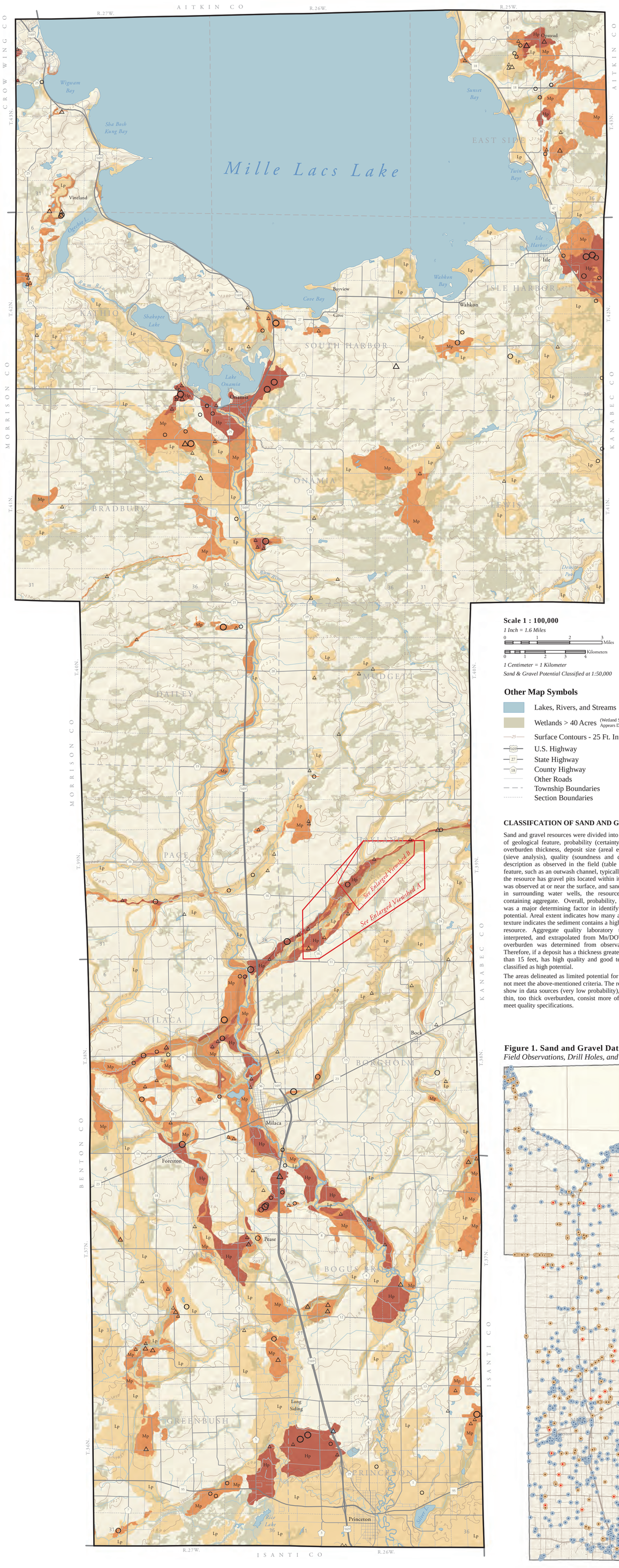


Scale 1 : 100,000

1 Inch = 1.6 Miles

0 1 2 3 Miles

0 1 2 3 4 Kilometers

1 Centimeter = 1 Kilometer

Sand & Gravel Potential Classified at 1:50,000

Other Map Symbols

- Lakes, Rivers, and Streams
- Wetlands > 40 Acres (Wetland Symbol Color Appears Different Over Potential)
- Surface Contours - 25 Ft. Intervals
- U.S. Highway
- State Highway
- County Highway
- Other Roads
- Township Boundaries
- Section Boundaries

CLASSIFCATION OF SAND AND GRAVEL POTENTIAL:

Sand and gravel resources were divided into four categories based the type of geological feature, probability (certainty), sand and gravel thickness, overburden thickness, deposit size (areal extent), textural characteristics (sieve analysis), quality (soundness and durability), and the sediment description as observed in the field (table 1). For example, a geologic feature, such as an outwash channel, typically contains sand and gravel. If the resource has gravel pits located within its boundaries, sand and gravel was observed at or near the surface, and sand and gravel were encountered in surrounding water wells, the resource has a high probability of containing aggregate. Overall, probability, or the amount of information, was a major determining factor in identifying and delineating aggregate potential. Areal extent indicates how many acres a resource covers. Good texture indicates the sediment contains a high percentage of gravel within a resource. Aggregate quality laboratory test results were compiled, interpreted, and extrapolated from Mn/DOT pit sheets. Thickness and overburden was determined from observations and well information. Therefore, if a deposit has a thickness greater than 15 feet, overburden less than 15 feet, has high quality and good texture, then the resource was classified as high potential.

The areas delineated as limited potential for sand and gravel resources did not meet the above-mentioned criteria. The resources may not exist, did not show in data sources (very low probability), too small in areal extent, too thin, too thick overburden, consist more of sand than gravel, or did not meet quality specifications.

AGGREGATE POTENTIAL: For the purpose of this study, aggregate potential is defined as an assessment of the relative probability that an aggregate deposit exists within a given mapping unit. Almost all emphasis is place upon geologic evidence, physical parameters such as areal extent, and interpretation at the reconnaissance level, rather than upon economic feasibility, site-specific level of evaluation, or other related parameters. This assessment does not imply that economic aggregate deposits exist everywhere within a given map unit designated as "Potential Sand and Gravel Resources", but rather, that within such a map unit, geologic processes were active that could have created aggregate deposits at specific sites. Geologic measurements of aggregate deposits such as thickness or quality test data remain constant, but economic criteria and environmental permitting vary across time and at different locations. Important site-specific factors such as ownership, zoning, protected waters and wetlands, sensitive or protected environments, permitting, distance to markets, royalties, and individual site characteristics, such as access, all contribute to the feasibility of mining specific parcels; however, these factors were not considered in this reconnaissance-level study.

POTENTIAL SAND AND GRAVEL RESOURCES: Geologic units that are inferred to contain sand and gravel. These units exhibit the geologic characteristics that typically produce sand and gravel resources. Existing gravel pit and MN/DOT aggregate sources lying within these units are considered identified, or known resources, that increase the level of confidence for that mapping unit.

Hp **High Potential for Sand and Gravel Resources:** Glaciofluvial features, outwash plains, channels, and terraces as well as ice contact features like eskers, fans and kames (see Viewshed A and B). Predominant sediment consists typically of sand and gravel. The probability[1] that a potential sand and gravel resource exists within any mapping unit is moderately high to very high. Thickness of the deposits ranges from 15 to 40+ feet with less than 15 feet of overburden. These resources are moderately large to very large in areal extent[2] and the textural characteristics[3] are moderately good to very good. The quality[4] is typically moderately high to very high relative to other sand and gravel resources within Mille Lacs County.

Mp **Moderate Potential Sand and Gravel Resources:** Glaciofluvial features, outwash plains, channels, and terraces as well as ice contact features like eskers, fans and kames. Predominant sediment ranges from sand with gravel to sand and gravel. The probability that a potential sand and gravel resources exists within this unit is moderate to very high. Deposit thickness ranges from 10 to 40+ feet with less than 20 feet of overburden. These resources are moderate to large in areal extent and the textural characteristics are moderate to very good. The quality is typically moderate to high.

Lp **Low Potential Sand and Gravel Resources:** Glaciofluvial features, outwash plains, channels, and terraces; ice contact features like eskers, fans and kames; and alluvial channels. Predominant sediment varies and can include sand, sand with gravel, and/or silty sand and gravel. The probability that a potential resource exists within this unit is low to moderately low. Thickness of the deposits ranges from 5 to 40+ feet with overburden thickness ranging from 0 to 50+ feet. These resources are small to moderate in areal extent and the textural characteristics are moderately poor to good. The quality ranges from low to high.

LIMITED POTENTIAL SAND AND GRAVEL RESOURCES: Units that generally have little or no potential for significant aggregate resources. These units exhibit geologic characteristics that are typically not consistent with significant aggregate resources. These units typically contain clay, silt, fine sand, unsorted sediments (till), or very thin layers of sand and gravel. These units may include aggregate resources that are too small to map (<10 acres).

Limited Potential for Sand and Gravel Resources: Units that include glacial features such as scoured glaciofluvial channels, ground moraines, end moraines, and small alluvial features such as flood plains and streams. The deposits of this unit contain all or one of the following: clay with boulders, silt, sand, and/or gravel. The probability that a significant sand and gravel resource exists within this unit is very low to moderately low. The thickness of these deposits is typically less than 10 feet but can range from 0 to 30+ feet with overburden thickness ranging from 0 to 100 feet. The aggregate resources occurring in this unit are very small to moderately small in areal extent. The textural characteristics are poor to moderately good with the quality ranging from very low to moderately low.

IDENTIFIED AGGREGATE RESOURCES: Areas where sand and gravel resources have been or are currently being mined. Pit locations have been gathered from several different sources, including topographic maps, aerial photographs, county records, county highway department maps, soil surveys, Mn/DOT files, fieldwork, gravel operators, and other miscellaneous sources. The gravel pits range in size from less than 1 acre to greater than 50 acres and may be active, inactive, depleted, or reclaimed. The aggregate quality of the pits varies.

Small	Medium	Large
< 5 Ac.	5-15 Ac.	> 15 Ac.

Gravel Pits: Size of point indicates the relative areal extent of the pit.

Gravel Pits – Mn/DOT: Initial locations were gathered from Mn/DOT Aggregate Source Information System. Some locations were modified to better correlate to present gravel pit boundaries. Any given pit may be active, inactive, depleted, or reclaimed. Size of point indicates the relative areal extent of the pit.

Footnotes associated with potential sand and gravel resources seen throughout map text and table 1

[1]*Probability*: The degree of certainty that aggregate exists within a mapping unit largely defined by the amount of available information.

[2]*Areal Extent*: The size, horizontal extent, or distribution of a unit (e.g. area in acres). This attribute does not necessarily reflect the size of an individual polygon but the size of a deposit found within that polygon.

[3]*Textural Characteristics*: Particle size distribution defined as the percent of gravel or sand vs. silt or clay (e.g. sieve analysis).

[4]*Quality*: The physical characteristics of the material, such as soundness (e.g. magnesium sulfate test), durability (Los Angeles rattler test), and percent of deleterious rock types such as shale, iron oxide, and unsound chert.

Table 1: Classification Matrix of Sand and Gravel Potential Used for Mille Lacs County

Characteristics	Potential Rating			
	High	Moderate	Low	Limited
Surficial Geology Features	Glaciofluvial outwash channels and ice contact features	Outwash channels and terraces; kames and eskers; alluvial terraces, fans, bars	Outwash channels and terraces; kames and eskers; alluvial terraces, fans, bars	Moraines; collapsed channels; glacial lake beds; colluvial slopes; alluvial features
Predominant Sediment Description	Sand and gravel	Sand with gravel to sand and gravel	Sand to sand with gravel	Clay/silt/sand/ sand and gravel
Probability[1]	Moderately high to very high	Moderate to very high	Low to moderately low	Very low to low
Sand and Gravel Thickness (in feet)	15-40+	10-40+	5-40+	0-30+
Overburden Thickness (in feet)	0-15	0-20	0-50+	0-100+
Sand and Gravel Deposit Size (areal extext[2])	Moderately large to very large (30-50+ acres)	Moderate to large (10-40 acres)	Small to moderate (10-50+ acres)	Very small to moderately small (0-10 acres)
Sand and Gravel Textural Characteristics[3]	Moderatley good to very good	Moderate to very good	Moderately poor to good	Very poor to moderately good
Sand and Gravel Quality[4]	Moderately high to very high	Moderate to high	Low to high	Very low to moderately low

Figure 1. Sand and Gravel Data Sources:
Field Observations, Drill Holes, and County Well Index Sources

Data Sources

- MN DNR Test Holes
- Field Observations
- County Well Index Data With Aggregate Information

Field Observations, Test Holes, & the County Well Index (CWI)

A total of 322 field observations, including 40 test holes and 218 gravel pits, were logged during the fall of 2004 and spring of 2007. Surficial geologic sediment, glacial stratigraphy, and bedrock formations were observed in road cuts, stream exposures, excavations, such as basements, judicial ditches, construction projects, trenches (cable, pipe, tiling), and even animal holes. The County Well Index (CWI) is an online database maintained by the Minnesota Geological Survey containing approximately 905 (as of 2004) wells located in Mille Lacs County. Almost two-thirds of the wells have geological descriptions.

Figure 2. Significant Aggregate Resources:
High and Moderate Potential Aggregate Resources

Significant Aggregate Resources

- Significant Sand & Gravel Potential
- Significant Crushed Stone Potential
- Significant Sand & Gravel & Crushed Stone Potential

Significant Aggregate Resources

Significant Aggregate Resources are defined as those deposits most likely to be explored and evaluated for future commercial use. They include moderate and high potential sand and gravel; as well as crushed stone resources.

AGGREGATE RESOURCES

SAND & GRAVEL POTENTIAL

Mille Lacs County, MN

Produced by the Aggregate Resource Mapping Program
Division of Lands and Minerals

Minnesota Department of Natural Resources

Mapped By Heather E. Arends
St. Paul, Minnesota - October 2008

Aggregate Resource Mapping Webpage
http://www.dnr.state.mn.us/lands_minerals/aggregate_maps

INTRODUCTION: The purpose of this project is to identify and classify potential construction aggregate resources (sand, gravel, and crushed stone) in Mille Lacs County, Minnesota. Having locally available, low-cost construction aggregates is fundamental to building and maintaining public infrastructure and private sector development. This information is intended to assist local planners and others in making comprehensive land-use and zoning decisions regarding aggregate resources, introduce aggregate resource protection, spread the burden of development, and promote orderly and environmentally sound development of the resource. To accomplish these goals, two plates and a comprehensive data set on a CD-ROM were created. Plate A shows potential sand and gravel deposits. Plate B shows potential crushed stone aggregate resources.

There are several factors related to aggregate resources that affect their availability, usability, and supply. These factors include the transportation costs, the quality of the material, and land-use conflicts. Aggregate materials are high-bulk, low-value commodities, which means transportation costs can account for a considerable amount of the delivered price. Having a local supply of aggregate means lower costs for public and private projects. Aggregate products, such as concrete and asphalt, have specific quality requirements depending on the end use. Therefore aggregate deposits must be evaluated in relation to quality standards. At the same time, land-use conflicts between aggregate mining and urban developments are becoming more common. Land-use conflicts can be caused by cities expanding into adjacent rural areas, aggregate resource deposits being covered by new developments, or new development occurring adjacent to aggregate resources. As a result, the distance from the aggregate source to its consumers is increasing. Due to the increased use of aggregate material in and around urban areas, aggregate resources are being depleted rapidly.

With these and other issues in mind, the 1984 Minnesota Legislature passed a law (Minn. Stat, sec 84.94, Aggregate Planning and Protection) that directs the Minnesota Department of Natural Resources, in cooperation with the Minnesota Geological Survey and the Minnesota Department of Transportation, to identify and classify potential aggregate resources. When the mapping is completed, the information is provided to local governments and the public. Since this is a reconnaissance-level survey of aggregate resources, site-specific evaluations are still necessary prior to any development of the resource, especially in regards to aggregate quality or environmental review. Factors such as ownership, zoning, protected waters and wetlands, environmental permitting, and other individual site characteristics are not part of the geological resource data summarized here.

METHODOLOGY: The method used for aggregate mapping integrates traditional geologic mapping techniques (i.e. fieldwork and drilling) with computer software programs (like Geographic Information Systems or GIS). Sand and gravel mapping is accomplished in several phases: 1) preliminary information gathering consisting of compiling, interpreting, and summarizing data 2) fieldwork and ground verification of data, and 3) aggregate resource classification. Although the general approach to mapping aggregate is similar for crushed stone and sand and gravel, the details related to crushed stone mapping are described on Plate B.

Data Gathering: Gathering existing data was the first step to aggregate resource classification. Both literature and data searches were conducted to obtain an understanding of the geology in the area and to compile various digital datasets. The data compilation included aerial photographs, topographic maps, digital elevation models, shaded relief, subsurface data, gravel pit and quarry data, surficial and bedrock geology, wetlands, lakes, streams, vegetation, soils, land-use, as well as several datasets of background information, including roads, railroads, township - range - section boundaries, and others.

Subsurface data used for this study included the County Well Index (CWI) database and the gravel pit information from Minnesota Department of Transportation's (Mn/DOT). CWI is an online database maintained by the Minnesota Geological Survey (MGS) that contains basic information for over 300,000 wells drilled throughout Minnesota. The Mn/DOT Aggregate Source Information System (ASIS) digital files consist of aggregate quality and textural (i.e., sieve or particle size) data, and pit sheets displaying the descriptions of shallow test hole logs and diagrams of test hole locations (the associated quality data were summarized in a database). The subsurface information was used to look for buried sand and gravel deposits, determine the depth to bedrock, and identify the type of bedrock encountered.

Once all of this information was digital, a computer program by ESRI called ArcGIS©, was used to help interpret, compile, and summarize the data. Compiled information was then incorporated into the development of a working geologic history for Mille Lacs County. Color infrared and black-and-white aerial photographs were then used in conjunction with geological modeling to delineate geological landforms and aggregate resources. Stereoscopic pairs of color infrared aerial photographs (NAPP, 9"x 9" at 1:40,000 scale, April 1991 and 1992) were used. Aerial photographs (DOQs) were also available digitally and used within ArcGIS© (1:12,000 scale, 1991).

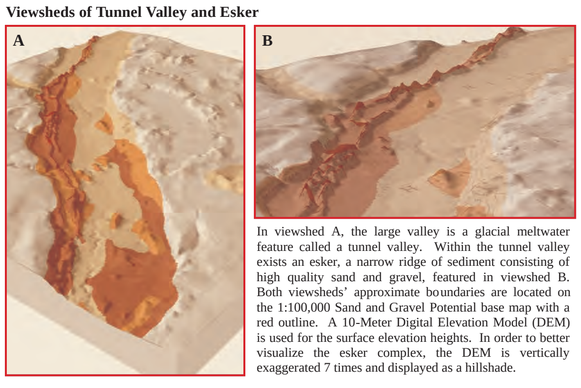
Aerial photographic interpretation was completed with a glacial mapping technique known as the landsystems approach. This technique relies on the principle that depositional glacial landforms are composed of a predictable range of sediments, some consisting of sorted sand and gravel and others consisting of silts, clays, or unsorted materials. In addition to the landsystems approach, several other general characteristics helped determine the nature of the material, such as tonal contrasts, texture, context, shape, size, trend, association, and patterns. These characteristics help determine the properties of the surface materials (e.g., certain vegetation grows on well drained soils, such as sand and gravel, which on an aerial photograph have a distinctive texture, tone, and pattern).

The landform-sediment association (part of the land systems approach) was also used when interpreting the topography within Mille Lacs County; glacial landforms have distinct and unique shapes and patterns that can be observed in their topographic expression. Topographic maps (USGS 1:24,000), digital elevation models, and shaded relief maps were all used to help delineate the sand and gravel bearing features. The topographic expression of a feature can also be observed by looking at the distribution of lakes and wetlands. For example, a string of lakes and/or wetlands may be the signature of a collapsed outwash channel, which may host sand or gravel deposits. Several aggregate bearing features (outwash channels, ice contact features, and eskers) were located in Mille Lacs County using this technique.

Fieldwork: Fieldwork consisted of driving every accessible road in the county looking for outcrops and exposures of geological sediments, as well as drilling test holes where needed. Sediments exposed in road cuts, stream exposures, excavations, judicial ditches, construction projects, trenches (cable, pipe, tiling), and even animal holes offered several places where the surficial materials, and glacial stratigraphy were observed (see figure 1 for distribution and types of observation sites). Drilling was conducted in the road right of way to further confirm the presence of sand and gravel.

Classification of Resources: After completing fieldwork, the field observations, gravel pit survey, Mn/DOT quality data, aerial photograph interpretation and other information was used to delineate and classify the potential of the aggregate resources (see table 1). Significant aggregate resources included high and moderate potential (see figure 2). Aggregate resources were classified at a scale of 1:50,000 for sand and gravel resources.

Viewsheds of Tunnel Valley and Esker



In viewshed A, the large valley is a glacial meltwater feature called a tunnel valley. Within the tunnel valley exists an esker, a narrow ridge of sediment consisting of high quality sand and gravel, featured in viewshed B. Both viewsheds' approximate boundaries are located on the 1:100,000 Sand and Gravel Potential base map with a red outline. A 10-Meter Digital Elevation Model (DEM) is used for the surface elevation heights. In order to better visualize the esker complex, the DEM is vertically exaggerated 7 times and displayed as a hillshade.

General References:
Ellingson, B.E., 2002, Aggregate Resources, Benton County, Minnesota Department of Natural Resources, Division of Lands and Minerals, Report 356, Plates I, II, III, and IV.
Eyles, N., 1983, Glacial Geology, A Landsystems Approach, Glacial Geology, An introduction for engineers and earth scientists, Pergamon Press, Oxford, p. 1-18.
Johnson, M.D, and Mooers H.D., 1998, Ice-margin positions of the Superior Lobe during late Wisconsinan deglaciation, *in* Patterson, C.J., and Wright, H.E., Jr., eds., Contributions to Quaternary studies in Minnesota; Minnesota Geological Survey Report of Investigation 49, p. 17-14.
Meyer, G., 2008, Surficial Geology of the Mora 30 x 60 minute quadrangle, east-central Minnesota, Minnesota Geological Survey, *in press*.
Mooers. H.D., 1988, Quaternary history and ice dynamics of the late Wisconsin Rainy and Superior lobes, Central Minnesota, PhD dissertation, University of Minnesota.
Patterson, C.J., 1995, Tunnel-valley fans of the St. Croix moraine, east-central Minnesota, U.S.A., *in* Warren W.P., and Croot, D.G., eds., Formation and deformation of glacial deposits: Rotterndam, A.A. Balkema p. 69-87
Wright, H.E., Jr., 1972, Quaternary of Minnesota, *in* Sims, P.K., and Morey, G.B., eds., Geology of Minnesota: A Centennial Volume; St. Paul, Minnesota, Minnesota Geological Survey, p. 561-578.

Mapping and Cartographic Sources:
Aerial photograph interpretation, field work, and delineation of mapping units by Heather Arends, 2005, Aggregate Resource Mapping Program, Division of Lands and Minerals, Minnesota Department of Natural Resources. Source information included aerial photographs from NAPP (National Aerial Photography Program), 1991-1992, 9" x 9" color infrared photos at 1:40,000: DOQs (Digital Orthophoto Quadrangles) at 1:12,000 from USGS (United States Geological Survey); 2003-2004 Farm Services Agency DOQQ (Digital Orthophoto Quarter Quads) color air photos from USDA (United States Department of Agriculture) with +/- 3 meter horizontal accuracy; DRGs (Digital Raster Graphics) at 1:24,000 from USGS; 7.5-minute USGS topographic quadrangles at 1:24,000 (dating from 1964-1992); the Soil Survey of Mille Lacs County, 2006 from the USDA-NRCS (United States Department of Agriculture - Natural Resource Conservation Service); and CWI (County Well Index) database from the Minnesota Geological Survey, downloaded in 2004.

Cartography and GIS processing by Kevin Hanson. GIS database design by Renee Johnson and Heather Arends. Field and drilling assistance by Ricco Riihiluoma, Doug Rosnau, and Pat Geiselman. Copy editing assistance by Nicholas Kroska.

Base Map Data Sources:
Hillshade and 25-foot contour intervals derived from the USGS (United States Geological Survey) National Elevation Dataset's 1-arc second (30m) DEM (Digital Elevation Model), and where available 1/3-arc second (10m) DEM.
Lakes, wetlands, and rivers from National Wetland Inventory, U.S. Fish and Wildlife Service, compiled at 1:24,000.
Public Land Survey from PLS Project, 2001, Minnesota Department of Natural Resources.
Roads from MN/DOT BaseMap 2001, Minnesota Department of Transportation.
Civil Townships and Municipal Boundaries from MN/DOT Basemap 2001, Minnesota Department of Transportation.

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Mineral Diversification projects are determined by a committee composed of Governor-appointed members from the public and private sectors.

Products of this project include a CD/ROM of maps, data, and metadata in a digital format and the following plates:
***Plate A, Report 366, Mille Lacs County Sand & Gravel Potential* & Plate B, Report 366, Mille Lacs County Crushed Stone Potential**