This map was prepared from publicly available information. Every reasonable effort has been made to ensure the accuracy of the factual data on which this map interpretation is based. However, the Department of Natural Resources does not warrant the accuracy, completeness, or any implied uses of these data. Users may wish to verify critical information; sources include both the references here and information on file in the offices of the Minnesota Geological Survey and the Minnesota Department of Natural Resources. Every effort has been made to ensure the interpretation shown conforms to sound geologic and cartographic principles. This map should not be used to establish legal title, boundaries, or locations of improvements.

Base Map Data Sources

Lakes, rivers, streams, and drainage ditches from NWI (National Wetland Inventory), Mn/DOT (Minnesota Department of Transportation) Base map, MN DNR 24K Streams, compiled at 1:24,000 from aerial photography (1979 - 1988) and USGS quadrangle maps (1981-1990).

PLS (Public Land Survey) townships and sections layers extracted from PLS Project, 2001, MN DNR, Division of Lands and Minerals.

Minor civil divisions from Minnesota Department of Revenue, 2007.

Populated places were derived from the GNIS (Geographic Name Information System) by pulling out the features that were coded as populated places. A selected subset of these was used for this map, 2003.

County boundaries from MN DNR, derived from combination of 1:24,000 scale PLS lines, 1:100,000 scale TIGER, 1:100,000 scale DLG, and 1:24,000 hydrography lines, 1993.

Fond du Lac Reservation boundary derived from the Bureau of Indian Affairs (BIA), 2003.

Roads from Mn/DOT Base map, Fall of 2006.

Railroad Tracks from Mn/DOT Base map, 2001.

Contour Intervals created by smoothing the Digital Elevation Model (see topographic relief) and then applying ArcGIS 9.3 Spatial Analyst to create the contours.

Topographic relief or hillshade created from a combination of 30-meter and 10-meter digital elevation models (DEM) from the USGS National Elevation Dataset, 2007.

GIS and **Cartography** by Kevin J. Hanson, MN DNR, Division of Lands and Minerals. Copy edited by Nick Kroska, MN DNR Division of Waters.

Base Map and Generalized Aggregate Resources Legend

Transportation Features

- Interstate Highway
- US Highway
- MN Highway
- County Highway
- County Road
- Township and Other Roads
- Municipal Roads
- Railroad Tracks

Bounding Features

- County Boundaries
- Fond du Lac Reservation Boundary
- PLS Township Boundaries
- Section Boundaries
  Sections 1,6,31, & 36 labeled
- Minor Civil Divisions
  Townships are labeled.
  Includes boundaries of townships, cities, and unorganizedtownships

Physical Features

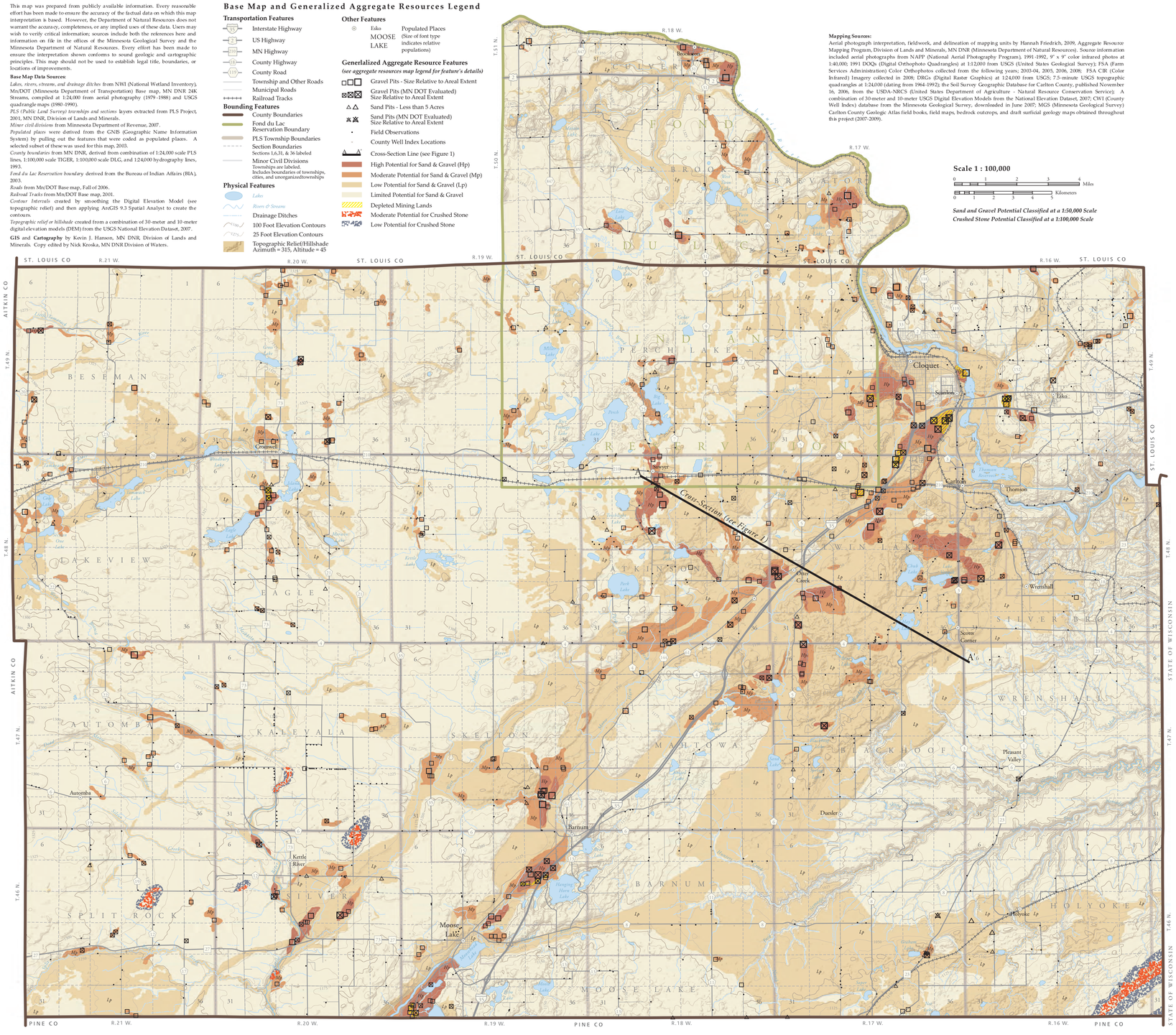
- *Lakes*
- *Rivers & Streams*
- Drainage Ditches
- 100 Foot Elevation Contours
- 25 Foot Elevation Contours
- Topographic Relief/Hillshade
  Azimuth = 315, Altitude = 45

Other Features

- Esko — Populated Places (Size of font type indicates relative populations)
- MOOSE LAKE

Generlalized Aggregate Resource Features
(see aggregate resources map legend for feature's details)

- Gravel Pits - Size Relative to Areal Extent
- Gravel Pits (MN DOT Evaluated) Size Relative to Areal Extent
- Sand Pits - Less than 5 Acres
- Sand Pits (MN DOT Evaluated) Size Relative to Areal Extent
- Field Observations
- County Well Index Locations
- Cross-Section Line (see Figure 1)
- High Potential for Sand & Gravel (Hp)
- Moderate Potential for Sand & Gravel (Mp)
- Low Potential for Sand & Gravel (Lp)
- Limited Potential for Sand & Gravel
- Depleted Mining Lands
- Moderate Potential for Crushed Stone
- Low Potential for Crushed Stone



Scale 1 : 100,000

0 1 2 3 4 Miles
0 1 2 3 4 5 Kilometers

Sand and Gravel Potential Classified at a 1:50,000 Scale
Crushed Stone Potential Classified at a 1:100,000 Scale

Mapping Sources:
Aerial photograph interpretation, fieldwork, and delineation of mapping units by Hannah Friedrich, 2009; Aggregate Resource Mapping Program, Division of Lands and Minerals, MN DNR (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; 1991 DOQs (Digital Orthophoto Quadrangles) at 1:12,000 from USGS (United States Geological Survey); FSA (Farm Services Administration) Color Orthophotos collected from the following years; 2003-04, 2005, 2006, 2008; FSA CIR (Color Infrared) Imagery collected in 2008; 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 Geographic Database for Carlton County, published November 16, 2006, from the USDA-NRCS (United States Department of Agriculture - Natural Resource Conservation Service); A combination of 30-meter and 10-meter USGS Digital Elevation Models from the National Elevation Dataset, 2007; CWI (County Well Index) database from the Minnesota Geological Survey, downloaded in June 2007; MGS (Minnesota Geological Survey) Carlton County Geologic Atlas field books, field maps, bedrock outcrops, and draft surficial geology maps obtained throughout this project (2007-2009).

AGGREGATE RESOURCES MAP LEGEND

AGGREGATE RESOURCE POTENTIAL: Aggregate potential is defined as an assessment of the relative probability that an aggregate deposit exists within a given mapping unit. 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 mapped unit and is classified within the range of potential observed in the study area. Almost all emphasis is placed on geological evidence, physical parameters such as areal extent, and interpretation at the reconnaissance level, rather than upon economic feasibility, site-specific evaluation, or other related parameters. Criteria used to define aggregate potential within Carlton County may not extend into surrounding areas where geologic parameters can change. Furthermore, this assessment does not imply that economic aggregate deposits exist everywhere within a given map unit designated as "Significant Potential Aggregate 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 are not considered in this reconnaissance-level study. Sand and gravel resources are classified at a scale of 1:50,000.

SIGNIFICANT POTENTIAL FOR SAND AND GRAVEL RESOURCES: Units inferred to contain sand and gravel resource potential. Data for these units exhibit geological characteristics associated with sand-and-gravel-bearing landforms. Existing gravel pit and Mn/DOT aggregate sources lying within these units are considered identified or known resources which increases the level of confidence for the mapping unit.

Hp — **High Potential for Sand and Gravel Resources:** Glaciofluvial features; outwash plains; glacial meltwater channels; and terraces; as well as ice contact features like eskers, fans, and kames (Figure 1). Sand and gravel is the predominant sediment. 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 10 to 60+ feet with less than 15 feet of overburden. These resources are moderate to very large in areal extent[3] and the textural characteristics[4] are good to very good. The quality[5] is moderately high to very high.

Mp — **Moderate Potential for Sand and Gravel Resources:** Glaciofluvial features; outwash plains; glacial meltwater 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 resource exists within this unit is moderate to very high. Deposit thickness ranges from 10 to 50+ feet with less than 20 feet of overburden. These resources are moderately small to large in areal extent and the textural characteristics are moderately good to good. The quality is typically moderate to high.

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

Lp — **Low Potential for Sand and Gravel Resources:** Glaciofluvial features, ice-walled lakes, outwash plains, glacial meltwater 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 75+ feet with overburden thickness ranging from 0 to 50+ feet. These resources are small to moderately small in areal extent and the textural characteristics are poor to moderately good. The quality ranges from low to moderately high.

Limited Potential for Sand and Gravel Resources: Units that include glacial features such as ground moraines, end moraines, lake plains, and small alluvial features such as flood plains and streams. The deposits of this unit contain one or more 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 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 200+ feet. The aggregate resources occurring in this unit are very small to small in areal extent. The textural characteristics are very poor to moderately poor with the quality ranging from very low to moderately low.

DEPLETED SAND AND GRAVEL RESOURCES

Depleted Mining Lands: Information gathered from aerial photographs and verbal communication on areas showing indication(s) that sand and gravel resources are significantly depleted. For Carlton County and Fond du Lac Reservation delineated areas are 20 acres or larger. Indicators include reclamation of mine lands, secondary use of mine lands, and/or reclaimed extent of mine lands bounded by other land uses. Additional resources may exist at depth. Areas labeled as depleted are limited to mine lands where aggregate resources have been partially or entirely extracted and do not include development (i.e. residential or commercial) over resources that have not been mined.

CRUSHED STONE RESOURCE POTENTIAL: Two factors control the distribution of crushed stone potential in Carlton County and the Fond du Lac Reservation: bedrock quality and thickness of overburden. Bedrock mapping was completed by Minnesota Geological Survey (Boerboom, 2009) and crushed stone potential is based on those bedrock units. Only two bedrock mapping units, a basalt (MGS map unit Pmc) and a metavolcanic group containing two identified units defined as porphyritic metabasalt (MGS map unit Pvg) and metagabbro (MGS map unit Pga) appear to have physical characteristics suitable for crushed stone. The second factor, overburden thickness, was based on broad observations of bedrock elevation and thickness of glacial overburden (Setterholm, 2009). Exposures of bedrock are observed as isolated knobs. In areas where well data are available, overburden was interpreted to grade increasingly away from the outcrop to approximately 25+ feet thick. Therefore, crushed stone potential is conservatively delineated and spatially limited to areas near outcrops. Crushed stone resources are classified at a scale of 1:100,000.

SIGNIFICANT POTENTIAL FOR CRUSHED STONE RESOURCES: Basalt and metavolcanics suitable for aggregate use. Neither formation has been quality tested; however, physical characteristics exhibit a suitable hardness and competency to be considered for crushed stone potential. Both of these units are inferred to be relatively thick (greater than 25 feet), with overburden thicknesses estimated to range from 0 to 10 feet.

Moderate Potential for Crushed Stone Resources: Metavolcanics exposed near or at the surface with overburden thickness estimated to range from 0 to 10 feet. Although observed fabric may cause preferential fracturing, the rock unit appears to be significantly competent to withstand crushing. Basalt, identified as part of the Chengwatana Formation, exposed near or at the surface with overburden thickness ranging from 0 to 10 feet. This rock was observed to be massive with limited fabric and appears to be significantly competent to withstand crushing.

NONSIGNIFICANT POTENTIAL FOR CRUSHED STONE RESOURCES:

Low Potential for Crushed Stone Resources: Metavolcanics and basalt with overburden thickness ranging from 10 to 20 feet.

Limited Potential for Crushed Stone Resources: Metavolcanics and basalt with overburden thickness ranging from 20 to 50+ feet and other metasediments and sandstones with overburden thicknesses ranging from 0 to 50+ feet. Metasediments and sandstones are friable and have a strong fabric making these rock types unsuitable for crushed stone resources.

IDENTIFIED SAND AND GRAVEL RESOURCES: Locations where sand and gravel have been or are currently being mined. Several sources of information identify gravel mine locations: topographic maps, aerial photographs, soil surveys, MGS field mapping sites, Mn/DOT files, fieldwork, gravel operators, and other miscellaneous sources. Gravel mines 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 mines varies. Size of point indicates the relative areal extent of the pit.

Small <5 Acres	Medium 5-15 Acres	Large >15 Acres	
□	□	□	**Gravel Pits:** Contain significant amount of sand and gravel. Includes sites that have been or are currently being mined.
⊠	⊠	⊠	**Gravel Pits – Mn/DOT ASIS:** Sites were identified by Mn/DOT as part of the Aggregate Source Information System (ASIS). Some locations shown on this map were modified to better correlate to present gravel pit boundaries.
△	△		**Sand Pits:** Contain significant amount of sand with little to no gravel. Includes sites that have been or are currently being mined.
⋇	⋇		**Sand Pits – Mn/DOT ASIS:** Sites were identified by Mn/DOT as part of ASIS. Although they are identified as a potential resource site, sites have not necessarily been mined or geologically evaluated. Some locations were modified to better correlate to present sand pit boundaries.

GEOLOGIC DATA SOURCES FOR MAP UNIT INTERPRETATION: Field observations and County Well Index (CWI) database were data sources used in the interpretation of aggregate potential.

- **Field Observations:** A total of 1212 field observations were logged during the spring and fall of 2008. Pits were also inventoried during this time, including 372 gravel pits, 33 sand pits, and 19 borrow and clay pits. Surficial geologic sediment, glacial stratigraphy, and bedrock formations were observed in road cuts, stream exposures, excavations for basements, judicial ditches, construction projects, trenches (cable, pipe, tiling), and animal holes. Field observations of gravel pits and sand pits are shown on the map as Gravel Pits and Sand Pits (See Identified Sand and Gravel Resources).
- **County Well Index Database Locations:** CWI dataset (www.health.state.mn.us/divs/eh/cwi) is maintained by the Minnesota Department of Health and comes in two levels of data accuracy: *located* and *unlocated*. *Located* CWI data are assumed to be accurately located. *Unlocated* CWI data are used as a source only if the address information on the well log can be verified and located using address information and online address location websites. Approximately 5700 wells located within Carlton County and Fond du Lac Reservation and the surrounding area were referenced to create this map.

General References

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AGGREGATE RESOURCES
AGGREGATE POTENTIAL
Carlton County, MN, and Fond du Lac Reservation

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

Minnesota Department of Natural Resources
St. Paul, Minnesota - June 2009
Mapped By Hannah G. Friedrich

Scale 1 : 100,000

INTRODUCTION: The purpose of this project is to identify and classify potential construction aggregate resources (sand, gravel, and crushed stone) in Carlton County, Minnesota. This Aggregate Resource Plate is a coordinated project with the Minnesota Geological Survey (MGS) County Atlas Mapping Program and funded by the Minerals Diversification Program. 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 impact of development, and promote orderly and environmentally sound development of the resource. To accomplish these goals, one plate and a comprehensive data set on a CD-ROM were created. Plate A shows both potential sand and gravel deposits and crushed stone resources.

Several factors related to aggregate resources affect their availability, usability, and supply. These factors include transportation costs, 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 lowers the 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 demand for aggregate material in and around growing urban areas, aggregate resources are being depleted rapidly.

With these and other issues in mind, the 1984 Minnesota Legislature passed a law (Minn. Statute, sec. 84.94, Aggregate Planning and Protection) that directs the Minnesota Department of Natural Resources (MN DNR), in cooperation with the Minnesota Geological Survey (MGS) and the Minnesota Department of Transportation (Mn/DOT), to identify and classify potential aggregate resources. When 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 relation 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 data gathering and mapping techniques (i.e., fieldwork and drilling) with computer mapping software programs like geographic information systems (GIS). Sand and gravel mapping is accomplished in several phases: 1) preliminary information gathering that consists of compiling, interpreting, and summarizing existing data; 2) verification of data and the collection of new data from fieldwork; and 3) aggregate resource classification.

Aggregate Data Gathering: The first step in mapping is to conduct a literature and data search to understand the geology in the area. Some of the data used are aerial photographs, topographic maps, digital elevation models, subsurface data, gravel pit data, surficial and bedrock geology, wetlands, lakes, streams, vegetation, soils, land use data, as well as several datasets of background information, including roads, railroads, township-range-section (Public Land Survey) boundaries, and others.

Two notable data sets used to map aggregate resources and provide subsurface geologic information include the County Well Index (CWI) and Aggregate Source Information System (ASIS). CWI is an online database maintained by the MGS and the Minnesota Department of Health that contains location and well log information for over 300,000 wells drilled throughout Minnesota. Approximately 5700 of these wells were located in and immediately surrounding Carlton County and Fond du Lac Reservation and most of these wells contain geologic descriptions. ASIS is a dataset compiled and maintained by Mn/DOT. ASIS consists of aggregate quality data, 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 data were summarized in a database). Subsurface information is important to identify buried deposits, determine the depth to bedrock, and identify bedrock type.

Fieldwork: Several weeks are spent in the field driving every accessible road in Carlton County and Fond du Lac Reservation looking for outcrops and exposures of geological sediments, as well as drilling test holes to further define aggregate deposits. Sediments exposed in road cuts, stream exposures, excavations such as basements, judicial ditches, construction projects, trenches (cable, pipe, tiling); and animal holes offer observation sites where the surface materials and glacial stratigraphy are inventoried. A total of 1212 observation sites were logged in Carlton County. Fieldwork also includes 372 existing gravel pit observations. Gravel pit observations provide additional quality data and stratigraphic cross-sections to help interpret the various modes of deposition. Test holes drilled in county ditches or with permission of the landowner generate additional data needed to confirm the presence of sand and gravel. A total of 53 sites were drilled and the data is incorporated into the field observations dataset.

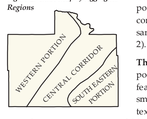
Aggregate Data Compilation and Interpretation: Aggregate resource mapping was completed as a collaborative effort with MGS surficial geologic mapping (Knaeble and Hobbs, 2009). Additional field observation sites as well as drilling sites were compiled from MGS field data. Results of MGS surficial geologic mapping were used as a source of information, especially in areas where there is little to no aggregate potential. MN DNR conducted a 1:50,000 scale resource assessment and further defined areas of aggregate potential. Other compiled and interpreted datasets include Surficial Geology of Carlton County (Eng, unpublished) and Soil Survey Geographic Database for Carlton County (2006).

Using field observations and compiled datasets, interpretations of aggregate resources are delineated by applying a glacial mapping technique known as the landsystems approach. This technique relies on the principle that glacial landforms deposit a predictable range of sediments, some consisting of sorted sand and gravel and others consisting of silts, clays, or unsorted materials. Several other general characteristics also help 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 surface materials. For example, certain vegetation grows on well-drained soils, such as sand and gravel, and has a distinctive texture, tone, and pattern in aerial photographs. Several aggregate-bearing features (eskers, terraces, outwash channels, and other outwash features) are recognized using this technique.

Using GIS software, aggregate resources are delineated by layering multiple datasets. Topographic maps (USGS 1:24,000), digital elevation models, shaded relief maps, aerial photographs (multiple sets of varying scales), subsurface data, field observations , location and distribution of existing pits, and soils are all used to identify the sand and gravel bearing features.

AGGREGATE RESOURCES MAPPING RESULTS

Figure 2: Inset Map of Aggregate Regions



Sand and gravel resources account for most of the aggregate potential within Carlton County and the Fond du Lac Reservation in comparison to crushed stone. Three broad geographical regions of sand and gravel potential occur within the mapped area (see Figure 2).

The Western Portion of the county contains smaller, isolated pockets of sand and gravel formed by ice contact and outwash features. The ice contact and outwash deposits of this area are smaller (5-10+ acres) and result in thin (5-25 feet) deposits with finer texture, more sand and a lower stone count. The high water table creates large peat expanses which increases the amount of possible overburden and reduces the amount of easily excavated aggregate material.

The Central Corridor is an approximately 12-mile-wide region paralleling Interstate 35 and the St. Louis River. Large, generally north-south trending glacial outwash channels deposited coarse sand and gravel in terraces. West of the outwash channels, eskers, or sinuous ridges of sand and gravel, and their associated outwash fans contain coarse aggregate material. Deposits are generally larger (10-20+ acres) and thicker (10-50+ feet) than deposits in the Western Portion. Overburden in this region is generally less than 5 feet thick and the water table is lower, which restricted peat growth to smaller areas.

The Southeastern Portion contains the former Glacial Lake Superior Lake Basin and surrounding beaches. This region consists of clayey glacial till, lake basin clay, and sandy beaches which result in a natural scarcity of coarse aggregate material. Remnant till located around the perimeter of the basin was washed, which produced a few small, isolated pockets of coarser aggregate material. The overburden is less than 10 feet thick and the water table is variable throughout this region.

Overall, within Carlton County and Fond du Lac Reservation sand and gravel quality is high due to the competent nature of Superior Lobe source rock. However, the local influence of soft bedrock increases spall and could potentially limit use for concrete. Many of the easily accessible deposits closest to main roads in both the Central Corridor and Western Half are either depleted or are close to depletion. Significant mineable deposits remain but are farther from areas of need such as population centers and main roads.

Except for a few outcrops, the overall bedrock quality is generally poor, which restricts its use as a crushed stone resource. The two bedrock units suitable for crushed stone are basalt and a metavolcanic formation. Metavolcanics are exposed in small outcrops near Kettle River in the southwestern portion of Carlton County. Five outcrops of this bedrock unit were directly observed in DNR and MGS mapping and appear to have the durability, or competency, to be considered for crushed stone potential. Other outcrops of this rock type exist; yet their suitability as a crushed stone resource is less certain since the bedrock has been variably metamorphosed and has not been tested. Because this rock type has not been tested in a materials lab, the aggregate potential is based on direct geologic observations and is conservatively delineated. Basalt is exposed in the extreme southeastern corner of Carlton County. Although this rock has not been further tested, there are several quarries within this unit in Pine County, Minnesota and in Wisconsin. Therefore, it is classified as moderate potential as a crushed stone resource.

Table 1: Classification of Sand and Gravel Potential

Characteristics	SIGNIFICANT RESOURCES		NONSIGNIFICANT[1] RESOURCES	
	High Potential	Moderate Potential	Low Potential	Limited Potential
Surficial Geology Features	Eskers, outwash channels, outwash terraces, ice contact features	Collapsed outwash channels, outwash terraces, ice contact features	Alluvial terraces, glacial beaches, outwash channels, ice contact features	Alluvial valleys, glacial lake plains, moraines
Predominant Sediment Description	Sand and gravel	Sand with gravel to sand and gravel	Silty sand to sand and gravel	Clay/silt/sand sand and gravel
Probability[2]	Moderately high to very high	Moderate to very high	Low to moderately low	Very low to low
Sand and Gravel Thickness (in feet)	10-60+	10-50+	5-75+	0-30+
Overburden Thickness (in feet)	0-15	0-20	0-50+	0-200+
Sand and Gravel Deposit Size (areal extext[3])	Moderate to very large (20-50+ acres)	Moderately small to moderately large (10-40 acres)	Small to moderately small (10-20 acres)	Very small to small (0-10 acres)
Sand and Gravel Textural Characteristics[4]	Good to very good	Moderately good to good	Poor to moderately good	Very poor to moderately poor
Sand and Gravel Quality[5]	Moderately high to very high	Moderate to high	Low to moderately high	Very low to moderately low

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

[1]*Nonsignificant:* Having or yielding a value that is small in size or quantity and variation is attributed to lack of data.

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

[3]*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.

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

[5]*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.

CLASSIFICATION OF SAND AND GRAVEL POTENTIAL: Sand and gravel resources were divided into four categories based on 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 geological feature, such as an outwash terrace, 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 was encountered in surrounding water wells, the resource has a high probability of containing aggregate. Probability, or the amount of information, was a major 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. Laboratory test results of aggregate quality were compiled, interpreted, and extrapolated from Mn/DOT pit sheets. Thickness and overburden were determined from observations and well information. Therefore, if a deposit has areal extent greater than 20+ acres, has thickness greater than 10 feet, has overburden thickness less than 15 feet, and 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; were lacking supporting data sources (very low probability); were too small in areal extent; were too thin; were under too thick of an overburden; consisted of more sand than gravel; or did not meet quality specifications.

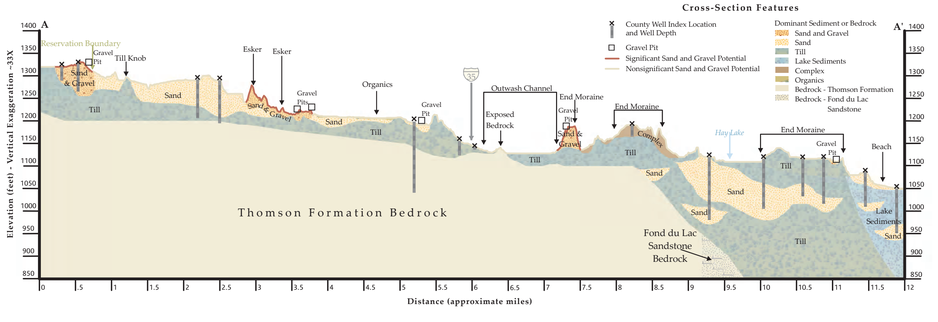


Figure 1: Cross Section of Predominant Sediment Relative to Sand and Gravel Potential

Cross-Section A-A' on Base Map

The above cross section highlights landforms and their respective sediment associations. Major aggregate-bearing landforms in the cross section include ice contact features, an end moraine, and outwash features. Non-bearing landforms are composed of unsorted glacial till, fine sand, or a complex of till and sand with gravel. The main outwash channel is classified as nonsignificant aggregate potential because it was soured by erosional processes creating a region of near-surface bedrock with little to no deposition of coarse aggregate material. The color of the line representing surface elevation correlates to sand and gravel potential. Construction aggregate, sand and gravel, is the only material classified as having significant potential. Surface and sub-surface sediment and their associations were interpreted from field observations, the gravel pit survey, and county well information. Bedrock lithology in this area consists of Thomson (greywacke) and Fond du Lac (sandstone) Formations (Boerboom, 2009). Bedrock elevation was derived from the Depth to Bedrock Plate created by Setterholm, 2009. Although exposures of bedrock occur within an outwash channel, the bedrock here is not suitable for crushed stone.

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Products of this project include a CD/ROM of data and metadata in a digital format and the following map:
Plate A, Report 374, Carlton County & Fond du Lac Reservation Aggregate Resource Potential