Environmental Quality Board

Report on Silica Sand

Final Report

March 20, 2013

Minnesota Environmental Quality Board

The Environmental Quality Board (EQB) brings together leaders of nine state agencies, five citizens, and a representative of the Governor. The Board reviews interagency issues that affect Minnesota's environment, advises policymakers, and creates long-range plans. Strategic planning and coordination activities are important EQB functions. Minnesota Statutes direct the EQB to:

- Study environmental issues of interdepartmental concern
- Coordinate programs that are interdepartmental in nature and affect the environment
- Ensure compliance with state environmental policy
- Oversee the environmental review program
- Develop the state water plan and coordinate state water activities
- Convene environmental congresses
- Develop energy and environment reports
- Advise the Governor and the Legislature

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I. INTRODUCTION

A. Purpose of This Report

The technologies of horizontal drilling in conjunction with hydraulic fracturing have greatly expanded the ability to profitably recover natural gas and oil from shale. Hydraulic fracturing, also called fracking or hydrofracking, is a method used to access oil bearing shales and limestones and extracting oil and natural gas. Fracking requires a proppant, which are particles that hold open fractures in the shale that allow the oil or gas to be collected. Silica sand is used as a proppant. Nationwide, frac sand production almost doubled from 2009 to 2010, to 12.1 million tons, according to the U.S. Geological Survey (USGS). However, this estimate is likely low because submitting data to the USGS is voluntary. Industry estimates report nationwide production numbers as high as 22 million tons ("US Silica: The First IPO in the 'Fracking Sand", 2012).

Although hydraulic fracturing for the extraction of oil and natural gas is not occurring in Minnesota, the silica sand resources used in hydraulic fracturing are located in Minnesota. Large silica sand deposits are located in south central and southeast Minnesota and western Wisconsin. The demand for sand for hydraulic fracturing has resulted in many new mining and processing plant proposals being submitted to local and state government agencies. The potential economic impacts on the local and state economies have generated great interest. Potential impacts to the landscape, natural resources, and health of residents in the areas of these proposed facilities have generated great concern.

In 2012 the Environmental Quality Board (EQB) received a petition supporting the preparation of a Generic Environmental Impact Statement (GEIS) to analyze the potential environmental effects of the industry. Such a study would require significant time and financial resources. While the preparation of a GEIS remains an option, the EQB has prepared this report to provide background information on the topic of silica sand.

This report provides a summary of information relevant to the questions at hand. It does not pretend to be encyclopedic. The report does not advocate a particular perspective on the silica sand issues: it is not pro- or anti-silica sand mining. The intent is to provide a basis for further research, whether that occurs through a GEIS or by other means. It is recognized that the information presented here can and should be augmented and improved as more is learned.

II. BACKGROUND ON SILICA SAND

A. What is Silica Sand?

Silica or silicon dioxide (SiO_2), also called quartz, is one of the most common minerals found on the earth's surface. Silica is major component of many different kinds of rocks (like granites and gneiss) and comes in many different varieties.

Sand refers to a particle size. All sands are not the same. For example, construction sand and gravel is used to build and maintain roads and bridges. Construction sand and gravel consists of many different rock types and sizes. Some rocks are angular and other rocks are rounded. In contrast, silica sand is mined from sandstone formations that have undergone geologic processes that produced well-rounded, well-sorted sand and gravel that consists of almost pure quartz (silicon dioxide).

Figure 1. Industrial Silica Sand

Mining of silica sand has occurred in Minnesota and Wisconsin for over 100 years. Some of the sand caves in Minneapolis and St. Paul are mines, the sand from which was used for making beer bottles and for foundry sand. Mining of silica sand has been continuously occurring in Le Sueur County for over 50 years. Washington County has intermittently hosted silica sand mining for over 60 years. Counties that have historically hosted silica sand mines include: Ramsey, Hennepin, Dakota, Goodhue, Anoka, Pine, Le Sueur, and Scott (DNR Industrial Minerals, 1990).

Silica sand is widely used in many applications. In 2010, about 41% of the U.S. tonnage was used as hydraulic fracturing sand and well-packing and cementing sand, 26% as glassmaking sand, 11% as foundry sand; 6% as other whole-grain silica; 6% as whole-grain fillers and building products; 3% as ground and unground sand for chemicals; 2% as golf course sand; 2% for abrasive sand for sandblasting; and 3% for other uses (U.S. Geological Survey, 2012).

B. What is 'Fracking' and Why is Sand Needed?

Hydraulic fracturing, also called fracking or hydrofracking, is a method used to access oil-bearing shales and limestones to extract oil and natural gas. The process involves the pumping of a fracturing fluid under high pressure to generate fractures or cracks in the target rock formation (Figure 2). This allows the natural gas (or oil) to flow out of the shale to the well in economic quantities. For shale gas development, fracture fluids are primarily water based fluids mixed with additives that help the water to carry sand proppant (frac sand) into the fractures. Water and sand make up over 98% of the fracture fluid, with the rest consisting of various chemical additives that improve the effectiveness of the fracture job. Each hydraulic fracture treatment is a highly controlled process designed to the specific conditions of the target formation (USDOE, 2009).

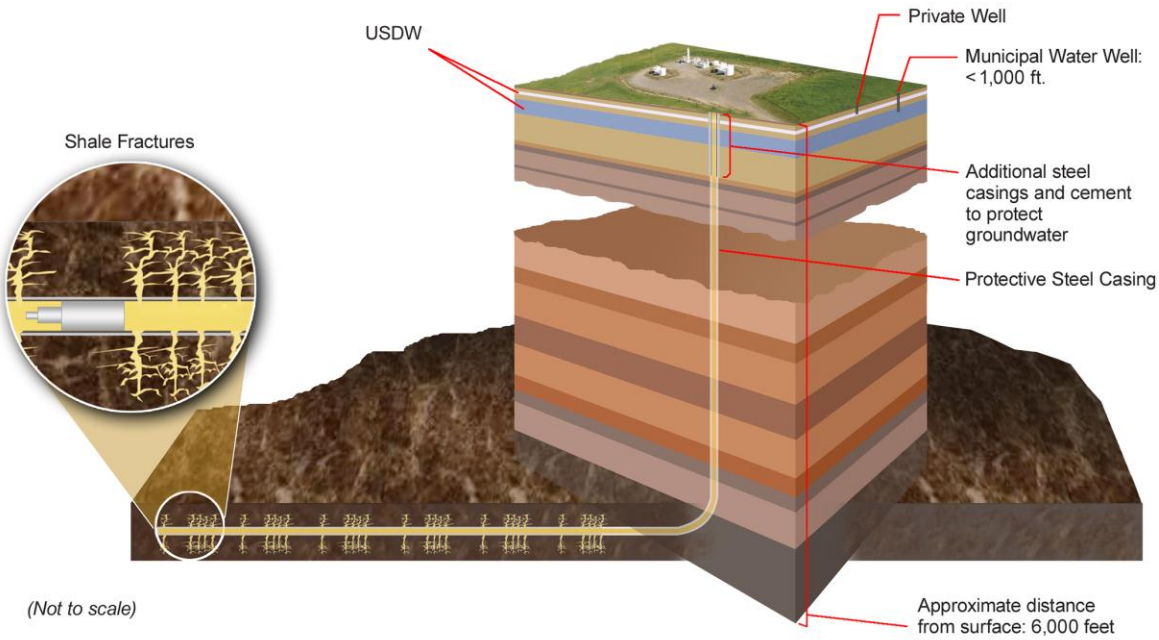


Figure 2. Diagram of Hydraulic Fracturing. Source: U.S. Department of Energy, 2012.

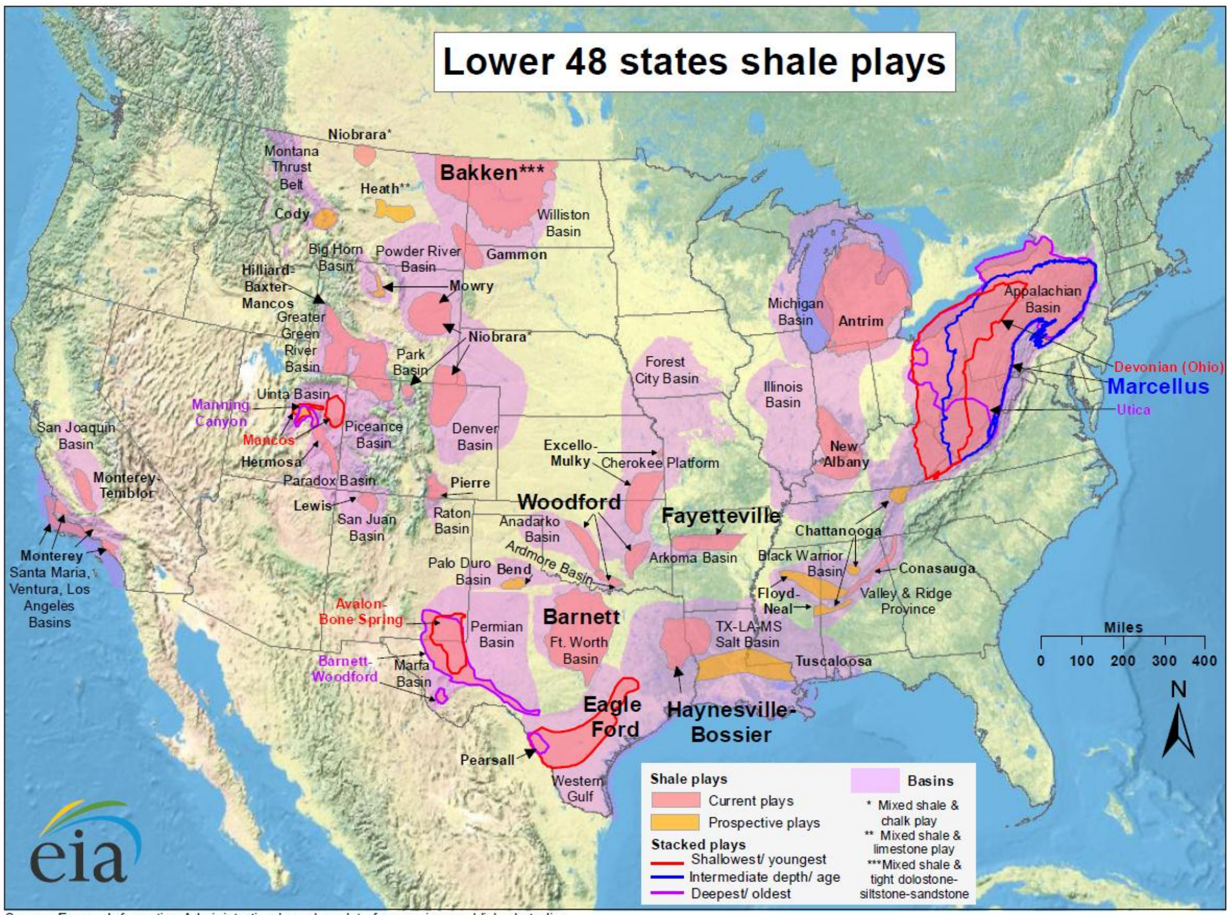
A typical gas well is drilled vertically one to two miles below the surface. In North Dakota, the wells average between 9,000 to 10,000 feet deep. When the oil shale is reached, the well is drilled laterally, typically for 5,000 to 10,000 feet. There can be up to three lateral extensions within a well. The actual thickness of the bed can be very thin, eight feet or so.

Fracture fluid base is usually water but can include methanol, liquid dioxide, and liquefied petroleum gas. Proppant consists of particles that hold open the fractures. Silica sand is used as a proppant. Chemical additives include friction reducers, scale inhibitor, solvents, acids, and niocides that are added to protect equipment.

The propped fracture is only a fraction of an inch wide and held open by the frac sand. A well uses thousand of tons of sand, depending on how many stages of pumping and fracking occurs.

There has been some misunderstanding about mining that occurs in Minnesota. There are no oil or gas fracking mines in Minnesota. It is the silica sand (aka frac sand) that is being mined in Minnesota. This sand is transported elsewhere in the county to oil fields as well as foundries and glass manufacturers.

A particular stratigraphic or structural geologic setting is also often known as a "play". Figure 3 shows the locations of shale gas and shale oil plays.



Source: Energy Information Administration based on data from various published studies.
Updated: May 9, 2011

Figure 3. Map of U.S. Shale Gas and Shale Oil Plays

C. Silica Sand Specifications for Hydraulic Fracturing

Silica sand specifications for hydraulic fracturing are set by the American Petroleum Institute (API). The primary considerations are the physical characteristics of the sand such as size (Table 1), sphericity, roundness, crush resistance, and mineralogy. Not all the sandstones in Minnesota meet the specifications for silica sand.

Table 1. API Recommended Silica Sand Specifications

Product Mesh Size (holes per square inch)	8/12	10/20	20/40	70/140
Grain Size (Diameter)	2.38 to 1.68 millimeter	2.00 to 0.84 millimeter	0.84 to 0.42 millimeter	210 to 105 microns
Sediment	Fine Gravel to Coarse Sand	Very Coarse Sand to Coarse Sand	Coarse Sand to Medium Sand	Fine Sand to Very Fine Sand

Source: American Petroleum Institute and MDNR

Grain size 20/40 mesh is most widely used. 90% of the sand is to fall within the specified particle range. Not more than 1% of the total sample can fall on the first or last sieve in the series. Clay and silt size particles >105 microns are removed with the processing, as well as weak and crusted grains.

D. Location of Silica Sand Resources

The last mineral survey was completed by USGS in 2010. As defined in the *USGS 2010 Minerals Yearbook*, sand and gravel, often called "silica," "silica sand," and "quartz sand," includes sands and gravels with high silicon dioxide (SiO_2) content. There were 29.9 million metric tons (Mt) of sand and gravel produced in the United States in 2010. The Midwest led the Nation with 49%, followed by the South with 39%, the West with 7%, and the Northeast with 5%. The leading producing States were, in descending order: Illinois, Texas, Wisconsin, Minnesota, Oklahoma, North Carolina, California, and Michigan. Their combined production represented 64% of the national total. Minnesota produced 1,940 Mt, or 6% (USGS, 2010, Tables 2 and 3). Note that the mineral survey was voluntary, so estimated numbers are likely lower than actual.

Table 2. Industrial Sand and Gravel Sold or Used in the United States

Geographic region	Quantity (thousand metric tons)	Percentage of total	Value (thousands)	Percentage of total
Northeast:		5		6
New England	127	*	$6,380	1
Middle Atlantic	1,440	5	47,000	5
Midwest:		48		49
East North Central	9,910	33	346,000	33
West North Central	4,600	15	163,000	16
South:		39		39
South Atlantic	3,480	12	93,400	9
East South Central	1,290	4	40,900	4
West South Central	6,880	23	274,000	26
West:		8		6
Mountain	500	2	14,000	1
Pacific	1,680	6	49,900	5
Total	29,900	100	1,030,000	100

Data are rounded to no more than three significant digits; may not add to totals shown.

*Less than ½ unit.

source: USGS 2010 Minerals Yearbook, Table 2

In 2010 the U.S. produced an estimated 12,100 thousand metric tons of sand used for hydraulic fracturing. The Midwest produced 8,080 thousand metric tons, 67% of the national total (USGS, 2010, Table 6).

The map below (Figure 4) shows first encountered bedrock. Depending on the geologic setting (like Illinois) there may be areas where the first bedrock (i.e. limestone and shales) are being removed to access sandstone. The upper Midwest hosts significant sandstone resources. The deposits in Wisconsin and Minnesota are spread out over very large areas and near the land surface compared to other states.

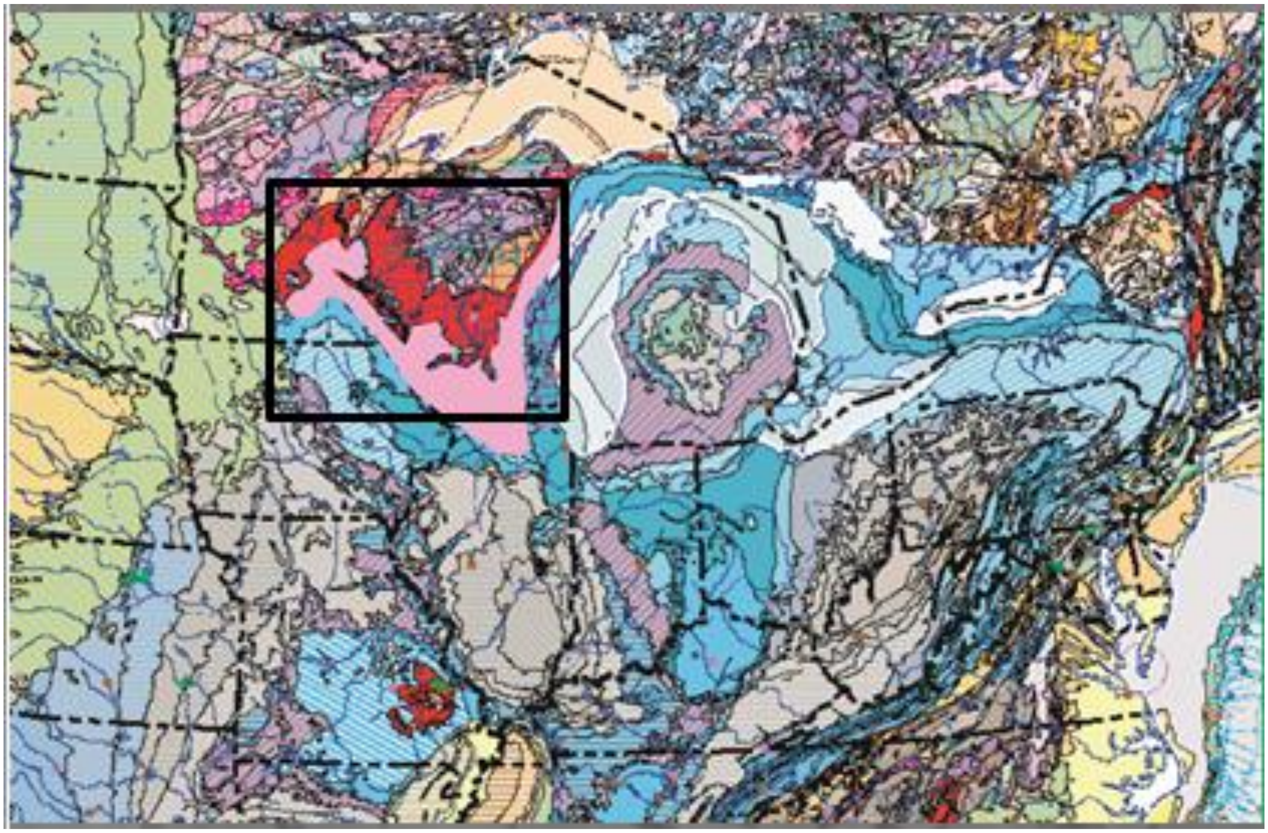


Figure 4. First encountered bedrock. Silica sand deposits are displayed in red and solid pink. Source: Runkel, 2012.

The areas in red show the distribution of Cambrian quartz-rich sandstone . Minnesota and Wisconsin also contain St. Peter Sandstone, part of the Ordovician bedrock formation, which is displayed in light pink directly below the red. Combined, these two areas represent sandstone formations that are relatively close to the land surface, contain a high percentage of quartz, are monocrystalline, and have high sphericity. In other words, these areas contain the best accessible frac sand. In Minnesota, the best frac sand is found in the southeast portion of the state.

The next map (Figure 5) is a simple categorization of counties by the accessibility to mine silica sand resources. The brown color indicates where extensive quartz-rich sandstone resources are within 50 feet of the land surface (Runkel, 2012). The gray areas represent counties where glacial sediment and/or bedrock limit the access to silica sand resources or where near surface resources are small in areal extent.

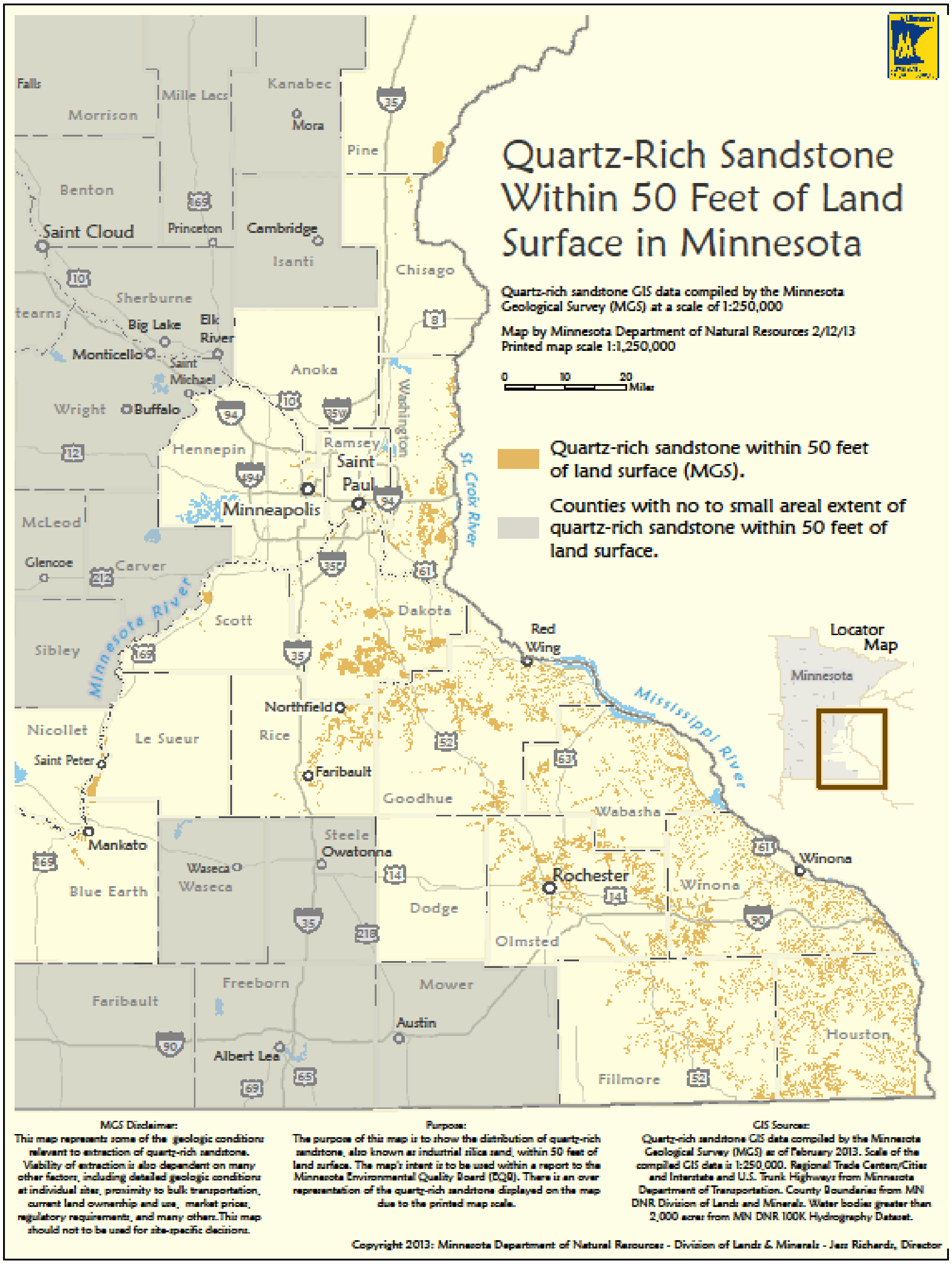


Figure 5. Quartz-Rich Sandstone Within 50 Feet of Land Surface

Five mines have been identified by the Minnesota Geologic Survey that extract silica sand in Minnesota (Runkel, 2012). One additional mine has come on-line since December of 2012. A number of small silica sand mines supplying local uses of sand exist in southeastern Minnesota. These mines extract sand for agricultural uses (such as cow bedding) and fill.

The next graphic (Figure 6) is a stratigraphic column that represents the vertical order, or stratigraphy, of Paleozoic rock units with the oldest on the bottom and the youngest on the top.

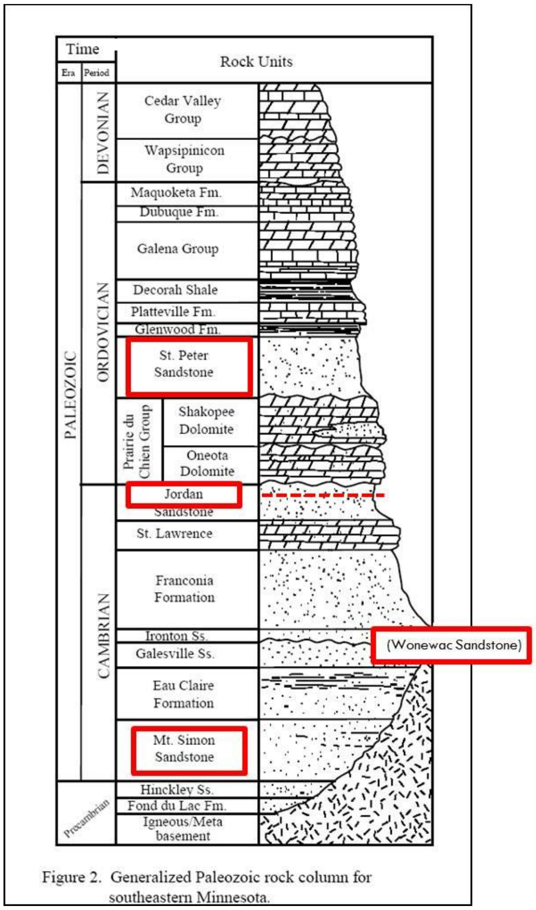


Figure 2. Generalized Paleozoic rock column for southeastern Minnesota.

Figure 6. Generalized Stratigraphy of Paleozoic rock in southeast Minnesota (left) and actual exposed rock (right). Source: MGS and MDNR.

Depending on its depth, sand is accessed by surface mining, bench mining, or underground mining. For example, mining in the central part of the state along the Minnesota River corridor is dominated by surface mining. Southeastern Minnesota has the potential for surface mining, bench mining, and underground mining (Figure 7).

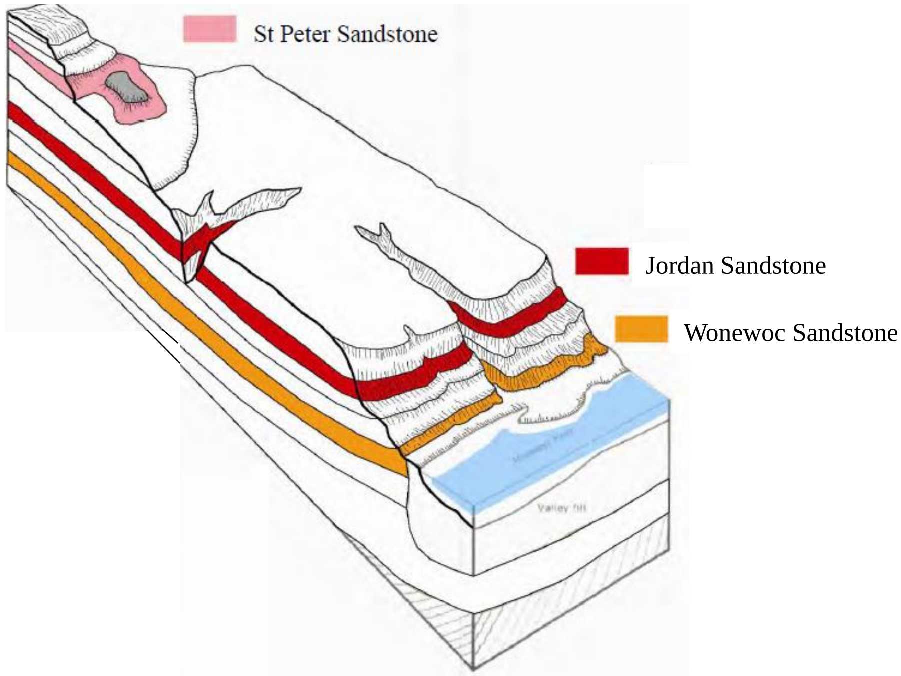


Figure 7. Representation of areas with the potential for surface, bench and underground mining. Source: modified from Runkel, 2012.

E. Comparison of Silica Sand Mining to Other Sand and Gravel Mining

With hardrock mining (e.g. taconite, granite, and quartzite), blasting and crushing are used to fracture and break rocks into smaller, manageable pieces, which produces angular, freshly broken rock faces. In silica sand mining, blasting and the use of crushers are used to loosen weakly cemented sandstone, while keeping the individual, round grains intact (Figure 8). When the grains break, it lowers the performance for use as frac sand. After processing, much of the silt and clay is removed and very few grains would have freshly exposed surfaces.

Table 3. Similarities and Differences - Construction Sand and Silica Sand. Source: MDNR

	Construction Sand and Gravel	Silica Sand
Same	• Surface mining: backhoes, bulldozers, excavators, screens, and conveyors	• Surface mining: backhoes, bulldozers, excavators, screens, and conveyors
Different	• Episodic • No underground mining • Washing plants tend to <u>not</u> use flocculants • Does <u>not</u> require blasting	• Long term • Underground mining and bench mining • Washing plants may use flocculants • May require blasting

Construction Sand and Gravel

Silica Sand

Figure 8. Size and Shape Comparison - Construction Sand to Silica Sand

F. Processing of Silica Sand

Frac sand must be of uniform size and shape. Raw silica sand must be processed into frac sand to be used for oil and gas drilling. Commercial silica sand mines may or may not process the sand on-site. Several off-site processing plants are currently known to receive silica sand from various mining operations in Minnesota and Wisconsin.

Processing begins by washing the sand to remove fine particles. Washing is done by spraying the sand with water as it is carried over a vibrating screen. The fine particles are washed off the sand and the coarse particles are carried along the screen by the vibration. An alternative method uses an upflow clarifier, where water and sand flow into a tank. Fine particles overflow the tank while the washed sand falls by gravity to the bottom.

After washing, the sand is then sent to a surge pile where water adhering to the sand particles infiltrates back into the ground. From the surge pile the sand is sent to the dryer and screening operation where the sand is dried in a drum with hot air blasted into it. Then the sand is cooled and often further sorted to separate sand that is suitable for fracking from sand that is not suitable. Some specialized processing plants may further treat the sand by applying a resin coating to the sand particles. This coating helps the sand to flow as a slurry and increases the crush strength (WDNR, 2012).

Some nonmetallic mining processors use 4500 to 6000 gallons of water per minute. Local aquifers cannot provide this much water, so reuse of water is necessary. Typical operations used unlined sedimentation ponds for water clarification and source water for processing. More sophisticated techniques reduce the amount of water being used. This is advantageous both economically and environmentally. Water quality concerns arise from the use of chemicals. There is a need to establish baseline water quality before starting processing, and ongoing monitoring also is needed, to avoid contaminating local aquifers through chemical use (McCurdy, 2012).

While sand that is not suitable for fracking has other industrial uses, it may be difficult to sell it due to the remote locations of many processing plants (Kelley, 2012).

G. Proppant Alternatives to Silica Sand

There are three types of proppants used for hydro fracking: silica sand, resin-coated silica sand, and man-made ceramic beads known as manufactured proppants. Unlike frac sand and resin-coated proppants, which are primarily industries based in North America, ceramic proppant manufacturers are distributed throughout the world. Figure 9 shows a shipment of manufactured silica sand that made the Duluth Shipping News.

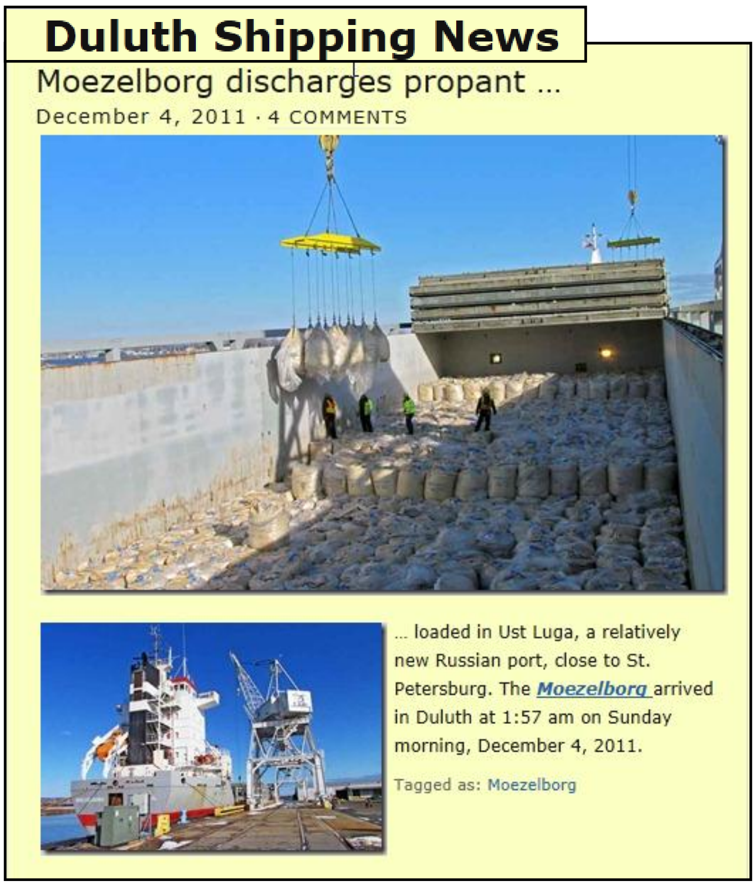


Figure 9. Manufactured Silica Sand Shipped from Russia to Duluth, MN. Source: Duluth Shipping News.

This barge came from Russia and unloaded in Duluth harbor in 2011. Instead of sand mines, ceramic proppants are made from kaolinite or nonmetallurgical bauxite, or clay mines, and are being mined in places like China, Brazil, and India. To make the proppant, the clay undergoes a process called sintering where high temperature kilns bake the clays to form well rounded, strong sand-sized particles. An article in the Journal of Petroleum Technology noted a global shortage of proppants (Beckwith, 2011).

H. Multiple Industry Elements: Mining, Processing, Transporting of Silica Sand

The silica sand industry comprises several locational elements: mining, processing, and transporting. The location of the mine is determined by geology: the location of the sand resource. Mining and processing may or may not occur at the same location or even in proximity to one another. When they are at different locations, transporting the sand from the mine to the processing facility is one stage of transportation. This typically occurs by truck. Once the sand is processed, it must be transported from the processing facility to the oil or gas fields. This typically occurs by rail or barge. Processing facilities may be sited near rail or barge terminals. When this is not the case, trucks bring the processed sand to the rail or barge loading site. The simple diagram in Figure 10 illustrates the multiple elements of the industry.

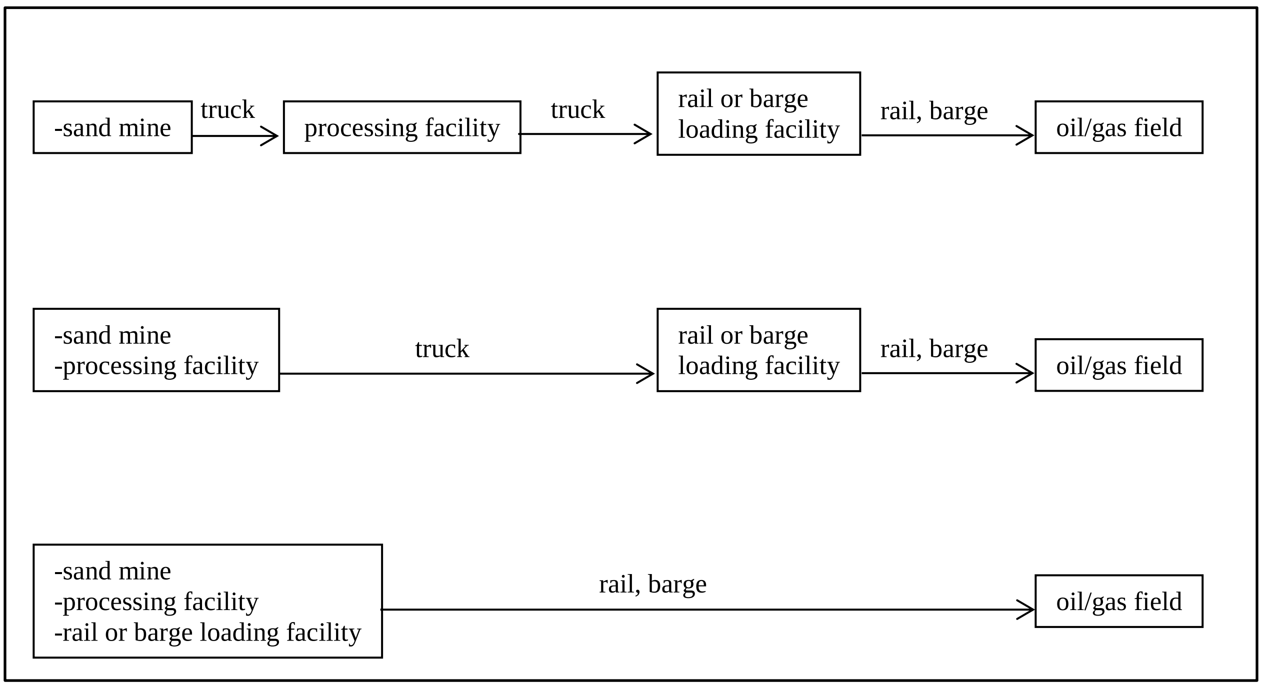


Figure 10. Mining, Processing, Transportation Variations

The potential for impacts on existing landscapes, land uses, and sensitive resources can vary greatly from one site to another. For example, a great increase in the number of trucks between facilities may have little effect in an unpopulated area. Those same trucks likely will have a much greater impact when traveling on a road passing near a neighborhood or down the main street of a small town dependent on tourism.

The economic impacts on an area such as increased employment and tax revenues can be great. At the same time, the multiple-element nature of the industry increases the complexity of addressing questions and challenges.

III. FRACKING AND SAND MARKET SUMMARIES, SOCIOECONOMICS

A. Fracking Overview

The following excerpt from a publication by a federal agency provides a useful history of fracking and the shale gas and oil market. This is not intended to be a comprehensive description of the oil and gas market. The following is excerpted from: "Review of Emerging Resources: U.S. Shale Gas and Shale Oil Plays." July 2011, U.S. Energy Information Administration.

> "The use of horizontal drilling in conjunction with hydraulic fracturing has greatly expanded the ability of producers to profitably recover natural gas and oil from low-permeability geologic plays—particularly, shale plays. Application of fracturing techniques to stimulate oil and gas production began to grow rapidly in the 1950s, although experimentation dates back to the 19th century. Starting in the mid-1970s, a partnership of private operators, the U.S. Department of Energy (DOE) and predecessor agencies, and the Gas Research Institute (GRI) endeavored to develop technologies for the commercial production of natural gas from the relatively shallow Devonian (Huron) shale in the eastern United States. This partnership helped foster technologies that eventually became crucial to the production of natural gas from shale rock, including horizontal wells, multi-stage fracturing, and slick-water fracturing. Practical application of horizontal drilling to oil production began in the early 1980s, by which time the advent of improved downhole drilling motors and the invention of other necessary supporting equipment, materials, and technologies (particularly, downhole telemetry equipment) had brought some applications within the realm of commercial viability.
>
> "The advent of large-scale shale gas production did not occur until a private firm experimented during the 1980s and 1990s to make deep shale gas production a commercial reality in the Barnett Shale in North-Central Texas. As the success of this became apparent, other companies aggressively entered the play, so that by 2005, the Barnett Shale alone was producing nearly 0.5 trillion cubic feet of natural gas per year. As producers gained confidence in the ability to produce natural gas profitably in the Barnett Shale, with confirmation provided by results from the Fayetteville Shale in Arkansas, they began pursuing other shale plays, including Haynesville, Marcellus, Woodford, Eagle Ford, and others.
>
> "Although the U.S. Energy Information Administration's (EIA) National Energy Modeling System (NEMS) and energy projections began representing shale gas resource development and production in the mid-1990s, only in the past 5 years has shale gas been recognized as a "game changer" for the U.S. natural gas market. The proliferation of activity into new shale plays has increased dry shale gas production in the United States from 1.0 trillion cubic feet in 2006 to 4.8 trillion cubic feet, or 23 percent of total U.S. dry natural gas production, in 2010. Wet shale gas reserves increased to about 60.64 trillion cubic feet by year-end 2009, when they comprised about 21 percent of overall U.S. natural gas reserves, now at the highest level since 1971. Oil production from shale plays, notably the Bakken Shale in North Dakota and Montana, has also grown rapidly in recent years." (USEIA, 2011)

B. Sand Market Overview

Section II includes a data table for sand production is different parts of the U.S. The following excerpt from a different publication by another federal agency provides a useful background on recent history of the silica sand market and concerns regarding the industry. The following list of statement are excerpted are from “Sand Surge” in the Fedgazette, written by Phil Davies and published by the Federal Reserve Bank of Minneapolis, July 16, 2012. This is not intended to be a comprehensive description of the market or related issues. Rather, it highlights many of the issues being recognized in Minnesota.

- Nationwide, frac sand production almost doubled from 2009 to 2010, according to the U.S. Geological Survey.

- High-grade frac sand commands a premium in the marketplace. Large mining firms, many of them based outside the region, have invested hundreds of millions of dollars in mines and processing facilities.

- Many new, large mines are situated on rail lines, the most economical shipping method. (Rail patterns dictate that most frac sand mined in the region goes to shale oil and gas fields in the eastern and southern United States, rather than to the Bakken.)

- In Minnesota, the frac sand industry is less developed. That’s partly due to geology; accessible deposits of high-grade sandstone are less extensive in Minnesota than in Wisconsin. Another impediment to mine development in Minnesota is logistics—the task of getting millions of tons of sand to distant markets.

- In contrast to Wisconsin, southeastern Minnesota has little rail capacity to ship sand to transportation hubs such as Winona and the Twin Cities. Hundreds of miles of rural rail lines have been abandoned since the 1970s, leaving trucks as the only viable means of moving sand overland. In addition, much rail and barge capacity in Winona is already taken up by agricultural commodities.

- Despite these limiting factors, several new mines have been developed or proposed over the past couple of years.

- Industry sources believe that frac sand mining in southeastern Minnesota will remain small in scale until more rail and barge capacity is developed to ship sand to oil and gas fields.

- No official job numbers exist for sand mining in the district—the industry is too new. But it’s evident that expanded mining has contributed to rising private employment since the recession. On average, one frac sand mine employs between 10 and 20 people, while 40 to 50 people work at a typical processing plant, according to industry sources. So over the past five years, new mines and processing plants—not counting existing, expanded mines—have created roughly 500 jobs in the Ninth Federal Reserve district portion of Wisconsin. At many mines, large numbers of trucks are needed to haul frac sand to processing plants and rail terminals, creating job openings for truck drivers and crews.

- Local governments and taxpayers in rural areas also benefit from increased economic activity linked to mining. Lodging tax revenue could increase, and school district mill rates may decrease as new processing plants begin paying property taxes.

- Economic gains from frac sand mining don't come without costs; mining activity can damage infrastructure and the natural environment, and compromise public health and safety. Many of these costs are borne by taxpayers, or by society at large in the form of extra personal expense or forgone benefits.

Closer to home, sand for the petroleum industry has been mined in Wisconsin for four decades, but the demand for frac sand increased exponentially from 2008-2011. In January of 2012, there were about 60 mines producing an estimated 12 million tons per year (Wisconsin Dept. of Natural Resources 2012).

C. Research on Impacts of Mining on Communities

Carol MacNenna, an environmental anthropologist at Michigan Technological University, has studied mining communities for ten years. MacNenna cautions in an interview with Michigan Tech News (January 2012 issue) "the worst type of communication has to do with the simplification of the mining issues. I think the biggest problem is creation of polar opposites so that one has to choose between employment or environmental and health protection." She continues by saying "characterizing it [mining] that way is very destructive because you're never forced to confront the complexity of the issue."

A study by Deller and Schreiber at the University of Wisconsin-Madison reviewed academic literature in an attempt to "provide some insights into the economics of sand mining with particular attention to economic growth and development opportunities associated with the mines." Very little academic research exists that examines impacts of mining on local communities. While there may be many consultant reports, it is difficult to draw generalities from them because funding sources—whether mining companies or environmental advocacy groups—may affect objectiveness. Internationally, much of the research on mining in developing nations often conclude that the ownership structure, and lax environmental safety standards, the local communities don't retain economic benefits. This aligns with the concept of the "resource curse". Some studies conclude that strong economic growth from resource extraction is the exception rather than the rule. However, these conclusions are not directly transferrable to Wisconsin (Deller and Schreiber 2012). It seems logical that the conclusions also should not automatically be applied to Minnesota.

Perhaps the best conclusion is that there is not enough known about the relatively recent phenomenon of the demand for silica sand for fracking regarding the long term effects of sand mining on local or regional communities.

D. Employment Data

As noted in the Fedgazette, official specific employment data is difficult to come by for silica sand mining. This is partially due to the recent increases in activity of this industrial sector, and partially because employment data is not separated from other mining activities. However, data for mining overall is available. The Minnesota Department of Employment and Economic Development (DEED) recently published data comparing various industry sectors, including mining, in terms of wages and education (Macht, 2012). The following tables are based on 2011 data.

Table 4. Minnesota's Workforce, Educational Attainment by Industry, 2011

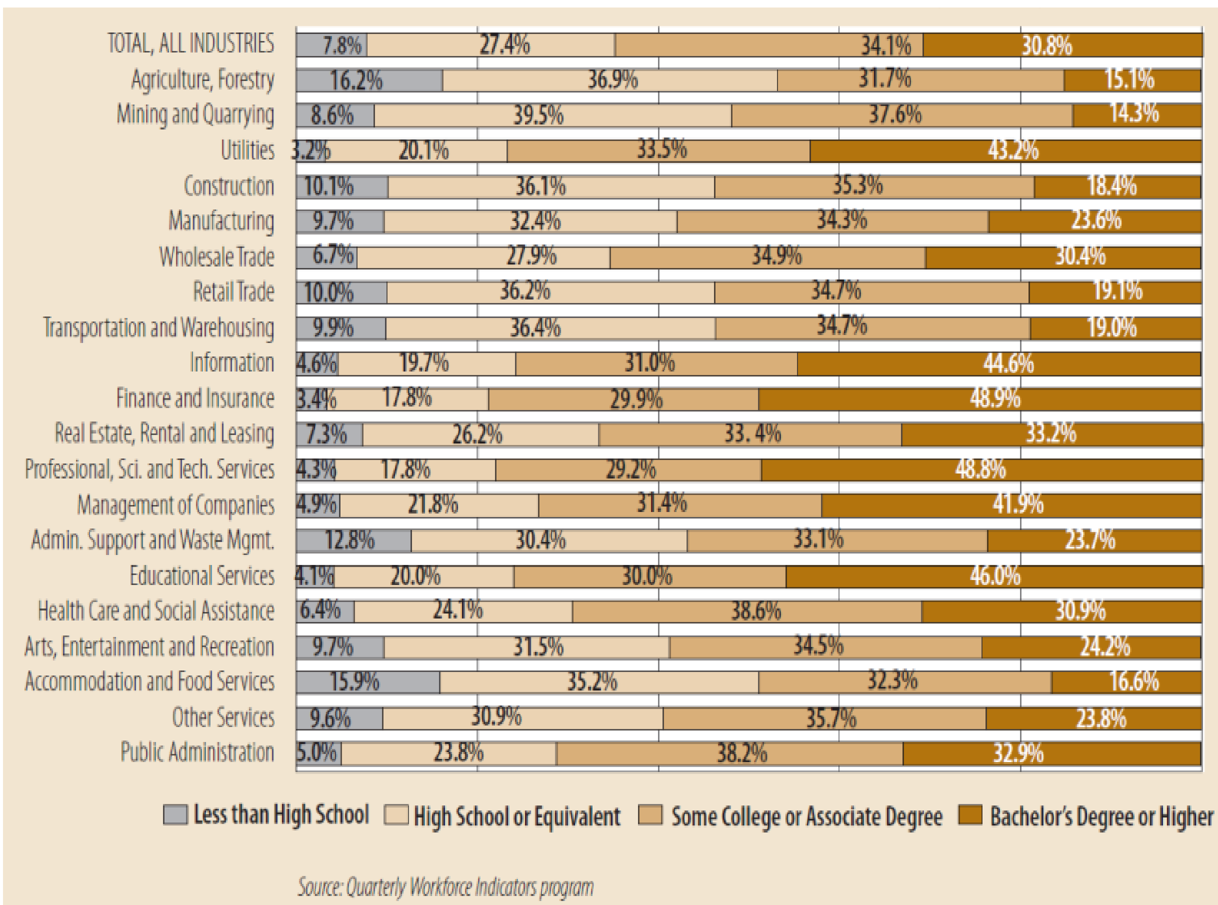


Table 5. Average Monthly Earnings by Educational Attainment, 2011

Industry Title	Average Monthly Earnings, 2011: Average Monthly Wages	Less than H.S. Diploma	H.S. Diploma or Equivalent	Some College or Associate Degree	Bachelor's Degree or Higher	Difference between Bachelor's Degree or Higher and H.S. Diploma
TOTAL, ALL INDUSTRIES	$4,435	$2,778	$3,291	$3,959	$6,361	93.3%
Management of Companies	$8,143	$4,336	$5,270	$6,576	$11,268	113.8%
Mining and Quarrying	$7,183	$6,155	$6,641	$7,067	$9,548	43.8%
Finance and Insurance	$7,172	$3,937	$4,372	$5,467	$9,467	116.5%
Utilities	$6,988	$5,622	$5,922	$6,491	$7,951	34.3%
Professional, Scientific and Technical Services	$6,651	$4,098	$4,537	$5,426	$8,341	83.8%
Wholesale Trade	$5,988	$3,752	$4,457	$5,437	$8,511	91.0%
Information	$5,548	$3,407	$3,879	$4,734	$7,071	82.3%
Manufacturing	$5,099	$3,596	$4,189	$4,912	$7,231	72.6%
Real Estate, Rental and Leasing	$4,823	$2,739	$3,328	$4,210	$7,078	112.7%
Construction	$4,713	$3,880	$4,325	$4,725	$5,845	35.2%
Public Administration	$4,088	$3,085	$3,505	$3,970	$4,786	36.5%
Health Care and Social Assistance	$3,977	$2,342	$2,701	$3,427	$5,931	119.6%
Educational Services	$3,785	$2,589	$2,812	$3,319	$4,606	63.8%
Transportation and Warehousing	$3,455	$2,842	$3,199	$3,486	$4,195	31.1%
Administrative Support and Waste Management	$3,067	$2,093	$2,558	$2,983	$4,305	68.3%
Agriculture, Forestry, Fishing and Hunting	$2,902	$2,588	$2,804	$2,943	$3,385	20.7%
Arts, Entertainment and Recreation	$2,687	$1,961	$2,103	$2,489	$4,023	91.3%
Retail Trade	$2,641	$2,061	$2,344	$2,653	$3,493	49.0%
Other Services (except Public Administration)	$2,618	$1,996	$2,245	$2,565	$3,421	52.4%
Accommodation and Food Services	$1,680	$1,535	$1,611	$1,714	$1,900	17.9%

Source: DEED Quarterly Workforce Indicators program

C. Potential Research Topics

- **Future market for silica sand for hydrofracking**: Data from industry and government sources could be assembled and compared to consider market projections of demand. This likely will involve market projections for oil and gas. Such projections could serve as the bases for analyzing potential impacts in a number of the topic areas addressed elsewhere in this report.

- **Economical depth for mining:** We know where the sand is, but the depth at which mining is economical is changing. In the past, it was not economical to mine sand beyond certain depths. With the surge in demand due to hydrofracking, this changed. Further consideration of this may be useful.

- **Impacts on property values:** It may be possible to assemble data for properties near mines, processing sites, and transportation facilities to see what, if any, property value changes have occurred and if the changes are correlated to those activities and facilities. Such studies have been conducted on other types of land use to address questions of the impacts on property values in the vicinity. However, the sand facilities may be too recently created for any such analyses to be possible.

- **Potential effects on tourism:** Determining potential effects on tourism would be very useful. Determining what data and methodology would be needed in order to conduct such a study is a challenging question in itself.

- **Tax revenues available:** Minnesota Statute 298.75 establishes a tax on aggregate mining, including silica sand. Property taxes apply as well. It may be useful to assemble information to describe the potential revenues from these sources and determine what other tax or fee revenue sources are available.

- **Employment:** Reliable research is scant or nonexistent regarding short term and long term employment created by silica sand mining.

IV. AIR QUALITY

A. Health Impacts

1. Potential Health Impacts of Crystalline Silica

Silica exists in two forms: amorphous and crystalline. The toxicity of crystalline silica to humans has been well characterized. In occupational settings where exposures tend to be higher than ambient exposures, silica is capable of causing a number of diseases. The best known disease is silicosis (silicotic nodules and fibrotic scarring of the lung), but exposure to crystalline silica is associated with other health concerns. Silica exposure contributes to other diseases of the lung including emphysema, chronic obstructive pulmonary disease, tuberculosis, and lung cancer. Silica exposure has also been associated with several diseases of the immune system.

When discussing the toxicity of silica, the real concern is with respirable crystalline silica particles with a diameter of 4 micrometers (4 μm or 4 microns) or smaller. Particulate matter 4 microns or smaller is referred to as PM_4. Particles this small are invisible to the naked eye (Figure 11). PM_{10} is respirable but only reaches upper levels of the respiratory system when it's larger than PM_4. PM_4 can travel much deeper in the lungs and reach the lower respiratory surfaces (alveoli) where the changes that produce silicosis take place.

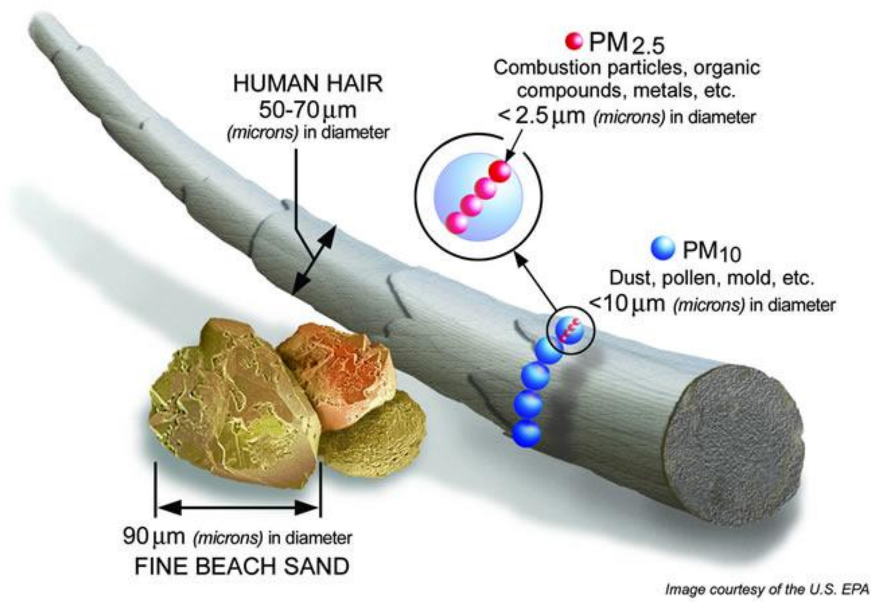


Figure 11. Size Comparison of Particulate Matter.

Disease risk is related to both the levels and duration of silica exposure and the onset of disease may occur long after the exposure has ceased. The U.S. Occupational Safety and Health Administration (OSHA) recently issued a "Hazard Alert" on worker exposure to silica during hydraulic fracturing operations (OSHA, 2012).

Mining activities have the potential to generate high concentrations of fine silica dust. As noted above, exposure to silica dust has been shown to cause a number of lung diseases, including silicosis and cancer, although there's no conclusive evidence linking these conditions to sand mining (Davies, 2012).

However, there have been studies identifying non-occupational silicosis due to elevated ambient exposures to silica particulate. There also are studies identifying silicosis in exposed animals downwind of peak sources of respirable crystalline silica (Bridge, 2009). More study is needed, but there is evidence of potential health risks in areas of elevated silica concentration. It is unknown what health impacts silica has at lower concentrations such as those typically found in ambient air.

2. Exposure Limits for Crystalline Silica

The OSHA permissible exposure limit (PEL) for crystalline silica is 0.100 parts per million (ppm) (which is the same as 100 micrograms per cubic meter or $\mu g/m^3$) for an 8-hour time-weighted average exposure. Adjustment of the OSHA PEL for a 24-hour exposure gives a level of 24 $\mu g/m^3$. The National Institute for Occupational Safety and Health (NIOSH) recommended exposure limit is 0.05 ppm (50 $\mu g/m^3$) for a 10-hour time-weighted exposure which would be adjusted to 15 $\mu g/m^3$ for a 24-hour exposure.

The California Environmental Protection Agency's Office of Environmental Health Hazard Assessment (OEHHA) has developed a chronic reference exposure limit for silica in ambient air of 3 $\mu g/m^3$. This value is eight-fold lower than the time adjusted OSHA limit and five-fold lower than the time-adjusted NIOSH recommendation. The OEHHA value for the general population is therefore more protective than federal recommendations for occupational exposure. The differences between acceptable risk levels for occupational settings and those for the general population are typically much greater than five- to eight-fold.

The Minnesota Department of Health (MDH) has recommended that the Minnesota Pollution Control Agency (MPCA) use a long-term exposure limit of 3 $\mu g/m^3$ of crystalline silica. The MPCA has accepted this value for the purpose of risk assessment. The MPCA has requested that MDH develop a short-term exposure limit for respirable crystalline silica in air.

3. Are the Occupational Exposure Limits Adequately Protective?

A number of studies suggest that silicosis is underdiagnosed when X-ray is used as the diagnostic tool, and that there is significant risk to workers exposed to silica concentrations lower than the occupational levels. OEHHA reports that "silicosis is still being diagnosed at autopsy following death in workers who were supposed to be exposed to occupational levels of 50-100 $\mu g/m^3$."

4. Ambient Levels of Crystalline Silica Associated With Frac Sand Mining

The MDH has little or no information on the levels of respirable silica generated by frac sand mining or processing. MDH has not been provided with any information on the ambient air levels of silica that result from frac sand mining operations. Two Minnesota facilities recently started monitoring for crystalline silica: Great Plains Sand and Tiller North Branch. These two sites received construction authorization from the MPCA in October 2012, and January 2013, respectively. Both sites are expected to start operating at full capacity by Spring 2013. MDH has been told that there are plans to monitor ambient air for silica associated with frac sand mining in Wisconsin.

5. Other Possible Health Concerns Associated With Frac Sand Mining

Because frac sand mining operations are expected to operate for many hours a day, some 24 hours per day for 7 days a week, the increase in truck traffic could be a problem. Increased dust, noise, risk of accidents and increased levels of engine exhaust will present health and nuisance issues. Emissions from the mining process--blasting, digging equipment, conveyors, crushing, drying, sorting, storage, and other fixed machinery—have the potential to result in more dust and chemicals being placed into the air.

B. Permits and Standards

- MPCA always regulates a silica-sand-related facility if they meet any of the following descriptions:
    - Has a dryer that was constructed after April 23, 1986
    - Has a stationary crusher capable of processing 25 tons per hour of non-metallic minerals (i.e. sandstone), and that crusher was constructed after August 31, 1983
    - Has a portable crusher capable of processing 150 tons per hour of non-metallic minerals (i.e. sandstone, and that crusher was constructed after August 31, 1983
    - Has potential PM_{10} emissions of 25 tons per year or more

- The MPCA regulates 'particulate matter' in three size ranges: Total Suspended Particulate, PM_{10}, and $PM_{2.5}$

- Silica sand primarily falls into the Total Suspended Particulate size category, but can also be found in PM_{10} and $PM_{2.5}$ size categories. The grain sizes used in the oil and gas extraction process fall into the Total Suspended Particulate size category..

- There is no Federal or State standard for silica in ambient air (PM_4); ambient air is defined as the portion of the atmosphere, external to buildings, to which the general public has access. The MPCA cannot build a specific limit in our air permits for PM4 without a standard although the Agency can request practices to mitigate emissions and exposure.

- Health benchmarks are similar to air standards in that they are health based, but they are less enforceable within the permitting process. They may be used to inform air permitting and respond to public comments. The MDH is currently reviewing other states' health benchmarks to compare to Minnesota's.

- Local units of government may also have air-quality-related ordinances and requirements that apply in addition to those found in MPCA-issued permits. However, MPCA does advise local units of government on ways to mitigate potential health and environmental concerns (e.g. advice on how to limit fugitive dust).

- OSHA regulates air quality in occupational settings to protect the health of workers through a respirable crystalline silica standard. OSHA defines respirable as particles below 4 micrometers, or PM_4.

- MDH and the MPCA have found that the majority of the silica exposure data are collected for the PM_4 size category.

- There are no federal reference methods for ambient air monitoring of the PM_4 size category. A federal reference method is a procedure for collecting and analyzing the ambient air for a specific pollutant.

- The MPCA has ambient air monitors for Total Suspended Particulate, PM_{10}, and $PM_{2.55}$ arranged in a state-wide array; these locations are not intended to represent any specific facility, but are intended to represent neighborhoods or larger geographic areas such as regions.

- A paper was published by Richards, et. al., in 2009 in the Journal of Air and Waste Management Association regarding a method in which a $PM_{2.5}$ monitor was modified to collect PM_4 data. This data was collected at several sand and gravel facilities in California. The published data includes emission factors for silica and ambient monitoring of silica. The results of the study suggest that the monitored levels are below the Reference Exposure Level of 3 $\mu g/m^3$, which is the limit developed by OEHHA and recommended by MDH. This Reference Exposure Level is intended to protect the general public over the long term. It is important to note that the silica content of the California sand and gravel was approximately 30% by weight and that the silica sand found in Minnesota is nearly 100% silica by weight. This silica content difference makes it difficult to directly apply the findings of the California study to Minnesota sands.

- Certain industries in Wisconsin, of their own initiative, have hired the above-mentioned Richard et. al in an attempt to monitor for PM_4. This data will be further analyzed in order to assess what portion of the collected PM_4 material is composed of silica. Due to the nature of the project's funding, it is unclear if the data will ever be published or peer reviewed.

- A facility in Scott County has agreed to monitor for Total Suspended Particulate, PM_{10}, and silica. A facility in Chisago County has agreed to monitor for PM_{10}, $PM_{2.5}$, PM_4, and silica. The data from these sites may inform whether or not there are exposure risks to the general public. The MPCA will receive this data on a quarterly and semi-annual basis from the two facilities.

- The MPCA has received approximately six months of ambient data from the Great Plains Sand facility. The data indicate that the facility is not exceeding the NAAQS. The data also indicate the facility is not exceeding the long-term crystalline silica health benchmark. The

MPCA understands the facility will not be fully operational until Spring 2013, so the current six-month dataset is not representative of an operational silica sand facility.

C. Potential Research Topics

- **Concentrations of crystalline silica associated with silica sand mining:** As noted above, there is little or no information on the amount of silica in the air that results from silica sand mining, processing, and transportation operations. There are plans to monitor silica levels in ambient air associated with frac sand mining in Wisconsin. However, MPCA reports that the Wisconsin study is being funded by industry and therefore the results may or may not be made public. A study funded by the State of Minnesota would ensure public availability of the results. Such a study might provide a basis for new state air quality standards for silica.

  In order to predict (i.e. model) the ambient impacts of a silica-sand facility, the MPCA needs additional information, such as: (1) an acceptable PM_4 monitoring method, and (2) a set of silica emission factors for PM_4-sized material for processes that occur at silica sand facilities. Both the monitoring method and emission factors would be used to support any air quality standard developed by the State.

- **Health Impact Assessment:** A Health Impact Assessment (HIA) is a research and community engagement process that can be used to help ensure that people's health and concerns are being considered when decisions on infrastructure and land use projects are being made. The National Research Council defines HIA as "a structured process that uses scientific data, professional expertise, and stakeholder input to identify and evaluate public-health consequences of proposals and suggests actions that could be taken to minimize adverse health impacts and optimize beneficial ones."

  HIAs have been used to provide important health information to decision makers on a wide range of projects outside the typical health arena, including comprehensive plans, brownfield redevelopment, transportation projects, energy policies, and housing projects. Over 100 HIAs have been performed in the U.S. to help improve public health. Ten HIAs have been completed in Minnesota, mostly on comprehensive plans and transportation projects.

  To date, no HIA has been used to evaluate frac sand mining in the U.S., but HIAs have been used to inform decision makers about additional health effects in projects that have some similarities, including oil and gas leasing, coal mine proposals, and copper, zinc and gold mining. These HIAs may review health issues that are typically included in an EIS, such as water and air quality, but they also review additional health effects that are related to the specific site and community. Some health effects considered in these HIAs include reviewing the health effects of newly built infrastructure and traffic to support mining, the influx of migrant workers, and the disturbance of food sources relied upon by subsistence cultures.

An HIA on silica sand mining could provide additional health information for policy makers in determining how to balance health and citizens' concerns with the economic benefits of silica sand mining. The HIA would need to include an air monitoring study. It also could include additional primary data collection and analysis of other issues, such as the economic impacts on tourism, to be most helpful. Also, the HIA should provide a quality public process that helps to articulate and clarify citizens' concerns. An HIA could provide recommendations to policy makers to support possible positive health outcomes and to mitigate or prevent possible negative health outcomes to improve the public's health and to inform zoning, permitting, monitoring, and reclamation policies. Performing an HIA on silica sand mining is beyond the scope of a standard agency project and would require dedicated funding. MDH provides training, technical assistance, and communications about HIA activities in Minnesota. A HIA may take between several months to several years, depending on the scope and scale of the review.

- **Alternative proppants:** Proppants other than pure silica sand exist that are used for fracking. Are other proppants, such as manufactured ceramics or resin coated proppants, viable alternatives to silica sand? Do alternative proppants avoid the air quality and other potential environmental impacts generated by the silica sand industry elements? Should the State consider the availability of non-sand proppants in policy decisions regarding sand mining, processing, and transporting in Minnesota?

V. WATER QUALITY

A. Groundwater

1. Potential Impacts to Groundwater from Mining

Any mine may create a pathway for pollutants (chemicals and/or bacteria) to more easily reach the groundwater, especially if the bottom of the mine is near or below the water table. Typical mining activity involves the use of heavy equipment and the potential exists for leaks or spills of petroleum products and solvents related to that machinery, although these tend to be fairly infrequent and small in volume. Runoff from contaminant sources near the mine or waste illegally dumped in the mine may also be potential concerns. Additional information regarding potential risks to drinking water associated with mining activities and actions required by the state to minimize or eliminate those risks can be found in the August 2009 MDH whitepaper titled: “Wellhead Protection Issues Related to Mining Activities” (MDH, 2009).

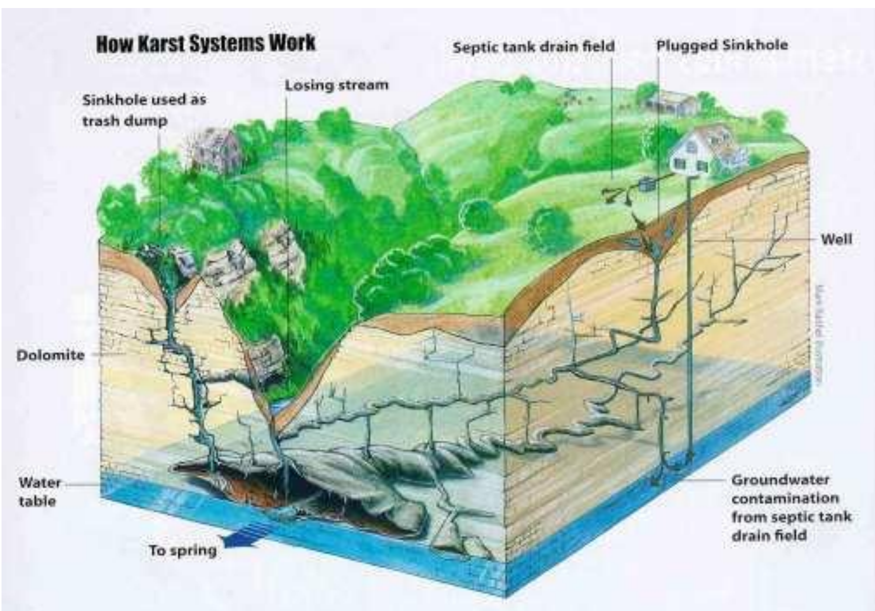


Figure 12. Representation of Karst Formation and Contamination Sources. Source: Missouri State Parks.

In some areas where silica sand mining is planned, particularly southeastern Minnesota, the underlying limestone bedrock is prone to karst formation (i.e., dissolution of the bedrock creating caverns, sinkholes, and other features). Groundwater is particularly vulnerable to contamination in karsted regions, due to highly interconnected vertical and horizontal pathways and high flow velocities within the bedrock. Contaminants can enter the groundwater through many different avenues, such as through septic tank drain fields, landfills, sinkholes, disappearing streams, and mine pits, among others (Figure 12). Mining activities that remove the protective cover of sediment above karsted bedrock formations may help to accelerate movement of surface contaminants to the groundwater. Even after reclamation, a covered mine pit from underground mining may remain as a depression on the surface of the bedrock (i.e., sinkhole) where infiltrating water may collect, potentially concentrating infiltration in a small area, accelerating the formation of karst features and increasing the potential for groundwater contamination.

As the map below (Figure 13) shows, most Minnesota karst landforms are found in the red zone ("active karst"), and some are found in the yellow zone ("transitional karst"). Relatively few karst landforms are found in the green zone ("covered karst"). Karst aquifers are very difficult to protect from activities at the ground surface. For while pollutants are quickly transported to drinking water wells or surface water, conventional hydrogeologic tools such as monitoring wells are of limited usefulness. The best strategy is pollution prevention ("Karst in Minnesota", 2013).

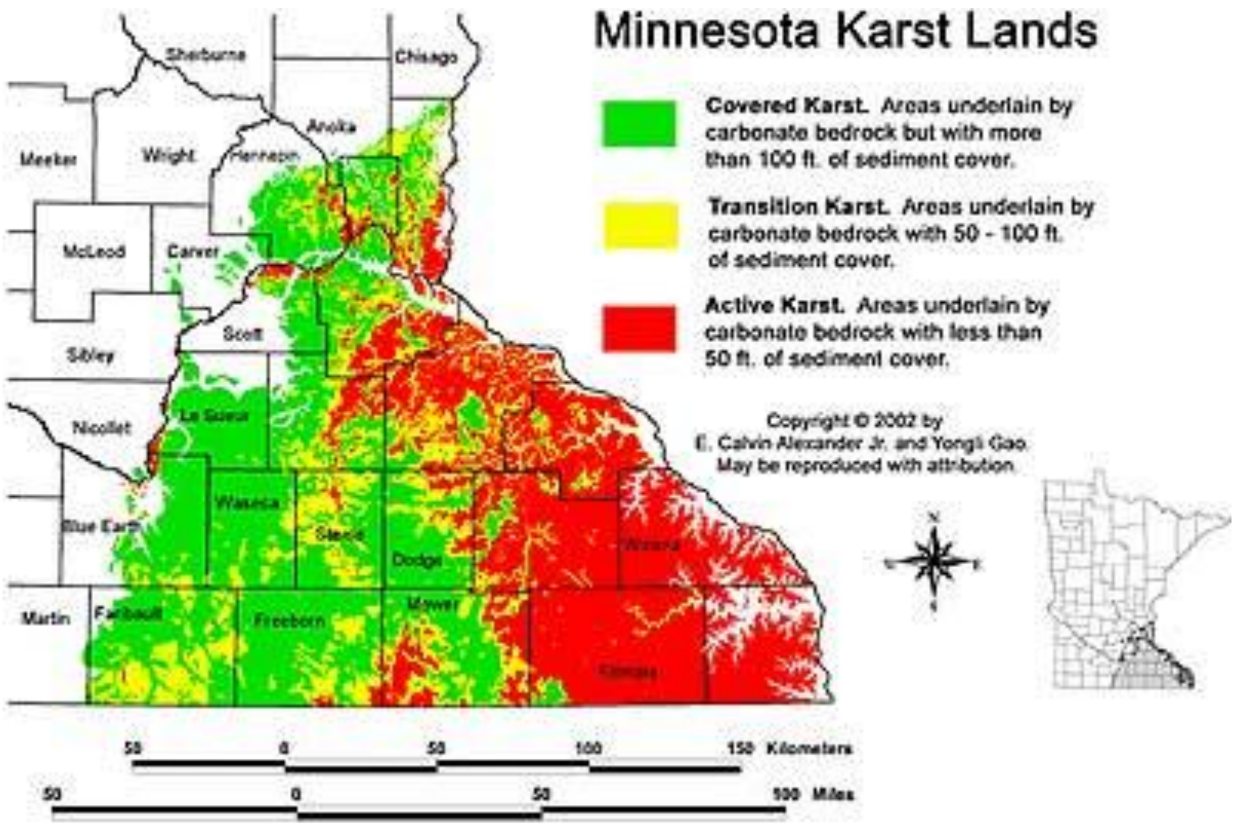


Figure 13. Location of Karst in Minnesota. Source: E. Calvin Alexander, University of Minnesota.

2. Potential Water Quality Impacts Associated with Silica Sand Mines

Some silica sand mines use chemicals called flocculants to settle out silt and clay from the water used in the sand washing process. Two commonly used flocculants are polyacrylamide and poly-diallyldimethylammonium chloride. While these chemicals are generally considered to be environmentally safe, they often contain low concentrations of related chemicals (acrylamide and diallyldimethylammonium chloride, or DADMAC) which are of concern. The U.S. Environmental Protection Agency (EPA) classifies acrylamide as "likely to be carcinogenic to humans" and has set a National Primary Drinking Water Regulation of 0.5 parts per billion. DADMAC, in the presence of water disinfectants, may lead to the formation of N-nitrosodimethylamine. The U.S. Environmental Protection Agency (EPA) has just begun to evaluate nitrosamines as possible drinking water contaminants and has not established any drinking water standards for them. Although the concentrations of these chemicals in the sand wash water is likely to be low, MDH recommends monitoring of the groundwater at facilities where these chemicals are to be used and stored to ensure safe drinking water levels are not exceeded. Often times the finer fraction of sand that an operation cannot sell, called “waste sand”, is returned to the mine site as part of the reclamation process. The returned waste sand may have been in contact with flocculants. The use of contaminated waste sand in a reclaimed pit introduces concerns of groundwater contamination. This concern is elevated in heavily karsted areas.

There have been anecdotal reports that groundwater near silica sand mines becomes slightly more acidic (lower in pH) as a result of mining. It is not known whether this is typical of all sand mining operations, silica sand mines in general, or specifically related to the geology of the particular mines that were studied. MDH conducted a preliminary review of water quality literature but was unable to verify or refute these reports. Increasing the acidity of groundwater may cause naturally occurring minerals such as iron and manganese to more easily dissolve into the water. While generally not a health concern, these minerals can cause water to have unpleasant taste and odor and may cause staining, resulting in the need for treatment to make the water potable. Until the relationship between silica sand mines and water chemistry is better understood, MDH recommends that, among other water chemistry measures, pH be monitored in the groundwater near silica sand mining operations.

B. Surface Water

In karst landscapes, the distinction between groundwater and surface water is commonly blurry, and sometimes very tenuous. Groundwater may emerge as a spring, flow a short distance above ground, only to vanish in a disappearing stream, and perhaps re-emerge farther downstream again as surface water (Figure 12).

The intimate connection between groundwater and surface water gives rise to large number of cold water streams in southeastern Minnesota where trout and other important species thrive. Pollution traveling rapidly along a groundwater path may emerge at a lake or stream, thus posing a threat to the animals and plants living there. In the same way, pollution that has reached surface water can easily become groundwater pollution, thus posing a pollution risk to people whose drinking water is groundwater.

C. Permits and Standards

- MPCA regulates a facility or site through general and individual National Pollutant Discharge Elimination Systems/ State Disposal System (NPDES/ SDS) water permits. The permits regulate wastewater and stormwater discharges to ground and surface waters from sites.

- Sand mining and processing facilities that have a surface water discharge are required to monitor their discharge. Depending on whether the facility has an individual or general permit, the discharge will be monitored for Total Suspended Solids (TSS), Potential of Hydrogen (pH), Flow and Turbidity at a frequency determined within the facility/ site's NPDES/ SDS permit. The results of the monitoring will be submitted to the MPCA.

- Chemical use: As part of the NPDES/SDS program, MPCA reviews requests for the use of chemical additives at facilities. The MPCA considers surface water quality standards as well as health risk limits/health based values set for groundwater as part of this evaluation. Chemical additive reviews are done to avoid/minimize environmental or health risks from chemical use at permitted facilities. The Minnesota Department of Health (MDH) has not set a health risk limit/health risk value for acrylamide, a flocculant known to be used at silica sand processing facilities. To inform chemical additive reviews, MPCA staff developed a screening threshold for acrylamide using MDH methods. If MDH develops health risk limits/health based values, or if new and better information becomes available, for chemicals proposed for use at silica sand processing facilities, the MPCA will consider it when reviewing chemical additive requests.

D. Potential Research Topics

- **Cumulative Impacts:** The cumulative impacts to water quality (and quantity) of multiple silica sand mines in close proximity are not well understood. Monitoring wells should be required at mines to measure groundwater elevations, flow directions and water quality.

- **Guidance for Drinking Water:** No state or federal drinking water standards exist for chemicals of potential concern associated with silica sand operations (i.e. flocculants). Federal regulation regulates the amount of acrylamide in the polymeric coagulant aids to .05% by weight and the dosage of polymeric coagulant aid which can be added to raw water to remove particulates to 1ppm (http://water.epa.gov/drink/contaminants/basicinformation/acrylamide.cfm). If these chemicals are detected in groundwater, MDH could evaluate whether drinking water guidance can be developed.

- **Testing Methods:** No commonly accepted analytical testing methods have been developed for the chemicals of potential concern (i.e. flocculants) and very few commercial laboratories offer testing for these chemicals – MDH Public Health Laboratory could explore the feasibility of developing analytical test methods for acrylamide, DADMAC and NDMA. Despite there being no commonly accepted analytical testing method, Chippewa County, Wisconsin has required mines to test groundwater and waste material (clay and silt particulate) for acrylamide.

- **Long Term Effects in Karst Regions:** More information is needed on the long-term implications for groundwater quality of reclaimed mines in karst-prone regions of the state – water quality monitoring should be required following mine closure. The MDNR, University of Minnesota, and Minnesota Geological Survey are actively researching karst and groundwater in Minnesota and should be consulted regarding additional mining-related research needs/opportunities.

VI. WATER QUANTITY

Sandstone layers in Minnesota that could be valuable as silica sand may be saturated or unsaturated with water depending on the local depth to the water table. The water table is defined as the surface that separates unsaturated earth materials (i.e. sandstone, limestone, sand and gravel etc.) from the underlying fully saturated materials (Figure 14).

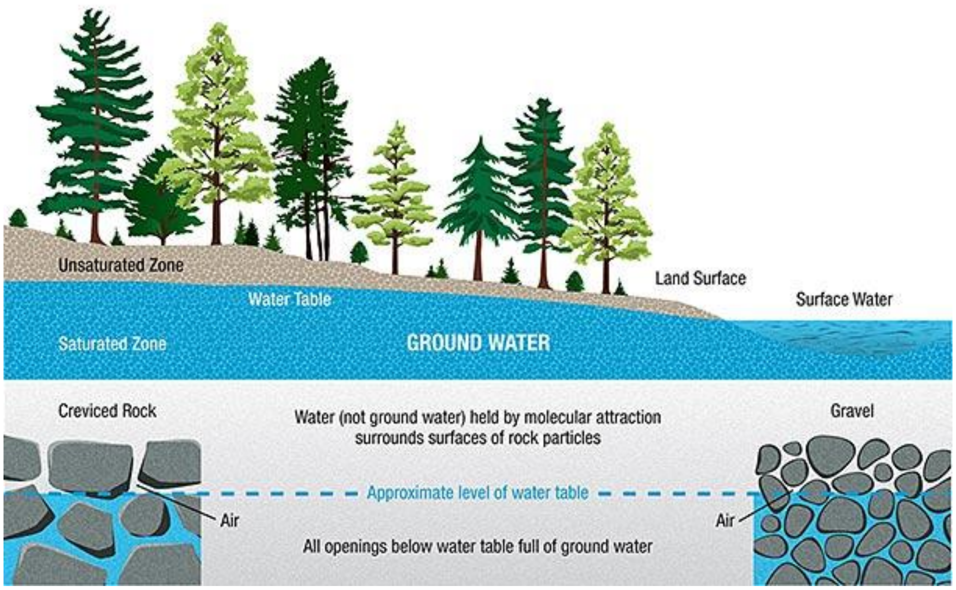


Figure 14. An illustration of fundamental groundwater concepts.

Two proposed mining examples—dry mining and wet mining—are presented in this section to help illustrate some of the water quantity related issues that will be encountered with silica sand mining in southeastern Minnesota. The general geologic setting of both examples is shown on the regional geologic cross section (Figure 15). Near the center of the cross section shallow upland St. Peter Sandstone exposures are shown in pink. This is the regional setting for the dry mining example. Near the left (western) portion of the cross section Jordan sandstone exposures are shown in a valley setting of the Minnesota River where wet mining conditions exist.

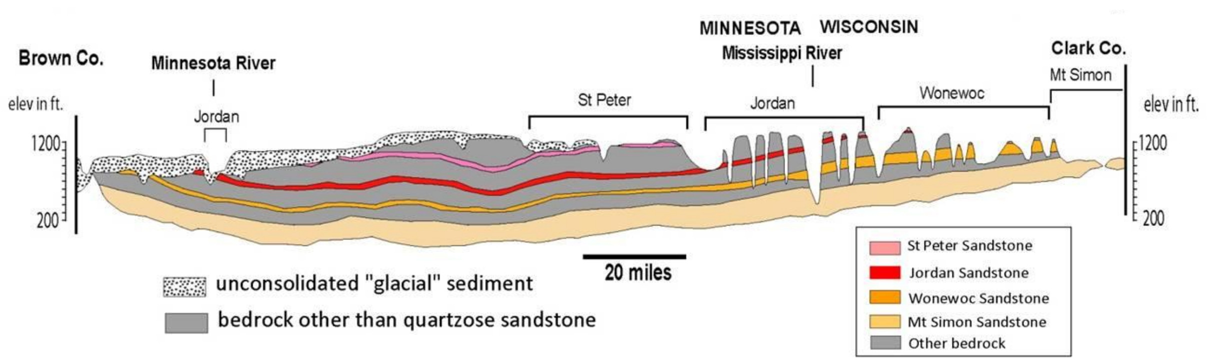


Figure 15. Regional cross section across south-eastern Minnesota showing the general geologic settings of major sandstone formations. Source: Runkel, 2012.

A. Dry Mining - Winona County Example

Portions of sandstone formations in southern Minnesota occur above the water table and may be suitable for dry mining. The St. Peter Sandstone is most likely to be unsaturated over large areas. The Jordan Sandstone, and to a lesser extent the Wonewoc Sandstone, are also unsaturated in some areas including some valley side slopes (Figure 16).

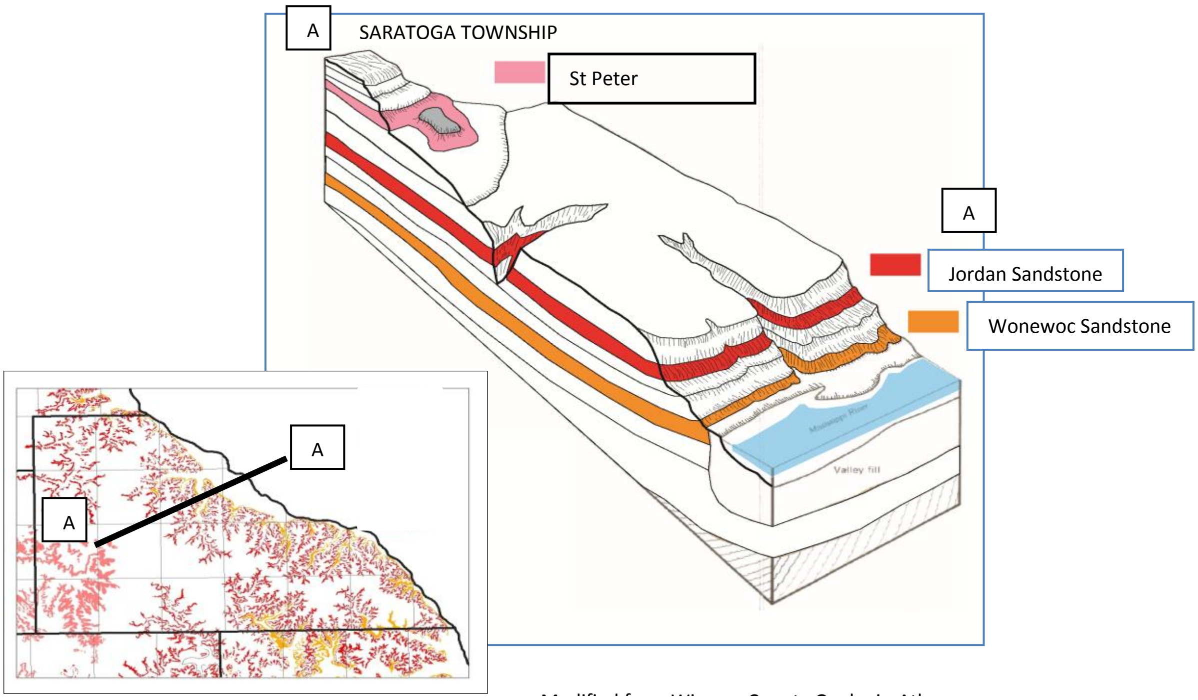


Figure 16. Sandstone layers that are accessible in southeastern Minnesota. Source: modified from Mossler and Book, 1984.

The sandstone that forms this hill shown in Figure17 is above the regional water table. A proposed project to mine the sandstone from a similar hill in Winona County has a reported water table of approximately 50 feet below the elevation at the base of the hill. The EAW for the project reports "Hydrologic alteration through dewatering for mining will not be necessary at the site" (Dabelstein Quarry EAW, 2012). In landscapes like these, natural lakes, streams, and wetlands typically are rare or absent. Thus, in this example, large changes to the water table aquifer would not be anticipated. However, if said processing requires the use of a large amount of water from an onsite well, the effect of that groundwater withdrawal may require analysis of the water table elevation according to MDNR permitting requirements.

Figure 17. St. Peter Sandstone hills are common features of the landscape in southern Minnesota. Source: MDNR.

B. Wet Mining - Kasota Area example

Within the Minnesota River Valley; especially in the counties of Blue Earth, Nicollet, Le Sueur, and Scott; some of the valley slopes are characterized by a ledge or "bench" of resistant bedrock (Figures 18 & 19). Mining in these settings affects water resources. Expansion of mining from the pit visible at the northern portion of the bench has been proposed (Figure 18, right).

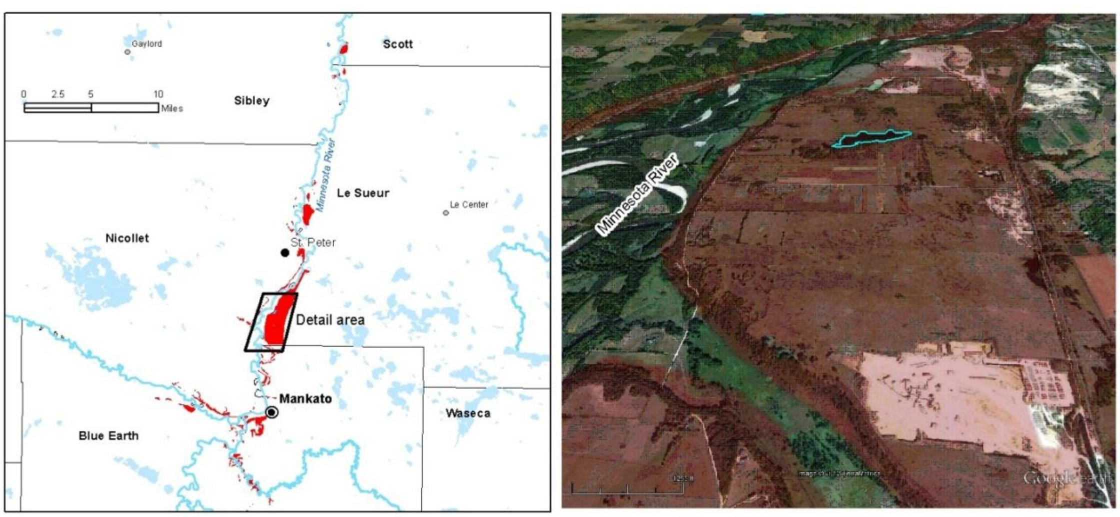


Figure 18. Some of the shallow (less than 50 feet from ground surface) bedrock "benches" in the Minnesota River Valley are shown in the Blue Earth, Le Sueur, and Nicollet County areas (left figure). An oblique aerial view of the largest bench (right). Source: MDNR.

Silica sand mining of the Jordan Sandstone would first require the removal of a terrace deposit, removal of the Oneota Formation of the Prairie du Chien Group and dewatering (pumping) from the pit floor to lower the water table (Le Sueur County, 2010). The proposed open-pit mining would extend to an average depth of 70 to 80 feet and would remove approximately the uppermost 40 to 45 feet of the Jordan Sandstone. Water related issues that are considered for this project and similar projects include the effect on water levels in surrounding water supply wells, domestic wells, protected wetlands such as the calcareous fens that are fed by the Jordan aquifer (Figure 19), Public Water wetlands, and Wetland Conservation Act (WCA) wetlands.

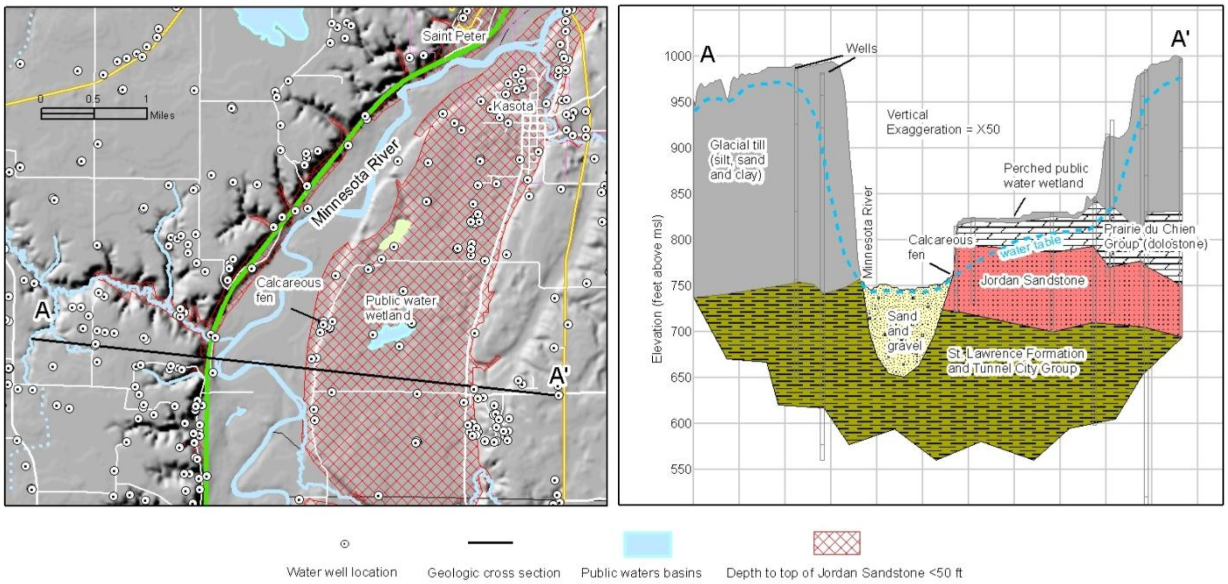


Figure 19 Bedrock benches in the Minnesota River Valley south of Kasota (left figure). Cross section through the area (right figure) shows the relationship to water resources. Source: MDNR.

Figure 19 shows the location of one of the large bedrock benches in the Minnesota River Valley south of Kasota (left figure). A vertically exaggerated cross section through the area (right figure) shows the relationship of the Jordan Sandstone to the water table, a calcareous fen, and a perched Public Water feature.

C. Possible Hydraulic Impacts of Mining

As explained in the wet mining example, silica sand mining has the potential to affect both groundwater levels and groundwater flow paths (Green et al, 2005).

1. Groundwater Levels

One essential part of mining below the water table is "dewatering." Dewatering refers to the lowering of the water table around the mine to prevent mine pit flooding, stabilize mine walls, and reduce operational costs (Figure 20).

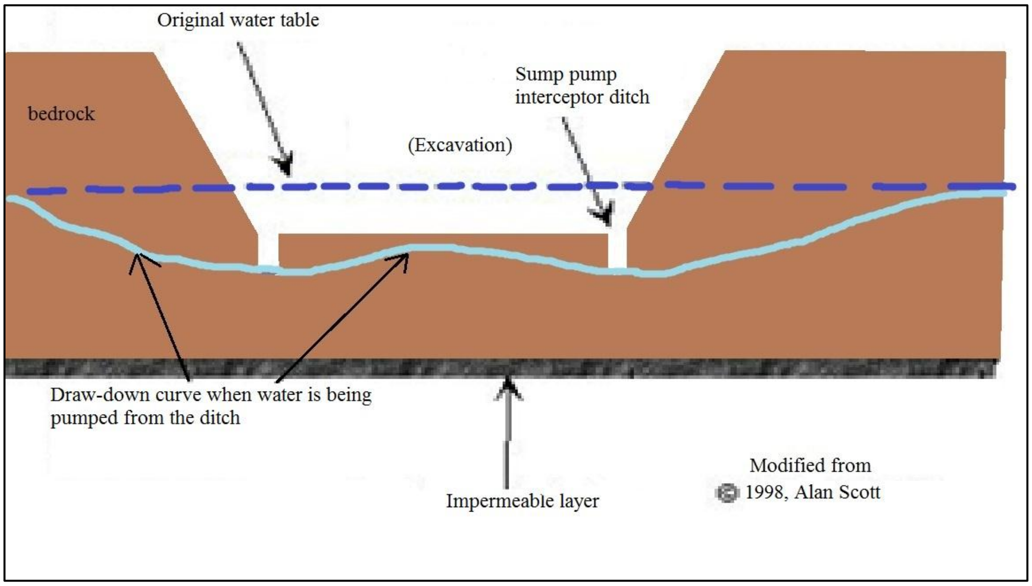


Figure 20. Mine Pit dewatering lowers the water table level and alters the flow direction. Source: Adapted from Groundwater Basics, 2012.

When quarries are dewatered, they alter groundwater levels and flow direction. In essence, the quarries become huge wells. This lowering of the groundwater 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.

2. Groundwater Flow Paths

Quarries can alter groundwater flow paths by the removal of the aquifer material. Groundwater that previously discharged to a spring or wetland may discharge in the quarry due to mining. This premature surfacing of the groundwater also alters its temperature, changing the temperature characteristics of receiving streams and potentially affecting its aquatic life. This scenario is most likely to occur when quarries are located upgradient from and close to springs.

Furthermore, mining may disturb overlying and underlying limestone-dolomite formations such as units of the Prairie du Chien Group or Platteville Formation, which may contain karst formations. Due to the nature of karst conduit groundwater flow, limestone quarries have the potential to affect water resources that are not immediately adjacent to the site. Dye tracing to determine the groundwater flow path and the potential connection of the site to the springs in the area may be necessary. This information will help to ensure that the quarry site is in an area with the least likelihood of affecting local springs through dewatering, contaminant introduction, or thermal degradation.

D. Permits and Standards

Minnesota Statute 103G.265 requires MDNR to manage water resources to ensure an adequate supply to meet long-range seasonal requirements for domestic, agricultural, fish and wildlife, recreational, power, navigation, and quality control purposes. The Water Appropriation Permit Program exists to balance competing management objectives that include both development and protection of Minnesota's water resources. A water appropriation permit from MDNR is required for all users withdrawing more than 10,000 gallons of water per day or 1 million gallons per year. Some silica sand operations will likely meet, if not exceed, this threshold through dewatering and/or processing activities.

The Minnesota DNR Ecological and Waters Division reviews large water removal activities to ensure such groundwater use will not harm wells in the area. When a high capacity well is pumping, a portion of the aquifer around it is dewatered in a pattern known as a "cone of depression" (Figure 21).

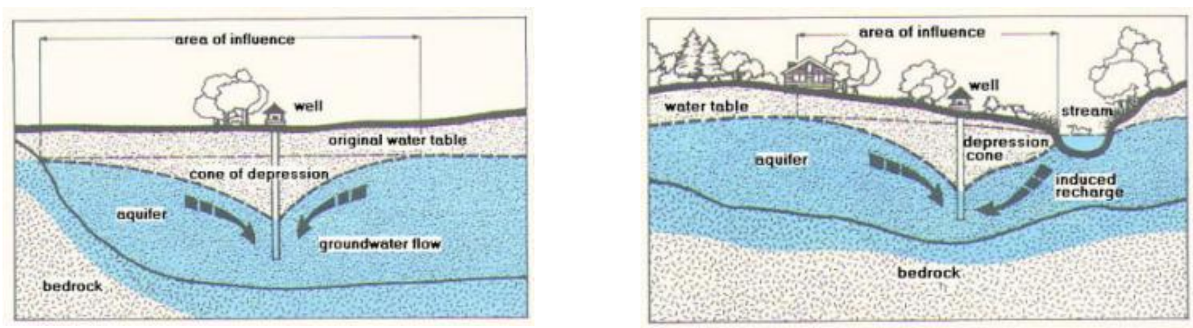


Figure 21. This cross section depicts the effects of well pumping on the water table, groundwater flow and nearby water bodies. Source: http://www.hillsdalecounty.info/planningeduc0019.asp

Wells located within the cone of depression's area of influence may experience lower water levels and have problems getting water if water levels drop below the pump in the well. This condition is referred to as "well interference".

Minnesota Statutes 103G.261 establish domestic water use as the highest priority of the state's water when supplies are limited. Procedures for resolving well interferences are defined by Minnesota Rules 6115.0730. Domestic well owners and municipal water suppliers that have problems obtaining water and believe the situation is due the operation of a high capacity well that pumps in excess 10,000 gallons per day or one million gallons per year can submit a well interference complaint to the Department for investigation.

The cone of depression may also affect water quantity of nearby water bodies. When the cone of depression is lowered below a stream, wetland or lake, the water body loses its connection to the groundwater. This is called "induced recharge." Induced recharge from well pumping could cause nearby water bodies to dry up (Groundwater Basics, 2012).

E. Water Abundance

Minnesota is generally considered to have abundant groundwater. But that resource is not evenly distributed across the state. That uneven distribution can limit the amount of groundwater available to industry and development in some areas.

MDNR's Minnesota Groundwater Provinces Map (Figure 22) summarizes aquifer and groundwater resource differences at the regional level. The occurrence of groundwater in Minnesota is related primarily to local geologic conditions that determine the type and properties of aquifers. Within each province, groundwater sources and the availability of groundwater for drinking water, industrial and agricultural, uses are similar.

Most of the best silica sand resources lie in Groundwater Provinces 2 and 3 (dark yellow/tan and orange). This area of Minnesota gets the majority of its water from bedrock aquifers, as opposed to surficial sand or buried sand. On a scale of "limited-moderate-good", Provinces 2 and 3 are considered to have "good" availability of bedrock groundwater.

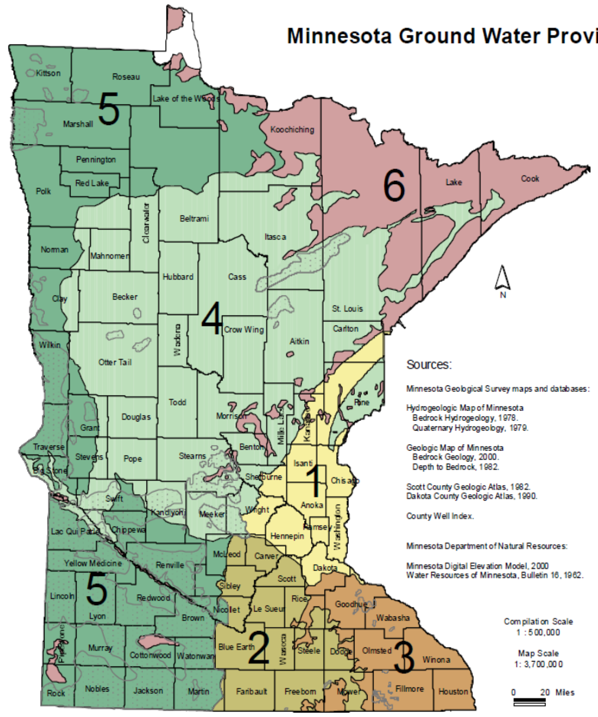


Figure 22. MN Groundwater Provinces. Source: MDNR.

Table 6 lists the general availability of groundwater by source for each of the Groundwater Provinces. As described above, Provinces 2 and 3 have "good" availability of bedrock groundwater. This "water-rich" area of Minnesota (i.e., southeast Minnesota) has been considered to have sufficient water for industry appropriation. That being said, large water appropriations must still be monitored and regulated so as not to compromise the supply for other uses (e.g., drinking water, recreational, wildlife, agricultural).

Table 6. General Availability of Groundwater by Source. Source: MDNR.

Area	Surficial Sands	Buried Sands	Bedrock
1	Moderate	Moderate	Good
2	Limited	Moderate	Good
3	Limited	Limited	Good
4	Good	Moderate	Limited
5	Moderate	Limited	Limited
6	Limited	Limited	Limited

F. Potential Research Topics

- **Groundwater:** Depth to groundwater has not been fully documented in southeastern Minnesota.
- **Cumulative Impacts:** The cumulative impacts to water quantity of multiple silica sand mines in close proximity are not well understood. Monitoring wells should be

required at mines to measure groundwater elevations, flow directions and water quality.

- **Long Term Effects in Karst Regions:** More information is needed on the long-term implications for groundwater of mines in karst-prone regions of the state. The MDNR, University of Minnesota, and Minnesota Geological Survey are actively researching karst and groundwater in Minnesota and should be consulted regarding additional mining-related research needs/opportunities.

VII. TRANSPORTATION

As a transportation commodity, silica sand is considered a common non-metallic mineral. It is normally handled as a dry bulk commodity, easily transferred by mechanical means including bucket loaders, clamshells, and conveyors. Silica sand is transported both packaged and in bulk by all modes; truck, rail, barge, and intermodal container. It is a chemically inert material included in the non-hazardous United States Department of Transportation hazmat classification.

While Wisconsin already has 10 times the silica sand mining activity of Minnesota, state residents here have concerns around the rapid expansion of non-metallic mineral production and its transport. Transportation safety is a significant issue resulting from frequent heavy truck and rail trips, and is being addressed in road design, traffic safety, and grade crossing safety initiatives. Local, light duty roads are being most rapidly and directly impacted by concentrated truck traffic. Local jurisdictions have limited resources to react to the damage, but are negotiating through use permits for private sector compensation.

A. Trucking and Road Systems

1. Federal, State Trunk, and State Aid Roadways and Bridges

In January of 2012, there were about 60 mines producing 12 million tons per year by the state's conservative estimate (Wisconsin Dept. of Natural Resources 2012). This is an average of 200,000 tons per mine per year. If a large truck holds 26 tons (Tennessee Tombigbee), this averages to about 7,700 trucks per year, or 150 per week. Larger mines producing more sand would create correspondingly more truck traffic.

Traffic routes and volumes are determined in consultation with local road authorities and MnDOT. Factors include the most direct route as well as highway condition and capacity. Road capacity to handle the new traffic and current traffic levels is derived from existing data.

MnDOT and county engineers have authority over road designs, safety configurations, and programmed maintenance. Engineers have developed benchmark wear impacts and costs. Wear produced by concentrated traffic is determined based on design standards and life of a specific road versus the new traffic.

The Federal and State trunk highway system is generally able to handle the increased traffic without significant immediate impact. Because these are public thoroughfares with users engaged in traffic crossing jurisdictional boundaries, including interstate commerce, specific commodity or industry-targeted user fees are normally not allowed for non-permit loads. Funding thus is usually attached to mining and conditional use permit fee structures. Non-programmed funding for sand-associated repairs on light duty roads is most commonly negotiated between mining interests and local officials.

2. Local Roads Designed for Lower Capacity and Loading

The greatest immediate impacts due to mine operations and concentrated heavy truck traffic occur on local township and county roads designed for low traffic volumes and 5-9 ton axle loadings. Normal highway funding available to these governmental units is far from adequate to offset the new and immediate needs for road repair and rebuilds. Serious road degradation may occur in the first 1-3 years, versus a life of the mining operations that is expected to extend for 5-30 years.

3. Regulation of Trucks (Commercial Vehicle Operations)

MnDOT is charged with administering and enforcing both state and federal commercial vehicle safety regulations, including inspections and audits. Regulatory and statutory direction also covers several areas that directly apply to silica sand transport.

All trucks hauling commodities subject to blowing or dust production, including sand and gravel, must be covered by full tarps at all times on Federal and State highways, and at any speeds over 30 MPH on local Minnesota roads, compliant with M.S.169.81.

Condition of equipment must be maintained by the operator at all times to ensure safe operations of the vehicle and to minimize risk and impacts to other traffic. This includes condition of tires, brakes, signals, operating controls, installed safety equipment, and potential for spill or leakage of commodities.

Legal weight loadings must be observed at all times, to minimize and control wear on roads and bridges. Sand transporters are limited to the default weight limits of 80,000 pounds GVW on five axles without exception. The Department of Public Safety (DPS) may enforce these limits through ticketing and fines, and both DPS and MnDOT provide safety data to the national driver and carrier data bases, which may trigger probation or suspension of driver and carrier licensing. MnDOT maintains strategically located Weigh-In-Motion scales and cameras to provide observation and protection of key infrastructure, including major bridges, to monitor operations within legal limits.

4. General Highway Safety: Motorized Vehicle and Non-Motorized Shared Use on Identified Mine-Haul Routes

MnDOT and local authorities have a direct responsibility for the safety of all highway users. Heavy truck traffic on a historically light-use road has the potential to significantly increase safety risks for other users, in particular non-motorized use.

Pedestrian, bicycle, and horse & buggy conflicts have been identified in the potential mining areas. This is due to the presence of heavy recreational uses in the region and to local communities such as the Amish, who by choice use horse and buggy for normal transportation. Unless specific allowances are made in traffic routing or road design, such as adequate shoulder widths, these conflicting uses may increase the incidence of serious or fatal accidents.

MnDOT and local engineers and road authorities are pursuing safety mitigation by design. This may include truck climbing lanes, turn and queuing lanes, shoulders, use separations (trails and paths), and proper signage and signaling. All these need to be considered to maintain or improve the highway safety environment. Signage and awareness campaigns, trucker advisements, and other educational efforts also fall under the responsibility of MnDOT and local partners to mitigate possible impacts.

B. Rail and Rail Systems

1. Rail Grade-Crossing Safety, Particularly at Processing Plants or Trans-load Sites

Besides commercial truck traffic, major frac sand operations ship virtually all of their production by railroad to the end users in the oil fields. By rail, raw sand typically is shipped in open hoppers while processed silica sand typically is shipped in covered hoppers to prevent loss of the commercial product during transport. Using the sources discussed above for trucking, each sand mine producing 200,000 tons per year would generate a full unit train of 100 cars every two weeks, plus return trips. Larger mines producing more sand would create correspondingly more rail traffic. This can raise the level of road/rail conflicts in many of the affected rural areas and add noticeable rail traffic in urban areas. MnDOT administers the state and federally funded rail grade crossing safety program.

MnDOT is responsible for determining the adequacy and the selection of grade crossing warning devices throughout the state. Additional tracks through existing crossings and creation of new highway rail grade crossings must receive approval from MnDOT prior to use. Significant additional truck traffic over existing crossings may warrant consideration of additional warning devices such as flashing lights and gates, cantilevers and traffic signals.

2. Rail Safety and Operations Regulation

MnDOT has been granted limited authority for rail safety inspection and regulation by statute and by agreement with the Federal Railroad Administration (FRA). FRA and state inspectors coordinate on safety inspections, hazardous materials handling, infrastructure condition, highway overpass and grade crossing construction, and accident investigation. Regulation of commodity handling, safety, and rates defers to Federal jurisdiction due to its status as interstate commerce. This includes Surface Transportation Board federal commerce regulation, design and safety regulation, and all OSHA and EPA regulations that apply.

3. Branch and Short Line Rail Upgrades and Funding to Improve Rail Condition and Safety

Minnesota, along with Wisconsin and Iowa, have a record of proactively working to preserve and upgrade local, low-volume rail lines to ensure market access for rail-oriented and bulk materials. This supports the economic vitality of rural communities. New mine operations and processing plants require rail access to be economically viable. The Minnesota Rail Service Improvement (MRSI) program has been the state's vehicle for offering low-interest loans and earmarked grants to local shippers and railroad short lines to maintain and upgrade lines and promote rail shipping. It is administered by MnDOT Office of Freight & Commercial Vehicle Operations.

Figure 23) shows rail access—and lack thereof—serving the mining and processing areas in southeast Minnesota.

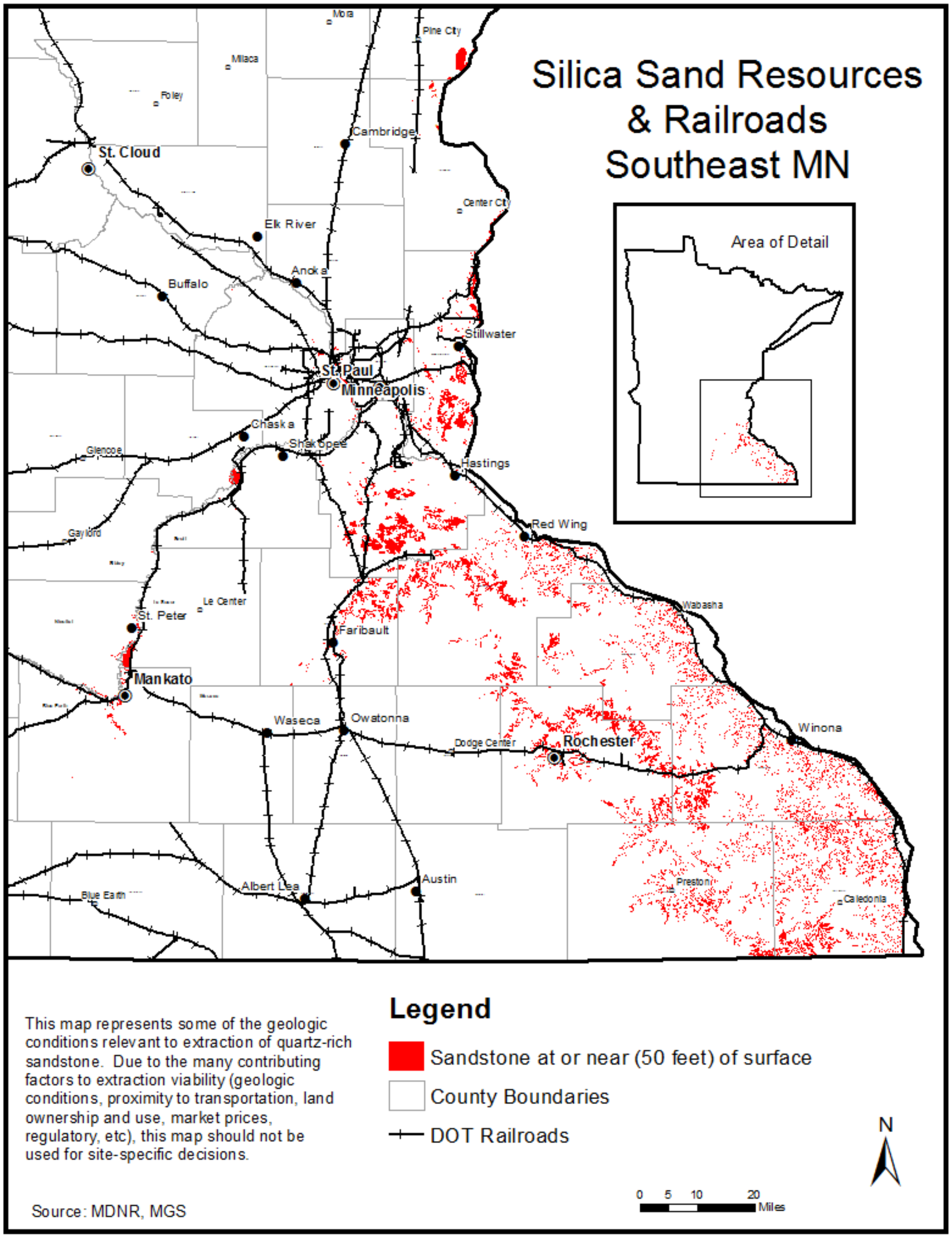


Figure 23. Silica Sand Resources and Proximity to Rail.

C. Barge and Barge Systems

Silica sand is hauled by barge in applications similar to rail, open or closed depending on condition of sand. Environmental Protection Agency air and water rules apply. Normal payload is 1,500 tons per barge. A river tow (collection of barges under control of a single towboat) may carry 22,500 tons or more.

There are over two dozen intermodal freight terminals located on the Mississippi and Minnesota Rivers in Minnesota (MnDOT) (Figure 24), though only one currently handles silica sand. Port activities, like commercial truck, rail, and barge transport, constitute interstate commerce and cannot be materially restricted by local & state jurisdictions.

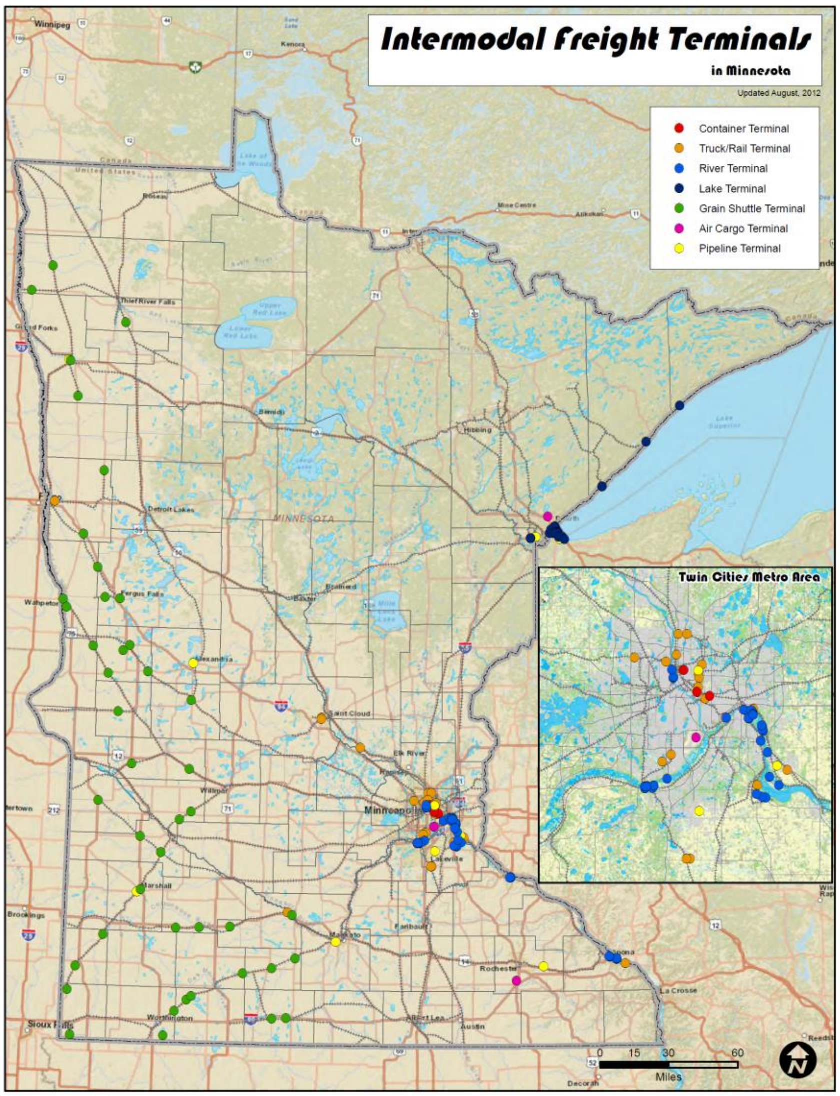


Figure 24. Intermodal Freight Terminals in Minnesota. Source: MnDOT.

D. Potential Research Topics

- **Air quality issues (ambient air and impacts) created by transportation:**
  -loading and transporting
  -by truck
  -by rail
  -by barge
  -near mines
  -near processing sites
  -near loading sites

- **Traffic projections:** If an analysis is prepared projecting demand for silica sand, it may be possible to model projected truck and rail traffic to analyze potential impacts on transportation infrastructure.

- **Funding options for local road jurisdictions:** Local roads designed for lower volumes that state highways are being impacted by concentrated truck traffic from sand mining industry operations. Local jurisdictions have limited resources to address this. Are the funding means available to local and state government adequate to address the needs?

- **How many barge terminals are capable of serving the silica sand industry? Is there a potential for more?**

- **Do publicly owned transportation terminals (truck, rail, barge) have management or regulatory differences if privately owned versus publicly owned? If so, which terminals are owned by public entities (port authorities, cities, etc.) versus privately owned?**

- **What EPA air and water rules apply for rail and barge facilities related to transporting silica sand? How are the rules implemented?**

VIII. Governance

A. Local Government Land Use, Planning

The following summary of a discussion found in an article by the Federal Reserve Ninth District is a good description of the land use planning challenges faced by residents, local governments, and the mining industry.

> Sand mining has sparked protests from residents who have formed groups to monitor mining activity and challenge projects at normally uneventful township and village board meetings. Many of these are small communities where controversy was rare at their meetings. Local governments across the region have responded to the controversy around frac sand mining by imposing bans on new mining operations or expansions. Federal and state governments have some oversight of nonmetallic mines but sand mining in Minnesota and Wisconsin is mostly regulated at the local level. This includes zoning codes and land use permits that require mining companies to fulfill specified conditions. Moratoriums on sand mining enacted by municipal, town and county boards are intended to provide a chance for community leaders and planners to consider stricter regulations for sand mining (Davies, 2012).

Air quality and water quality regulation is described in the respective sections of this report, but in Minnesota and other states, land use planning and regulatory authority rests primarily with local government: county, municipality, township. Such authorities are granted by enabling acts in Minnesota Statutes. There are similarities across the planning and regulatory powers of these three types of local government. However, there also are differences.

Comprehensive planning, or planning that addresses a local government's decision making for the future, is required only in seven county metropolitan area around Minneapolis and St. Paul. This includes the following counties: Anoka, Carver, Dakota, Hennepin, Ramsey, Scott, and Washington. The comprehensive plan of communities in these counties must include specified elements such as land use, housing, parks and opens space, transportation, surface water management, utilities, capital improvements, and the like. In other areas of the state, communities are not required to prepare comprehensive plan (often called general plans) but have the authority to do so. One of the important purposes of a comprehensive plan is to avoid land use conflicts caused by incompatible uses locating in near proximity to one another. A large sand processing facility next to a retail or residential area might be an example. The noise, dust, and light created by industrial activities can and should be considered when planning the future of a community.

Unfortunately, many communities choose not to develop comprehensive plans for reasons of cost, nonchalance, or ideology. The lack of a long range, comprehensive plan often leaves the county, city, or town without guidance or policies on how to deal with issues that arise.

Once policies are established by a comprehensive plan, they are implemented by official controls such as a zoning code, subdivision regulations, or other ordinances. Local government approval of a mining and/or processing facility typically is granted through a conditional use permit or special use permit as well as other elements of a zoning ordinance or official control. There might be a site plan approval, building permit, or others, depending on the specifics of the official controls of the government unit. These official controls, or regulations, are best when written and administered to promote and implement the policies established by the long range plan. Instead, revisions to official controls often are driven solely by reaction to a project proposal. Such situations lack the guidance of long range visions and policies.

Planning and regulatory questions become more complex when considering transportation issues. Major roadways fall under several jurisdictions. A municipality has jurisdiction over its own roads, but access onto a county highway requires approval by the county. Access to a state highway requires review and approval by MnDOT. Different roads are intended for differing types and volumes of traffic. "Main Street" in many small cities is a state highway. What might seem normal for a state highway—for example, dozens or even hundreds of sand trucks in a day—often is considered disruptive and destructive to a small town's main street character. While it is easy in retrospect to say that such conflicts could or should have been foreseen and avoided through good land use and transportation planning, the fact is that such situations are common and cannot be shrugged off.

The conflicts are not limited to 'main street' locations or transportation issues. As described earlier, communities known for their scenic attributes draw great numbers of regional visitors, which has created a tourism economy. Destruction of bluffs that contain silica sand or the creation of large mines in scenic areas, along with the associated noise, traffic, dust, and other disruptive elements may significantly reduce the attractiveness of these areas for visitors. An additional fear is that a mining economy is limited to the time during which the sand is available and profitable to mine. Once the landscape has been altered, tourism may no longer be an option.

Local governments with mining experience typically require reclamation of a mining site. This will include landscaping, adequate water management design, ensuring stable land on slopes, and other elements. This ensures a site will not be left in an unstable or unsightly condition. However, it does not avoid the changes discussed above—elimination of bluffs or other scenic features, impacts on small town economies, unknown air quality issues, etc.—that have raised concerns among many residents of areas potentially affected by the changes.

The spectrum of planning and regulatory knowledge and experience is vast. Not all counties have the same regulatory controls. Ordinances from one city to another can vary greatly. Though there are issues with silica sand mining that don't apply to aggregate mining, there are common elements. A governmental unit that has been reviewing and regulating aggregate mining for decades will have a greater ability to deal with silica sand mining than a governmental unit that has no history with mining of any kind. Nonetheless, because of the separate elements of mining, processing, and transportation, the nature of sand mining is posing new challenges even for experienced governmental units.

These complexities and conflicts point out the need for inter-governmental, multidisciplinary cooperation, coordination, and planning. Local government authorities and regulatory practices should be reviewed and amended to address current needs. A long range plan and official controls based on current needs and the missions and requirements of other jurisdictions will better accommodate real world situations.

B. State Agency Rules and Permitting

Several chapters in this report discuss state rules and permitting standards. Such regulatory tools were established to address many of the issues that arise with the silica sand industry elements (mining, processing, transportation). Permits are important tools and when standards are met and permitting processes implemented they are very effective tools in accomplishing their specific goals. Nonetheless, it is worthwhile to ask whether or not the scope of the rules and permits address concerns as well as possible and, if not, what can be improved. The silica sand issues present a good venue for such discussions.

As noted above, inter-governmental understanding and planning is needed. An examination of state rules and permit standards should include how state rules and local controls interact: how they affect, depend on, and maybe even contradict one another. There may be assumptions made in one government level that specific safeguards are in place at other government levels.

C. Environmental Review Categories

Minnesota Rules 4410 were prepared to implement the environmental review program established by Minnesota Statutes Chapter 116D, the Minnesota Environmental Protection Act (MEPA). The Rules include mandatory categories for environmental review and the responsible governmental unit (RGU) for each category. Each category included a threshold, usually based on project size, the crossing of which places the project in the mandatory review category. The review might be an Environmental Assessment Worksheet (EAW) or an Environmental Impact Statement (EIS). The following mandatory review categories do or may apply to silica sand mining facilities:

<u>4410.4300, Mandatory Environmental Assessment Worksheet</u>

- Subp. 12. Nonmetallic mineral mining. RGU: local government
- Subp. 14. Industrial, commercial, and institutional facilities. RGU: local government
- Subp. 15. Air pollution. RGU: Minnesota Pollution Control Agency
- Subp. 24. Water appropriation and impoundments. RGU: local government
- Subp. 27. Wetlands and public waters. RGU: local government
- Subp. 36. Land use conversion. RGU: local government
- Subp. 36a. Land conversion in shoreland. RGU: local government

<u>4410.4400, Mandatory Environmental Impact Statement</u>

- Subp. 9. Nonmetallic mineral mining. RGU: local government
- Subp. 11. Industrial, commercial, and institutional facilities. RGU: local government
- Subp. 20. Wetlands and public waters. RGU: local government
- Subp. 27. Land conversion in shorelands. RGU: local government

The rules also give governmental units, including the EQB, the authority to require an EAW for projects that may have the potential for significant environmental effect even if the project does not cross a mandatory review threshold.

The various elements of the silica sand industry (mining, processing, transporting) create a significant challenge in determining if a proposed project crosses a size threshold established by the mandatory categories and thus requires environmental review. The concepts of ‘phased project’, ‘connected actions’ will apply. The rules require that “multiple projects and multiple stages of a single project that are connected actions or phased actions must be considered in total when comparing the project or projects to the thresholds” of the mandatory review categories. For example, several mines operated by the same firm often are phased actions. A new mine and its new processing facility located off site may well be connected actions.

D. Noise

Minnesota Rules 7030 establish maximum noise levels in noise area classifications. These standards may or may not be an issue near sand mining or processing facilities. Noise monitoring to ensure the standards are met requires specialized expertise.

E. Quality of Life

There are intangibles that should not be overlooked. The rural character of an area and the small town character of a city are examples. Many people believe these considerations extend beyond discussions of specific regulatory authorities or rights. In fact, planning, regulations, and property rights established by law are tools for identifying, prioritizing, promoting, and protecting these intangibles.

F. Potential Research Topics

- **Guidance and Best Management Practices for Local Governmental Units:** The nature of sand mining with its varied elements is posing challenges even for experienced governmental units. A multi-discipline study resulting in a guidance document would be useful for local governments. This effort would examine and provide guidance on such things as:

    - statutory authorities for planning and regulating
    - review topics and information needs, e.g., water quality, water use quantity, air quality
    - identifying location and impacts on existing natural resources
    - provision of and maintaining necessary infrastructure
    - how to address the different elements: mining, processing, transporting
    - best management practices for local governments in permitting and ongoing monitoring
    - best management practices for facility operators for planning and managing facilities
    - reclamation methods and requirements

- **Additional Review and Guidance on Connected Actions and Phased Actions in Environmental Review:** Further examination of these concepts as they apply to the varied elements of the silica sand mining industry would be useful to local governments.

- **Interaction of Regulatory Practices Across State and Local Governments:** An examination of state rules and permit standards as well as local government authorities and regulatory practices should include how state rules and local controls interact: how they affect, depend on, and possibly contradict one another. There may be assumptions made in one government level that specific safeguards are in place at other government levels.

- **Subsurface Rights vs. Surface Rights:** Questions have arisen regarding subsurface mining rights and the effects on surface rights owned by another person.

IX. Potential Impacts on Sensitive Resources

Silica sand mining has the potential to negatively affect many sensitive resources through the destruction of rare plants, rare native plant communities, or habitat for rare animals. Rare features may also be affected through the introduction or spread of invasive species and through increased erosion, sedimentation, or pollution. The resources that will actually be affected will depend on the specific areas that will be mined. Depending on the extent to which the silica sand resources are mined, the cumulative effect on Minnesota's sensitive resources may be significant.

To determine potential impacts to sensitive ecological resources, the geographic extent of the silica sand deposits less than 50 feet deep was compared to the locations of Audubon Important Bird Areas, Minnesota Biological Survey (MBS) Important Prairie Landscapes, MBS Sites of Biodiversity Significance, MBS Native Plant Communities, and known occurrences of rare species. Not surprisingly, the majority of these resources are associated with the Mississippi, St. Croix, Minnesota, Cannon, Zumbro, and Root rivers. The MBS systematically collects, interprets, and delivers baseline data on the distribution and ecology of rare plants, rare animals, native plant communities, and functional landscapes needed to guide decision making.

A. State Wildlife Action Plan

The State Wildlife Action Plan identifies Species in Greatest Conservation Need (SGCN) and Key Habitats for each ecological subsection within Minnesota. Silica sand resources in Minnesota are found predominantly within the Blufflands, Rochester Plateau, Oak Savanna, and St. Paul-Baldwin Plains and Moraines subsections (Figure 25).

The Blufflands Subsection is dominated by the Mississippi River and is characterized by bluffs, prairies, and stream valleys. Numerous cold-water streams feed major rivers and Mesic Hardwood Forests and Floodplain Forests grow along these streams and rivers. This subsection provides a critical migratory corridor for birds, has the highest number of SGCN of all the subsections, is the most important subsection for reptiles, and is one of the most important subsections for mollusks.

The Rochester Plateau Subsection is an area of level to gently rolling terrain that contains the headwaters of several rivers as well as some cold-water trout streams.

The Oak Savanna Subsection consists of gently rolling hills that historically were covered with oak savanna, tallgrass prairie, and maple-basswood forest.

The St. Paul-Baldwin Plains and Moraines Subsection is dominated by the Mississippi and St. Croix rivers. Historically, oak savanna, tallgrass prairie, and maple-basswood forest were common. This subsection is a significant migratory corridor for birds and has a large diversity of mussels and small stream fish.

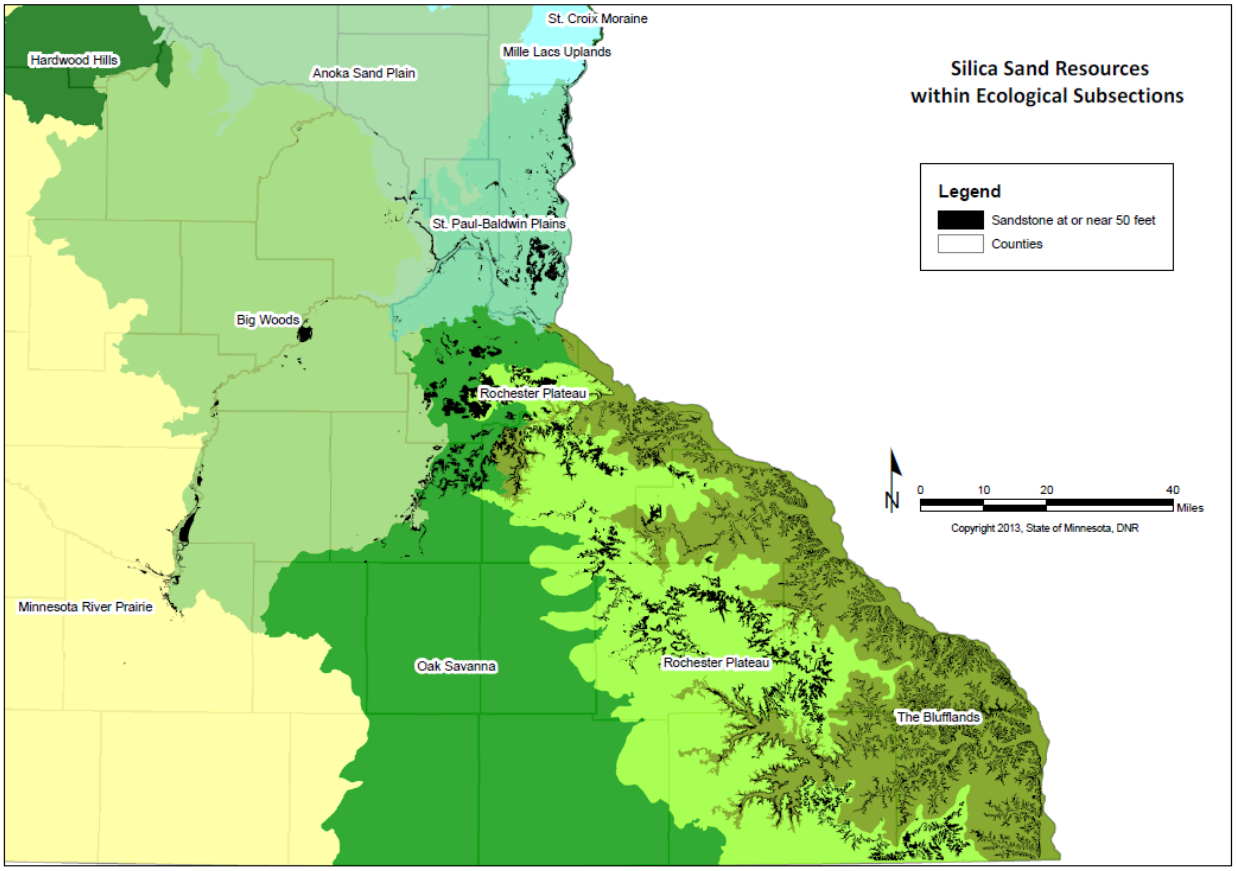


Figure 25. Ecological Subsections and Silica Sand Resources. Source: MDNR.

Key habitats found within the above subsections include Deciduous Forests, Oak Savanna, Prairie, Grassland, Cliff/Talus, and Rivers.

Table 7. Species of Greatest Conservation Need and State or Federally Listed Species in Ecological Subsections

Ecological Subsection	# of SGCN	# state or federally listed species
Blufflands	156	82
Rochester Plateau	94	36
Oak Savanna	93	36
St. Paul-Baldwin Plains and Moraines	149	74

B. Important Bird Areas

Important Birds Areas, identified by Audubon Minnesota in partnership with the DNR, are part of an international conservation effort aimed at conserving critical bird habitats. In southeastern Minnesota, the Important Bird Areas (shown in blue, Figure 26) tend to follow rivers and streams. Silica sand mining has the potential to impact these areas.

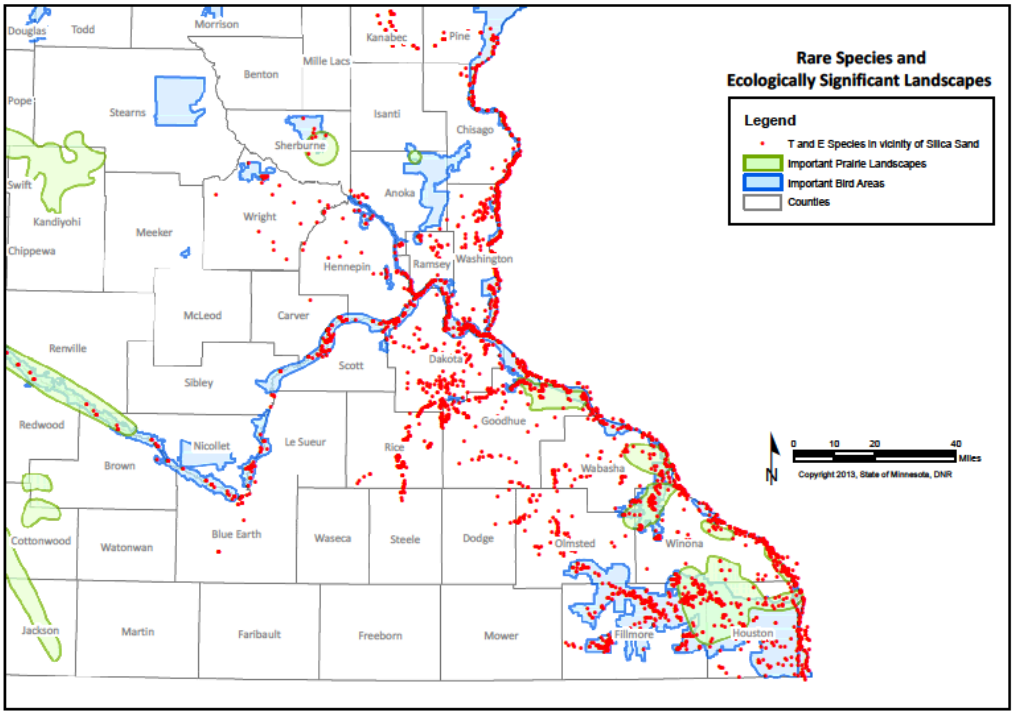


Figure 26. Rare (T&E) Species and Ecologically Significant Landscapes. Source: MDNR.

C. MBS Important Prairie Landscapes

The Minnesota Biological Survey has identified 38 important prairie landscapes within Minnesota (http://files.dnr.state.mn.us/eco/mcbs/prairies_highlighted_areas.pdf). The seven prairie landscapes (389,022 acres) in southeastern Minnesota all contain silica sand resources (approximately 50,000 acres) and are at risk of becoming fragmented and degraded if mining occurs within the landscapes. These areas are shown above in green on Figure 26.

D. MBS Sites of Biodiversity Significance

Silica sand mining has the potential to impact many areas that the Minnesota Biological Survey has identified as Sites of Biodiversity Significance. Sites of Biodiversity Significance have varying levels of native biodiversity and are ranked based on the relative significance of this biodiversity at a statewide level. Factors taken into account during the ranking process include the number of rare species documented within the site, the quality of the native plant communities in the site, the size of the site, and the context of the site within the landscape (http://files.dnr.state.mn.us/eco/mcbs/biodiversity_significance_ranking.pdf). Sites ranked as Outstanding contain the best occurrences of the rarest species, the most outstanding examples of the rarest native plant communities, and/or the largest, most intact functional landscapes present in the state. Sites ranked as High contain very good quality occurrences of the rarest species, high quality examples of the rare native plant communities, and/or important functional landscapes. Sites ranked as Moderate contain occurrences of rare species and/or moderately disturbed native plant communities, and/or landscapes that have a strong potential for recovery. In southeastern Minnesota, the MBS Sites of Biodiversity Significance predominantly fall along the blufflands and the river and stream valleys (Figure 27). The map inset shows how water, sites of biodiversity and silica sand resources tend to be interconnected. Given their proximity to one another, decisions involving these resources are challenging.

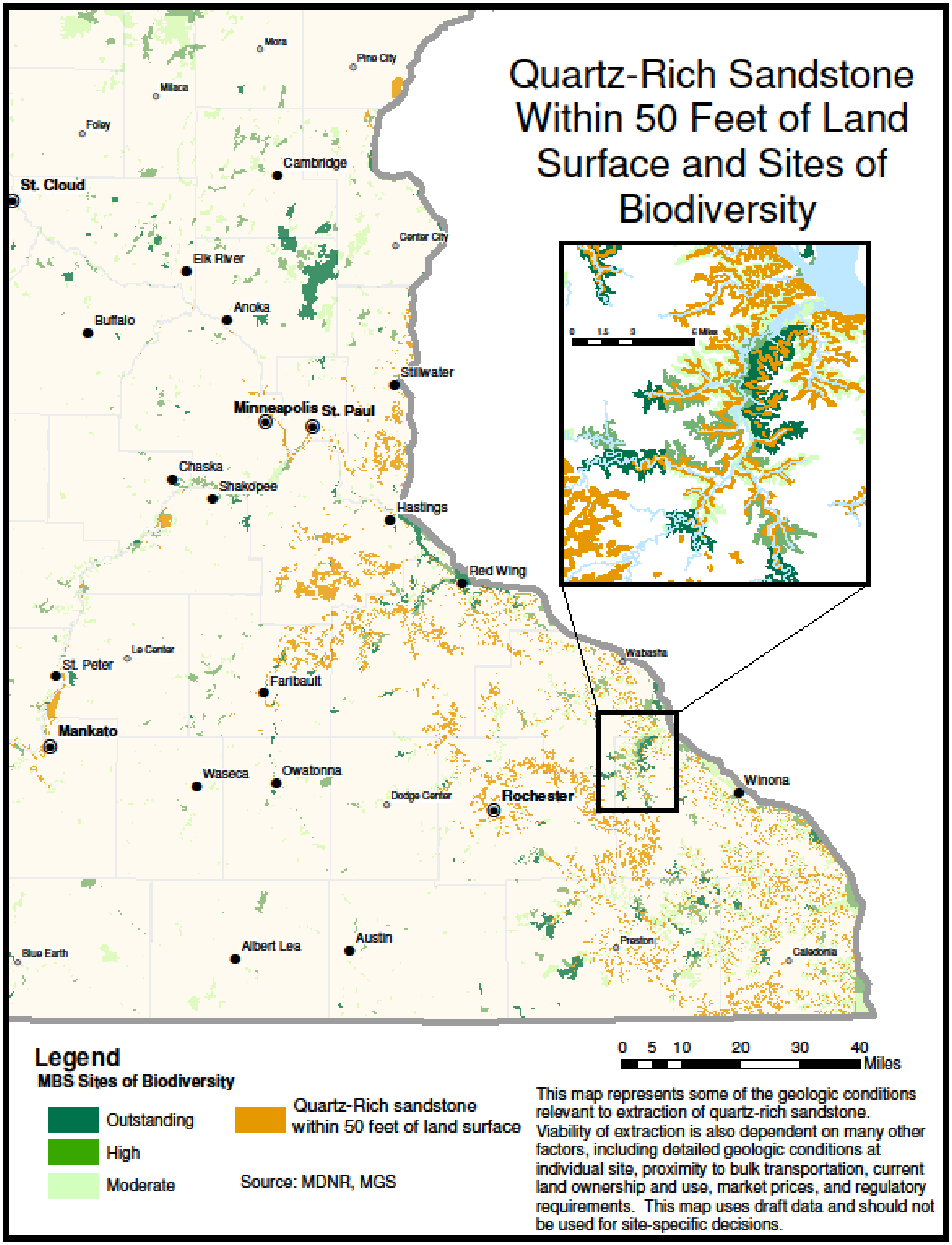


Figure 27. Silica Sand Resources and MBS Sites of Biodiversity - Southeast MN

The extent to which MBS Sites of Biodiversity Significance may be impacted from silica sand mining varies among the counties (Appendix A). For instance, if the silica sand deposits were fully mined in Houston or Winona County almost all of the Sites of Biodiversity Significance within the county would be impacted (Table 8). However, avoidance of most of the MBS Sites may be feasible as approximately 70% of the silica sand resources in these two counties are outside of the MBS Sites. The full MBS table is in Appendix A.

Table 8. MBS Sites with Silica Sand Resources—Houston and Winona County. Source: MDNR.

	MBS Sites Within County			MBS Sites With Silica Sand Resources				Silica Sand Resources			
	#	**Acres**	**%**	**#**	**%**	**Acres**	**% of Total MBS Acreage**	**Acres**	**%**	**Acres in MBS**	**%**
Houston	**192**	**81,780**	**22%**	**162**		**78,863**		**51,575**	**14%**	**14,419**	**28%**
Outstanding	5	3,686		5	100%	3,686	100%				
High	17	13,159		12	71%	12,321	94%				
Moderate	170	64,934		145	85%	62,856	97%				
Winona	**104**	**74,206**	**18%**	**96**		**70,212**		**46,841**	**11%**	**12,574**	**27%**
Outstanding	10	11,374		10	100%	11,374	100%				
High	22	17,563		22	100%	17,563	100%				
Moderate	72	45,269		64	89%	41,275	91%				

E. MBS Native Plant Communities

The Minnesota Biological Survey has delineated and classified the native plant communities found within the above Sites of Biodiversity Significance. Native plant communities are groups of native plants that interact with each other and their surrounding environment in ways not greatly altered by modern human activity or by introduced plants or animals. These communities are generally classified and described by considering vegetation, hydrology, landforms, soils, and natural disturbance regimes. The MBS uses a hierarchical classification, with vegetation units described at levels ranging from broad landscape-scale ecological systems to native plant community subtypes that are based on finer distinctions in canopy composition, substrates, or other environmental factors. The MBS has assigned conservation status ranks to the native plant community types and subtypes recognized in Minnesota (http://files.dnr.state.mn.us/natural_resources/npc/s_ranks_npc_types_&_subtypes.pdf. The ranks reflect the risk of elimination of the community from Minnesota and range from S1 (critically imperiled) to S5 (secure, common, widespread, and abundant).

Many rare (S1 to S3) types of native plant communities intersect with the silica sand resources at or within 50 feet of the surface (Appendix B). The most common native plant communities found over the silica sand resource include Southern Dry – Mesic Oak Forest (S3 and S4), Southern Mesic Oak – Basswood Forest (S3), Oak – Shagbark Hickory Woodland (S3), Upland Prairie (S1 and S2 and S3), and Floodplain Forest (S1 and S2 and S3). As S1 through S3 native plant communities are at risk of extirpation within Minnesota, impacts to these communities may have significant permanent effects.

F. Known Occurrences of Rare Species

Category	# Species
Mammal	1
Bird	5
Reptile	4
Amphibian	1
Fish	7
Mussels	23
Landsnails	5
Insects	6
Vascular Plant	80
Moss/Lichen/Fungus	6
TOTAL	138

Table 9. Number of Current and Proposed State-Listed Threatened and Endangered Species within an approximate one-mile radius of Silica Sand Resources located < 50 feet deep. See Appendix C for full data. Source: MDNR.

The Rare Features Database contains known locations of state-listed species, as well as some species that are proposed for state-listing. The database is not based on an exhaustive inventory and does not represent all of the occurrences of rare species within the state. A query of the Rare Features Database within an approximate mile of the silica sand resource documented 138 current and proposed state-listed threatened and endangered species (see Figure 26; Summary Table 9; Appendix C). The majority of these species are associated with the rivers and streams, prairies, and blufflands found within the ecological resources mentioned above.

1. Rivers and Streams

Silica sand mining has the potential to impact rivers and streams through dewatering, changes in hydrology, sedimentation, pollution, and temperature alterations. Species that may be affected include the wood turtle, Blanding's turtle, several fish, numerous mussels, and a few aquatic plants. As stated above, both the Blufflands Subsection and the St. Paul-Baldwin Plains and Moraines Subsection are extremely important for mussels. If silica sand mining affects the water quality of these rivers, impacts to state-listed species are likely. There are also approximately 1,600 acres of Floodplain Forest over the silica sand resource. Floodplain forests are rare in Minnesota and are critical for maintaining the water quality in rivers. They also provide habitat for threatened and endangered turtles and plants. Thus any negative impacts to floodplain forests would also negatively impact state-listed species. Measures to minimize disturbance to the protected species found within rivers and floodplains include avoidance, setbacks, and effective erosion and sediment control.

2. Prairies, including Oak Savanna and Bluff Prairies

Silica sand mining has the potential to directly affect approximately 3,000 acres of native prairie (Appendix B). Native prairie is an extremely rare resource in Minnesota. More than 98% of the prairie that was present in the state before settlement has been destroyed, and more than one-third of Minnesota's state-listed species are now dependent on the remaining small fragments of Minnesota's prairie ecosystem. Rare species that may be affected include the Blanding's turtle, timber rattlesnake, Henslow's sparrow, loggerhead shrike, Ottoe skipper, and several prairie-dependent plants. If silica sand mining results in the destruction of native prairie, permanent negative impacts to state-listed species are likely. Prairies that are adjacent to mining activities may also become degraded through invasive species, surface runoff, or other disturbance.

G. Potential Research Topics

- **Site-Specific Data:** Given the multitude of rare species and native plant communities in the vicinity of the silica sand resources it is highly probable that silica sand mining will negatively affect rare resources to some degree. However, without site-specific details it is impossible to determine which sensitive ecological resources will be impacted and the extent to which they will be impacted (e.g., Takings Permits).

- **Development Pressure:** Calculating the surface area of silica sand resources within each county that resides outside of the MBS Sites of Biodiversity Significance or Important Prairie Landscapes will help to assess the amount of development pressure that will occur within these ecologically significant areas.

X. MAPPING PROJECT

Areas with the potential for silica sand mining extend across large areas of the state. Processing sites and associated transportation facilities exist and may be proposed for locations not in direct proximity to mines. Many sensitive resources exist in these areas and could be subject to significant impacts. Planning for the different elements of the industry would benefit from identifying what other resources could be affected. Assembling currently held information will allow for studying the potential impacts. It also will help determine what information is not available but that would be useful to obtain. The overall purpose would be to provide information on the potential impacts on habitat, impacts on threatened and endangered species, and on other sensitive resources.

Summarized below is a mapping project proposal that would pull together these data layers to create a tool that would be usable or available to state and local government units. This is not a standard agency project and therefore would require dedicated funding.

A. Proposed Mapping Project Scope of Work

Purpose: Develop GIS based mapping project for counties that contain silica sand resources for local governments and potential project proposers as a planning tool for siting mines and to help scope out potential issues that would need to be addressed with specific proposals.

Deliverable:

1) An ArcMap project that contains prebuilt data layers of interest that would be converted to an interactive map available on the internet. The maps would be organized by county. A series of static maps would also be prepared for silica sand resources in each county. The interactive map and static map would provide text, interpretation, and data for potential users.

2) As a separate but related project, several hydrogeological settings could be identified for further evaluation. A three dimensional depiction of setting will be provided to assist in development of conceptual models for better understanding impacts from mining proposals.

Map Content:

<u>ArcMap Data including:</u>

- Geologic Atlas is available in some counties, but not in others
    - Houston – in progress
    - Winona – in progress
    - Wabasha – complete pdf and GIS
    - Goodhue – complete pdf and GIS
    - Dakota – complete pdf, limited GIS
    - Washington – GIS only
    - Scott – complete pdf and GIS
    - Carver – complete pdf and GIS

   - Sibley – complete pdf and GIS
   - Nicollet – complete pdf and GIS
   - LeSueur – no atlas
   - Blue Earth – complete pdf and GIS

The following GIS data sources are available from the MDNR:

- Karst features
- Trout streams
- Public waters
- Official Fens
- Sites of Biodiversity (moderate, high, and outstanding)
- Land cover data
- LIDAR topographic data

Other GIS data sources available from others:

- Railroads
- Highway corridors
- Population Centers
- Silica sand resources within 50 feet of the ground surface

Potential Additional Data: These data layers would need to be assembled from a variety of sources, including individual local governments. Some work has been accomplished on this but the data is varied and requires verification and updating. These layers would be useful in considering cumulative potential effects, connected actions, and phased actions.

- Silica sand mines and processing facilities
- Sensitive populations:
  - schools
  - licensed daycare centers
  - nursing homes
  - hospitals
  - clinics
- Wetlands
- Prevailing wind
- Wind speed

B. Level of Effort

Production of a web based interactive map and static county maps would require the following tasks:

- Compilation and verification of data (meta data)
- Map production
- Development of web instructions, caveats, and data limitations

- Development of scripts or analysis tools
- Development of hydrogeological settings (4-6)
- Web design and testing
- Data maintenance

C. Example Map Output:

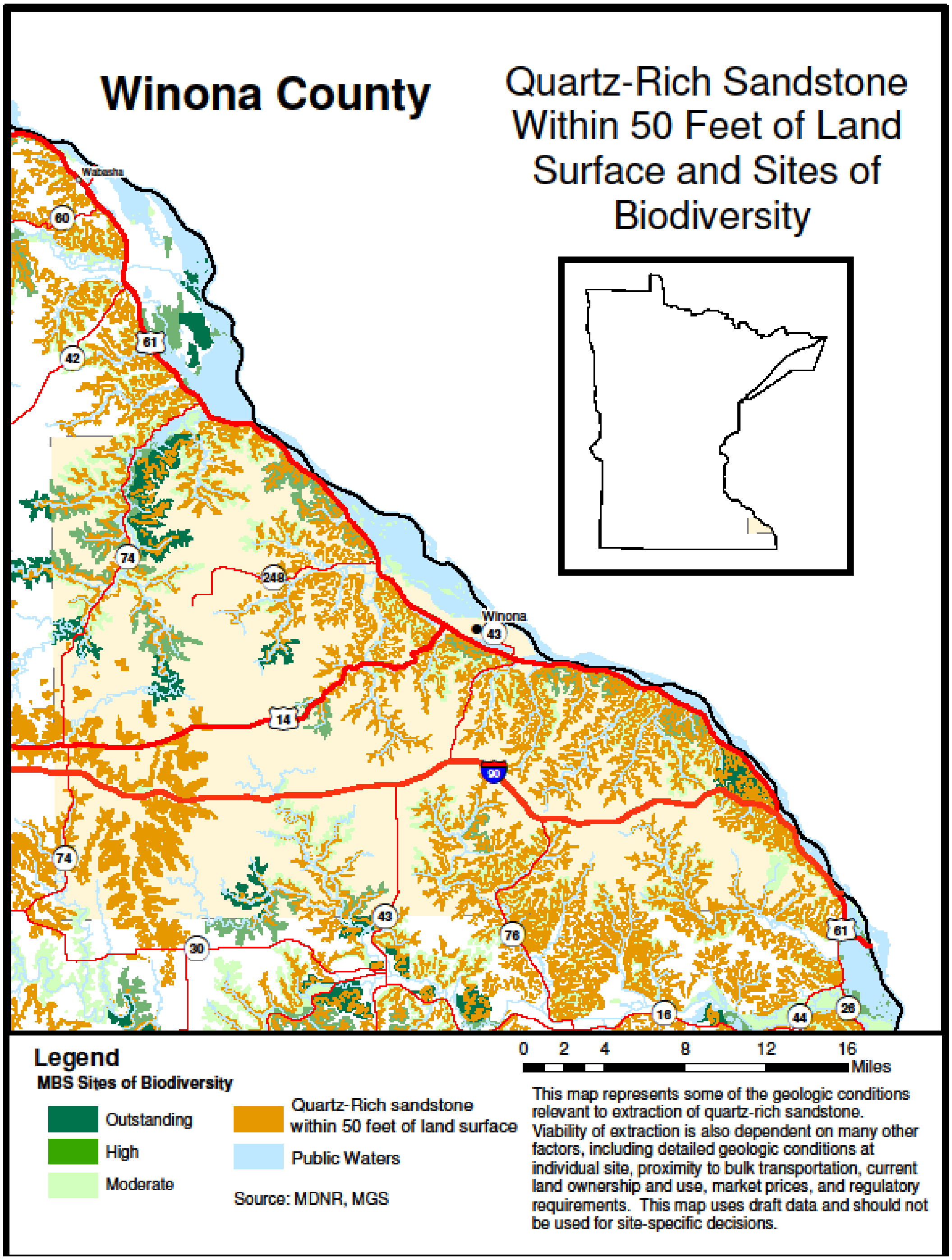


Figure 28. Sample Output map, Winona County

XV. Potential Research Topics

The following list assembles the potential research topics listed in the chapters.

Fracking and Sand Market Summaries, Socioeconomics

- **Future market for silica sand for hydrofracking**: Data from industry and government sources could be assembled and compared to consider market projections of demand. This likely will involve market projections for oil and gas.

- **Economical depth for mining:** We know where the sand is, but the depth at which mining is economical is changing. In the past, it was not economical to mine sand beyond certain depths. With the surge in demand due to hydrofracking, this changed. Further consideration of this may be useful.

- **Impacts on property values:** It may be possible to assemble data for properties near mines, processing sites, and transportation facilities to see what, if any, property value changes have occurred and if the changes are correlated to those activities and facilities. Such studies have been conducted on other types of land use to address questions of the impacts on property values in the vicinity. However, the sand facilities may be too recently created for any such analyses to be possible.

- **Potential effects on tourism:** Determining potential effects on tourism would be very useful. Determining what data and methodology would be needed in order to conduct such a study is a challenging question in itself.

- **Tax revenues available:** Minnesota Statute 298.75 establishes a tax on aggregate mining, including silica sand. Property taxes apply as well. It may be useful to assemble information to describe the potential revenues from these sources and determine what other tax or fee revenue sources are available.

- **Employment:** Reliable research is scant or nonexistent regarding short term and long term employment created by silica sand mining.

Air Quality

- **Concentrations of crystalline silica associated with silica sand mining:** As noted above, there is little or no information on the amount of silica in the air that results from silica sand mining, processing, and transportation operations. There are plans to monitor silica levels in ambient air associated with frac sand mining in Wisconsin. However, MPCA reports that the Wisconsin study is being funded by industry and therefore the results may or may not be made public. A study funded by the State of Minnesota would ensure public availability of the results. Such a study might provide a basis for new state air quality standards for silica.

In order to predict (i.e. model) the ambient impacts of a silica-sand facility, the MPCA needs additional information, such as: (1) an acceptable PM_4 monitoring method, and (2) a set of silica emission factors for PM_4-sized material for processes that occur at silica sand facilities. Both the monitoring method and emission factors would be used to support any air quality standard developed by the State.

- **Health Impact Assessment:** A Health Impact Assessment (HIA) is a research and community engagement process that can be used to help ensure that people's health and concerns are being considered when decisions on infrastructure and land use projects are being made. An HIA on silica sand mining could provide additional health information for policy makers in determining how to balance health and citizens' concerns with the economic benefits of silica sand mining. The HIA would need to include an air monitoring study. Performing an HIA on silica sand mining is beyond the scope of a standard agency project and would require dedicated funding. A HIA may take between several months to several years, depending on the scope and scale of the review.

- **Alternative proppants:** Proppants other than pure silica sand exist that are used for fracking. Are other proppants, such as manufactured ceramics or resin coated proppants, viable alternatives to silica sand? Do alternative proppants avoid the air quality and other potential environmental impacts generated by the silica sand industry elements? Should the State consider the availability of non-sand proppants in policy decisions regarding sand mining, processing, and transporting in Minnesota?

WATER QUALITY

- **Cumulative Impacts:** The cumulative impacts to water quality (and quantity) of multiple silica sand mines in close proximity are not well understood. Monitoring wells should be required at mines to measure groundwater elevations, flow directions and water quality.

- **Guidance for Drinking Water:** No state or federal drinking water standards exist for chemicals of potential concern associated with silica sand operations (i.e. flocculants). Federal regulation regulates the amount of acrylamide in the polymeric coagulant aids to .05% by weight and the dosage of polymeric coagulant aid which can be added to raw water to remove particulates to 1ppm (http://water.epa.gov/drink/contaminants/basicinformation/acrylamide.cfm). If these chemicals are detected in groundwater, MDH could evaluate whether drinking water guidance can be developed.

- **Testing Methods:** No commonly accepted analytical testing methods have been developed for the chemicals of potential concern (i.e. flocculants) and very few commercial laboratories offer testing for these chemicals – MDH Public Health Laboratory could explore the feasibility of developing analytical test methods for acrylamide, DADMAC and NDMA. Despite there being no commonly accepted analytical testing method, Chippewa County, Wisconsin has required mines to test groundwater and waste material (clay and silt particulate) for acrylamide.

- **Long Term Effects in Karst Regions:** More information is needed on the long-term implications for groundwater quality of reclaimed mines in karst-prone regions of the state – water quality monitoring should be required following mine closure. The MDNR, University of Minnesota, and Minnesota Geological Survey are actively researching karst and groundwater in Minnesota and should be consulted regarding additional mining-related research needs/opportunities.

WATER QUANTITY

- **Groundwater:** Depth to groundwater has not been fully documented in southeastern Minnesota.

- **Cumulative Impacts:** The cumulative impacts to water quantity of multiple silica sand mines in close proximity are not well understood. Monitoring wells should be required at mines to measure groundwater elevations, flow directions and water quality.

- **Long Term Effects in Karst Regions:** More information is needed on the long-term implications for groundwater of mines in karst-prone regions of the state. The MDNR, University of Minnesota, and Minnesota Geological Survey are actively researching karst and groundwater in Minnesota and should be consulted regarding additional mining-related research needs/opportunities.

TRANSPORTATION

- **Air quality issues (ambient air and impacts) created by transportation:**
  -loading and transporting
  -by truck
  -by rail
  -by barge
  -near mines
  -near processing sites
  -near loading sites

- **Funding options for local road jurisdictions:** Local roads designed for lower volumes that state highways are being impacted by concentrated truck traffic from sand mining industry operations. Local jurisdictions have limited resources to address this. Are the funding means available to local and state government adequate to address the needs?

- **How many barge terminals are capable of serving the silica sand industry? Is there a potential for more?**

- **Do publicly owned transportation terminals (truck, rail, barge) have management or regulatory differences if privately owned versus publicly owned? If so, which terminals are owned by public entities (port authorities, cities, etc.) versus privately owned?**

- **What EPA air and water rules apply for barge facilities?**

GOVERNANCE

- **Guidance and Best Management Practices for Local Governmental Units:** The nature of sand mining with its varied elements is posing challenges even for experienced governmental units. A multi-discipline study resulting in a guidance document would be useful for local governments. This effort would examine and provide guidance on such things as:

  - statutory authorities for planning and regulating
  - review topics and information needs, e.g., water quality, water use quantity, air quality
  - identifying location and impacts on existing natural resources
  - provision of and maintaining necessary infrastructure
  - how to address the different elements: mining, processing, transporting
  - best management practices for local governments in permitting and ongoing monitoring
  - best management practices for facility operators for planning and managing facilities
  - reclamation methods and requirements

- **Additional Review and Guidance on Connected Actions and Phased Actions in Environmental Review:** Further examination of these concepts as they apply to the varied elements of the silica sand mining industry would be useful to local governments.

- **Interaction of Regulatory Practices Across State and Local Governments:** An examination of state rules and permit standards as well as local government authorities and regulatory practices should include how state rules and local controls interact: how they affect, depend on, and possibly contradict one another. There may be assumptions made in one government level that specific safeguards are in place at other government levels.

- **Subsurface Rights vs. Surface Rights:** Questions have arisen regarding subsurface mining rights and the effects on surface rights owned by another person.

POTENTIAL IMPACTS ON SENSITIVE RESOURCES

- **Site-Specific Data:** Given the multitude of rare species and native plant communities in the vicinity of the silica sand resources it is highly probable that silica sand mining will negatively affect rare resources to some degree. However, without site-specific details it is impossible to determine which sensitive ecological resources will be impacted and the extent to which they will be impacted (e.g., Takings Permits).

- **Development Pressure:** Calculating the surface area of silica sand resources within each county that resides outside of the MBS Sites of Biodiversity Significance or Important Prairie Landscapes will help to assess the amount of development pressure that will occur within these ecologically significant areas.

XII. DEFINITIONS

Ambient	Of the surrounding area or environment.
Amorphous (silica)	A non-crystalline, or non-crystal-like solid.
Aquifer	An underground layer of water-bearing permeable rock or unconsolidated materials (gravel, sand, or silt) from which groundwater can be extracted.
Bench Mining	An open pit method of extracting rock or minerals from the earth through layer-by-layer removal.
Carcinogenic	Having the potential to cause cancer.
Crystalline (silica)	A crystal-like solid. Associated with health concerns where exposures tend to be higher than ambient exposures.
Flocculant	A substance that promotes the clumping of particles, esp. one used in treating waste water.
Frac sand	Silica sand that has characteristics suitable for hydraulic fracking.
Fracking, Fracing, or Frac Mining	Variations of the term "hydraulic fracturing".
Fracture Fluids	Primarily water-based fluids mixed with additives that help the water to carry sand proppant into the fractures.
Generic Environmental Impact Statement	A comprehensive environmental review of an activity or entity (i.e., silica sand mining) that is applicable in many situations and locations, not just one specific site.
Hopper	A type of railroad freight car used to transport loose bulk commodities such as coal, ore, grain and gravel.
Horizontal Fracturing	A wellbore that starts down through the rock in a vertical direction, but is then turned horizontally for some length into the producing formation. Fractures are often placed along the horizontal wellbore to help spur new production.
Hydraulic Fracturing	A process used in drilling that involves pumping *fluid* into a wellbore at a pressure high enough to *fracture* and create fissures in the formation rock.
Hydrocarbon	Any of numerous organic compounds, such as benzene and methane, that contain only hydrogen and carbon.
Incised	Made by cutting.
Infiltrate	To cause to permeate something by penetrating its pores.
Kaolinite	A clay mineral, part of the group of industrial minerals.

Karst	An area of irregular limestone in which erosion has produced fissures, sinkholes, underground streams, and caverns.
Methanol	A chemical also known as methyl alcohol, carbinol, wood alcohol, wood naphtha, or wood spirits. It is the simplest alcohol.
Micron	One micrometer, which is one millionth of a meter or approximately 1/25,000 of an inch.
Mill rate	The tax per dollar of assessed value of property. The rate is expressed in mills, where one mill is one-tenth of a cent ($0.001).
Mineralogy	A subset of geology specializing in the scientific study of chemistry, crystal structure, and physical (including optical) properties of minerals.
Moratoria	A temporary prohibition of an activity.
Nonmetallurgical bauxite	A non-metal, amorphous clayey rock.
Overburden	Rock or soil overlying a mineral deposit, archaeological site, or other underground feature.
Paleozoic	The Paleozoic Era is the earliest of three geologic eras of the Phanerozoic Eon, spanning from roughly 541 to 252.2 million years ago.
Play (Geologic)	A particular stratigraphic or structural geologic setting is also often known as a play. (see also Stratigraphy)
Proppant	A contraction of the words "propping" and "agent". A particle used to hold open cracks in the geologic formation so that oil or gas can be collected. Can be natural or man-made.
Reclamation	The act or process of reclaiming. A restoration, as to productivity, or usefulness.
Sedimentation	The tendency for particles in suspension to settle out of the fluid in which they are entrained, and come to rest against a barrier.
Silica Sand	Sands and gravels with high silicon dioxide (SiO_2) content. Also called “silica” and “quartz sand”.
Silicosis	A form of lung disease caused by inhalation of crystalline silica dust, and is marked by inflammation and scarring in forms of nodular lesions in the upper lobes of the lungs.
Silt	A granular material of a size somewhere between sand and clay whose mineral origin is quartz and feldspar.
Sintering	The process of using high temperature kilns to bake clay into well-formed, round, sand-sized particles.
Sphericity	A measure of how spherical (round) an object is.

Stratigraphy	The study of rock strata, especially the distribution, deposition, and age of sedimentary rocks.
Surface Mining	A broad category of mining in which the soil and rock overlying the mineral are removed. The opposite of underground mining.
Turbidity	Having sediment or foreign particles stirred up or suspended; muddy: *turbid* water.
Underground Mining	The practice of mining that leaves the overlying surface soil and rock in place, and the underlying mineral is removed by way of shafts or tunnels.

XIII. References

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XIV. Appendices

A. Minnesota Biological Survey Sites

B. Native Plant Communities Over Silica Sand Deposits < 50’ Deep

C. Minnesota Natural Heritage Information System Current and Proposed Threatened and Endangered Species Within 1 Mile Radius of Silica Sand Deposits < 50' Deep

Appendix A

	MBS Sites Within County			MBS Sites With Silica Sand Resources				Silica Sand Resources			
	# of MBS Sites in County	Acres of MBS in County	% of County with MBS	#	% of MBS Sites with SS	Acres	% of Total MBS Acreage	Acres of SS in County	% of County with SS	Acres of SS in MBS	% of SS in MBS
Anoka	**51**	**46,027**	**16%**					**334**	**< 1%**	**-**	**0%**
Outstanding	5	27,021		-		-	-				
High	16	9,174		-		-	-				
Moderate	30	9,832		-		-	-				
Blue Earth	**87**	**8,918**	**2%**					**2,695**	**1%**	**341**	**13%**
Outstanding	1	12		-		-	-				
High	11	1,669		2	18%	1,083	65%				
Moderate	75	7,238		11	15%	1,388	19%				
Carver	**47**	**5,348**	**2%**					**336**	**< 1%**	**6**	**2%**
Outstanding	4	504		-	-	-	-				
High	19	1,713		-	-	-	-				
Moderate	24	3,131		2	8%	521	17%				
Chisago	**77**	**29,997**	**11%**					**2,484**	**1%**	**1,493**	**60%**
Outstanding	9	6,216		7	78%	5,424	87%				
High	18	7,134		4	22%	1,808	25%				
Moderate	50	16,647		2	4%	1,990	12%				
Dakota	**100**	**15,253**	**4%**					**35,954**	**10%**	**1,225**	**3%**
Outstanding	8	5,474		3	38%	2,821	52%				
High	25	5,563		15	60%	2,840	51%				
Moderate	67	4,216		24	36%	1,603	38%				

	MBS Sites Within County			MBS Sites With Silica Sand Resources				Silica Sand Resources			
	# of MBS Sites in County	Acres of MBS in County	% of County with MBS	#	% of MBS Sites with SS	Acres	% of Total MBS Acreage	Acres of SS in County	% of County with SS	Acres of SS in MBS	% of SS in MBS
Dodge	**55**	**6,483**	**2%**					**567**	**< 1%**	**3**	**1%**
Outstanding	3	989		-	-	-	-				
High	7	1,342		-	-	-	-				
Moderate	45	4,152		3	7%	421	10%				
Fillmore	**203**	**75,619**	**14%**					**31,400**	**6%**	**7,072**	**23%**
Outstanding	55	19,653		27	49%	15,226	77%				
High	24	14,058		13	54%	11,645	83%				
Moderate	124	41,908		59	48%	32,300	77%				
Goodhue	**216**	**45,653**	**9%**					**44,430**	**9%**	**7,125**	**16%**
Outstanding	60	17,196		35	58%	10,499	61%				
High	77	16,533		45	58%	11,850	72%				
Moderate	79	11,924		48	61%	9,482	80%				
Hennepin	**107**	**13,952**	**4%**					**2,000**	**1%**	**263**	**13%**
Outstanding	6	667		-	-	-	-				
High	32	5,069		-	-	-	-				
Moderate	69	8,215		4	6%	3,781	46%				
Houston	**192**	**81,780**	**22%**					**51,575**	**14%**	**14,419**	**28%**
Outstanding	5	3,686		5	100%	3,686	100%				
High	17	13,159		12	71%	12,321	94%				
Moderate	170	64,934		145	85%	62,856	97%				

	MBS Sites Within County			MBS Sites With Silica Sand Resources				Silica Sand Resources			
	# of MBS Sites in County	Acres of MBS in County	% of County with MBS	#	% of MBS Sites with SS	Acres	% of Total MBS Acreage	Acres of SS in County	% of County with SS	Acres of SS in MBS	% of SS in MBS
Le Sueur	**62**	**8,117**	**3%**					**4,430**	**1%**	**1,314**	**30%**
Outstanding	5	2,407		2	40%	934	39%				
High	14	1,763		3	21%	814	46%				
Moderate	43	3,947		1	2%	8	0%				
Nicollet	**110**	**21,882**	**7%**					**1,297**	**< 1%**	**199**	**15%**
High	21	16,099		1	5%	590	4%				
Moderate	89	5,783		6	7%	1,173	20%				
Olmsted	**92**	**14,956**	**4%**					**39,067**	**9%**	**825**	**2%**
Outstanding	14	4,146		3	21%	2,752	66%				
High	20	2,688		5	25%	1,336	50%				
Moderate	58	8,122		23	40%	3,468	43%				
Ramsey	**51**	**3,982**	**4%**					**2,182**	**2%**	**242**	**11%**
Outstanding	5	1,071		-	-	-	-				
High	6	668		2	33%	359	54%				
Moderate	40	2,243		10	25%	534	24%				
Rice	**101**	**14,264**	**4%**					**14,802**	**4%**	**2,120**	**14%**
Outstanding	14	4,788		11	79%	4,550	95%				
High	42	6,745		9	21%	736	11%				
Moderate	45	2,732		10	22%	580	21%				

	MBS Sites Within County			MBS Sites With Silica Sand Resources				Silica Sand Resources			
	# of MBS Sites in County	Acres of MBS in County	% of County with MBS	#	% of MBS Sites with SS	Acres	% of Total MBS Acreage	Acres of SS in County	% of County with SS	Acres of SS in MBS	% of SS in MBS
Scott	**83**	**14,443**	**6%**					**3,250**	**1%**	**1,682**	**52%**
Outstanding	12	1,946		1	8%	488	25%				
High	19	7,193		4	21%	1,922	27%				
Moderate	52	5,304		2	4%	304	6%				
Sibley	**46**	**10,574**	**3%**					**50**	**< 1%**	**5**	**10%**
High	7	2,512		-	-	-	-				
Moderate	39	8,062		2	5%	366	5%				
Wabasha	**107**	**40,725**	**12%**					**25,324**	**7%**	**6,237**	**25%**
Outstanding	5	4,551		2	40%	1,812	40%				
High	21	11,796		12	57%	8,836	75%				
Moderate	81	24,378		69	85%	22,853	94%				
Waseca	**50**	**4,339**	**2%**					**3**	**< 1%**	**-**	**0%**
High	2	422		-	-	-	-				
Moderate	48	3,917		-	-	-	-				
Washington	**111**	**12,542**	**5%**					**23,632**	**9%**	**1,360**	**6%**
Outstanding	7	822		2	29%	403	49%				
High	32	4,863		15	47%	1,241	26%				
Moderate	72	6,858		32	44%	2,477	36%				
Winona	**104**	**74,206**	**18%**					**46,841**	**11%**	**12,574**	**27%**
Outstanding	10	11,374		10	100%	11,374	100%				
High	22	17,563		22	100%	17,563	100%				
Moderate	72	45,269		64	89%	41,275	91%				

	MBS Sites Within County			MBS Sites With Silica Sand Resources				Silica Sand Resources			
	# of MBS Sites in County	Acres of MBS in County	% of County with MBS	#	% of MBS Sites with SS	Acres	% of Total MBS Acreage	Acres of SS in County	% of County with SS	Acres of SS in MBS	% of SS in MBS
Wright	**74**	**8,481**	**2%**					**1**		**-**	**0%**
Outstanding	5	2,350		-	-	-	-				
High	21	2,732		-	-	-	-				
Moderate	48	3,399		-	-	-	-				

Appendix B

MBS Native Plant Communities
over Silica Sand Deposits < 50 feet deep

MBS Native Plant Communities
over Silica Sand Deposits < 50 feet deep

			State Rank	Acres
	18 Acres			
LAKE BED				**1**
Other Water Body		OW		**17**
Cliff/Talus System	**198 Acres**			
Algific Talus: Dolomite Subtype		CTs46a2	1	**17**
Dry Limestone - Dolomite Cliff (Southern)		CTs12b	4	**9**
Dry Sandstone Cliff (Southern)		CTs12a	2	**10**
Maderate Cliff: Dolomite Subtype		CTs43a2	1	**0**
Mesic Limestone - Dolomite Cliff (Southern)		CTs33b	3	**5**
Mesic Limestone - Dolomite Talus (Southern)		CTs23b	3	**4**
Mesic Sandstone Cliff (Southern)		CTs33a	2	**7**
Southern Dry Cliff		CTs12		**109**
Southern Mesic Cliff		CTs33		**27**
Southern Open Talus		CTs23		**7**
Southern Wet Cliff		CTs53		**2**
Wet Sandstone Cliff (Southern)		CTs53a	1	**0**
Fire-Dependent Forest	**3,269 Acres**			
Black Oak - White Oak Woodland (Sand)		FDs27c	2	**66**
Central Dry Oak-Aspen (Pine) Woodland		FDc25		**49**
Oak - (Red Maple) Woodland		FDs37a	4	**418**
Oak - Shagbark Hickory Woodland		FDs38a	3	**2,327**
Pin Oak - Bur Oak Woodland		FDs37b	3	**329**
Red Pine - White Pine Woodland (Eastcentral Bedrock)		FDn22d	2	**5**
Southern Dry-Mesic Oak (Maple) Woodland		FDs37		**33**
White Pine - Oak Woodland (Sand)		FDs27b	1	**42**
Floodplain Forest	**1,627 Acres**			
Elm - Ash - Basswood Terrace Forest		FFs59c	2	**645**
Silver Maple - (Virginia Creeper) Floodplain Forest		FFs68a	3	**839**
Silver Maple - Green Ash - Cottonwood Terrace Forest		FFs59a	3	**132**
Southern Terrace Forest		FFs59		**10**
Swamp White Oak Terrace Forest		FFs59b	1	**0**
Forested Rich Peatland	**47 Acres**			
Tamarack Swamp (Southern)		FPs63a	S2S3	**47**
Mesic Hardwood Forest	**16,273 Acres**			
Basswood - Black Ash Forest		MHc47a	3	**188**
Basswood - Bur Oak - (Green Ash) Forest		MHs38b	3	**0**
Central Dry-Mesic Oak-Aspen Forest		MHc26		**35**
Elm - Basswood - Black Ash - (Blue Beech) Forest		MHs49b	2	**680**
Elm - Basswood - Black Ash - (Hackberry) Forest		MHs49a	3	**135**
Red Oak - Basswood Forest (Noncalcareous Till)		MHc36a	4	**259**
Red Oak - Sugar Maple - Basswood - (Bitternut Hickory) Forest		MHs38c	3	**2,256**
Red Oak - Sugar Maple - Basswood - (Bluebead Lily) Forest		MHn35b	4	**45**
Red Oak - White Oak - (Sugar Maple) Forest		MHs37b	4	**5,232**
Red Oak - White Oak Forest		MHs37a	3	**2,513**
Southern Dry-Mesic Oak Forest		MHs37		**1,709**
Southern Mesic Maple-Basswood Forest		MHs39		**189**
Southern Mesic Oak-Basswood Forest		MHs38		**78**
Southern Wet-Mesic Hardwood Forest		MHs49		**359**
Sugar Maple - Basswood - (Bitternut Hickory) Forest		MHs39a	2	**656**
Sugar Maple - Basswood - Red Oak - (Blue Beech) Forest		MHs39b	3	**1,321**
Sugar Maple Forest (Big Woods)		MHs39c	2	**529**

MBS Native Plant Communities
over Silica Sand Deposits < 50 feet deep

			State Rank	Acres
	18 Acres			
LAKE BED				**1**
Other Water Body		OW		**17**
Cliff/Talus System	**198 Acres**			
Algific Talus: Dolomite Subtype		CTs46a2	1	**17**
Dry Limestone - Dolomite Cliff (Southern)		CTs12b	4	**9**
Dry Sandstone Cliff (Southern)		CTs12a	2	**10**
Maderate Cliff: Dolomite Subtype		CTs43a2	1	**0**
Mesic Limestone - Dolomite Cliff (Southern)		CTs33b	3	**5**
Mesic Limestone - Dolomite Talus (Southern)		CTs23b	3	**4**
Mesic Sandstone Cliff (Southern)		CTs33a	2	**7**
Southern Dry Cliff		CTs12		**109**
Southern Mesic Cliff		CTs33		**27**
Southern Open Talus		CTs23		**7**
Southern Wet Cliff		CTs53		**2**
Wet Sandstone Cliff (Southern)		CTs53a	1	**0**
Fire-Dependent Forest	**3,269 Acres**			
Black Oak - White Oak Woodland (Sand)		FDs27c	2	**66**
Central Dry Oak-Aspen (Pine) Woodland		FDc25		**49**
Oak - (Red Maple) Woodland		FDs37a	4	**418**
Oak - Shagbark Hickory Woodland		FDs38a	3	**2,327**
Pin Oak - Bur Oak Woodland		FDs37b	3	**329**
Red Pine - White Pine Woodland (Eastcentral Bedrock)		FDn22d	2	**5**
Southern Dry-Mesic Oak (Maple) Woodland		FDs37		**33**
White Pine - Oak Woodland (Sand)		FDs27b	1	**42**
Floodplain Forest	**1,627 Acres**			
Elm - Ash - Basswood Terrace Forest		FFs59c	2	**645**
Silver Maple - (Virginia Creeper) Floodplain Forest		FFs68a	3	**839**
Silver Maple - Green Ash - Cottonwood Terrace Forest		FFs59a	3	**132**
Southern Terrace Forest		FFs59		**10**
Swamp White Oak Terrace Forest		FFs59b	1	**0**
Forested Rich Peatland	**47 Acres**			
Tamarack Swamp (Southern)		FPs63a	S2S3	**47**
Mesic Hardwood Forest	**16,273 Acres**			
Basswood - Black Ash Forest		MHc47a	3	**188**
Basswood - Bur Oak - (Green Ash) Forest		MHs38b	3	**0**
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Elm - Basswood - Black Ash - (Blue Beech) Forest		MHs49b	2	**680**
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Red Oak - Basswood Forest (Noncalcareous Till)		MHc36a	4	**259**
Red Oak - Sugar Maple - Basswood - (Bitternut Hickory) Forest		MHs38c	3	**2,256**
Red Oak - Sugar Maple - Basswood - (Bluebead Lily) Forest		MHn35b	4	**45**
Red Oak - White Oak - (Sugar Maple) Forest		MHs37b	4	**5,232**
Red Oak - White Oak Forest		MHs37a	3	**2,513**
Southern Dry-Mesic Oak Forest		MHs37		**1,709**
Southern Mesic Maple-Basswood Forest		MHs39		**189**
Southern Mesic Oak-Basswood Forest		MHs38		**78**
Southern Wet-Mesic Hardwood Forest		MHs49		**359**
Sugar Maple - Basswood - (Bitternut Hickory) Forest		MHs39a	2	**656**
Sugar Maple - Basswood - Red Oak - (Blue Beech) Forest		MHs39b	3	**1,321**
Sugar Maple Forest (Big Woods)		MHs39c	2	**529**

Appendix C

Minnesota Natural Heritage Information System
Current and Proposed Threatened and Endangered Species
within 1 mile radius of Silica Sand Deposits < 50' deep:

Rare Features Database:

Species	# of Records	Federal Status	MN Status	Draft Status
Vertebrate Animal **# of species: 18**				
Acris blanchardi (Blanchard's Cricket Frog)	8		END	no change
Alosa chrysochloris (Skipjack Herring)	18		SPC	END
Ammodramus henslowii (Henslow's Sparrow)	15		END	THR
Crotalus horridus (Timber Rattlesnake)	32		THR	no change
Crystallaria asprella (Crystal Darter)	15		SPC	END
Cygnus buccinator (Trumpeter Swan)	5		THR	SPC
Emydoidea blandingii (Blanding's Turtle)	122		THR	no change
Erimystax x-punctatus (Gravel Chub)	19		SPC	THR
Falco peregrinus (Peregrine Falcon)	43	No Status	THR	SPC
Glyptemys insculpta (Wood Turtle)	22		THR	no change
Hybopsis amnis (Pallid Shiner)	12		SPC	END
Ictiobus niger (Black Buffalo)	10		SPC	THR
Lanius ludovicianus (Loggerhead Shrike)	28	No Status	THR	END
Notropis anogenus (Pugnose Shiner)	3		SPC	THR
Pantherophis obsoletus (Western Ratsnake)	2		SPC	THR
Polyodon spathula (Paddlefish)	8		THR	no change
Rallus elegans (King Rail)	2		END	no change
Spilogale putorius (Eastern Spotted Skunk)	1		THR	no change
Invertebrate Animal **# of species: 34**				
Actinonaias ligamentina (Mucket)	78		THR	no change
Alasmidonta marginata (Elktoe)	39		THR	no change
Arcidens confragosus (Rock Pocketbook)	13		END	no change
Cicindela lepida (Little White Tiger Beetle)	2		THR	no change
Cumberlandia monodonta (Spectaclecase)	5	C	THR	END
Cyclonaias tuberculata (Purple Wartyback)	35		THR	END
Ellipsaria lineolata (Butterfly)	15		THR	no change
Elliptio crassidens (Elephant-ear)	10		END	no change
Elliptio dilatata (Spike)	89		SPC	THR
Epioblasma triquetra (Snuffbox)	2		THR	END
Erynnis persius persius (Persius Dusky Wing)	2		END	no change
Fusconaia ebena (Ebonyshell)	13		END	no change
Hesperia ottoe (Ottoe Skipper)	3		THR	END
Lampsilis higginsii (Higgins Eye)	16	LE	END	no change
Lampsilis teres (Yellow Sandshell)	8		END	no change
Lasmigona costata (Fluted-shell)	58		SPC	THR
Limnephilus rossi (A Caddisfly)	1		SPC	THR
Lycaeides melissa samuelis (Karner Blue)	1	LE	END	no change
Megalonaias nervosa (Washboard)	16		THR	END
Novasuccinea n. sp. minnesota a (Minnesota Pleistocene Ambersnail)	2	No Status	THR	Watchlist
Novasuccinea n. sp. minnesota b (Iowa Pleistocene Ambersnail)	1		END	Watchlist
Ophiogomphus susbehcha (St. Croix Snaketail)	4	No Status	SPC	THR
Plethobasus cyphyus (Sheepnose)	8	C	END	no change
Pleurobema sintoxia (Round Pigtoe)	58		THR	SPC
Quadrula fragosa (Winged Mapleleaf)	6	LE	END	no change
Quadrula metanevra (Monkeyface)	43		THR	no change
Quadrula nodulata (Wartyback)	11		END	THR
Simpsonaias ambigua (Salamander Mussel)	6		THR	END
Tritogonia verrucosa (Pistolgrip)	40		THR	END

Minnesota Natural Heritage Information System
Current and Proposed Threatened and Endangered Species within 1 mile radius of Silica Sand Deposits < 50' deep:

Rare Features Database:

Species	# of Records	Federal Status	MN Status	Draft Status
Invertebrate Animal **# of species: 34**				
Truncilla donaciformis (Fawnsfoot)	7		N/A	THR
Venustaconcha ellipsiformis (Ellipse)	19		THR	no change
Vertigo hubrichti hubrichti (Midwest Pleistocene Vertigo)	2		END	Watchlist
Vertigo hubrichti variabilis n. subsp. (Variable Pleistocene Vertigo)	3		THR	Watchlist
Vertigo meramecensis (Bluff Vertigo)	3		THR	no change
Vascular Plant **# of species: 80**				
Agalinis gattingeri (Round-stemmed False Foxglove)	2		END	no change
Agrostis hyemalis (Ticklegrass)	1		NON	END
Allium cernuum (Nodding Wild Onion)	34		THR	SPC
Aristida tuberculosa (Sea-beach Needlegrass)	8		SPC	THR
Arnoglossum plantagineum (Tuberous Indian-plantain)	15		THR	no change
Arnoglossum reniforme (Great Indian-plantain)	8		NON	THR
Asclepias amplexicaulis (Clasping Milkweed)	24		SPC	THR
Asclepias stenophylla (Narrow-leaved Milkweed)	1		END	no change
Asclepias sullivantii (Sullivant's Milkweed)	1		THR	no change
Aureolaria pedicularia (Fernleaf False Foxglove)	2		THR	no change
Bacopa rotundifolia (Water-hyssop)	1		SPC	THR
Besseya bullii (Kitten-tails)	75		THR	no change
Botrychium oneidense (Blunt-lobed Grapefern)	6		END	THR
Carex careyana (Carey's Sedge)	6		THR	END
Carex conjuncta (Jointed Sedge)	2		THR	no change
Carex davisii (Davis' Sedge)	6		THR	no change
Carex formosa (Handsome Sedge)	3		END	no change
Carex jamesii (James' Sedge)	12		THR	no change
Carex laevivaginata (Smooth-sheathed Sedge)	20		THR	no change
Carex laxiculmis (Spreading Sedge)	18		THR	no change
Carex plantaginea (Plantain-leaved Sedge)	3		END	no change
Carex sterilis (Sterile Sedge)	10		THR	no change
Chrysosplenium iowense (Iowa Golden Saxifrage)	3		END	no change
Desmodium cuspidatum var. longifolium (Big Tick-trefoil)	6		SPC	THR
Desmodium nudiflorum (Stemless Tick-trefoil)	18		SPC	THR
Diarrhena obovata (American Beakgrain)	1		SPC	END
Diplazium pycnocarpon (Narrow-leaved Spleenwort)	18		THR	no change
Dryopteris marginalis (Marginal Shield-fern)	2		THR	END
Eleocharis rostellata (Beaked Spike-rush)	1		THR	no change
Eleocharis wolfii (Wolf's Spike-rush)	1		END	no change
Erythronium propullans (Dwarf Trout Lily)	30	LE	END	no change
Eupatorium sessilifolium (Upland Boneset)	6		THR	no change
Floerkea proserpinacoides (False Mermaid)	8		THR	no change
Hamamelis virginiana (Witch-hazel)	12		SPC	THR
Hasteola suaveolens (Sweet-smelling Indian-plantain)	8		END	no change
Hudsonia tomentosa (Beach-heather)	5		SPC	THR
Huperzia porophila (Rock Clubmoss)	4		THR	no change
Hybanthus concolor (Green Violet)	1		NON	END
Hydrastis canadensis (Golden-seal)	10		END	no change
Iodanthus pinnatifidus (Purple Rocket)	2		END	no change
Juglans cinerea (Butternut)	4		SPC	END
Juncus articulatus (Jointed Rush)	1		NON	END

Minnesota Natural Heritage Information System
Current and Proposed Threatened and Endangered Species within 1 mile radius of Silica Sand Deposits < 50' deep:

Rare Features Database:

Species	# of Records	Federal Status	MN Status	Draft Status
Vascular Plant # of species: 80				
Lechea tenuifolia var. tenuifolia (Narrow-leaved Pinweed)	4		END	no change
Leersia lenticularis (Catchfly Grass)	8		SPC	THR
Lespedeza leptostachya (Prairie Bush Clover)	9	LT	THR	no change
Melica nitens (Three-flowered Melicgrass)	7		THR	no change
Minuartia dawsonensis (Rock Sandwort)	7		SPC	THR
Montia chamissoi (Montia)	1		END	no change
Napaea dioica (Glade Mallow)	29		THR	no change
Orobanche fasciculata (Clustered Broomrape)	5		SPC	THR
Orobanche ludoviciana var. ludoviciana (Louisiana Broomrape)	4		SPC	THR
Orobanche uniflora (One-flowered Broomrape)	6		SPC	THR
Paronychia canadensis (Canadian Forked Chickweed)	5		THR	END
Paronychia fastigiata var. fastigiata (Forked Chickweed)	2		END	no change
Parthenium integrifolium (Wild Quinine)	1		END	no change
Phegopteris hexagonoptera (Broad Beech-fern)	5		THR	END
Phemeranthus rugospermus (Rough-seeded Fameflower)	11		END	THR
Physaria ludoviciana (Bladder Pod)	9		END	no change
Platanthera flava var. herbiola (Tubercled Rein-orchid)	6		END	THR
Platanthera praeclara (Western Prairie Fringed Orchid)	1	LT	END	no change
Poa paludigena (Bog Bluegrass)	12		THR	no change
Polanisia jamesii (James' Polanisia)	7		END	no change
Polygala cruciata (Cross-leaved Milkwort)	1		END	no change
Polystichum acrostichoides (Christmas Fern)	2		THR	END
Potamogeton bicupulatus (Snailseed Pondweed)	1		END	no change
Potamogeton pulcher (Spotted Pondweed)	1		NON	END
Psoralidium tenuiflorum (Slender-leaved Scurf Pea)	3		END	no change
Rhynchospora capillacea (Hair-like Beak-rush)	3		THR	no change
Rubus stipulatus (Big Horseshoe Lake Dewberry)	1		NON	END
Rudbeckia triloba var. triloba (Three-leaved Coneflower)	5		SPC	THR
Scleria triglomerata (Tall Nut-rush)	2		END	no change
Scleria verticillata (Whorled Nut-rush)	2		THR	no change
Scutellaria ovata var. versicolor (Ovate-leaved Skullcap)	10		THR	no change
Silene nivea (Snowy Campion)	8		THR	no change
Sullivantia sullivantii (Reniform Sullivantia)	15		THR	no change
Symphyotrichum shortii (Short's Aster)	24		THR	SPC
Trichophorum clintonii (Clinton's Bulrush)	2		SPC	THR
Valeriana edulis var. ciliata (Valerian)	33		THR	no change
Viola lanceolata var. lanceolata (Lance-leaved Violet)	1		THR	no change
Vitis aestivalis (Silverleaf Grape)	11		SPC	THR
Nonvascular Plant # of species: 1				
Bryoxiphium norvegicum (Sword Moss)	1		SPC	END
Fungus # of species: 5				
Buellia nigra (A Species of Lichen)	2		END	SPC
Coccocarpia palmicola (Salted shell lichen)	1		THR	no change
Parmelia stuppea (Powder-edged ruffle lichen)	1		THR	no change
Psathyrella cystidiosa (A Species of Fungus)	2		END	no change
Psathyrella rhodospora (A Species of Fungus)	2		END	no change

Minnesota Natural Heritage Information System
Current and Proposed Threatened and Endangered Species
within 1 mile radius of Silica Sand Deposits < 50' deep:

Total # of Species: 138

Federal Status: The status of the species under the U.S. Endangered Species Act: LE = endangered; LT = threatened; LE,LT = listed endangered in part of its range, listed threatened in another part of its range; LT,PDL = listed threatened, proposed for delisting; C = candidate for listing. If null or 'No Status,' the species has no federal status.

MN Status: The legal status of the plant or animal species under the Minnesota Endangered Species Law: END = endangered; THR = threatened; SPC = special concern; NON = tracked, but no legal status. Native plant communities, geological features, and colonial waterbird nesting sites do not have any legal status under the Endangered Species Law and are represented by a N/A.

Draft Status: Proposed change to the legal status of the plant or animal species under the Minnesota Endangered Species Law: END = endangered; THR = threatened; SPC = special concern; Watchlist = tracked, but no legal status.