FINAL REPORT

7(a)

2001 Project Abstract
For the Period Ending June 30, 2005
TITLE: Hydraulic Impacts of Quarries and Gravel Pits
PROJECT MANAGER: Jeffrey A. Green
AFFILIATION: DNR
MAILING ADDRESS: 2300 Silver Creek Road NE, Rochester MN 55906
WEB SITE ADDRESS: www.dnr.state.minnesota.us
FUND: Minnesota Environment and Natural Resources Trust Fund

LEGAL CITATION: ML 2001, First Special Session [Chap. 2], Sec.[14], Subd. 7A and ML 2003, Art. 1, Ch.128, Sec. 9, Subd. 20, Hydraulic impacts of quarries and gravel pits.
APPROPRIATION AMOUNT: $320,000

<u>Overall Project Outcome and Results</u>
Project results are documented in the final report entitled Hydrologic Impacts of Quarries and Gravel Pits, 2005, Pavlish, J.A.; Green, J.A.; Merritt, R.G. and Leete, J.L., Minnesota Department of Natural Resources, Division of Waters.

During the course of this project three sand and gravel mines and five rock quarries were evaluated in an effort to begin to quantify several aspects of the hydrologic impacts of aggregate mining. Climate monitoring was conducted at five of these sites and ground-water level monitoring networks were established at six sites, which included the drilling of nine wells with project funds. Project partners and other funding provided the remaining ground-water level monitoring wells for network buildout. Taken together, the research at these sites provides the first comprehensive look at aggregate mining impacts on ground-water systems in Minnesota. This information can be used for planning purposes at the state and local level. It can also be used to guide the siting of new aggregate mines and to more accurately assess their impact on local ground-water resources.

A foundation has been laid for identifying the natural resource impacts of pits and quarries, which will aid both state and local decision-making as we seek to avoid negative impacts on the resource and on neighbors in the vicinity of aggregate extraction sites.

<u>Project Results Use and Dissemination</u>
The project final report is available on the DNR web site. The results of this project will be used by DNR hydrologists as they make permitting decisions about aggregate pits and quarries, by local governments faced with the same types of decisions, and by responsible owners of pits and quarries as they plan their operations to avoid conflicts with neighbors and with resources dependent on ground water and surface water.

Acknowledgements

Funding provided by the Minnesota Environment and Natural Resources Trust Fund as recommended by the Legislative Commission on Minnesota Resources. Assistance for the project was provided by the following project partners:

- Aggregate Industries
- Roverud Construction of Spring Grove, Minnesota
- City of Harmony Volunteer Fire Department
- Crane Creek Construction of Owatonna, Minnesota
- Kraemer and Sons of Plain, Wisconsin
- Leitzen Concrete of Rochester, Minnesota
- Minnesota Geological Survey, University of Minnesota
- Milestone Materials Division of Mathy Construction, Onalaska, Wisconsin
- Pederson Brothers Construction of Harmony, Minnesota
- Salem Township, Olmsted County, Minnesota
- University of Minnesota, Geology and Geophysics Department, Hydrogeochemistry Lab

We appreciate the efforts of Tim Schlagenhaft, Jon Ellingson, and DNR Waters' staff in St. Paul who provided peer review of the report, as well as Nick Kroska, who edited the report.

Date of Report: June 30, 2005
LCMR Final Work Program Report
Date of Next Status Report: Project has reached completion date
Date of Work Program Approval: June 29, 2001
Project Completion Date: June 30, 2005
LCMR Work Program 2001

I. PROJECT TITLE: Hydraulic Impacts of Quarries and Gravel Pits
Project Manager: Jeffrey A. Green
Affiliation: Minnesota Department of Natural Resources
Mailing Address: 2300 Silver Creek Road NE, Rochester MN 55906
Telephone Number: (507) 285-7429 **E-Mail:** jeff.green@dnr.state.mn.us **Fax:** (507) 285-7144

Total Biennial Project Budget: $320,000

$ LCMR Appropriation: $320,000.00 - $319,357.51 = **$ Balance:** $642.49

Legal Citation: ML 2001, First Special Session [Chap. 2], Sec.[14], Subd. 7A.

Appropriation Language: $160,000 the first year and $160,000 the second year are from the trust fund to the commissioner of natural resources to research and evaluate the impact of aggregate extraction on groundwater quality and quantity. This appropriation is available until June 30, 2004, at which time the project must be completed and final products delivered, unless an earlier date is specified in the work program.

Carryforward Language: The availability of the appropriation for the following project is extended to June 30, 2005, unless an earlier date is specified in the work program: ML 2003, Art. 1, Ch.128, Sec. 9, Subd. 20, Hydraulic impacts of quarries and gravel pits.

II. and III. FINAL PROJECT SUMMARY:

Project results are documented in the final report entitled "Hydrologic Impacts of Quarries and Gravel Pits, 2005, Pavlish, JA; Green, JA; Merritt, RG and Leete, J.L., Minnesota Department of Natural Resources Division of Waters.

During the course of this project three sand and gravel mines and five rock quarries were evaluated in an effort to begin to quantify several aspects of the hydrologic impacts of aggregate mining. Climate monitoring was conducted at five of these sites and ground-water level monitoring networks were established at six sites, which included the drilling of nine wells with project funds. Project partners and other funding provided the remaining ground-water level monitoring wells for network buildout. Taken together, the research at these sites provides the first comprehensive look at aggregate mining impacts on ground-water systems in Minnesota. This information can be used for planning purposes at the state and local level. It can also be used to guide the siting of new aggregate mines and to more accurately assess their impact on local ground-water resources.

A foundation has been laid for identifying the natural resource impacts of pits and quarries, which will aid both state and local decision-making as we seek to avoid negative impacts on the resource and on neighbors in the vicinity of aggregate extraction sites.

<u>Project Results Use and Dissemination:</u>
The project final report is available on the DNR web site. The results of this project will be used by DNR hydrologists as they make permitting decisions about aggregate pits and quarries, by local governments faced with the same types of decisions, and by responsible owners of pits and quarries as they plan their operations to avoid conflicts with neighbors and with resources dependent on ground water and surface water.

IV. OUTLINE OF PROJECT RESULTS:

Limestone Quarries

Limestone quarries are found in southeastern Minnesota from the Twin Cities south to Iowa and west to Mankato. Some of these operations mine below the water table. In order to do this, the quarries must be dewatered. Dewatering can locally depress the water table, altering ground-water flow paths and affecting nearby wells, springs, and surface-water bodies. Concerns have also been raised to DNR Waters and local government staff about the impacts of quarry blasting on domestic wells.

Three sites were studied to investigate these issues: the Kraemer quarry in Dakota County, the Golberg quarry at Rochester, and the Spinler quarry in Steele County southwest of Owatonna. Monitoring wells at these sites were equipped with devices to automatically monitor water level and turbidity.

Water-Level Impacts. At all three sites, the quarry dewatering has altered the local ground-water hydrology. In essence, the quarries act as huge wells, lowering the water table in the aquifer. This lowering could affect neighboring wells and testifies to the need for careful evaluation of quarry dewatering proposals and long-term monitoring of the dewatering impacts on the local aquifer.

Turbidity Impacts. Turbidity monitoring in the wells at these sites showed no impact from blasting. One of the tools purchased for this project, a downhole camera (a camera designed to video the inside of water wells) was used to inspect the wells. The camera allowed staff to visually inspect the condition of well casings. No damage from blasting or quarry operations was visible in any of the wells, including those within 20 feet (ft) to 200 ft of the quarry face. The wells will be checked again in several years to determine whether continuing quarry operations have had an impact as the wells age.

The quarry at Fountain in Fillmore County is a dry quarry (quarrying operations are above the water table) that has been shown by dye tracing to be hydraulically connected to a nearby spring. Project staff monitored this spring for blasting and quarrying impacts on turbidity in springs. This setting was chosen by staff to be analogous to the numerous older wells in southeastern Minnesota that are finished in the surficial limestone deposits that are being quarried. Typically, citizens with these wells are those who complain about quarrying impacts on their wells. The monitoring showed slight increases in turbidity after blasting. Based on known ground-water travel times, this material had to be present in the limestone's conduits (enlarged joints) prior to the blast. The blasting shook the limestone and the ground water and released some sediment. In an older well finished in the surface limestone deposit, this mechanism could cause turbidity levels to increase after a blast.

The disruption of ground-water conduit flow paths by rock removal was studied at the Big Spring quarry at Harmony in Fillmore County; quarrying operations penetrated the conduit system more than 40 years ago. Ground water that formerly emerged at the Big Spring on Camp Creek now rises in the quarry. This water either sinks back into the limestone to re-emerge at the Big Spring or flows overland to Camp Creek. Dye tracing demonstrated that approximately 90% of the ground-water basin is now being routed through the quarry. Without any dewatering occurring, this quarry has altered ground-water flow paths. This water is more vulnerable to impact by quarrying operations. Staff took temperature measurements and found that the Big Spring was 8 degrees Fahrenheit warmer (July measurement) than the water that first rises in the quarry, and the stream flowing out of the quarry to Camp Creek was 17 degrees warmer. Temperature changes of this magnitude could have a negative effect on fish populations in Camp Creek, a designated trout stream.

Sand and Gravel Pits

Impacts on Ground-Water Levels and Flow Direction. Sand and gravel pits are typically located in alluvial floodplains along streams and in glacial deposits. The sites that were studied for this project are shown in Figure 1 below.

Two alluvial sand and gravel pits, Donovan pit and the Leitzen-Grabau pit, along the Zumbro River in Olmsted County were studied. The Letizen-Grabau pit was only a few feet below the water table at its highest point after heavy rains or snowmelt. The Donovan pit had a pond area created by mining that is 500 ft by 400 ft by 30 ft deep; in this area, sand and gravel was mined by dredging. Neither pit was dewatered. At both sites, there was no significant impact on ground-water levels from mining. The fluctuations that were seen in the monitoring wells were due to precipitation events. A common concern about these operations is their impact on water levels in nearby sandpoint wells. Our results show that this type of mining should not affect the water level in these wells.

One sand and gravel site in a glacial deposit, Felton gravel pit, was studied for this project. The Felton pit is on a glacial lake beach ridge in Clay County. This operation mines sand and gravel with a dragline in an open pit below the water table. Although the pit is not dewatered, the mine has altered the ground-water flow direction in the sand and gravel deposit, which has affected a nearby calcareous fen (wetland with ground water for its water source). This type of wetland needs to be identified prior to mining in order to site and plan mining operations in a manner that will not disrupt the water supply to fens.

Temperature Impacts. A second concern at alluvial sites is the impact open ponds could have on the temperature characteristics of the adjacent streams. These ponds change the thermal character of the ground water and could conceivably change temperatures in the streams adjacent to the pits. While some temperature monitoring was done for this project, its results were inconclusive primarily because of the intermittent schedule for taking temperature measurements. In order to increase the frequency of measurements and automate the process, temperature recorders (thermochrons) were purchased and deployed at the Donovan pit 1 month prior to the end of this project. This will allow monitoring to continue at the site for an extended time period. DNR staff conducted a dye trace through the sand and gravel to determine ground-water velocity in the deposit. Combined with the temperature data from the thermochrons, this information will be very useful for future thermal modeling.

Conclusions

The project conclusions, based on our project monitoring and investigations, include the following:

- When limestone quarries are dewatered to allow mining below the water table, they alter ground-water levels and flow direction. In essence, the quarries become huge wells. Ground-water levels were found to have dropped up to 70 ft; this lowering of the ground-water levels can affect wells on neighboring properties and surface-water bodies. New quarries that will extract material below the water table will have to be sited carefully to avoid this impact, or a plan must be developed to provide an alternative water supply for property owners whose wells are affected.
- Limestone quarries can alter ground-water flow paths by the removal of the aquifer material and the subsequent breaching of the limestone conduits without active dewatering of the quarry. At the site investigated, 90% of the ground-water basin's flow is now surfacing in the quarry. Ground water that previously discharged at a spring now rises in the quarry where it is exposed to quarrying activities. This premature surfacing of the ground water also alters its temperature, changing the temperature characteristics of the receiving stream and potentially affecting its aquatic life. Our investigations found this scenario most likely to occur when quarries are located upgradient from and close to springs.
- Monitoring and visual inspections of the observation wells at two of the limestone quarry sites found no impact from quarry blasting on ground water turbidity or well integrity. Turbidity monitoring at a spring downgradient of one limestone quarry did find an increase in turbidity that could be attributed to quarry blasting; however, precipitation events had a greater impact on turbidity levels. Based on these findings, the domestic wells most likely to be affected by quarry blasting are older wells (completed before enactment of the state well code) finished in the surface limestone formation.
- Our monitoring found no negative impacts on ground-water levels from sand and gravel pits in alluvial deposits that operate below the water table but do not dewater. These pits will not affect the quantity of water available to shallow domestic wells on neighboring properties.

- In the complex geology of glacial beach ridge settings, the removal of sand and gravel can alter ground-water flow paths and affect the supply of water available to wetlands that are fed by discharge from the sand and gravel.
- Open water ponds created by sand and gravel mining change ground-water temperatures. The magnitude and extent of those changes is not yet known. This is an ongoing concern that needs further study.

Project Review

In retrospect, project staff tried to do too much with too little funding. Fewer sites should have been studied; this would have allowed us to learn more about the dynamics of each site. This would have allowed us to assess mining impacts to a greater degree.

Budget: Total= $289,208.12
Amount Spent=$288,565.63
Amount Remaining=$642.49

Personnel: ~~$183,623.55~~ $189,595.50 (Amendment request August 2005.)
Equipment: ~~$63,750.00~~ $51,715.99 (Amendment request August 2005.)
Other: ~~$41,834.57~~ $47,896.63 (Amendment request 2005.)

2. Calibrate ground-water models to predict future quarrying and mining impacts.

Located 6 miles southwest of Owatonna, Minnesota, the Spinler Quarry was analyzed in greater detail than the other project sites; its complex hydrogeologic setting includes the widest range of issues that local and state officials may encounter when considering requests to locate or expand a quarry or pit. Originally operated as a gravel pit, this site has been transformed into a limestone quarry. Encompassing 55 acres, the site's pit comprises 19 acres.

Emerging earth science software now allows the geoscientist to construct three-dimensional visual models to aid interpretation of the geologic and hydrologic framework. One of the geoscience's models, Rockworks 2004, was purchased with funds from this study to allow more detailed analysis of the impacts of quarrying on groundwater systems.

Rockworks 2004 aids in the analysis and presentation of the project information in a three-dimensional format. The software allows construction of a digital model using the following input data:

- well logs of the underlying geology;
- well location, elevation, and depth;
- pit configuration and depth; and
- water levels of each aquifer.

Rockworks 2004 is not a hydrodynamic model; it does not compute water levels based on a predictive algorithm. It is a representation of the investigator's hydrogeologic interpretation and observed water levels. It interpolates the information from known data sites to fill in the unknown areas. In spite of the above limitations, Rockworks 2004 is a powerful tool, which presents an unprecedented picture of the subterranean environment.

A summary of insights and observations facilitated by the three-dimensional model efforts are the following:

- Four stratigraphic units underlie the Spinler Quarry.
- One confined aquifer (Aquifer 2) and one unconfined aquifer (Aquifer 1) are separated by a clay aquitard.
- The Aquitard is leaky and Aquifer 2 is under artesian conditions. Depending on the height of the Aquifer 1 water surface, Aquifer 1 and Aquifer 2 supply water to each other. If Aquifer 1 is above the Aquifer 2 potentiometric surface, then Aquifer 2 receives water from Aquifer 1. If the case is reversed, the Aquifer 2 potentiometric surface controls Aquifer 1 water levels west of Straight River.
- The quarry has penetrated the two aquifers and Aquitard.

- Dewatering of the quarry has drawn the water surfaces of both aquifers down, causing a lowering of Aquifer 2's potentiometric surface.
- Domestic wells are constructed in Aquifer 2.
- Lowering of the potentiometric surface may have caused a reduction in domestic well efficiency.
- Prior to the quarry, the Straight River was gaining water from the ground water. Since dewatering has occurred, the stream no longer gains ground water and may be losing to the ground water because of the change in the hydraulic gradient of both aquifers' water surfaces west of the stream.
- Historic ground-water levels can be restored once pumping ceases. During periods of inactivity within the quarry, pumping should cease to allow restoration of domestic supply levels and to return ground-water supplies to the Straight River. If further monitoring of the quarry operations continues, it is recommended to periodically obtain water levels of surrounding domestic wells, particularly west of the quarry.
- A model is only as good as the information used to build the model. Well logs and historic water level measurements are the most important input data. Little funding currently exists to maintain and enhance these two crucial databases; expanded support for basic information is needed so that we can provide answers to questions being asked about the roles aggregate mining and rock quarrying play in our water resources.

Budget: Total= $30,791.88
Amount Spent=$30,791.88
Amount Remaining=$0.00

Personnel=$26,300.00
Equipment=$3,250.00
Other=$1,241.88

Completion Date: June 30 2005

Original Starting Budget 2001 LCMR Project Biennial Budget		
	Result 1	Result 2
Budget Item	Investigation of quarry and gravel pit hydrology.	Calibrate groundwater models to predict future quarrying and mining impacts.
Wages, Salaries & Benefits	Hydrologist 3, $79,100; Hydrologist 1, $84,600 (note: student intern may be used for approximately six weeks at project start prior to Hydrologist 1 position being filled ($2,000).	Hydrologist 3, $26,300
Professional/Technical Contract	Water chemistry & dye trace analysis. University of Minnesota Geology Department, E. Calvin Alexander, Jr., $45,000	
Other Contracts	Observation well drilling & installation. Private well drillers, $25,000	
Printing		$150
Communications, Telephone, Mail, etc.,	$3,000	
Office Supplies	Paper, computer storage media, ink	Paper, computer storage media, ink

Original Starting Budget 2001 LCMR Project Biennial Budget		
	Result 1	Result 2
	cartridges, $200	cartridges, $200
Local Automobile Mileage Paid	$4,950	
Other Travel Expenses in Minnesota	Lodging & Meals, $3,000	
Travel Outside Minnesota		Present preliminary findings at the 9th Multidisciplinary Conference on the Engineering and Environmental Aspects of Karst, Spring 2003, Huntsville, AL, $1,500
Tools and Equipment	Data loggers & transducers, $12,000; weather stations (2), $15,000; water sampling equipment, $12,500	
Office Equipment & Computers	$4,250	$3,250
COLUMN TOTAL	$288,600	$31,400

V. TOTAL PROJECT BUDGET:

All Results: Personnel: ~~$209,923.55~~ **$215,895.50 (Amendment request August 2005.)**
All Results: Equipment: ~~$67,000.00~~ **$58,618.29 (Amendment request August 2005.)**
All Results: Other: ~~$43,076.45~~ **$45,486.21 (Amendment request February 2005.)**

TOTAL BUDGET: $320,000

A.) ATTACHMENT A-

VI. PAST, PRESENT AND FUTURE SPENDING:

A. Past Spending: DNR Waters staff have reviewed mining and dewatering proposals on a case-by-case basis. In the last 2 years, this has been approximately 0.75 full-time equivalent (FTE) hydrologist 3 and 0.2 FTE hydrologist 2 in the central office, and 0.2 FTE hydrologist 3 in the Rochester office.

B. Current and Future Spending: In order to improve project efficiency, site selection by DNR Waters staff began prior to the start of the project. During the project, DNR Waters Regional Groundwater Specialist Jeff Green in Rochester served as project manager and directed the activities of the hydrologist 1 position. DNR Waters in St. Paul also provided time for personnel supervision and technical support. DNR Waters in St. Paul also provided both geophysics support and report production assistance.

C. Project Partners:

Roverud Construction of Spring Grove, Minnesota
Crane Creek Construction of Owatonna, Minnesota

Kraemer and Sons of Plain, Wisconsin
Leitzen Concrete of Rochester, Minnesota
Minnesota Geological Survey, University of Minnesota
Milestone Materials Division of Mathy Construction, Onalaska, Wisconsin
Pederson Brothers Construction of Harmony, Minnesota
Salem Township, Olmsted County, Minnesota
University of Minnesota, Geology and Geophysics Department, Hydrogeochemistry Lab

Contract for observation well drilling: Standard DNR Waters language and contract form was used to contract with private well drillers.

D. Time: The project was initially authorized for 3 years. A 1 year extension was requested and approved in order to monitor aggregate mining impacts for a longer time period.

VII. DISSEMINATION: The project final report is available on the DNR web site. The results of this project will be used by DNR hydrologists as they make permitting decisions about aggregate pits and quarries, by local governments faced with the same types of decisions, and by responsible owners of pits and quarries as they plan their operations to avoid conflicts with neighbors and with resources dependent on ground water and surface water.

VIII. LOCATION: This project focused on quarries and pits in the Metro area and the eleven county southeast Minnesota area. One site, the Felton gravel pit, was in northwestern Minnesota.

IX. REPORTING REQUIREMENTS: Periodic work program progress reports were submitted every 6 months during the course of the project.

X. RESEARCH PROJECTS: Work plan was submitted prior to project start.

Project Site Map

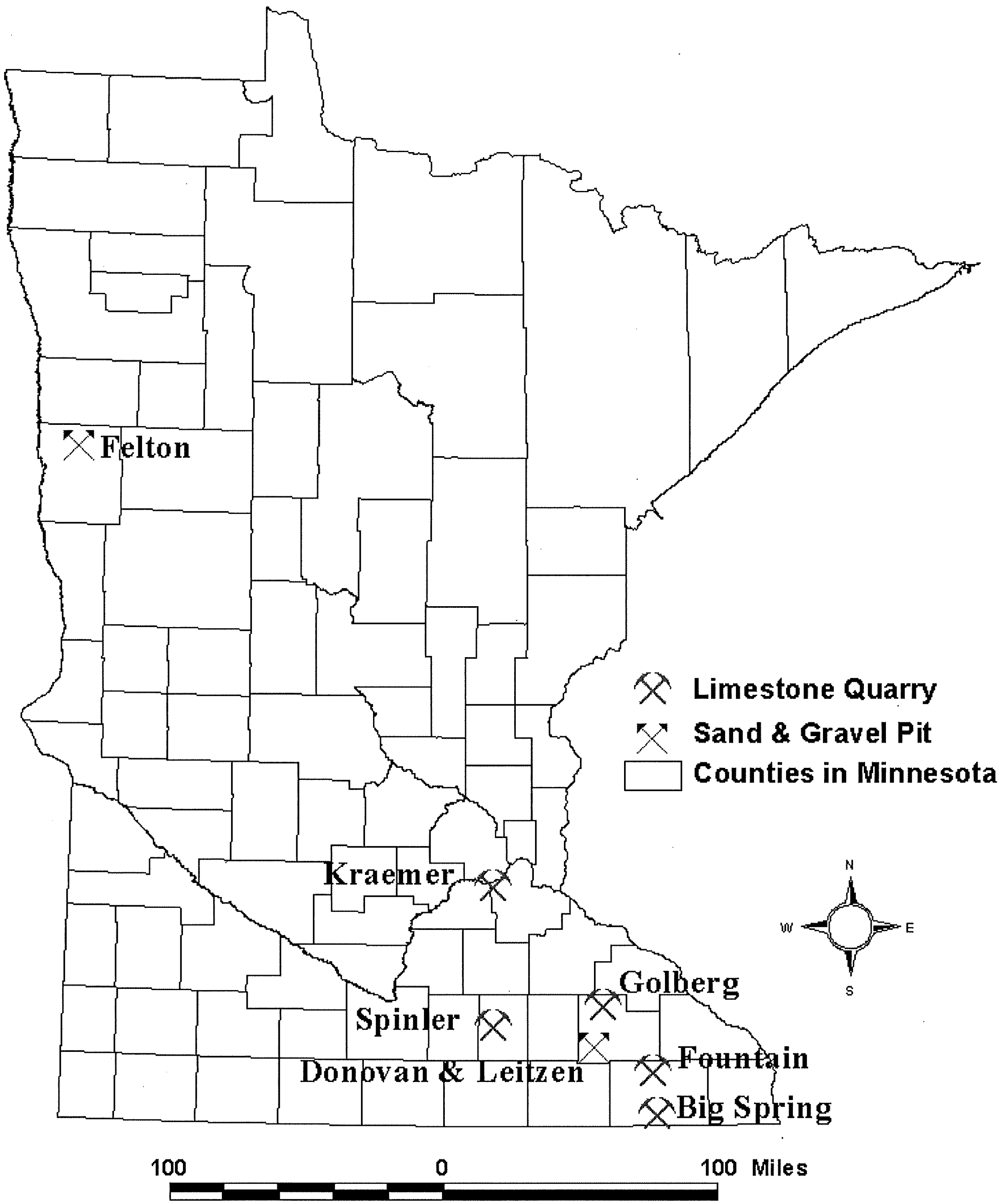

Figure 1. Site map.