84 samples collected in this study had reported values for total dissolved solids (TDS) ranging from 298 milligrams per liter (mg/L) to 2,599 mg/L. Most samples exceeded the U.S. Environmental Protection Agency's (EPA's) secondary standard for TDS of 500 mg/L. Other chemical constituents commonly exceeding EPA's secondary standards include sulfate (SO_4), iron (Fe), and manganese (Mn). Excessive quantities of these chemicals may give water an objectionable taste or odor, stain laundry and porcelain, or even plug well screens. The lowest TDS and sulfate concentrations in the sampled wells are found in the northeast, primarily eastern Swift County. This water chemistry likely represents a difference in the mineralogy of subsurface glacial sediment in that area. In the northeastern part of the study area, Des Moines lobe sediments originating from the northwest are thin and overlie glacial sediment originating from the northeast (C. Patterson, oral commun., 1999). The northeast-sourced glacial sediments are generally not as calcareous and lack gypsum. Glacial deposits of the Des Moines lobe incorporated materials that are more calcareous and are commonly associated with gypsum.

Nitrate (reported as nitrogen [NO_3-N]) at concentrations greater than 1 mg/L is an important indicator of human impacts on ground water. Principal sources include septic systems, feedlots, and agricultural chemicals. EPA's primary public water supply standard for nitrate, 10 mg/L, was exceeded in only one of the 84 sampled wells, and two other wells had elevated levels (greater than 1 mg/L). The low frequency of elevated nitrate concentrations in most of the sampled wells may have two explanations. First, nitrate is usually found in near-surface ground water, but most of the wells sampled in this study are screened below the water table in aquifers overlain by low-permeability glacial sediments. Second, biologically mediated nitrate removal (denitrification) may have occurred. The oxygen-poor (anoxic) ground water commonly found in buried aquifers and deeper parts of some water-table aquifers is a likely environment for denitrification.

Chloride (Cl) is another parameter that may indicate human impacts on ground water. Artificial sources of chloride include road salt; fertilizers; and industrial, human, and animal wastes. Several of the sampled wells in this study may have chloride from contaminant sources. Natural sources of chloride include precipitation and Cretaceous shale. Interpretations of chloride sources for individual wells are inconclusive because elevated natural sources of chloride levels were also encountered in some Cretaceous and buried glacial aquifers.

Major Ion Water Chemistry

The Piper trilinear diagram (Figure 1) shows the water chemistry results graphically. The sample points on each triangle (ternary diagram) reflect the percentages in milligram equivalents per liter (meq/L) of the major cations and anions in each sample.

The lower left ternary diagram of Figure 1 compares the major cations for calcium, magnesium and sodium, plus potassium. There is a fairly constant ratio of calcium to magnesium throughout the study area superimposed on a trend toward sodium-rich water. As waters containing calcium and magnesium pass through clays and shales, adsorbed sodium is exchanged into the water. This process is similar to how a household water softener works. Higher levels of strontium (Sr) associated with higher proportions of sodium support this ion exchange hypothesis.

The lower right ternary diagram compares the major anions, bicarbonate, sulfate, and chloride plus nitrate. Samples tend to plot along a narrow band ranging from bicarbonate-rich waters with low TDS toward sulfate-rich waters with higher TDS limited by the solubility of gypsum. Sulfate concentrations range from less than 1 mg/L to 1,630 mg/L. Common sources of sulfate are dissolution of gypsum and oxidation of sulfide minerals. Sulfate is one of the dominant components of TDS values for this study area. Based on the five sulfur isotope (delta [δ] ^{34}S) values in Table 2, most of the sulfate originates by the oxidation of sulfides ($\delta^{34}S$ = -20 to 0 per mille [parts per thousand or ‰]) and not from gypsum dissolution ($\delta^{34}S$ = +15 to +25‰) (Clark and Fritz, 1997). The central diamond-shaped field shows the overall chemical behavior of the ground water by plotting a third point representing the intersection of rays projected from the cation and anion triangles. An example is shown in the Piper diagram.

Aquifer Water Chemistry

The chemistries of water samples from Cretaceous aquifers completely overlap the range of chemistries in Quaternary aquifers (see Figure 1). This observation is not surprising since large amounts of Cretaceous materials are incorporated into the glacial drift. The wide scattering of points on the diagram illustrates the wide variation in major ion water chemistry for both Cretaceous and Quaternary aquifers. The amount of dissolved minerals in ground water in the study area apparently evolves in a fairly short period of time, a fact supported by the absence of a relationship between the total dissolved mineral content and the observed residence time (as determined by tritium). Residence time refers to the time that ground water has resided below the land surface. This means that most of the dissolved mineral content of ground water results from chemical evolution that occurs in less than 45 years.

The cation exchange with sodium observed in some samples is associated with waters having a greater than 45-year residence time. Conversely, samples younger than 45 years were not observed to have evidence of cation exchange. One possible explanation is that in sediments presently containing water with less than a 45-year residence time, any available sodium was exchanged and removed at an earlier time. It is also possible that these sediments never had sodium available for exchange.

Environmental Isotopes

Ground-water residence time. All 84 wells were sampled for tritium, an isotope of hydrogen. Tritium is a naturally occurring radioactive isotope of hydrogen with a 12.5-year half-life that is useful for estimating ground-water residence time. Before 1954, natural levels of tritium were about 3 to 5 tritium units (TU). Atmospheric testing of nuclear weapons during the 1950's and 1960's increased the tritium in precipitation more than a thousand-fold. Water that recharged before 1954 has lost most of its tritium by decay over several half-lives. The presence of more than about 8 TU in ground water indicates that recharge occurred since 1953 (modified from Alexander and Alexander, 1989).

Ground-water movement can be interpreted by relating the presence of tritium to well depth. Approximately 25 percent of the sampled wells contained detectable levels of tritium. Ground water less than 50 feet below the land surface will likely have measurable tritium, although two of the three wells sampled in this depth range did not have tritium. Less than half of the sampled wells screened at depths between 50 and 100 feet had detectable tritium. This depth range probably represents the maximum that tritium has penetrated since 1953. Only 16 percent of the sampled wells greater than 100 feet deep had tritium. This percentage likely overestimates the probability of tritium being present in wells greater than 100 feet deep. Well construction problems and geologic conditions may account for tritium being observed deeper than expected. For example, two wells completed at 150 feet and 215 feet deep had low but detectable levels of tritium. The two wells are close to each other and located southeast of the City of Appleton where some of the thickest sand and gravel aquifers in the entire study area are found. In the Appleton area (Figures 4 and 5 on Plate 2, Part A), some surficial sand and gravel deposits may be in direct connection with buried sand and gravel deposits. In these areas, water containing tritium could travel deeper into the aquifer system.

Wells completed deeper than 100 feet generally had water with no tritium. For these wells, the radioactive isotope of carbon was used to estimate ground-water residence time. Nine samples were collected for carbon-14 (^{14}C) age dating in wells ranging from 109 feet to 453 feet deep (Table 2). In addition, a 61-foot-deep well containing tritium was also sampled to calibrate the carbon-14 model.

The age-dating results show that water more than 100 feet below the land surface generally has a residence time from 1,000 to 9,000 years before present. The relatively young waters found in aquifers within 100 feet below the land surface suggest the presence of local and intermediate flow systems that recharge and discharge over shorter distances and times. The much older waters in aquifers below 100 feet are more likely to be associated with regional flow systems, which can discharge many miles from where they receive recharge.

Ground-water source. The 10 samples listed in Table 2 were also analyzed for ratios of stable isotopes of hydrogen and oxygen. The results indicate that ground water in the deep regional flow systems largely originates from precipitation. The $\delta^{18}O$ values reflect the temperatures of the precipitation. Results show small variations that might be related to small climatic fluctuations. There is no indication of water originating from glacial meltwater, which is consistent with the calculated postglacial ground-water ages.

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MAP EXPLANATION

Water Table

1100 — Water table elevation (feet above sea level), contour interval 50 feet

Supplementary contours (25-foot interval)

General direction of ground-water movement

Well Symbols

Shape indicates aquifer type

- ▲ Quaternary water table
- ▼ Quaternary buried outwash
- ● Cretaceous sandstone
- ■ Cretaceous regolith

Color indicates tritium age

- Recent—Waters with tritium concentrations of 8 tritium units (TU) or more entered the ground water after 1953.
- Mixed—Waters with 0.9 to 8 TU are a mixture of recent and vintage.
- Vintage—Waters with less than 0.8 TU entered the ground water before 1954.

Well Labels

113552 Unique well number of well not sampled for carbon-14

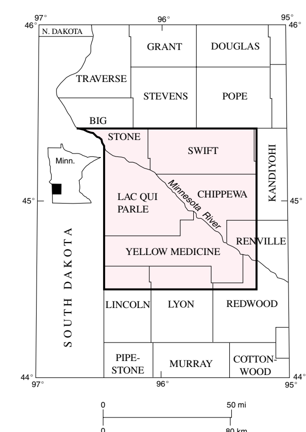
408547 Unique well number of well sampled for carbon-14

Relative Depths of Aquifers

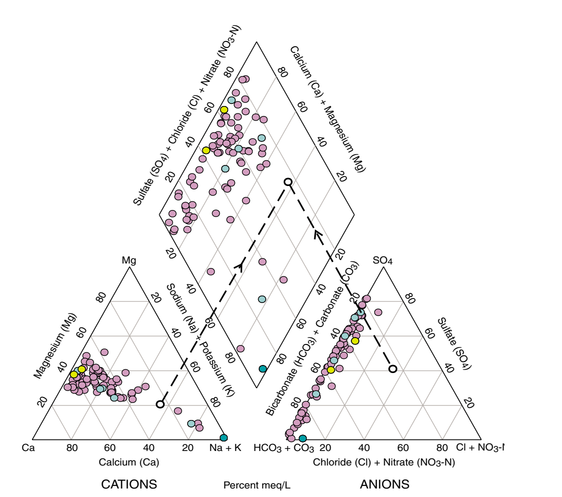
- Surficial sand and gravel. Map units Qdb, Qsd, Qsh, Qsld, Qssd, and Qsw as shown on Plate 1, Part A.
- Shallow Quaternary buried aquifer, elevation 950 to 1000 feet
- Quaternary buried aquifer, elevation 920 to 975 feet
- Sub-Quaternary buried aquifer, elevation 750 to 920 feet.

Seismic Refraction

9-10 S Numbers indicate range of depth in feet to the water table; arrow points to location of the midpoint of transect.



LOCATION OF STUDY AREA



EXPLANATION

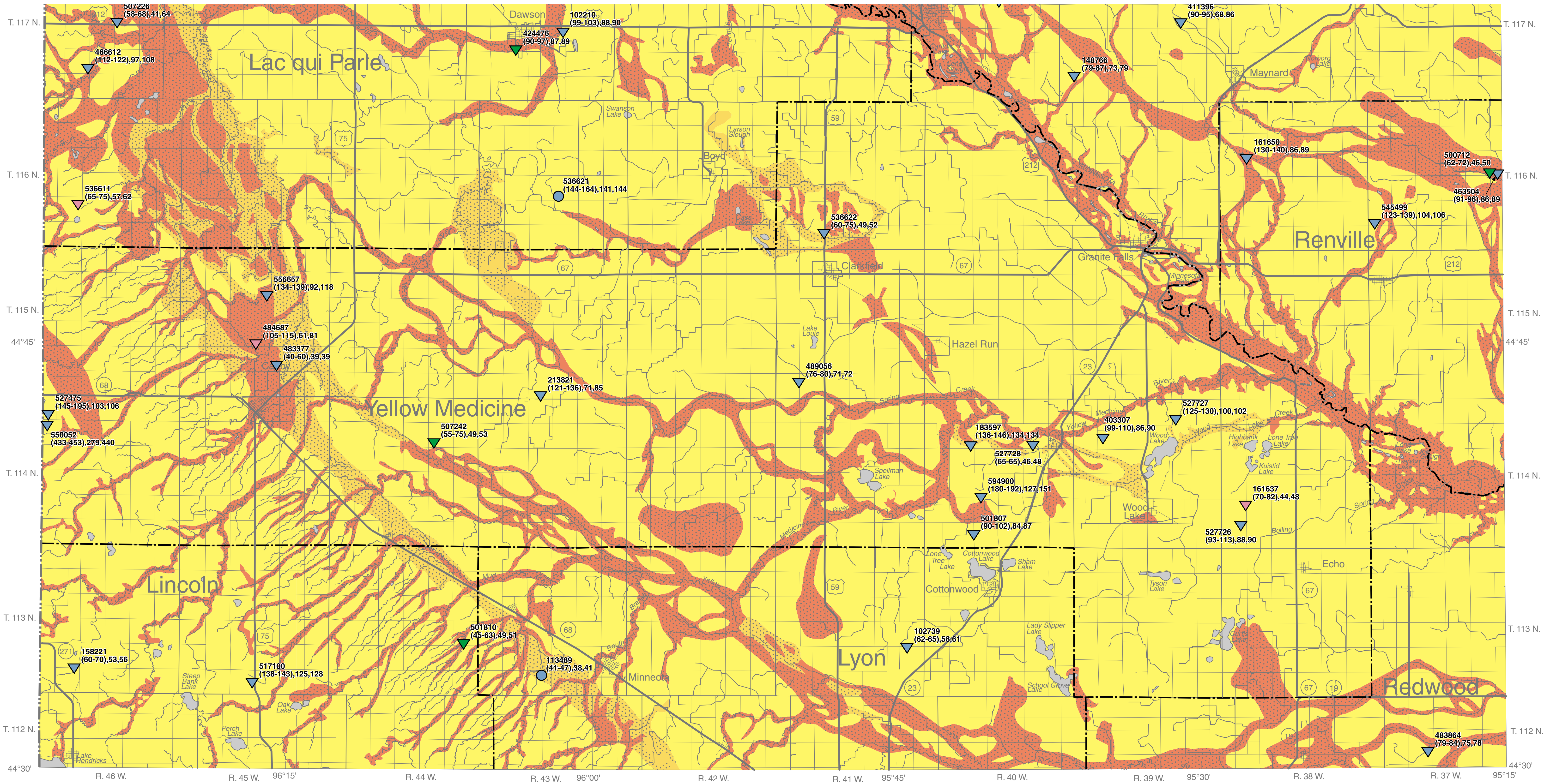
- Quaternary water table
- Quaternary buried outwash
- Cretaceous sandstone
- Cretaceous regolith
- Hypothetical sample point

FIGURE 1. ***Piper trilinear plot of major cations and anions by aquifer classification. Plotted on the lower left and right triangles are points representing the positively charged ions (cations) and negatively charged ions (anions), respectively. The diamond-shaped field combines the components in the triangular fields as shown by the hypothetical sample point.***

TABLE 1. Characteristics of natural waters by aqui

[Samples collected from 1997 to 1998 by Minnesota Department of Natural Resources staff; TDS, total diss
potential expressed in millivolts (mV); TU, tritium units; alkalinity expressed as $CaCO_3$; nitrate (NC

	Well depth (feet)	TDS (mg/L)	pH (pH unit)	Eh (mV)	Dissolved oxygen (mg/L)	Tritium (TU)	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Ir (m
Quaternary Aquifer											
Number of samples	78	78	78	78	78	78	78	78	78	78	7
Number of samples below detection	NA	NA	NA	NA	67	56	0	0	0	0	
Minimum	44	298	6.79	-88	<0.01	<0.8	24.6	9.75	5.39	1.96	<0
25th percentile	75	562	7.21	157	<0.01	<0.8	93	43.6	20.8	4.0	0.
Median	100	858	7.33	239	<0.01	<0.8	140	54.7	42.0	5.8	2
75th percentile	142	1250	7.49	307	<0.01	1.3	190	79.2	95.7	8.0	3
Maximum	453	2599	7.86	644	6.2	30.1	521	183	243	16.2	11
Cretaceous Aquifer											
Number of samples	6	6	6	6	6	6	6	6	6	6	
Number of samples below detection	NA	NA	NA	NA	5	4	0	0	0	0	
Minimum	47	549	7.12	39	<0.1	<0.8	3.0	0.66	22.6	2.1	0.
Median	169	1107	7.33	216	<0.1	<0.8	170	56	142	7.1	2
Maximum	375	1812	8.82	402	0.1	1.0	324	137.1	231	15.3	1



WARNING: This map provides an overview of ground-water contamination potential as interpreted from 1:200,000-scale geologic map information. THIS MAP SHOULD NOT BE THE BASIS FOR EVALUATION OF SPECIFIC SITES.

SCALE 1:200 000

5 0 5 10 Miles

5 0 5 10 Kilometers

Digital base map composite:
Roads and county boundaries - Minnesota Department of Transportation GIS Statewide Base Map (source scale 1:24,000)
Hydrologic features - U.S. Geological Survey Digital Line Graphs (source scale 1:100,000)
Digital base map annotation - Minnesota Geological Survey.

Project data compiled from 1997 to 1999 at the scale of 1:200,000. Universal Transverse Mercator projection, grid zone 15, 1983 North American datum. Vertical datum is mean sea level.

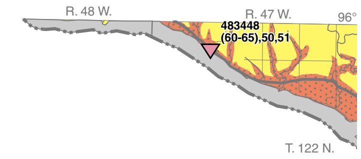
GIS and cartography by Randy McGregor (modified from Minnesota Geological Survey RHA-4, Pl. 1 [Surficial Geology]; digitized by Joyce Meints). Edited by Nick Kroska. Digital Assembly by Nordic Press.

GEOLOGIC SENSITIVITY TO POLLUTION OF NEAR-SURFACE GROUND WATER

By

Randy Bradt

2000



INTRODUCTION

Prevention of ground-water contamination is an important part of water resource management. An important first step is to recognize where ground water is particularly sensitive to pollution. The 1989 Minnesota Groundwater Protection Act requires the Minnesota Department of Natural Resources (DNR) to map geographic areas defined by natural features where there is a significant risk of ground-water degradation from activities conducted at or near the land surface. This plate describes the sensitivity to pollution of the shallow portion of near-surface ground-water systems, including surficial aquifers. The sensitivity map depicts the relative potential for ground-water contamination by using categories of travel time. The travel time categories, ranging from Very High to Very Low, describe the time needed for water-borne contaminants to travel from the land surface to the shallow portion of the near-surface ground water. The map shows that areas mapped as sand and gravel at or near the surface are more susceptible to rapid transport of contaminants than are areas mapped as glacial till and lake sediments. The information on this plate allows planners to include ground-water quality concerns in land-use decisions. The pollution sensitivity map is also useful for directing fiscal resources to areas of greater potential for ground-water contamination.

GEOLOGIC SENSITIVITY

DNR Geologic Sensitivity Guidelines

Geologic sensitivity as described in the DNR guidelines (Geologic Sensitivity Workgroup, 1991) is used to assess pollution sensitivity and prepare maps depicting areas sensitive to pollution. The guidelines focus on travel time: the time it takes for water-borne contaminants to vertically travel from the land surface to the water table. Travel time primarily depends on the permeability and thickness of geologic materials between the land surface and the water table. Geologic materials with the lowest vertical permeability are assumed to have the greatest capacity to retard the vertical movement of contaminants, resulting in the longest travel times. Conversely, geologic materials with the highest vertical permeability are assumed to be least capable of retarding the vertical movement of contaminants, resulting in the shortest travel times. The geologic sensitivity criteria are shown in Figure 1 as five overlapping classes of travel times. Each class is assigned a relative geologic sensitivity rating from Very High to Very Low. The ranges of travel time for each class overlap because of the uncertainty of travel-time estimates. Short travel times do not mean that ground water is or will be contaminated, and long travel times do not ensure that ground water in these areas is or will remain uncontaminated.

Assessing geologic sensitivity requires several simplifying assumptions: (1) contaminants are chemically inert and move with the water, (2) contaminants are released at or near the land surface and move vertically downward, (3) estimates of permeability can be made based on the general knowledge of saturated permeabilities for broad groups of geologic materials, and (4) surficial geologic map units from Plate 1 in Part A are representative of the geologic materials from the land surface to the water table.

Modifications of Vertical Travel Time Concept

Ground-water flow occurs through voids (pores) in the geologic material, which are categorized as either primary or secondary porosity. Primary porosity represents the pore space between grains already present when the glacial sediments were deposited, and secondary porosity is the pore space resulting from fractures, joints, worm burrows, and root traces that developed after the sediments were deposited.

Estimates of travel times to the water table are based on an assumption that flow rates through unsaturated geologic materials are equal to or slower than flow rates through the same materials under saturated conditions. The presence of secondary porosity, however, makes this assumption inaccurate. Several studies from the Midwest and Canada show order of magnitude increases in transmission rates for water as a result of secondary porosity. Although secondary porosity probably accounts for only a small percentage of the total sediment porosity, it can be the route by which a significant percentage of the total recharge reaches the water table.

The presence of secondary porosity significantly decreases or disappears below the water table. In this study, geologic sensitivity is defined as the time it takes water-borne contaminants to travel vertically from the land surface to a target zone, a zone extending from the water-table surface to a depth of 20 feet below the water table (Figure 2). The objective for extending the sensitivity target depth an additional 20 feet below the water table was to ensure that the target zone included geologic material that is not influenced by secondary porosity.

Well drillers and geologists have noted that there is a color change in glacial till sediments at depth. As shown in Figure 2, the upper oxidized zone has lighter brown, yellow, or gold sediments that overlie unoxidized darker gray, blue, or black sediments. As water containing dissolved oxygen enters the till, various minerals in the till are oxidized causing the till color to change. Much of the color change probably can be attributed to the oxidation of iron. As the water moves through the till, microbes remove oxygen from the water. The dissolved oxygen content decreases as water moves deeper into the till until no oxygen is available to oxidize minerals. An approximate median oxidized zone thickness was determined to be 22 feet for this study area based on well log information from the County Well Index (CWI) data base maintained by the Minnesota Geological Survey.

The significance of the oxidized zone is that most till fractures are associated with that zone. Studies by Ruland and others (1991), Hendry (1988), and others have used parameters such as isotopes, general water chemistry, water level measurements, and pump test data to evaluate the hydrogeology of glacial tills. The results show that the oxidized zone can be orders of magnitude more transmissive than the underlying unoxidized till. A study by Grisak and others (1976) determined that fractures could increase a till's ability to transmit water by approximately two orders of magnitude. Fracture density in till is usually greatest near the surface and decreases with depth. The fractures may extend into the unoxidized zone, but their numbers and effectiveness for transmitting water are significantly reduced.

An analysis of depth to water information from the CWI database shows that for most of the study area, the water table probably occurs in the oxidized zone. Because of the presence of fractures in the oxidized zone, there is concern that contaminants could be rapidly transmitted from the surface to the water table and below. However, the role of fractures in ground-water hydrology decreases significantly a few feet below the water table; therefore, a depth of 20 feet below the water table was chosen to define the maximum depth of the target sensitivity zone.

PREPARATION AND INTERPRETATION OF THE SENSITIVITY MAP

The surficial geologic map units from Plate 1 in Part A are the source of geologic information for the sensitivity map. Important textural information can be found in the detailed descriptions of the surficial geologic map units. Additionally, the "Correlation of Map Units" groups various geologic map units according to their mode of deposition and geologic age.

The first group, "ice deposits," contains the following eight mapped glacial till deposits: Qthd, Qtmd, Qtad, Qtfd, Qtld, Qtsd, Qtfr, and Qtbr. The texture of these mapped units ranges from loam to clay. The textures vary not only between the various mapped till units but also within each mapped till unit. The percentage of clay in tills in the study area, reported in Table 1, Plate 2, Part A, ranges from 10 to 40 percent with most tills averaging more than 20 percent. A clay content of 15 to 20 percent was determined to mark a threshold above which hydraulic conductivities are uniformly low (Stephenson and others, 1988). The term hydraulic conductivity refers to the geologic material's ability to transmit water. In a ground-water study involving 12 aquifer tests near the Pomme de Terre and Chippewa rivers, Delin (1986) reported an average vertical hydraulic conductivity for glacial till of 0.025 foot per day. Additionally, a review of water-level data from wells in the region shows that vertical hydraulic gradients are commonly 0.3 or less. Ground-water flow occurs through the pores, which constitute an estimated volume of 30 percent of the total till matrix. If these values are representative of tills in the study area, the calculated flow rate of water through till probably ranges from a few inches to as much as 10 feet per year. The travel time for contaminants moving with water from the land surface to the lower part of the target zone would best be described by a Moderate sensitivity rating for these sediments. This fact means that water-borne contaminants would take from several years to a decade to travel from the surface to the lower part of the target zone. These estimated flow rates are several orders of magnitude slower than flow rates through sand and gravel deposits.

The second group of deposits, "stream deposits," includes the following six geologic map units: Qssd, Qsd, Qsld, Qdb, Qsw, and Qsh. These are generally sorted sand, gravel, and silt-sized sediments that are capable of transmitting water from tens to hundreds of feet per day. Horizontal hydraulic gradients in areas not under the influence of pumping wells are generally low; therefore, actual flow rates are more likely to be from inches to a few feet per day, with most flow moving horizontally. Most of these deposits were rated Very High sensitivity, which means contaminants could reach the lower part of the target zone within a month and possibly within a few hours or days.

Not all of the stream sediments are simply sand and gravel deposits; other factors were considered when assigning a geologic sensitivity rating. Some of the mapped stream deposits are associated with unsorted or fine-grained sediments that are interbedded with or overlie the mapped stream sediments. For example, map unit Qsld is overlain by up to 10 feet of clay, silt, fine sand, and organic deposits. These deposits provide some additional protection, so the sensitivity rating was reduced from Very High to High. Additionally, if Qoh (organic deposits) overlies or is adjacent to stream sediments, a Very High sensitivity rating was assigned. There are also sand and gravel deposits that may be locally unsaturated. For example, map unit Qssd is interpreted as stream sediment that was deposited in channels walled by glacial ice. After the ice melted, these deposits remained as ridges of sand and gravel, which may be unsaturated as a result of gravity drainage. Another stream sediment that may also be locally unsaturated is the glacial River Warren (Qsw) sand and gravel that primarily forms terrace deposits along the Minnesota River. Since insufficient information is available to determine whether a water table is present for all mapped Qsw and Qssd sediments, the water table was assumed to occur within these mapped units, and they were assigned a geologic sensitivity rating of Very High.

The mapped stream sediments, which compose approximately 25 percent of the study area, were all classified as either Very High or High sensitivity. Where these sediments occur, contaminants could rapidly move into the subsurface and contaminate ground water. In some places, a potential pathway for contaminants could exist where a hydraulic connection exists between surficial and buried sand and gravel deposits. Another concern is lateral migration of contaminants. Even though transport of contaminants is vertically restricted by underlying, lower permeability material, they could move laterally through higher permeability sediments until discharging into nearby lakes, wetlands, and streams.

In the third group, four geologic map units (Qgl, Qlb, Qlh, and Qoh) make up the "lake deposits" category. The most widespread deposits are associated with glacial Lake Benson (Qlb), which consists of clay, silt, and some fine sand. The texture of Qoh does not significantly restrict ground-water movement. However, where Qoh occurs within other lake deposits or glacial till, it was assigned a Moderate sensitivity rating. This rating was based on the assumption that the surrounding geologic material also underlies Qoh and best represents the degree of protection provided to shallow ground water. Insufficient information is available concerning the hydrologic characteristics for the remaining three map units (Qgl, Qlb, and Qlh). The textures of these sediments are generally fine grained; therefore, they were assumed to provide a degree of protection similar to the glacial tills in the study area and were thus rated a Moderate geologic sensitivity.

The fourth group is characterized by one map unit (Ꜫ A), the "bedrock" category. Outcrops of these rocks are found in the Minnesota River valley where removal of overlying sediment and weathered rock has exposed various granite and gneiss bedrock. These rock units are characterized by very little primary porosity. Most of the water found in these rocks occurs where fracturing has created secondary porosity. Because the rocks have the potential to rapidly transmit contaminants through fractures and because these rocks are found close to stream sediment (Qsh), they were rated a Very High geologic sensitivity.

USING THE POLLUTION SENSITIVITY MAP

The sensitivity map portrays information that is generalized according to the scale at which it is shown. Enlarging the map could result in a false indication of precision. The sensitivity map does not account for changes in sensitivity as a result of human activities, such as improperly constructed or abandoned wells that may accelerate transport of contaminants to the water table. Additionally, map unit boundaries are a product of the geologic sensitivity assessment model and do not represent absolute differences in sensitivity. Each map unit represents a predominant sensitivity rating; therefore, this map should not be considered a substitute for site-specific information.

EVIDENCE SUPPORTING THE SENSITIVITY INTERPRETATIONS

The pollution sensitivity map is divided into regions having a range of estimated times for contaminants to travel from the land surface to the lower part of the target zone. Verifying the mapped ratings directly is difficult, so measurements of ground-water residence time and water quality are used as indirect tests. Residence time is the approximate time that ground water has resided below the land surface until it is discharged or pumped from an aquifer. Radiometric dating using isotopes of hydrogen or carbon provides estimates of ground-water residence times (Alexander and Alexander, 1989). Tritium (^{3}H), as discussed on Plate 3, is an isotope of hydrogen that is an indicator of recently recharged precipitation. If a ground-water sample has no detectable tritium, the sample is dominated by precipitation that entered the subsurface prior to 1954. Conversely, samples containing detectable tritium have some component of post-1953 recharge.

The wells sampled in this study are plotted on the sensitivity map along with their aquifer type and interpreted tritium results. The tritium information is useful for estimating how deeply water has vertically infiltrated during the last 45 years. The thickness and permeability of geologic materials between the land surface and the aquifer significantly affect the vertical flow rates. Labels posted for each well on the map include the sampling interval, confining score, and depth to the aquifer. This additional information is necessary to clarify the role of various geologic materials in providing protection for aquifers in the study area.

The sampling interval represents the depth to the top and bottom of the well screen through which the sampled water enters the well. The confining score is a calculated value that represents the cumulative thickness of low-permeability material between the land surface and the top of the aquifer. When each well was drilled, the driller recorded the thickness and type of geologic materials and other well construction information on a well log. To calculate a confining score, a value of 1 was assigned for every foot of low-permeability sediment (clay, shale, or till). Sand and gravel offer little protection and were assigned a zero value. Therefore, the confining score is a numerical value representing the cumulative thickness in feet of low-permeability material above the sampled aquifer. The last value reported on the label is the depth in feet below land surface to the top of the aquifer.

Mapped surficial sand and gravel deposits in the study area were interpreted as either Very High or High sensitivity. Several residents with wells completed in these deposits have reported rapid water-level changes that are occasionally associated with muddied water soon after a rain event. Additionally, water samples from these surficial aquifers generally have rather low concentrations of dissolved solids, elevated levels of dissolved oxygen, and detectable tritium. Surficial aquifers are also more likely to have elevated nitrate concentrations. All of these observations indicate rapid infiltration and support the Very High and High geologic sensitivity ratings.

Areas where gneiss or granite bedrock (Ꜫ A) is mapped at the land surface were interpreted as Very High sensitivity. Because so few wells were completed in these deposits, no samples were collected in this study. However, water samples were collected in another study (Bradt, 1997) from wells completed in Sioux Quartzite, a hydrologically similar but more fractured bedrock unit mapped at the land surface near Pipestone, Minnesota. Secondary porosity resulting from fracturing and weathering represents the primary storage and transmission routes for water contained in both Sioux Quartzite and gneiss and granite bedrock. Samples from wells completed in Sioux Quartzite commonly have relatively low concentrations of dissolved solids, elevated levels of dissolved oxygen and nitrates, and detectable tritium. All of these observations suggested recent recharge and supported the Very High and High sensitivity ratings assigned to gneiss or granite bedrock.

Till and lake deposits are portrayed on the map with a Moderate sensitivity rating. No water samples for age dating or general chemistry analysis were available because there are no water-table wells screened in these low-permeability sediments. Wells drilled in these deposits are usually completed in buried glacial sand and gravel deposits within the till or in the underlying Cretaceous sandstone units. Chemical analysis results from wells completed in these buried aquifers were used to estimate vertical recharge rates. Detectable tritium is absent in some sampled wells as shallow as 45 feet deep and detectable tritium is only rarely present in sampled wells more than 100 feet deep. These values may be indicating average vertical infiltration rates from 1 foot to 2.5 feet per year. This interpretation is based on the assumptions that vertical recharge velocities are uniform with depth, no horizontal flow occurs, and wells are providing water strictly from the aquifer where the well is screened. According to these estimated vertical infiltration rates, contaminant travel times from the land surface to near-surface ground water would be years to decades, thus supporting a Moderate sensitivity interpretation.

BURIED AQUIFER SENSITIVITY

Most of the wells in the study area are completed in buried aquifers that are usually located more than 20 feet below the water table. The pollution sensitivity map does not specifically address vertical travel times to these aquifers. In general, most of the buried aquifers are overlain by a sufficient thickness of low-permeability geologic material to be assigned a Moderate or Low sensitivity rating. Carbon-14 age dates ranging from 1,500 to 8,000 years before present support a Very Low sensitivity rating for aquifers more than 100 feet below land surface. The samples were collected from nine wells completed in Quaternary or Cretaceous deposits between 109 and 453 feet deep. As previously mentioned, if vertical flow rates at only 1 foot per year are assumed to be constant with depth, the oldest water from the sampled wells should be 453 years old. The carbon-14 age dates, however, are much older. One explanation for this disparity may be that lateral flow becomes increasingly important with depth. Shallow aquifers may be part of local or intermediate flow systems that have shorter ground-water residence times because recharge and discharge occur over relatively short distances. Deeper wells are probably located within regional ground-water flow systems that have a much longer residence time because of slower movement and longer flow paths from recharge to discharge areas.

Figure 3 is a schematic illustration showing the relationship between the vertical distribution of tritium and representative hydrogeologic conditions for the upper Minnesota River basin study area. The tritium sample results collected from buried aquifers within till suggest that tritium in till probably extends from the land surface to an average depth of approximately 50 feet. This is also where local and intermediate flow systems are found. From 50 to 100 feet deep is a transition zone representing the maximum depth that post-1954 water has infiltrated. Samples from aquifers below 100 feet are rarely found to have tritium; these aquifers are interpreted to be part of the regional flow system.

Figure 3 also shows four conditions in which local geologic and well construction factors could enhance water's ability to travel to the water table or to an aquifer. Condition 1 represents unmapped, localized zones of more permeable geologic materials within till providing a preferential pathway for water to enter the subsurface. Condition 2 shows how an aquifer could appear to be well protected by thick till in one location; however, in other locations the till is thin or absent, thus allowing more rapid recharge at those sites. Following recharge, horizontal ground-water movement transports the recently recharged water to other locations in the aquifer. Condition 3 shows an improperly constructed well acting as a conduit for water to enter from the surface or for water to move from one aquifer to another. Condition 4 is an example of fractures that are likely to be present in glacial tills or lake sediments (modified from Ruland and others, 1991). These fractures can allow water to move more quickly than expected.

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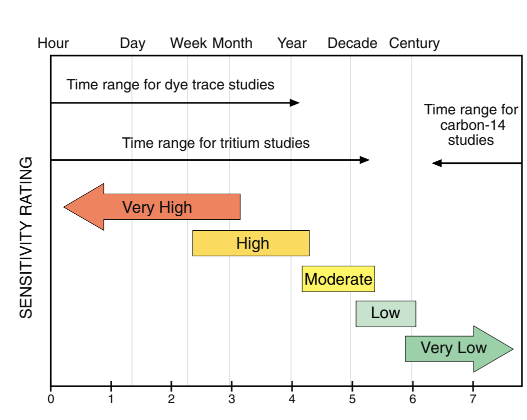


FIGURE 1. *Geologic sensitivity rating as defined by ground-water travel time. Ratings are based on the time required for water at or near the surface to travel vertically to the water table or other ground water of interest. Longer travel times imply a lower sensitivity to pollution. Dye trace, tritium, and carbon-14 studies can indicate the relative ages of ground water.*

MAP EXPLANATION

Sensitivity Ratings

Estimated vertical travel time for water-borne surface contaminants to reach near-surface ground water

VH — **Very High—**The estimated travel time is hours to months. Includes areas of mostly coarse-textured stream sediments, except where overlain by up to 10 feet of finer textured sediments. Also includes exposed bedrock.

H — **High—**The estimated travel time is weeks to years. Includes coarse-textured stream sediments overlain by up to 10 feet of finer textured sediments.

M — **Moderate—**The estimated travel time is years to decades. Includes areas of glacial till and lake deposits.

Well Symbols

Shape indicates aquifer type

▲ Quaternary water table

▼ Quaternary buried outwash

● Cretaceous sandstone

■ Cretaceous regolith

Color indicates tritium age

Recent—Waters with tritium concentrations of 8 tritium units (TU) or more entered the ground water after 1953.

Mixed—Waters with 0.9 to 8 TU are a mixture of recent and vintage.

Vintage—Waters with less than 0.8 TU entered the ground water before 1954.

Well Labels

503579

(335-375), 204, 335

Unique well number

Well information (feet):

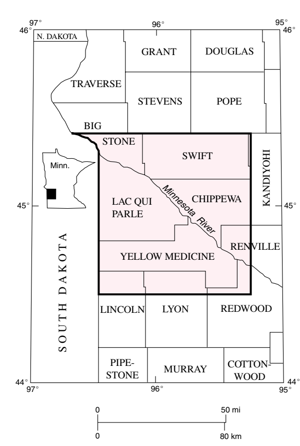
Depth to top of aquifer below land surface

Confining score—Cumulative thickness of low-permeability sediments

Sampling interval (depth below land surface)

Surficial Sand and Gravel Deposits

Map units Qdb, Qsd, Qsh, Qsld, Qssd, and Qsw as shown on Plate1, Part A.



LOCATION OF STUDY AREA

ACKNOWLEDGEMENTS

Mapped buried aquifers provided by Jim Berg represent a significant contribution to Plate 3. Fieldwork assistance for the project was provided by Jeremy Pavlish, Julie Ekman, Mike Liljegren, and John Mackiewicz. Geophysical information was collected and interpreted by Todd Petersen and Jim Berg.

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Appreciation is expressed to Randy McGregor, geographic information systems specialist, and Nick Kroska, technical editor, for their work on this report.

Special thanks are also expressed to the well owners who graciously allowed access to their wells.

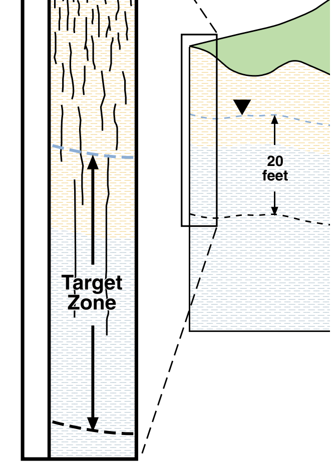

FIGURE 2. *Schematic illustration of target ... downward 20 feet. Fractures and joints in till ... water table surface.*

Appendix C:

Conservation Land Use

Summary Documents

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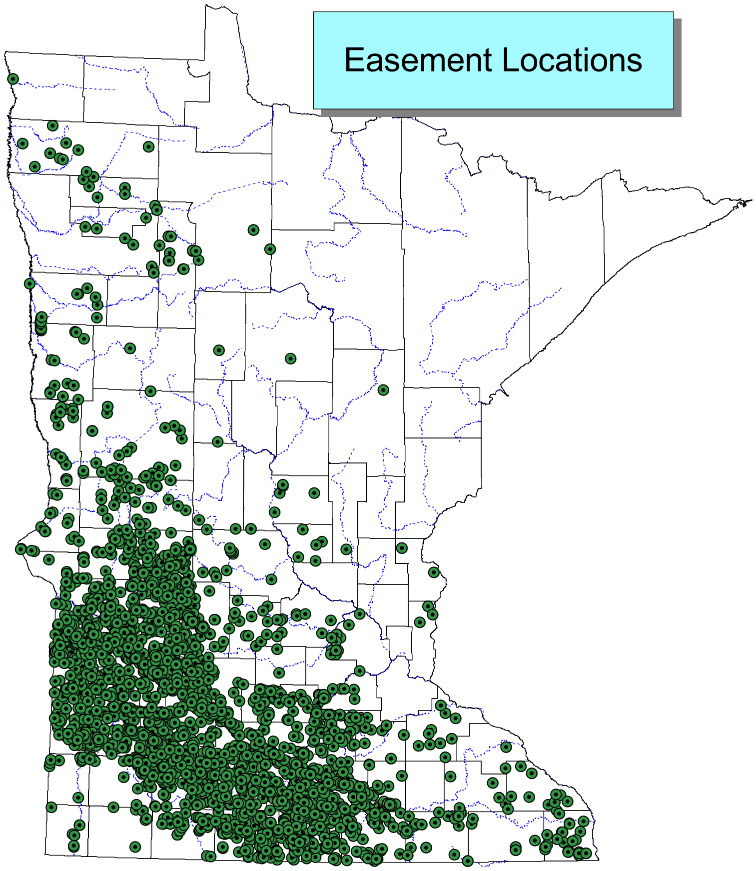
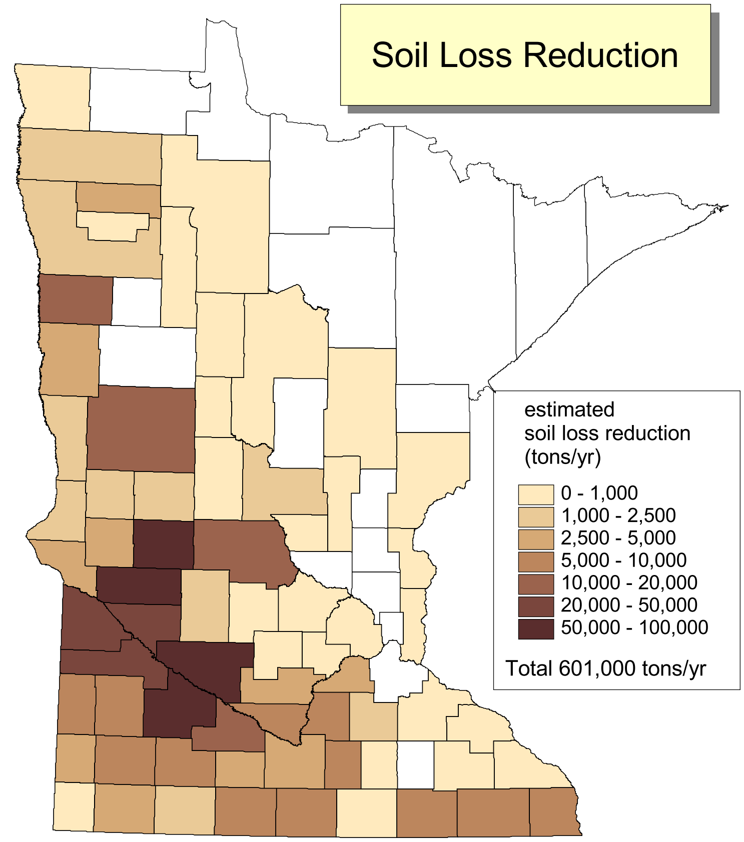
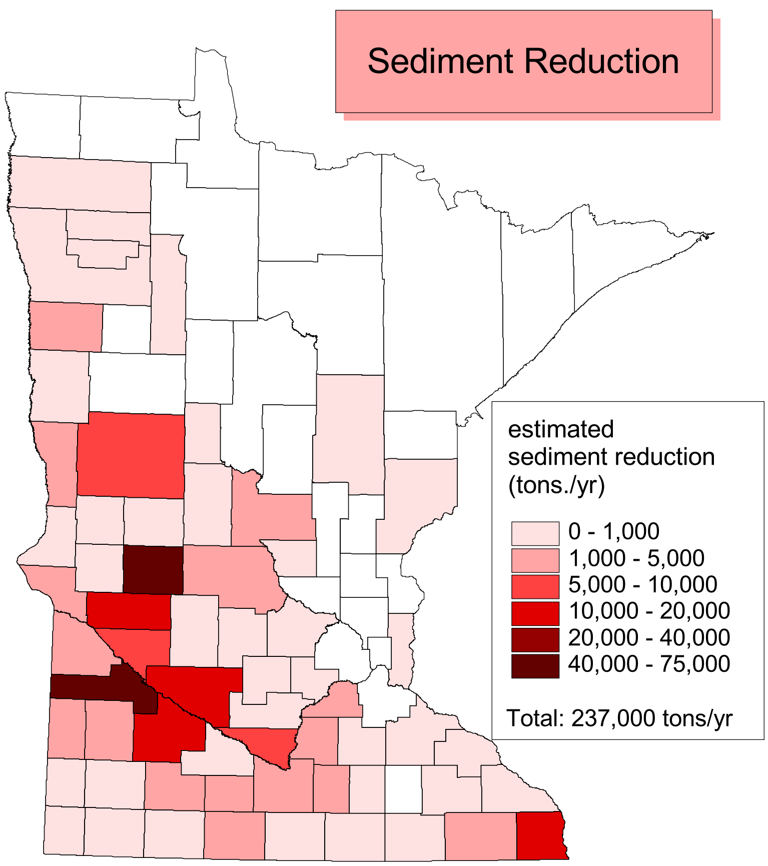
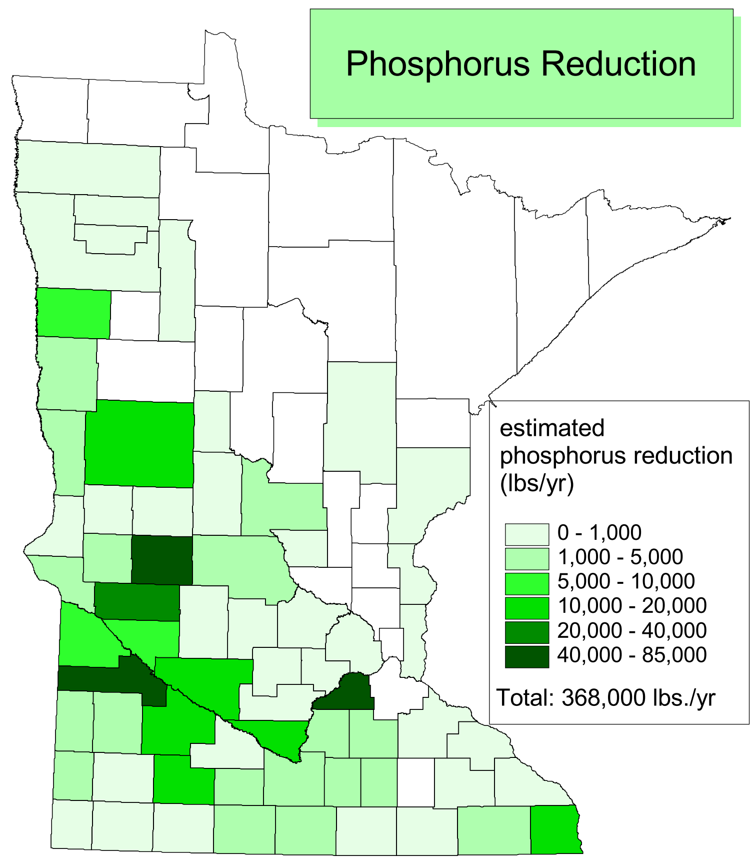
Pollution Reduction Benefits: Easements
(LARS Reporting 1997-2002)









Minnesota Board of Water & Soil Resources - Oct 2003

Minnesota River CREP Easement Summary by County

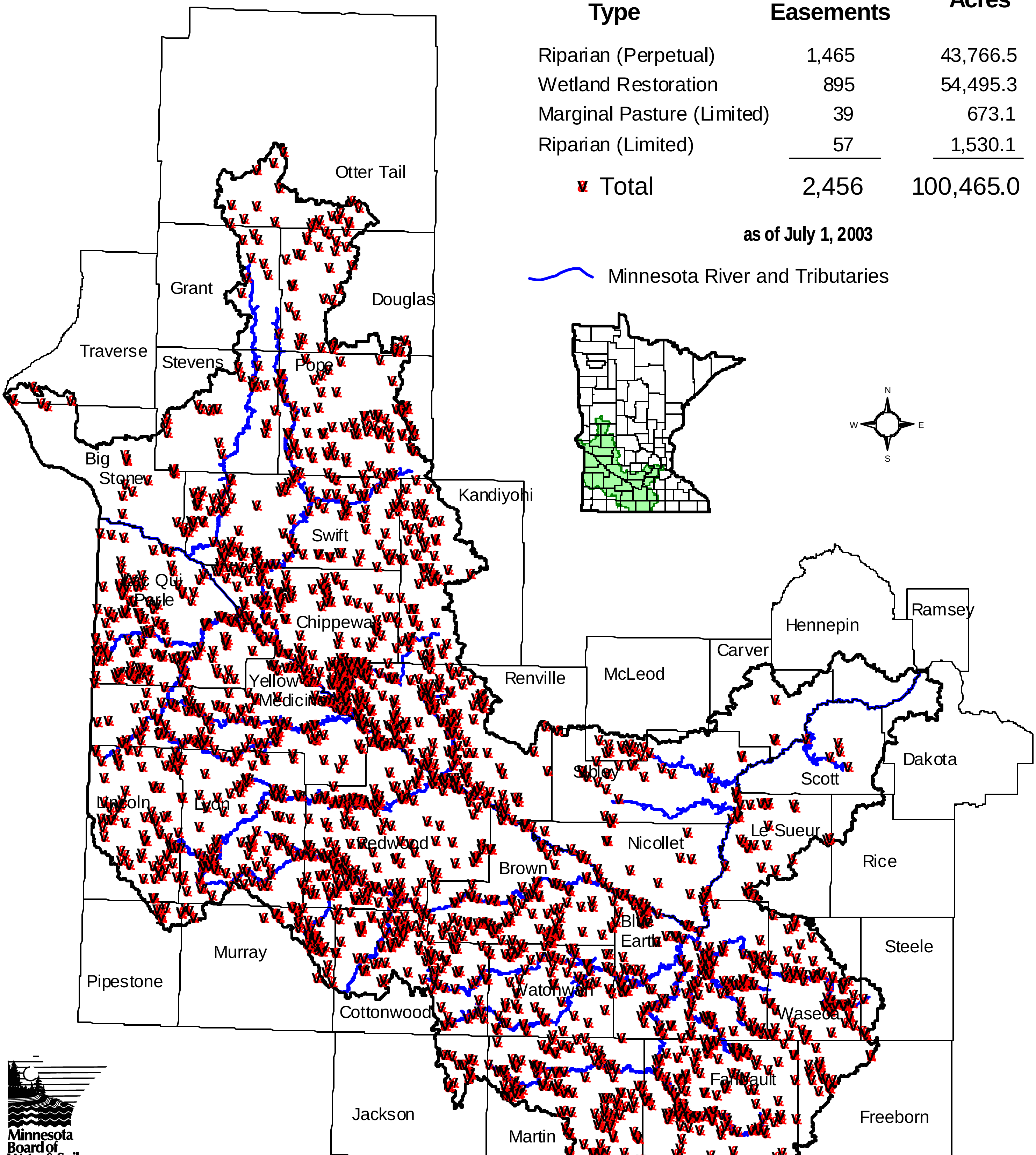
County	Acres	State Dollars	Easements
Big Stone	732.3	$361,061.28	18
Blue Earth	5,329.10	$4,517,746.46	172
Brown	4,968.00	$3,965,637.13	113
Carver	127.40	$81,332.46	3
Chippewa	7,815.70	$5,532,189.78	137
Cottonwood	3,302.20	$2,398,312.33	103
Dakota*	0.00	$0.00	0
Douglas	2,341.80	$1,045,137.37	38
Faribault	3,943.70	$3,387,153.89	153
Freeborn	612.00	$587,368.92	18
Grant	404.80	$220,709.38	9
Jackson	548.40	$434,618.04	15
Kandiyohi	2,973.80	$2,236,468.75	60
Lac Qui Parle	7,823.00	$4,715,801.37	144
Le Sueur	1,077.10	$878,744.95	43
Lincoln	2,868.20	$1,346,425.17	76
Lyon	4,485.10	$3,121,999.09	108
Martin	4,467.00	$3,835,773.69	148
McLeod	860.8	$718,456.61	12
Murray	2,615.80	$1,946,930.22	47
Nicollet	1,107.00	$833,631.84	30
Otter Tail	708.50	$343,382.17	20
Pipestone	217.30	$138,620.34	7
Pope	4,950.90	$2,234,957.90	84
Redwood	8,002.50	$6,162,392.89	210
Renville	9,501.40	$7,174,717.66	236
Scott	118.20	$84,585.32	6
Sibley	908.50	$824,708.91	25
Steele	211.70	$182,522.72	6
Stevens	790.50	$469,406.24	26
Swift	6,072.60	$3,876,940.92	109
Traverse	285.70	$118,317.02	6
Waseca	1,926.60	$1,812,570.32	74
Watonwan	2,914.50	$2,569,620.42	73
Yellow Medicine	5,452.90	$3,308,034.51	127
Totals	100,465.00	$71,466,276.07	2,456

7/1/2003

Conservation Reserve Enhancement Program (CREP) Easements

Easement Type	Number of Easements	Acres
Riparian (Perpetual)	1,465	43,766.5
Wetland Restoration	895	54,495.3
Marginal Pasture (Limited)	39	673.1
Riparian (Limited)	57	1,530.1
Total	2,456	100,465.0

as of July 1, 2003



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MINNESOTA RIPARIAN LANDUSE

100' / 100 yr. Zone

County	Total County Acres	Basin Acres	Riparian Zone Total Acres	Riparian Zone Cultivated	Cult%
REDRIVER MN CREP					
Becker	925,053	663,375	107,751	10,744	**10%**
Beltrami	1,954,919	1,435,347	348,999	7,918	**2%**
Big Stone	338,278	65,317	3,637	1,553	**43%**
Clay	674,348	674,170	49,950	22,319	**45%**
Clearwater	659,003	530,774	41,832	6,851	**16%**
Grant	368,560	242,426	19,382	9,451	**49%**
Itasca	1,872,344	21,063	908	0	**0%**
Kittson	706,936	706,928	127,875	97,052	**76%**
Koochiching	2,017,035	193,858	7,899	14	**0%**
Lake of the Woods	1,138,952	26,639	419	0	**0%**
Mahnomen	373,527	373,526	39,060	8,607	**22%**
Marshall	1,161,057	1,160,876	233,995	142,987	**61%**
Norman	561,579	561,456	94,061	7,403	**8%**
Otter Tail	1,423,942	894,768	171,278	8,415	**5%**
Pennington	395,633	395,633	38,191	28,339	**74%**
Polk	1,279,453	1,279,327	254,144	184,181	**72%**
Red Lake	277,189	277,190	24,576	13,684	**56%**
Roseau	1,074,139	924,934	240,500	112,122	**47%**
Stevens	368,351	91,883	7,384	4,788	**65%**
Traverse	375,284	353,716	31,197	16,669	**53%**
Wilkin	481,181	481,000	53,951	43,304	**80%**
Total Acres	18,426,763	11,354,204	1,896,990	726,400	**38%**
SE MN CREP					
Blue Earth	489,720	1,707	74	50	**67%**
Dakota	374,972	296,956	45,319	18,148	**40%**
Dodge	281,158	281,158	20,891	12,727	**61%**
Faribault	461,621	434	3	2	**57%**
Fillmore	551,448	551,394	48,518	13,828	**29%**
Freeborn	461,950	361,146	26,462	13,397	**51%**
Goodhue	499,082	499,006	74,125	20,781	**28%**
Houston	363,934	363,770	74,795	17,306	**23%**
Le Sueur	303,015	92,808	20,000	3,141	**16%**
Mower	455,000	454,960	40,266	23,859	**59%**
Olmsted	418,734	418,734	47,595	14,880	**31%**
Rice	329,907	298,819	32,397	10,318	**32%**
Scott	235,502	13,954	1,961	336	**17%**
Steele	276,470	253,569	14,039	8,311	**59%**
Wabasha	351,366	351,324	73,549	17,386	**24%**
Waseca	276,941	50,626	4,359	1,363	**31%**
Washington	270,974	8	12		**0%**
Winona	410,315	410,227	67,018	10,508	**16%**
Total Acres	6,812,110	4,700,600	591,382	186,341	**32%**

County	Total County Acres	Basin Acres	Riparian Zone Total Acres	Riparian Zone Cultivated	Cult%
SW MN CREP					
Cottonwood	415,034	105,320	9,837	3,048	**31%**
Jackson	460,258	399,995	31,219	11,154	**36%**
Lincoln	351,288	52,649	4,649	1,559	**34%**
Lyon	462,076	14,245	1,566	255	**16%**
Martin	466,604	109,767	7,404	2,340	**32%**
Murray	460,664	387,503	40,140	14,251	**36%**
Nobles	462,633	462,622	34,978	18,000	**51%**
Pipestone	298,520	281,858	25,852	10,975	**42%**
Rock	309,151	309,135	27,741	13,496	**49%**
Total Acres	3,686,229	2,123,095	183,386	75,077	**41%**
MN RIVER CREP					
Big Stone	338,278	272,898	26,597	7,856	**30%**
Blue Earth	489,731	487,998	36,268	12,772	**35%**
Brown	395,607	395,607	48,517	25,900	**53%**
Chippewa	376,407	376,407	49,186	29,478	**60%**
Cottonwood	415,044	309,721	19,473	12,350	**63%**
Douglas	460,946	205,716	7,624	2,287	**30%**
Faribault	461,485	461,051	17,127	11,014	**64%**
Freeborn	461,473	100,782	3,199	2,754	**86%**
Grant	368,568	126,136	17,357	3,230	**19%**
Jackson	460,268	60,233	2,219	1,505	**68%**
Kandiyohi	551,868	259,179	11,649	8,015	**69%**
Lac qui Parle	498,329	498,307	68,310	35,835	**52%**
Le Sueur	302,985	210,176	26,968	9,297	**34%**
Lincoln	351,298	298,634	29,518	12,643	**43%**
Lyon	462,086	447,841	34,553	18,163	**53%**
McLeod	323,360	41,653	3,702	2,330	**63%**
Martin	466,613	356,830	11,194	6,638	**59%**
Murray	460,673	73,163	4,042	1,667	**41%**
Nicollet	298,537	298,537	28,051	15,079	**54%**
Otter Tail	1,423,973	154,557	1,909	569	**30%**
Pipestone	298,526	16,650	1,248	532	**43%**
Pope	458,955	393,306	32,961	5,139	**16%**
Redwood	564,194	564,194	38,772	26,069	**67%**
Renville	631,739	465,741	28,461	17,336	**61%**
Rice	329,870	31,062	1,940	1,270	**65%**
Sibley	384,139	373,341	29,719	16,629	**56%**
Steele	276,476	22,902	642	453	**71%**
Stevens	368,359	276,475	30,419	15,882	**52%**
Swift	481,455	481,448	40,391	21,121	**52%**
Traverse	375,292	21,525	737	406	**55%**
Waseca	276,947	226,320	10,091	6,601	**65%**
Watonwan	281,255	281,255	12,388	8,105	**65%**
Yellow Medicine	488,667	488,660	58,084	39,068	**67%**
Total Acres	14,583,403	9,078,305	733,316	377,993	**52%**
GRAND TOTAL	**43,508,505**	**27,256,204**	**3,405,075**	**1,365,810**	**40%**

CONSERVATION LANDS SUMMARY

BWSR Prepared: 08/19/04

COUNTY	CRP ACRES	CONTINUOUS CRP ACRES	CREP ACRES	RIM	RIM WRP	WRP	TOTAL RESOURCE ACRES	CROPLAND ACRES	PERCENT ENROLLED	OTHER DATA: USF&W EASE./ACQ.	OTHER DATA: DNR WMA	OTHER DATA: NATURAL LANDS	OTHER DATA: COUNTY SIZE TOTAL ACRES	OTHER DATA: PERCENT HABITAT
AITKIN	131.9	556.4	0.0	61.8	0.0	0.0	750.1	77,034.8	1.0%	14,496.86	52,458.00	1,179,455.25	1,275,757	97.76%
ANOKA	105.0	212.7	0.0	0.0	0.0	0.0	317.7	44,632.9	0.7%	0.00	17,458.00	146,579.30	285,069	57.65%
BECKER	31,185.2	3,325.2	0.0	135.4	0.0	593.0	35,238.8	307,783.7	11.4%	52,739.10	6,650.00	548,460.37	925,043	69.52%
BELTRAMI	17,370.3	185.7	0.0	206.5	0.0	0.0	17,762.5	143,724.5	12.4%	0.00	192,509.00	1,602,946.44	1,954,893	92.75%
BENTON	664.0	1,498.9	0.0	423.2	0.0	0.0	2,586.1	133,396.9	1.9%	0.00	1,945.00	114,040.06	264,211	44.88%
BIG STONE	6,411.9	1,669.6	732.3	567.9	20.6	605.0	10,007.3	251,987.0	4.0%	20,716.39	10,454.00	49,885.21	338,272	26.92%
BLUE EARTH	4,706.1	2,875.2	5,329.1	486.3	287.3	1,462.0	15,146.0	392,239.0	3.9%	1,285.79	4,354.00	74,293.85	489,715	19.42%
BROWN	5,636.8	3,320.3	4,968.0	885.9	0.0	1,114.0	15,925.0	335,790.0	4.7%	0.00	2,769.00	44,779.98	395,590	16.05%
CARLTON	198.4	231.9	0.0	0.0	0.0	0.0	430.3	52,479.7	0.8%	0.00	3,659.00	532,287.11	559,738	95.83%
CARVER	2,006.2	564.4	127.4	535.7	23.6	162.0	3,419.3	137,077.9	2.5%	2,099.57	772.00	96,160.25	240,442	42.61%
CASS	452.8	295.8	0.0	53.3	0.0	0.0	801.9	80,935.2	1.0%	43.00	18,338.00	1,480,885.65	1,544,115	97.15%
CHIPPEWA	4,325.2	4,600.0	7,815.7	1,156.1	149.7	133.0	18,179.7	326,760.0	5.6%	411.10	11,361.00	29,402.30	376,390	15.77%
CHISAGO	439.2	301.4	0.0	59.6	0.0	0.0	800.2	97,257.4	0.8%	0.00	8,951.00	163,583.83	283,021	61.24%
CLAY	40,869.7	3,319.3	0.0	1,526.3	0.0	1,102.0	46,817.3	524,605.4	8.9%	14,072.31	6,102.00	87,060.59	674,342	22.84%
CLEARWATER	9,425.2	1,218.8	0.0	251.5	150.9	0.0	11,046.4	125,931.3	8.8%	864.00	4,652.00	513,979.92	658,995	80.51%
COOK	0.0	11.0	0.0	0.0	0.0	0.0	11.0	946.0	1.2%	0.00	0.00	1,023,245.97	1,027,613.04	99.58%
COTTONWOOD	8,479.3	3,008.9	3,302.2	1,267.6	65.0	48.0	16,171.0	360,943.0	4.5%	3,137.99	6,287.00	35,558.06	415,027	14.73%
CROW WING	480.0	40.7	0.0	0.0	0.0	0.0	520.7	60,183.3	0.9%	0.00	4,755.00	697,883.98	739,776	95.05%
DAKOTA	1,730.2	2,232.1	0.0	93.1	0.0	0.0	4,055.4	207,049.0	2.0%	270.95	3,350.00	112,944.99	374,970	32.17%
DODGE	1,979.0	1,551.6	0.0	45.4	0.0	0.0	3,576.0	226,715.9	1.6%	0.00	754.00	29,452.79	281,152	12.02%
DOUGLAS	28,584.8	2,570.1	2,341.8	1,184.6	23.6	510.0	35,214.9	236,375.0	14.9%	16,543.48	4,449.00	188,906.32	460,928	53.18%
FARIBAULT	1,054.0	1,157.2	3,943.7	868.6	0.0	41.0	7,064.5	415,041.0	1.7%	959.43	2,889.00	31,757.99	461,613	9.24%
FILLMORE	16,193.9	2,902.7	0.0	296.3	0.0	0.0	19,392.9	346,876.0	5.6%	0.00	1,641.00	189,576.37	551,443	38.19%
FREEBORN	6,039.5	4,917.1	612.0	491.7	1,929.5	2,572.0	16,561.8	390,339.0	4.2%	1,910.18	1,485.00	52,849.03	461,946	15.76%
GOODHUE	7,899.6	1,321.3	0.0	805.4	0.0	0.0	10,026.3	305,255.3	3.3%	0.00	4,349.00	155,693.74	499,078	34.08%
GRANT	14,411.4	13,363.0	404.8	633.2	0.0	971.0	29,783.4	293,726.0	10.1%	13,675.39	3,539.00	52,258.91	368,557	26.93%
HENNEPIN	800.3	426.7	0.0	158.9	0.0	4.0	1,389.9	58,618.2	2.4%	2,503.00	67.00	147,661.34	388,090	39.07%
HOUSTON	15,209.7	1,443.0	0.0	1,459.6	0.0	175.0	18,287.3	149,239.1	12.3%	12,221.00	346.00	202,978.50	363,930	64.25%
HUBBARD	1,661.8	432.7	0.0	0.0	0.0	0.0	2,094.5	80,716.7	2.6%	0.00	3,927.00	602,613.26	639,514	95.17%
ISANTI	549.4	293.7	0.0	63.5	0.0	0.0	906.6	106,567.7	0.9%	0.00	4,915.00	169,462.33	288,723	60.71%
ITASCA	723.5	553.3	0.0	0.0	0.0	0.0	1,276.8	30,959.4	4.1%	0.00	8,996.00	1,822,598.70	1,872,320	97.89%
JACKSON	6,110.1	2,872.6	548.4	1,446.9	52.6	482.0	11,512.6	397,517.0	2.9%	4,552.65	5,051.00	43,607.38	460,250	14.06%
KANABEC	171.9	198.5	0.0	181.2	0.0	0.0	551.6	71,727.1	0.8%	0.00	9,421.00	255,318.73	341,274	77.74%
KANDIYOHI	30,012.8	4,086.6	2,973.8	2,991.5	88.7	69.0	40,222.4	377,217.0	10.7%	17,827.68	3,409.00	135,232.92	551,859	35.64%
KITTSON	101,002.9	7,999.8	0.0	379.2	0.0	177.0	109,558.9	468,948.4	23.4%	0.00	56,024.00	175,972.36	706,925	48.32%
KOOCHICHING	57.9	94.0	0.0	0.0	0.0	0.0	151.9	41,861.3	0.4%	0.00	1,014.00	2,007,376.75	2,017,005	99.58%
LAC QUI PARLE	21,104.0	6,356.9	7,823.0	966.3	64.9	0.0	36,315.1	410,614.0	8.8%	15,930.49	20,941.00	41,929.52	498,310	23.10%
LAKE	0.0	2.9	0.0	0.0	0.0	0.0	2.9	1,606.0	0.2%	0.00	601.20	1,453,141.77	1,463,540.58	99.33%
LAKE of the WOODS	3,151.1	311.7	0.0	0.0	0.0	203.0	3,665.8	90,825.5	4.0%	0.00	158,429.00	917,393.08	1,138,938	94.78%
LE SUEUR	11,167.8	3,972.0	1,077.1	1,207.0	170.8	60.0	17,654.7	210,106.0	8.4%	622.94	3,141.00	76,638.72	303,008	32.36%
LINCOLN	30,992.9	5,054.9	2,868.2	496.5	55.2	0.0	39,467.7	278,292.0	14.2%	1,271.63	8,476.00	56,597.53	351,283	30.12%
LYON	11,756.6	3,030.1	4,485.1	1,075.1	164.2	18.0	20,529.1	387,950.0	5.3%	1,889.36	9,524.00	50,051.46	462,067	17.75%

COUNTY	CRP ACRES	CONTINUOUS CRP ACRES	CREP ACRES	RIM	RIM WRP	WRP	TOTAL RESOURCE ACRES	CROPLAND ACRES	PERCENT ENROLLED	OTHER DATA: USF&W EASE./ ACQ.	DNR WMA	NATURAL LANDS	COUNTY SIZE TOTAL ACRES	PERCENT HABITAT
MCLEOD	1,754.4	2,379.9	860.8	647.2	130.3	131.0	5,903.6	255,423.0	2.3%	1,690.93	2,709.00	49,528.53	323,347	18.50%
MAHNOMEN	22,070.8	1,842.5	0.0	0.0	0.0	0.0	23,913.3	160,028.8	14.9%	10,654.33	10,142.00	173,641.03	373,523	58.46%
MARSHALL	196,229.5	3,140.5	0.0	422.9	118.4	6,096.0	206,007.3	806,892.8	25.5%	61,052.00	114,496.00	162,476.13	1,161,043	46.86%
MARTIN	1,295.4	994.0	4,467.0	655.8	95.9	0.0	7,508.1	411,001.0	1.8%	342.54	2,547.00	40,349.53	466,598	10.88%
MEEKER	14,632.6	2,652.6	0.0	1,538.1	108.7	151.0	19,083.0	277,071.1	6.9%	7,087.13	2,657.00	97,949.56	412,467	30.74%
MILLE LACS	313.1	429.2	0.0	295.4	0.0	0.0	1,037.7	86,682.7	1.2%	0.00	36,590.00	351,037.11	435,718	89.20%
MORRISON	4,651.5	1,958.1	0.0	871.6	0.0	0.0	7,481.2	237,828.8	3.1%	1,688.00	5,615.00	473,856.00	737,760	66.23%
MOWER	394.0	4,134.2	0.0	808.1	495.8	306.0	6,138.1	381,563.5	1.6%	0.00	1,603.00	36,649.41	454,995	9.76%
MURRAY	13,994.6	6,303.4	2,615.8	572.6	0.0	0.0	23,486.4	388,780.0	6.0%	2,179.1	8661.00	51,783.6	460,659	18.69%
NICOLLET	1,331.6	2,246.8	1,107.0	1,798.9	105.4	1,363.0	7,952.7	234,169.0	3.4%	0.00	4,392.00	50,002.82	298,528	20.88%
NOBLES	1,897.7	5,077.0	0.0	224.0	0.0	0.0	7,198.7	399,175.8	1.8%	547.65	3,712.00	37,156.93	462,630	10.51%
NORMAN	49,015.4	4,256.0	0.0	1,115.7	0.0	0.0	54,387.1	481,471.4	11.3%	1,120.00	6,189.00	69,504.73	561,574	23.36%
OLMSTED	10,725.8	737.7	0.0	201.3	47.9	0.0	11,712.7	253,019.3	4.6%	0.00	3,231.00	144,748.20	418,726	38.14%
OTTER TAIL	68,800.6	14,626.1	708.5	850.4	95.4	790.0	85,871.0	630,658.7	13.6%	35,424.10	11,681.00	671,501.26	1,423,923	56.50%
PENNINGTON	76,056.5	1,511.6	0.0	38.0	0.0	0.0	77,606.1	302,391.9	25.7%	0.00	3,229.00	72,944.25	395,629	38.87%
PINE	101.4	169.2	0.0	0.0	0.0	0.0	270.6	129,121.2	0.2%	2,045.00	2,888.00	865,829.04	917,133	94.97%
PIPESTONE	8,050.5	4,629.9	217.3	401.1	0.0	0.0	13,298.8	242,801.0	5.5%	0.0	2,101.0	46,686.5	298,515.0	20.80%
POLK	147,139.7	8,533.2	0.0	304.4	0.0	10,418.0	166,395.3	1,000,145.9	16.6%	16,575.09	21,198.00	209,856.84	1,279,437	32.36%
POPE	30,473.6	5,815.6	4,950.9	2,456.7	389.1	255.0	44,340.9	285,591.0	15.5%	21,884.19	3,136.00	139,293.11	458,938	45.46%
RAMSEY	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5,934.7	0.0%	154.00	0.00	34,195.69	108,730.70	31.59%
RED LAKE	46,403.3	471.9	0.0	232.9	0.0	5.0	47,113.1	205,985.9	22.9%	0.00	2,264.00	52,791.09	277,184	36.86%
REDWOOD	6,665.0	2,708.7	8,002.5	3,838.0	242.0	218.0	21,674.2	510,646.0	4.2%	0.00	4,966.00	36,978.53	564,173	11.28%
RENVILLE	2,177.8	2,630.4	9,501.4	4,325.0	311.3	1,298.0	20,243.9	575,177.0	3.5%	1,496.03	1,234.00	41,403.04	631,718	10.19%
RICE	14,228.6	1,715.4	0.0	1,060.9	202.3	27.0	17,234.2	224,642.0	7.7%	885.84	2,569.00	85,035.70	329,901	32.05%
ROCK	521.4	1,799.3	0.0	464.5	0.0	0.0	2,785.2	257,380.9	1.1%	754.00	487.00	39,102.99	309,146	13.95%
ROSEAU	125,418.3	13,658.2	0.0	34.0	0.0	593.0	139,703.5	549,220.0	25.4%	0.00	94,051.00	426,907.80	1,074,125	61.51%
ST. LOUIS	30.0	111.1	0.0	0.0	0.0	0.0	141.1	61,532.8	0.2%	0.00	5,514.00	4,167,662.37	4,312,019	96.78%
SCOTT	1,934.6	1,008.2	118.2	780.3	0.0	21.0	3,862.3	105,357.4	3.7%	4,531.21	1,768.00	97,926.31	235,501	45.90%
SHERBURNE	840.5	677.8	0.0	0.0	0.0	51.0	1,569.3	93,107.0	1.7%	29,676.00	1,086.00	141,078.53	288,256	60.16%
SIBLEY	1,583.0	1,577.8	908.5	1,260.8	13.3	30.0	5,373.4	323,296.0	1.7%	1,159.13	1,662.00	48,192.25	384,128	14.68%
STEARNS	26,069.3	5,379.5	0.0	735.7	0.0	211.0	32,395.5	511,176.8	6.3%	11,163.42	5,027.00	311,027.11	889,248	40.44%
STEELE	5,692.0	5,379.6	211.7	1,126.0	853.9	776.0	14,039.2	231,158.0	6.1%	630.11	1,650.00	31,655.94	276,467	17.35%
STEVENS	8,140.8	7,105.6	790.5	1,160.9	0.0	656.0	17,853.8	315,465.0	5.7%	10,793.88	2,675.00	33,134.50	368,346	17.50%
SWIFT	22,977.3	6,857.3	6,072.6	1,503.0	0.0	520.0	37,930.2	400,611.0	9.5%	9,466.99	9,363.00	53,333.56	481,440	22.87%
TODD	14,534.2	1,589.7	0.0	55.8	38.5	0.0	16,218.2	272,395.9	6.0%	818.85	9,502.00	327,615.66	626,752	56.51%
TRAVERSE	2,587.7	10,913.0	285.7	321.5	78.4	165.0	14,351.3	335,488.0	4.3%	5,549.16	1,209.00	27,978.27	375,277	13.08%
WABASHA	10,284.2	500.7	0.0	777.2	0.0	0.0	11,562.1	183,650.9	6.3%	3,517.00	6,085.00	143,092.31	351,360	46.75%
WADENA	2,101.2	2,417.1	0.0	218.8	0.0	0.0	4,737.1	113,085.2	4.2%	0.00	5,087.00	225,984.66	347,597	67.84%
WASECA	3,685.8	3,641.5	1,926.6	723.0	95.0	71.0	10,142.9	235,099.0	4.3%	248.78	2,088.00	31,199.63	276,934	15.77%
WASHINGTON	579.6	57.9	0.0	20.6	0.0	0.0	658.1	68,738.4	1.0%	0.00	1,873.00	151,304.34	270,637	56.84%
WATONWAN	2,003.4	1,925.8	2,914.5	577.8	56.1	0.0	7,477.6	251,650.0	3.0%	225.07	1,284.00	20,758.17	281,242	10.58%
WILKIN	12,897.0	3,184.4	0.0	443.6	0.0	1,465.0	17,990.0	407,405.9	4.4%	2,742.26	5,510.00	25,913.29	481,178	10.84%
WINONA	9,024.9	906.5	0.0	354.5	10.1	0.0	10,296.0	186,347.5	5.5%	2,429.00	22,706.00	190,617.55	410,310	55.09%
WRIGHT	5,555.6	1,157.8	0.0	674.4	0.0	79.0	7,466.8	220,989.5	3.4%	2,938.42	4,245.00	178,340.77	457,171	42.21%
YELLOW MEDICINE	10,632.9	7,558.6	5,452.9	1,554.0	0.0	597.0	25,795.4	424,077.0	6.1%	1,194.67	5,087.00	49,211.98	488,646	16.64%
STATE TOTAL	**1,430,749.4**	**250,752.0**	**100,465.0**	**57,906.5**	**6,734.4**	**36,794.0**	**1,883,401.3**	**23,071,285.3**	**8.2%**	**452,708.12**	**1,115,981.20**	**28,109,739.20**	**53,993,362**	

s:/2crep/COENROL 081804.xls

Sources:
CRP Acres: www.fsa.usda.gov/crpstorpt/07Approved/r1sumyr/mn.htm (7/30/04)
CREP Acres: http://www.bwsr.state.mn.us/easements/crep/easementsummary.html (7/31/03)
WRP Acres: NRCS (8/16/04)
Cropland Acres: FSA - 2001

Sources: (Continued)
USF&W Easements: 2003 Annual Report
DNR WMA: 2001 GIS Layer
Natural Lands: 1990 MN Landuse - Forest, Wetland, Pasture, Water