The impact of aggregate mining in the Vermillion River Watershed, Minnesota

Overview provided for the Vermillion River Watershed Joint Powers Board

Carrie E. Jennings, PhD, P.G.

FRESHWATER

The impact of aggregate mining in the Vermillion River Watershed, Minnesota

Executive Summary

The Vermillion River watershed is rich in high quality aggregate resources that are being actively mined because of their proximity to the metropolitan area. The impact of aggregate extraction on the long-term quality and quantity of water being discharged to the Vermillion River is important to assess to avoid impact to the river's cold-water ecosystem.

Aggregate extraction rates have been steady and of low total volume in the southern Dakota County townships in the watershed. Higher amounts and rates of extraction have leveled off in Lakeville and Apple Valley where available deposits have been mined or where development restricts access to the deposits. Extraction rates are increasing in Empire Township and Rosemount and will likely equal or surpass those in Apple Valley.

Planned gravel extraction in UMore Park in Empire Township and Rosemount has been the subject of environmental review. General conclusions are that aggregate extraction is unlikely to directly impact surface water or base flow to the Vermillion River. Change in the flow of surface water will be primarily confined on the site and be directed towards the pit lake that will be created. A groundwater divide exists south of the property and groundwater flow is towards the northeast to the Mississippi; this will not change with aggregate mining. However, subsequent residential development of the site has not been assessed for potential impact to water table elevations.

Although it has been determined that the pit lake being created on the UMore Property will not affect groundwater flow to the Vermillion, the dense dataset could be used to predict thermal plume migration in similar settings. Thermal plumes that move away from mine-pit lakes in Canada have been modeled with monitoring data and isotopes. Variables affecting how far a temperature anomaly migrates before the excess heat is dissipated include: factors affecting the groundwater flow rate (advects heat); the thermal properties of the sand and gravel (dissipates heat); annual temperature variations at the surface (background variability).

The UMore Property has detailed measurements of flow rate, grain size and mineralogy and lends itself to modeling. The approaches developed there could be used to examine thermal plume migration from aggregate pit lakes along reaches of the Vermillion where mining is more likely to have an impact. The Dakota Aggregate mine in Eureka Township has three monitoring wells with quarterly temperature measurements going back a decade that might be utilized.

Townships in the watershed independently regulate aggregate extraction and have varying levels of oversight. The VRWJPO could create a model mining ordinance for adoption by the townships or revise watershed standards to create monitoring consistency across the watershed.

Say something about DNR, MPCA authority and if it needs to be coordinated.

Introduction

The Vermillion River Watershed Plan was approved by the State and adopted by the Vermillion River Watershed Joint Powers Board with the main objective of protecting or restoring water quality in lakes, streams, and wetlands. Objective Number 15 in the Plan outlined a study of the impact of aggregate mining on surface water and groundwater quality, quantity, and inflow to the Vermillion River and its tributaries. It prescribed the following actions:

a. Review existing research on aggregate mining impacts on water and groundwater in conditions comparable to the watershed.
b. Discuss research needs to evaluate cumulative landscape-scale impacts of aggregate mining in the watershed with partners.
c. Evaluate need for new Watershed Standards on aggregate mining if research shows potential water resource impacts.

The Vermillion River is centered in a broad sand plain and receives baseflow from groundwater that recharges the stream bed through this sand and gravel aquifer. Forty-nine miles of the nearly 60-mile river has a self-sustaining brown trout population owing to the moderating thermal influence of this influx. There is concern that the stream may be impacted by human activities that degrade the cold-water conditions required for trout.

The cumulative impact of aggregate mining of the near-surface sand and gravel deposits throughout the watershed and in the more carefully studied mining district in UMore Park are considered here. We provide and interpret the available background materials on the geology, hydrogeology and mining in the Vermillion Watershed and identify existing research on aggregate mining impacts in order to identify gaps that could be addressed with revised watershed standards.

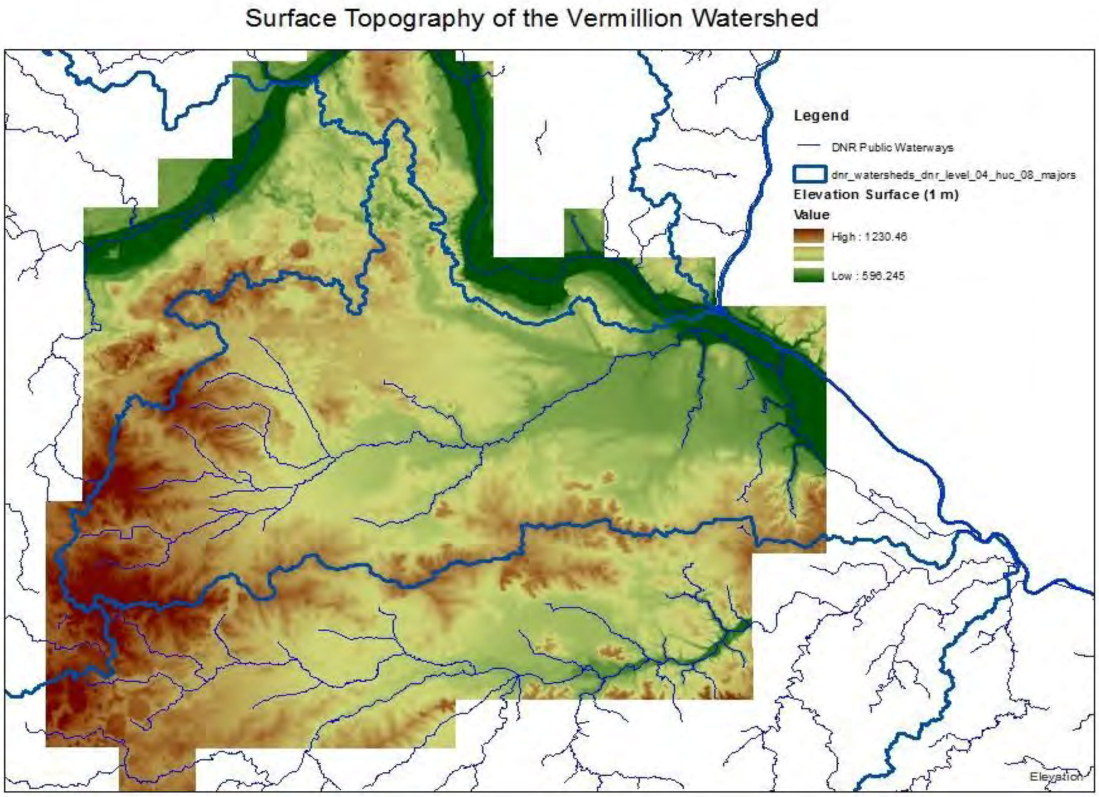
Geology and Geomorphology of the Vermillion Watershed

The Vermillion River watershed is a 335 sq mile area that extends from easternmost Scott County through central Dakota County. The river flows eastward for 59 miles from the headwaters near New Market to the confluence with the Mississippi River south of Lock and Dam 3.

Topography

The shape of the watershed is controlled by late-glacial events. Two different ice lobes built moraines creating the north and west divides. The draining of meltwater from these ice margins created the central, sandy lowlands of the watershed. However, the bedrock topography, even where buried, exerts strong control on the location of watershed divides and the position of the mainstem river within the central lowland. All of the divides are areas of high bedrock.

The western divide is created by a moraine of the Des Moines lobe that buries high elevation Paleozoic rock layers with glacial sediment (Fig. 1). The southern divide that separates the Vermillion from the Cannon River watershed is formed where the resistant Platteville Limestone is present locally. It protects the



the north and west and created broad meltwater streams that flowed to the east in the middle of the watershed. Dakota County GIS

underlying St. Peter Sandstone creating a discontinuous ridge of Paleozoic rock that is either at the surface or shallowly buried. The northern divide is located where a moraine of the Granstburg sublobe and the earlier Superior lobe buried a discontinuous bedrock high with glacial sediment, the western portion of which retains the upper, more resistant Platteville Limestone layer.

The buried bedrock layers influence the path and rate of groundwater flow to the major groundwater discharge areas, the Mississippi and Vermillion river valleys. The mainstem of the river flows to the east through a broad low in the surface that mirrors a low in the bedrock surface and aligns with a major fault related to the midcontinent rift system. The Vermillion discharges water to the bedrock in this reach.

The Vermillion River crosses a large, pre-existing valley in the bedrock surface just upstream of Hastings. Downstream of the buried valley and downstream of a waterfall on the Vermillion River, the river enters another bedrock channel, the one currently occupied by the Mississippi. From here, one branch (Vermillion Slough) flows to the north to join the Mississippi River near mile 813, and the other reach called the Vermillion Bottoms, parallels the Mississippi River for approximately 20 miles before joining

Bedrock Depth

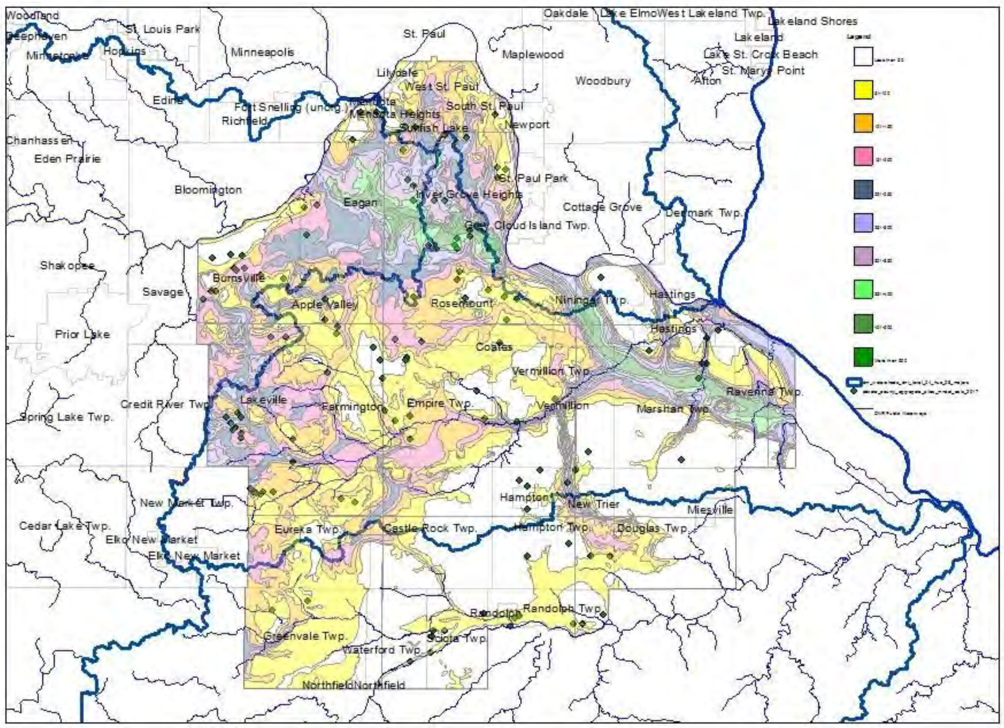


Figure 2. *Bedrock depth is a combination of the elevation of the bedrock surface and the thickness of the sediment that is burying it. Glacial sediment is thickest in the moraines of recent glaciers on the north and west divides of the watershed. Elsewhere in the County, deep valleys in the bedrock surface are filled with sediment. The southeast part of the watershed has bedrock at or near the surface. Scott County is not mapped here. Dakota County GIS*

it just downstream from Lock and Dam 3 near Red Wing, Minnesota. The angle that the tributaries enter the Vermillion Bottoms indicates that this reach may have reversed course at some time in its history.

Bedrock Geology and aquifer properties

Where glacial sediment aquifers overlie bedrock aquifers, the two systems are hydraulically connected therefore it is important to understand what the uppermost bedrock unit is and how water moves through it.

Layered Paleozoic rocks deposited during marine incursions hundreds of millions of years ago cover southeastern Minnesota. The deposits and therefore the resulting bedrock layers varied in grain size depending on the energy of the sea (near shore = high energy, offshore = low energy) and therefore the permeability of the rock layers also varies. Sand deposited in beach and backshore areas became sandstone that has primary porosity and permeability between the sand grains, even after cementation. Shallow water sediment, primarily clay, was deposited farther offshore and therefore lies directly above and below

Bedrock Geology

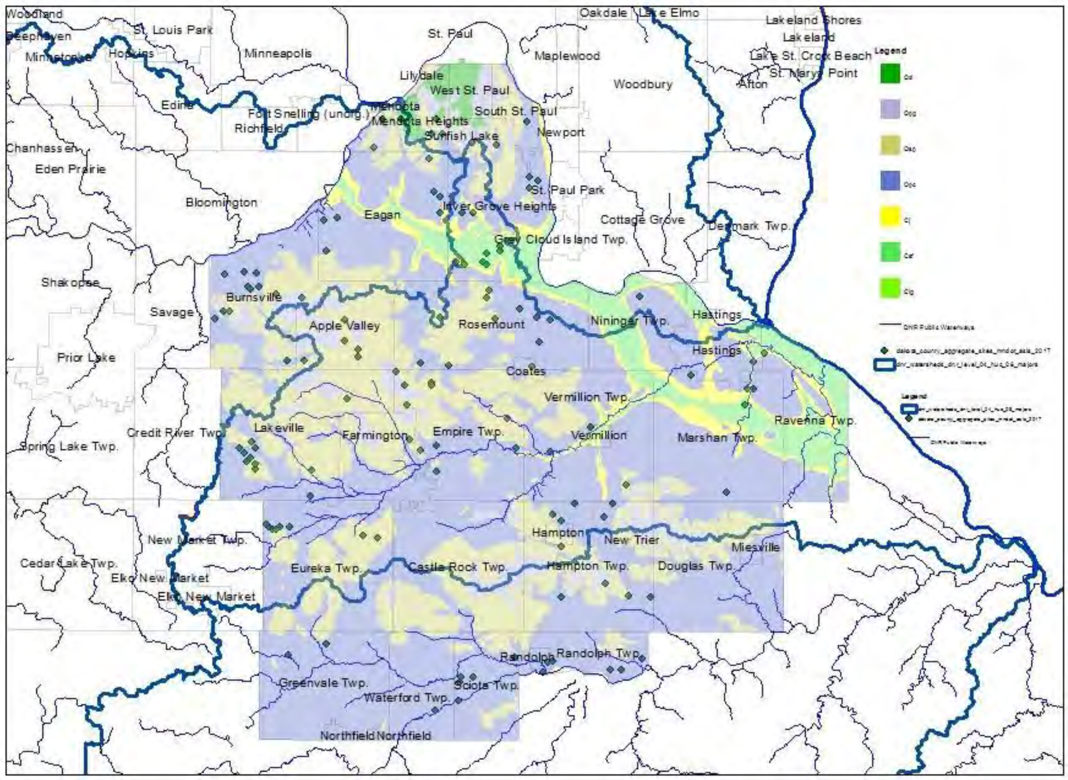


Figure 3. First bedrock layers as they would appear if surficial sediment cover were removed in the Vermillion watershed. The more resistant layers of Platteville Formation (purple) form flat-topped mesas where at the surface or highs in the subsurface. Where this unit is missing, the underlying St. Peter Sandston (tan) is easily eroded. The deep valley in the eastern watershed cuts into older and deeper layers of sandstone and carbonate (yellow and green). Dakota County GIS.

sandstones layers. The resulting thin shale layers are porous (hold water) but have low permeability because pores are not connected. The uppermost unit mapped in the watershed is the Platteville Formation. It and other carbonates like the Prairie du Chien represent offshore deposition of marine organisms that form a calcium carbonate ooze with some remnant fossils. These rock layers have limited primary porosity but varying permeability because joints and bedding planes within the rock layers can be widened by dissolution. These cracks can transmit water freely if they are continuous.

The Platteville Formation is not considered an aquitard because of fractures in its three members. The Platteville is typically mapped with the underlying Glenwood Shale, a confining unit. The underlying St. Peter Sandstone is an aquifer, though not in general use for water supply because of its proximity to the surface and vulnerability to contamination. Most municipal water-supply wells access the high-yielding, Prairie du Chien-Jordan aquifers.

Where present, the Platteville Formation forms flat-topped resistant uplands, even in the buried bedrock surface. Where it is missing, the St. Peter Sandstone is easily eroded. However it does subcrop beneath the Quaternary sediment near the divides in the watershed. The Prairie du Chien is resistant to erosion and subcrops beneath the central part of the watershed. It is only in a deep valley of glacial or interglacial origin that older and deeper units are exposed such as the underlying Jordan Sandstone.

After Paleozoic time, there is a missing period in the rock record that lasted for about four hundred million years. During this time, the bedrock surface was mostly exposed and subject to chemical weathering and physical erosion. Rocks and sediment of Cretaceous age have been mapped in southeastern Minnesota and as close as Goodhue County.

Glacial Deposits

The watershed was glaciated several times during the last two million years. The effects of the most recent glaciation are visible at the surface in the western portion of the watershed; deposits of older glaciations are at the surface in the eastern portion of the watershed and locally preserved in the subsurface elsewhere.

The watershed lay at the edge of two ice lobes during late glacial time and meltwater emanated from these ice margins at slightly different times, depositing the surface sand and gravel in the watershed. The deposits of meltwater from the Des Moines lobe created the broad sandy plain of the central watershed. It's deposits have been assigned to the New Ulm Formation. In places, the ice and meltwater streams of the Des Moines lobe incorporated the underlying, older Superior lobe deposits (Cromwell Formation). Where the two lithologically distinct sources are mixed, they are included in another formation, the Twin Cities Formation. These mixed deposits are generally associated with the Granstburg sublobe but also occur along the eastern margin of the Des Moines lobe.

Even older sand and gravel layers from previous glaciations may be preserved in valleys in the bedrock surface and appear at the surface east of the last ice margins where not covered by more recent meltwater sediment or mantled by wind deposits of silt (loess).

New Ulm Formation

The surface sand and gravel in the Vermillion watershed were deposited by meltwater issuing from the Des Moines lobe when it bordered the watershed on the west. The till of this formation is a loam to clay loam and not well drained. The gravel and coarse sand fraction of the New Ulm Formation contains rock types derived northwest of Minnesota, generally from the Riding Mountain Provenance but including Winnipeg Provenance rock types. These rock types include Cretaceous shale, chert, Paleozoic carbonate and secondary iron and manganese concretions. All of these rock types are considered deleterious by the aggregate industry because of their lack of competence, their water absorption properties or reactivity in concrete. Where the Des Moines lobe reworked deposits of the slightly older northeastern provenance they have a higher value for aggregate (Twin Cities Formation).

The coarsest sand and gravel fraction of the New Ulm Formation was deposited at the ice margin in fans, commonly at the point where subglacial tunnels discharged. A broad wetland in New Market Township marks the location of a former subglacial tunnel valley. The flow from this tunnel deposited a fan and sandplain on northern boundary of Eureka Township. Eureka

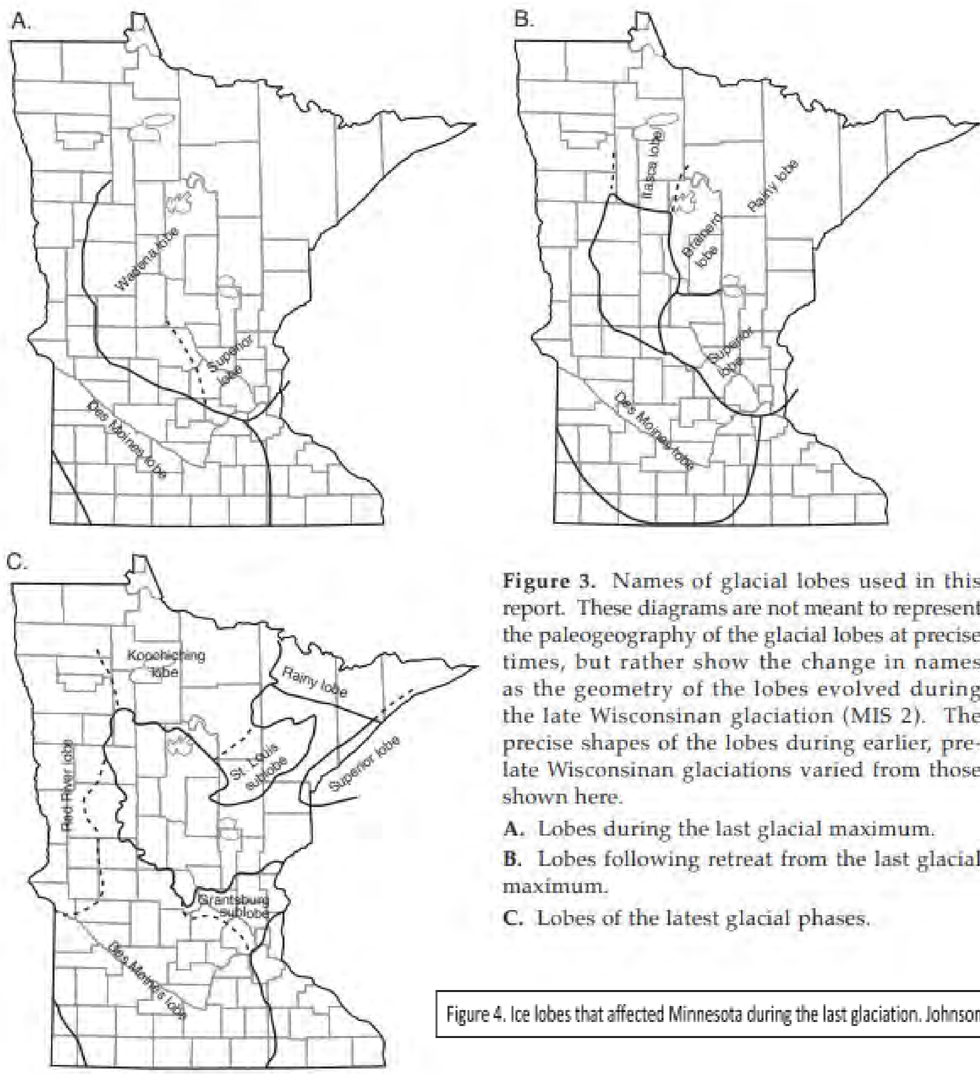


Figure 3. Names of glacial lobes used in this report. These diagrams are not meant to represent the paleogeography of the glacial lobes at precise times, but rather show the change in names as the geometry of the lobes evolved during the late Wisconsinan glaciation (MIS 2). The precise shapes of the lobes during earlier, pre-late Wisconsinan glaciations varied from those shown here.

A. Lobes during the last glacial maximum.

B. Lobes following retreat from the last glacial maximum.

C. Lobes of the latest glacial phases.

Figure 4. Ice lobes that affected Minnesota during the last glaciation. Johnson and other, 2016.

Sand and Gravel,Tiller Corporation and now Dakota Aggregates have mined the coarse deposits in the ice-marginal fan located in the irregular, morainic terrain along the ice margin. The east-sloping fan becomes low gradient within a short distance to the east and the dominant grain size of the deposit decreases to sand.

Lake Marion occupies a portion of another tunnel valley that discharged from beneath the Des Moines lobe. An ice-marginal fan with sand and gravel is located in hilly terrain on west end of the lake and coarse material possibly extends beneath the lake. East of the lake deposits are sandier.

Between the Lake Marion and Crystal Lake tunnels the surface is comprised of slightly older till of New Ulm Formation and clayeyier,

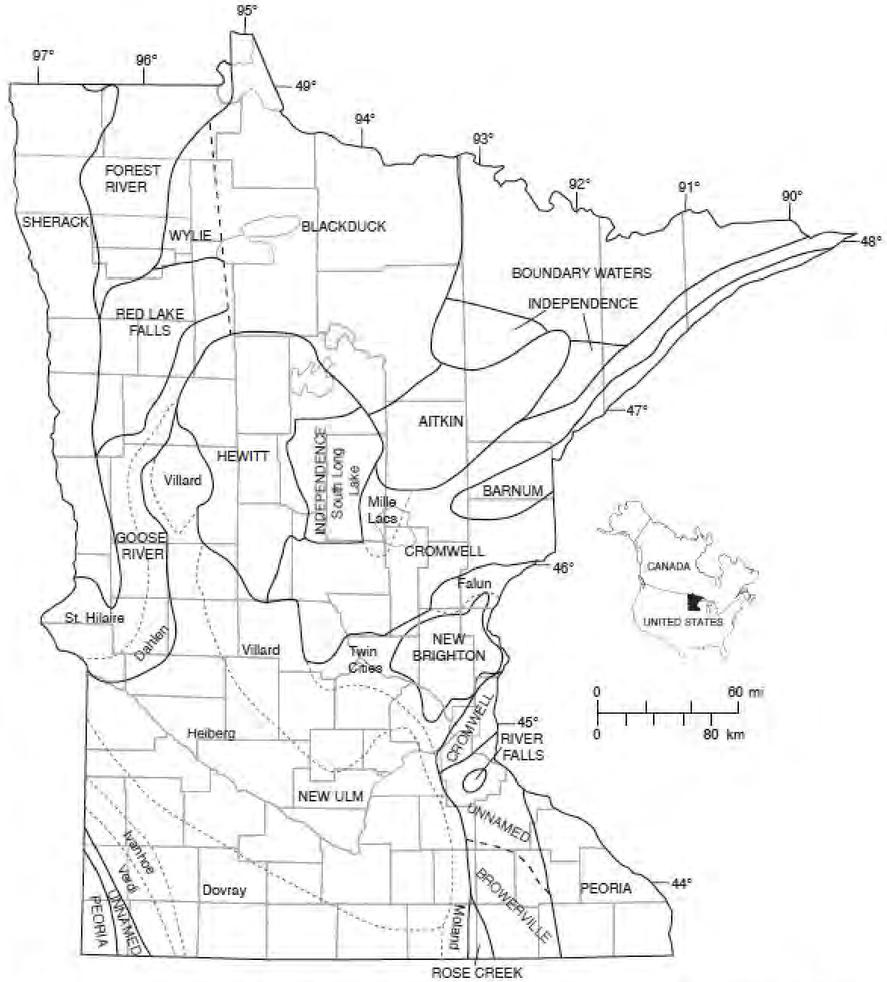


Figure 10. Surface lithostratigraphic units of Minnesota. Bold outlines represent the surficial extent of geologic formations, which are capitalized. Light dashed lines indicate the extent of members, written with lower-case letters. Bold, dashed lines are approximate formation boundaries.

Figure 5. Lithostratigraphic units at the surface that were recently formalized (Johnson and others, 2016). Till of the New Ulm Formation reaches the western part of the watershed and meltwater deposits also included in the New Ulm Formation extend to the Mississippi (not indicated in this figure). Till of the Cromwell Formation reaches the northern part of the watershed and the associated meltwater stream deposits extend across the watershed (not shown).

older glacial till that is dark gray to yellow brown where oxidized.

Twin Cities Formation

The Grantsburg sublobe had a flow path similar to the Des Moines lobe so had a similar lithologic composition. Where it overrode highlands created by the Superior lobe, it is distinguished by the incorporation of the underlying Cromwell Formation giving it a slightly sandier texture and varying lithology. The sublobe borders the northern boundary of the watershed; its meltwater streams flowed to the south near the present location of the Pine Bend Refinery.

Figure 6. End members of the two provenances that the New Ulm Formation is derived from. Upper photo, Winnipeg Provenance, lower photo, Riding Mountain Provenance. Minnesota Geological Survey https://www.mngs.umn.edu/pebbles.htm

Cromwell Formation

Ice that advance through the Lake Superior basin carried clasts derived from the North Shore volcanics (basalt, rhyolite and gabbro), the Canadian shield (granite, greenstone and metasediment) and the Superior basin (sandstone) that are generally more competent and less reactive, resulting in a higher quality aggregate. The till of this formation in Dakota County is a loamy sand texture.

Figure 7. The Cromwell Formation includes rock types of the Superior Provenance that are more durable and less reactive than those of the New Ulm Formation and are favored by the aggregate industry. https://www.mngs.umn.edu/pebbles.htm

The Superior lobe also discharged meltwater through subglacial tunnels prior to ice stagnation and because the ice of the Superior lobe was thicker, it applied more pressure to subglacial streams which resulted in larger fans like Buck Hill that are comprised of coarser material. The thicker ice also could have taken longer to stagnate, a possible explanation for the larger ice-walled lake plains and other features of ice stagnation along the northern edge of the watershed.

A slightly earlier ice advance from the Superior basin, the Emerald Phase (reference 2016 but also Savina and Johnson), covered the watershed as far south as Hampton and may explain the coarseness of the gravel in the subsurface near Rosemount and along highway 52 near Hampton. Exposures of gravel deposits in the Hampton area had ice-wedge casts filled with fine-grained sediment, indicative of permafrost in a periglacial setting where wind-blown silt mobilized by glacial winds or in a thawed, active layer during summer could fill them.

Older glacial formations

Sediment from earlier glaciations is at the surface in the highlands of the southern watershed. This dark gray, dense, clayey till is deeply leached and oxidized and is mantled by windblown silt (loess) in places. It has been assigned to the Pierce Formation.

A deep valley in the bedrock surface (Rich Valley) is filled with stream sediment and preserves a woody layer indicative of a cool climate. It has been interpreted as a prior course of a major river like the Mississippi and it trends southeast across the northeastern corner of the County. This valley is now buried by glacial sediment and is of unknown age.

The typical sequence of glacial units has been determined for the region and includes multiple advances of ice from the northeast carrying Superior provenance clasts and multiple advances from the north and northwest carrying Rainy, Winnipeg and Riding Mountain provenance clasts . However, not all units may be preserved in the subsurface. The sandier, northeast-sourced tills are more easily eroded. The stratigraphy at a given site should be determined locally because sediment layers can be discontinuous and their hydraulic properties vary.

Quaternary Aquifer Properties and Connections to Bedrock Aquifers

Where the water table aquifer is in the surficial sand and gravel layers, the saturated thickness is up to 50-feet thick near the mainstem of the river. These thicker parts of the saturated layer can yield over 100,000 gallons of water per minute to a well. These porous and permeable sand and gravel aquifers also support baseflow

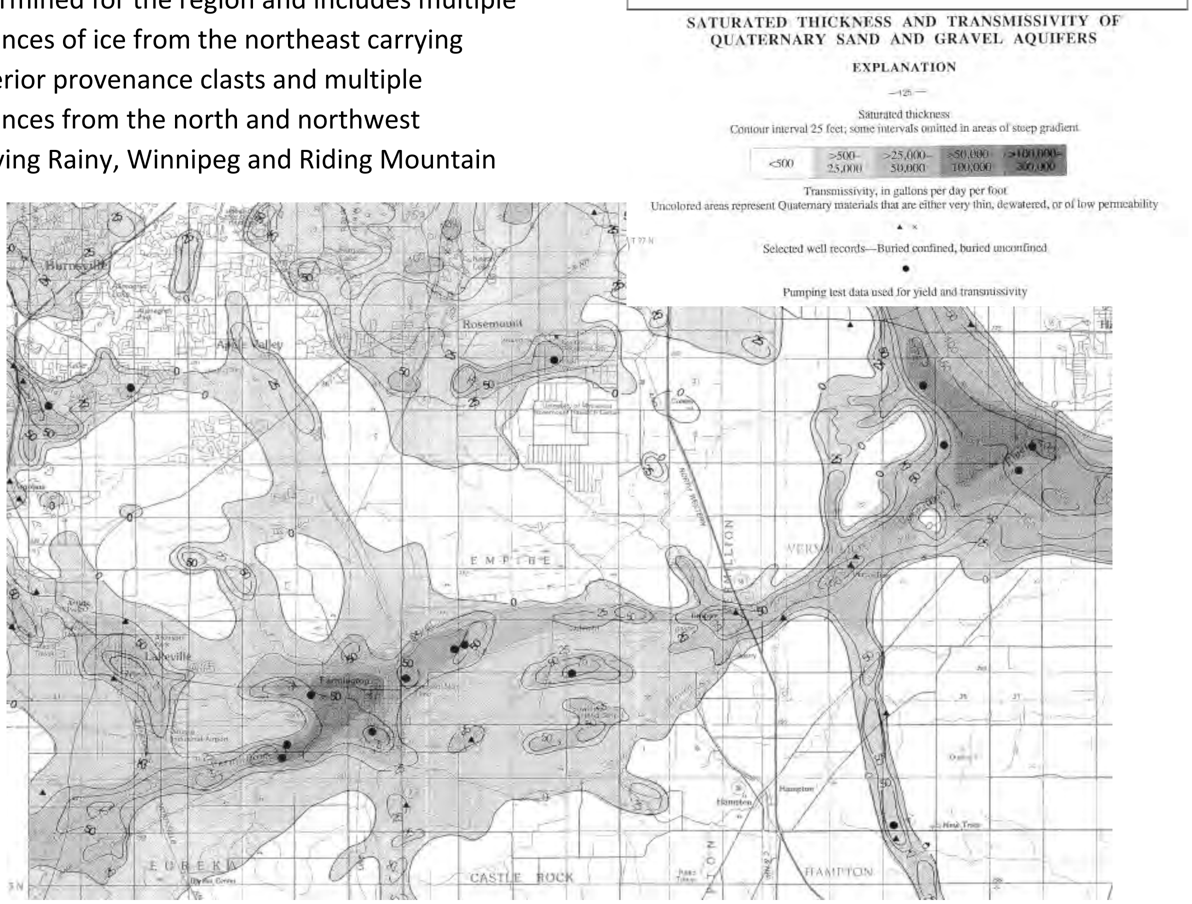


Figure 8. Thickness and transmissivity of the Quaternary sand and gravel layers in the Vermillion watershed.

to the stream and support the cold-water ecosystem. Flow in these Quaternary-age, sand-and-gravel, aquifers is subparallel to and towards the river. In places the Quaternary aquifer is in direct contact with the underlying Prairie du Chien-Jordan bedrock aquifer and where that occurs, the surficial layers recharge the bedrock (Balaban and Hobbs, 1990). This downward recharge is enhanced near the Empire Fault of the Mid-Continental Rift System just west of Hastings. A USGS study demonstrated a connection between the Vermillion River and the bedrock in a losing reach of the stream in the area of the fault (Almendinger and Mitton, 1995).

From mapping done for the original County Geologic Atlas there appears to be no direct connection through the Quaternary sand and gravel aquifer south of Rosemount in the area of UMore Park (Balaban and Hobbs, 1990). This interpretation was later verified by tests at the UMore property and is described below in the section on U More Park.

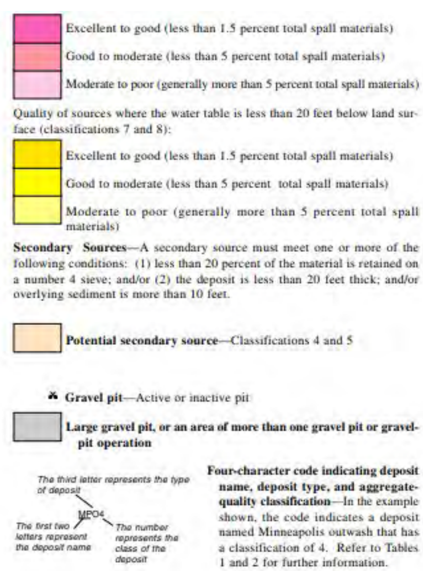
The Jordan aquifer is primary bedrock aquifer used in the watershed however, the shallow sand and gravel aquifer is the source for many private drinking water wells, especially within the buried bedrock valley area. Newer wells are being finished in the deep Franconia aquifer. Flow in the bedrock aquifers is perpendicular to the contours in the map below and generally to the northeast.

Aggregate Mining in the Watershed

Aggregate deposits in the 7-County metropolitan area have been classified by percentage of material retained on the number 4 sieve (4.76-millimeter spacing), sand and gravel thickness, thickness of overlying deposits, material above the water table, and confidence based on available information. Deposits were ranked and indicated as primary aggregate resources and potential secondary resources. Gravel pits existing at the time of mapping were also indicated (Meyer and Mossler, 1999).

Primary aggregate resources are higher quality, have a greater depth to water and are thicker (dark pinks). If the same gravel classifications exist in an area where the water table is high, dredging is a possible mining tool if allowed (dark yellow). The largest category mapped in the Vermillion watershed (peach) is generally less than 20' thick, has more sand, is buried, or has a high water table and therefore considered a secondary source.

The best source of consistent information on the history of aggregate mining are aggregate taxation records. However, relying on these assumes that mining is accurately reported. Aggregate taxation records for Dakota County from 1995 through 2015 show volume mined in each township or municipality. Of the 127 aggregate sites listed in the MnDOT's database



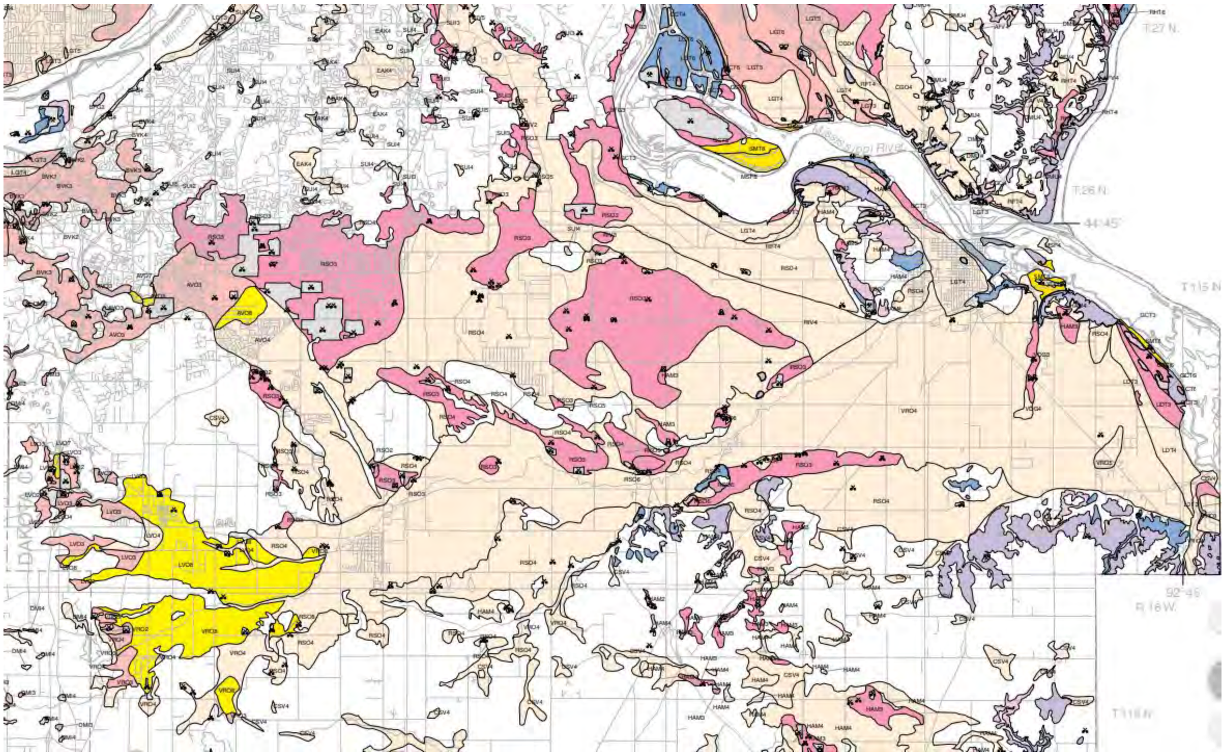


Figure 10. Classification of aggregate deposits by quality and other factors that determine ease of mining.

Table 2. Numerical Classification of Sand and Gravel Deposits

CLASSIFI-CATION NO.	PROPORTION OF MATERIAL RETAINED ON NO. 4 SIEVE[1]		THICKNESS OF SAND & GRAVEL DEPOSIT		THICKNESS OF OVERLYING SEDIMENTS	POSITION OF WATER TABLE	QUALITY OF SUBSURFACE DATA
1	More than 20%	***and***	More than 40 ft	***and***	10 ft or less	More than 20 ft below land surface	Good subsurface data: Deep Minn. Dept. of Transportation test borings or many detailed water-well records from several drillers
2	More than 20%	***and***	10–40 ft	***and***	10 ft or less	More than 20 ft below land surface	Good subsurface data
3	More than 20%	***and***	More than 20 ft	***and***	10 ft or less	More than 20 ft below land surface	Limited subsurface data: Few borings or water-well records. Soil maps and surficial geology suggest the presence of gravel deposits. Some good deposits probably available, but boundaries uncertain.
4	Less than 20%	***and/or***	Less than 20 ft	***and/or***	More than 10 ft	May be less than 20 feet below land surface	Limited subsurface data. Few or no soil-boring or water-well records, or well records are too generalized. Soil maps and surficial geology indicate possible sand and gravel deposits. Good deposits may be present in places, but in most cases this classification represents gravel-poor sand deposits or thick sand overlying gravel.
5	Less than 20%	***and/or***	Less than 10 ft	***and/or***	More than 10 ft	May be less than 20 feet below land surface	Good subsurface data
6	More than 20%	***and***	10–40 ft thick over dolostone	***and***	10 ft or less	More than 20 ft below land surface	Good to fair subsurface data. Presence of carbonate bedrock generally well established, but percentage of gravel in overlying sediments may vary, especially in the larger areas mapped.
7	More than 20%	***and***	More than 20 ft	***and***	10 ft or less	Less than 20 ft below land surface	Good subsurface data
8	More than 20%	***and***	More than 20 ft	***and***	10 ft or less	Less than 20 ft below land surface	Limited subsurface data. Few soil-boring or water-well records. Soil maps and surficial geology suggest gravel deposits. Good deposits probably available, but boundaries uncertain.

[1]The width of the pore space on a number 4 sieve is 4.76 millimeters.

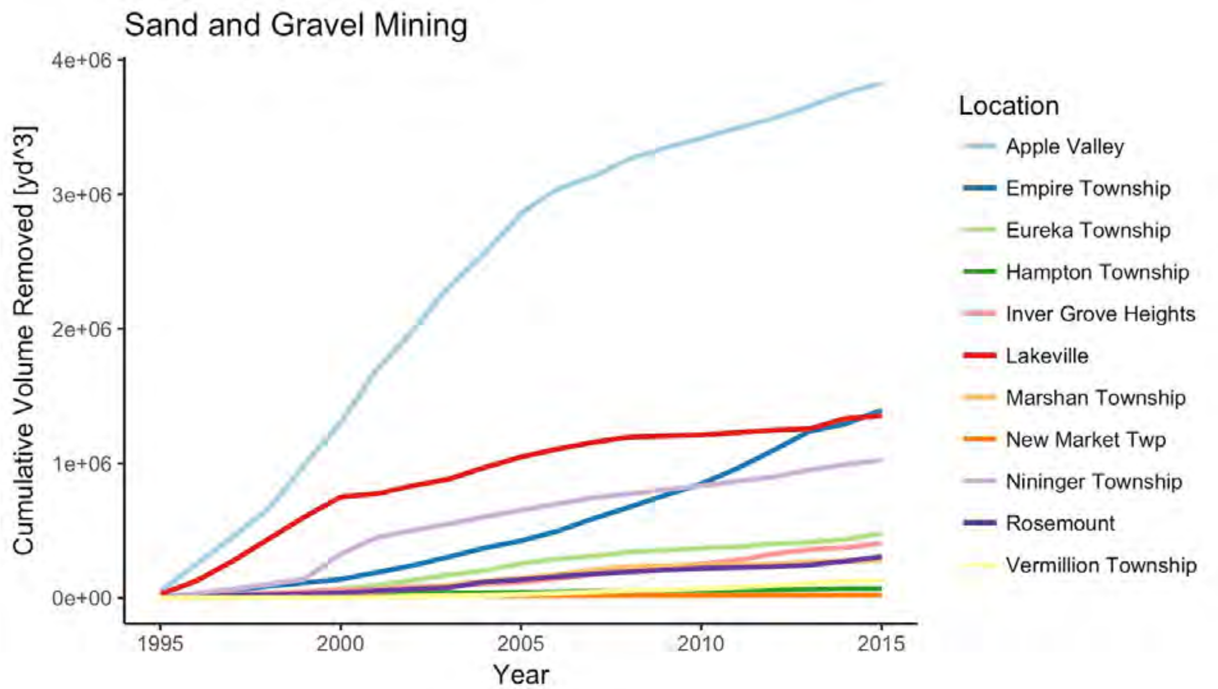


Figure 11. Area under the curve represents the volume of aggregate mined in Dakota and Scott counties based on volumes reported for taxation.

in Dakota County, 37 were active and submitted production records in 2015.

The area of land impacted and the effect on the water table depends on the thickness of gravel being mined. The reported volumes to the area disturbed as visible on airphotos and an average thickness calculated. Such a calculation would assume that the extent of the unit being mined lies within the property currently owned by the operator; it would average the thickness over that pit area; and there would be inherent assumptions regarding aggregate quality (percent gravel and sand). Aggregate deposits ranked as of high to very high quality aggregate will likely be completely exploited and the projected rate of extraction on the graph below could be used to roughly estimate the closure date of the pit. This was not done for this study.

The high quality deposit in the area of Apple Valley has yielded the most aggregate. Extraction in those pits is beginning to level off and the land is being reclaimed. The deposit in the Rosemount area and Empire Township referred to as UMore Park is beginning to be exploited and is of similar quality and area to the Apple Valley deposit. Similar or greater volumes of aggregate extraction are expected.

Map layers from Dakota County Government have fewer and smaller areas classified as having potential for mining than the MGS map. They exclude developed areas like those in Apple Valley and only show the highest category of primary deposits. A projection of total aggregate extraction on these mapped areas would represent the low end of the spectrum. The Minnesota DNR Land and Minerals Division, Aggregate Resource Mapping Program suggests that we are transitioning from a time of adequate aggregate availability to one of local scarcity. Pressure to find high quality aggregate resources near the metro in the future may lead to exploitation of secondary sources.

Existing Regulation of Mining

The Townships in southern Dakota County have zoning authority and have developed ordinances to address mining impacts through conditional-use permits. The level of control varies from township to township.

Eureka Township has the most developed ordinance with three levels of interim-use permit conditions for pits depending on the duration of mining, area impacted, and if mining is into the water table. The allowed depth of excavation is set by the Board. Dewatering is not allowed. Annual review is conducted and monitoring can be required.

Currently only one level-3 pit (mining into the water table) has been permitted and they have been required to install three monitoring wells, one up-gradient and two down-gradient, that are being measured quarterly for water level, temperature and water quality (see Ordinance 6, mining beginning on p. 203 http://eurekatownship-mn.us/ordinances/). The most recent annual report for this mine is included in the appendix.

Empire Township developed a mining ordinance when the UMore property was being discussed. Their ordinance does not distinguish permits based on the size or depth of mining. (http://www.township.empire.mn.us/vertical/sites/%7BC2524253-F75F-408D-8923-A2A3D0993A19%7D/uploads/%7BE823B79A-C247-4794-8326-FBC09A029F52%7D.PDF)

Other townships have mining districts but no specific standards other than those that minimize disruption to residents from nuisances such as dust and noise.

UMore Park Studies and Planned Mining

The high quality gravel deposits in Rosemount and Empire Township have been well studied through a series of voluntary and required documents that include a Draft Environmental Impact Study, Final Environmental Impact Study, Alternative Urban Areawide Review, Geological Assessment and Groundwater Assessment. These were necessary to plan for a 1,600-acre gravel mine in the northwest part of the park and then subsequent development of site into residential and commercial uses. The mining began in 2013 and is expected to last for up to 40 years (https://ci.rosemount.mn.us/DocumentCenter/View/845).

Figure 12. Exposure in Rosemount pit being mined by Dakota Aggregates on May 23, 2018.

Figure 13. Location of UMore Park

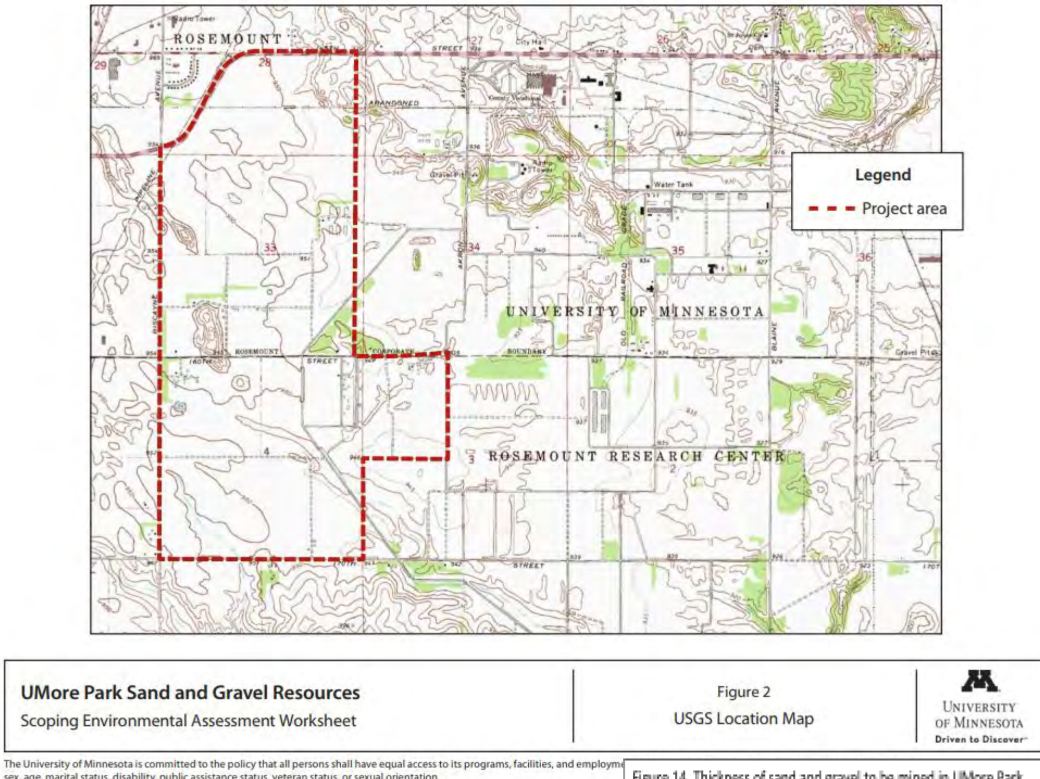
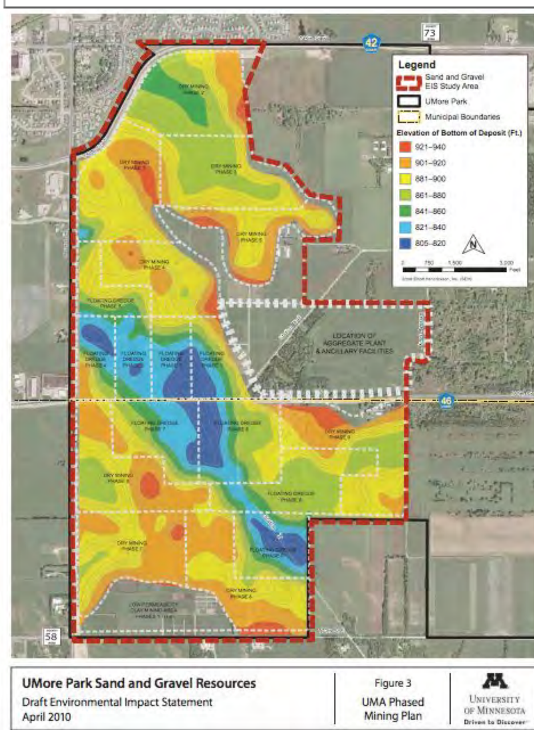


Figure 14. Thickness of sand and gravel to be mined in UMore Park.



Approximately 105 to 110 million tons (88-92 million cu yds) of sand and gravel will be extracted over the life of the mine. Annual rates will vary with demand; 250,000 tons (208,000 cu yds) in the first year and then between 700,000 to 3,000,000 tons per year after that (583,300 - 2,500,000 cu yds). Mining is expected to be 80 feet below the water table, which is estimated to be at approximately at a depth of 6' over the area of the park. http://www.umorepark.umn.edu/prod/groups/ssrd/@pub/@ssrd/@umorepark/documents/content/ssrd_content_214661.pdf

The Geologic Assessment, Groundwater Assessment Report (Barr, 2009a4) and Alternative Urban Areawide Review (AUAR) describe the site geology, groundwater flow, recharge rates, temperature and quality that were verified with site specific data.

Glacial stream sediment of the Cromwell Formation is at the surface and ranges in thickness from 15 to 160 feet. The surface sediment was discharged from an ice margin north of the site. It was initially a high-energy environment and erosion of underlying deposits likely occurred as the coarse material was deposited. As energy waned the average grain size decreased. The deposit is predominantly fine to coarse-grained quartz sand with gravel amounts ranging from less than 5% to approximately 30%. Gravel-rich lenses (> 50% gravel) occur in thicknesses of up to five feet as do lenses of finer-grained sediment, most commonly silty sand, and range from one to twenty feet thick (ProSource, 2008).

The Superior lobe covered the site during the slightly earlier Emerald Phase and deposited a layer underlies the stream sediment. Iron-stained sand and gravel at depth were interpreted as part of the Emerald Phase or from an earlier glaciation (ProSource, 2008).

An older, pre-last glacial period (probably Pierce Formation) diamicton layer has been identified in the subsurface (ProSource, 2008). This gray to dark gray, massive, overconsolidated diamicton has a texture of 60% fines (clay and silt) and 40% sand and gravel and porosity of 20%. It is up to 100 feet thick and is laterally continuous over distances from one half to two miles. It has few sand seams but in places has layers of poorly graded sand up to 8' thick.

These glacial deposits overlie an erosional bedrock surface with knobs of the St. Peter Sandstone that are generally deeply buried but are within 25 ft of the surface in the southern part of the park. The St. Peter Sandstone is a white to pale yellow, poorly cemented, fine grained sandstone with some highly cemented layers. Where overlain by sand and gravel there is good hydraulic communication.

The underlying Prairie Du Chien Group is a light gray dolomitic limestone that is laterally continuous and hydraulically separates the glacial sand from the underlying Jordan Formation. In some places it is weathered to a reddish brown. The Prairie du Chien and Jordan formations are used for crop irrigation and municipal water supply in the area. Deeper Paleozoic units are present and fairly continuous in the subsurface. These general relationships are schematically represented for the purposes of the groundwater model).

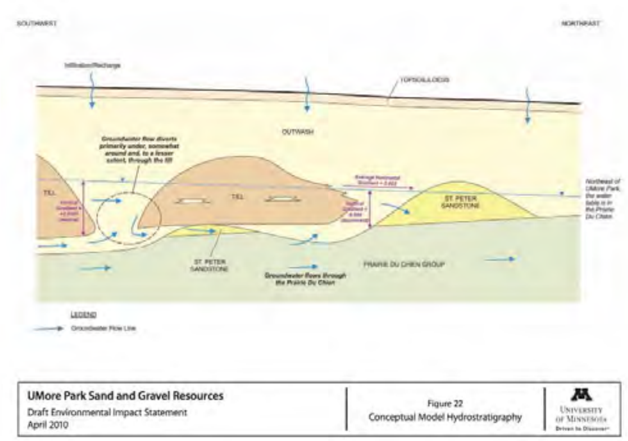


Figure 15. Schematic cross section of geology of UMore Park used to develop groundwater flow model.

Some surface water currently drains to the southeast toward the Vermillion river tributaries but most drains northeast to the Mississippi River. Where there is sand and gravel at the surface, most water infiltrates however, some water is said to be perched or slow to infiltrate, most likely where till or thick wind-blown sediment is at the surface. Infiltration is enhanced in deep depressions on the site(Bay West, 2008).

The water table is within Quaternary sediments across most of UMore Park except along the southern boundary where St. Peter sandstone is near the surface. Groundwater generally flows to the northeast, discharging to the Mississippi River. A groundwater divide lies to the south of UMore Park along a high in the buried bedrock surface (URS, 2005) and prevents groundwater from discharging to the Vermillion River directly.

Mining operations will lower and reshape the landscape. Progressive reclamation will ultimately result in an undulating pit floor with slopes of three-to-one or flatter. This reshaping will change the potentiometric surface that drives surface water and groundwater flow. The creation of a deep mine-pit lake that is in direct connection with the water table aquifer will also affect the potentiometric surface by flattening it over the lake area and will impact on groundwater flow direction by opening up a window into bedrock aquifers. This will also affect flow rate and temperature of water moving into deeper bedrock aquifers.

A three-dimensional (MODFLOW) metro-area-wide model of groundwater flow (Metro Model 2; Metropolitan Council, 2008) was modified by Barr Engineering to predict groundwater conditions in the park (Barr, 2009, Fig. 23, draft EIS). Site-specific details were used including the results from 18 soil borings; subsurface geologic core samples; installation and development of 13 monitoring wells; 1 pumping test well; groundwater elevation data; field and laboratory scale hydraulic conductivity data; and baseline groundwater quality data. The model was used to simulate pre- and post-mining scenarios. A range of hydraulic conductivities were measured or calculated that varied in a somewhat predictable way as the scale of the test varied. The pumping test results of 290 ft/d were used with an effective porosity of 0.25 for the glacial stream sediment, and a horizontal gradient of 0.003, the average linear velocity of the groundwater in the glacial stream sediment is on the order of 3.5 ft/day (Barr, 2009b).

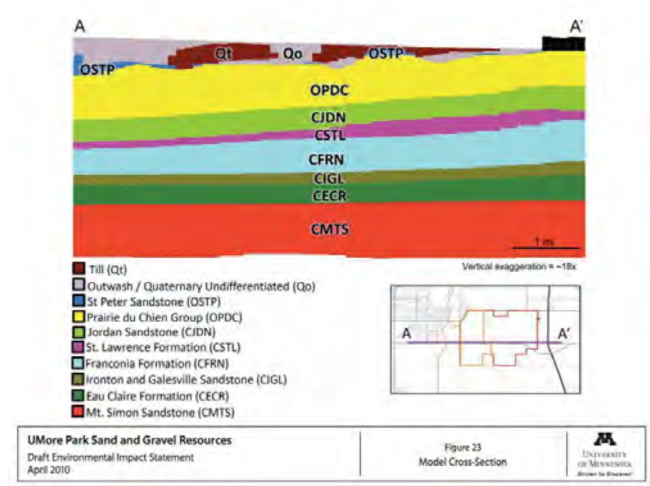


Figure 16. Geologic layers that were used in groundwater flow model.

Currently, 43% (542 acres) of the park's surface drains toward the Vermillion River. There is a slight downward vertical gradient with recharge entering the underlying Jordan aquifer. After mining, only 53 acres will drain to the Vermillion; the remaining 751 acres will drain to a mine-pit lake and that water will either infiltrate into the bedrock or evaporate.

Most of the groundwater flows to the northeast toward the Mississippi River. Mining is not

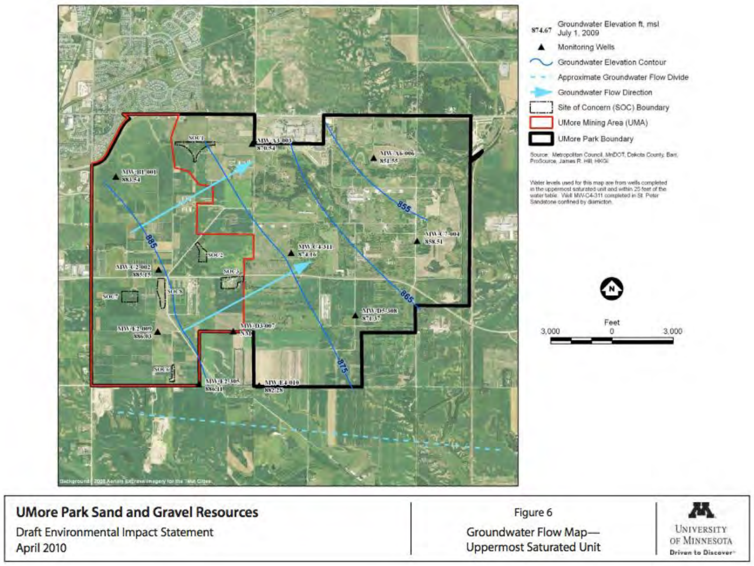


Figure 17. Modeled groundwater flow.

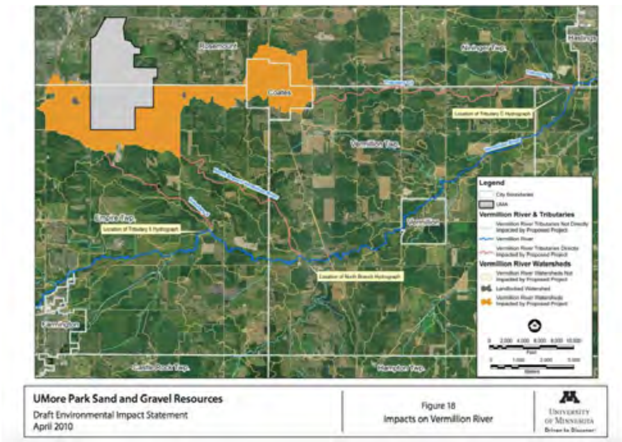
expected to impact the groundwater flow direction.

A Soil-Water Balance model used with the flow model and the mine-pit lake to simulate the difference in recharge. Average yearly precipitation was assumed to be 32.6 inches, runoff calculated at 11.2 inches per year, and annual evaporation was estimated at 27.4 inches. Results show that the projected decline in groundwater level (up to 15 feet) due to the future water consumption will be offset by the pit lake recharge to groundwater. It appears that the proposed mining operation will have no significant impact on groundwater flow direction or heads and groundwater flow will still be primarily towards the Mississippi River.

Under current conditions stormwater is conveyed to the Mississippi or Vermillion rivers with no treatment. Mining will not substantially alter the quantity of stormwater and development of the site may improve the quality because the untreated agricultural runoff will be replaced with regulated residential runoff. However, the increased use of winter chloride and potential increase in water temperature was not addressed. Land-use changes from agricultural to low-density residential land use did not significantly change the recharge according to the soil water balance model.

The demand for residential water is estimated to increase from 910 million gallons in 2008 to 3.49 billion gallons in 2050 (Ross, 2009). The additional demand from UMore development was not included in the Metropolitan Council regional projections because of uncertainties. If all future wells on UMore are open to the Jordan Sandstone, modeling results show a drawdown of up to 15 feet in water levels in the Jordan, Prairie du Chien, and Quaternary (glacial outwash) aquifers by 2050 in the area of UMore. Increased municipal demand was simulated to model the effect of the mine-pit lake on groundwater recharge.

Flow paths were simulated with and without the lake. The presence of the mine-pit lake slightly offsets the projected drawdown by increasing recharge to the bedrock aquifer (Barr Engineering, 2009).



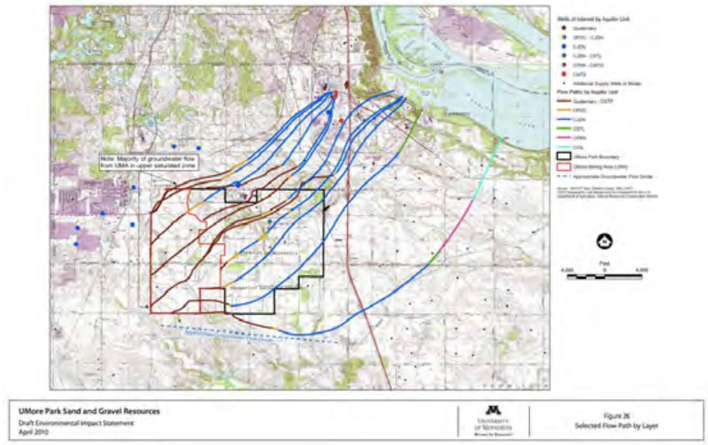


Figure 18. Surface and groundwater features of interest for impact to Vermillion River.	Figure 19. Modeled flow path of groundwater leaving UMore site.

The overall the conclusions of these detailed studies are that mining is unlikely to directly impact the Vermillion River. The detailed observations and modeling results reduce concern over the impact of mining from this location on the Vermillion River. However, it may still be useful to model the impact of the development of a mine pit lake at this location where data are dense, in order to estimate the travel time and distance from the mine that impact is observed. ***The results could be used to develop setbacks for other pits closer to the Vermillion River.*** Two active gravel mining operations within Empire Township are located south of the study AUAR study area and there are many other small pits near the Vermillion headwaters area and along the trend of the river that may have a greater hydraulic impact on the river. This will be further addressed in the recommendations section.

Summary of scholarly articles that apply to this situation

1. An early effort to predict the effects of mining on groundwater was undertaken by DNR geologists (Green, et al., 2005). It focused on rock quarries but included 3 aggregate mines, 2 of which are neighboring pits in Olmsted County. Although the thermal impacts to the Zumbro River were a concern, data were not sufficient to document impacts to surface-water streams from these pits. Groundwater temperature changes were inconsistent and monitoring was to have continued but an extensive study was not planned.

2. More sophisticated studies that measured and modeled thermal impact have been conducted in Canada and appear to be derived from PhD work of Jeffrey Markel (2011). His dissertation includes a detailed description of the numerical modeling and is the work upon which earlier, co-authored papers are based. Markel and Schincariol (2007) investigate the thermal impacts of a below-water-table aggregate pit on a cool-water stream with Brook trout and macroinvertebrates. They monitored temperatures over ten years and

had two, approximately 2-year-long, intense monitoring periods within that decade.

Normally, two distinct thermal pulses moved through the aquifer, one with the summer and one with the winter season. The surface temperature moves through the aquifer in summer and fall and a winter cooling reaches its peak in April when the latent heat of snow and frost melt, which removes heat from the aquifer, and the infiltration of cold meltwater impact the aquifer. A thermal plume migration related to mining is superimposed on the seasonal signal. It lags the groundwater velocity because of aquifer sediment heat capacity and thermal conductivity. ***The mining signal persists for 11 months and in that time, migrates 250m down gradient. This is a migration rates of 1.2 m/d. This is dependent on the hydraulic conductivity and thermal properties of the aquifer. In this instance, the water velocity was 2.8 m/d on average.***

To really understand and model the impact of a thermal plume on the ecosystem it is critical to understand the magnitude and timing of the temperature changes. ***In this case, a separation distance of greater than 250 m from the mine to the stream would be sufficient to mitigate significant thermal impacts.*** Those migration rates would have to be determined for the gravel pits of interest in the Vermillion watershed in order to apply these results.

3. The 2006 paper (Markle, et al., 2006) focuses on the thermal properties of the solid materials of the aquifer, the volumetric water content of the aquifer using ground-penetrating radar, modeling the thermal conductivity of the saturated medium, and numerically simulating the thermal conductivity with a finite element method. This approach may be of use to model thermal plume transport in the Vermillion aquifers. Eureka Township has the only temperature monitoring that I am aware of associated with annual reports for the level 3 Extraction Permit granted to Kelly Brosseth in the headwaters areas of the Vermillion.

4. Other Canadian researchers take a different approach to study the impact of gravel extraction on groundwater; they use stable isotopes of hydrogen and oxygen to interpret how quickly meteoric water infiltrates the ground (Smerdon et al., 2012). Those data can inform a groundwater flow model (MODFLOW) that can be used to quantify the effects of the land-use changes on the water budget. In this study, forest clearing and the excavation of an esker created a lake in an outwash plain and increased the recharge rate to the aquifer. This was documented in the isotopic shift to more meteoric water found in the aquifer. An increase in the cycling of shallow groundwater was modeled. Effects like those observed in this study will vary with the water table gradient and hydraulic conductivity of the sediment. Part of the isotopic fractionation observed in this study was due to the loss of forest evapotranspiration.

Freshwater Recommendations

Although an aggregate mine permitting process can require an EAW or EIS to examine the unique elements in landscape being impacted, there is currently not a process in place that takes a cumulative view of mining impacts on an aquifer. The Alternative Urban Areawide Review (AUAR) that was employed for UMore could be employed to address cumulative impacts.

The MPCA has authority over the quality of surface water discharge from mines but does not address quantity or where the water goes, as long as it meets standards. Coordination between the MPCA and DNR EcoWaters could be encouraged to address drawdown of the water table aquifer and require that cold, clean groundwater be discharged to the stream or infiltrated an area where it can recharge the stream.

The approach that the 2013 Minnesota Legislature took with silica sand mining may also be of interest. After a long period of study by the DNR and EQB, a draft rule prohibits the excavation or mining of silica sand in southeastern Minnesota within one mile of any designated trout stream and gives the DNR permitting authority.

Whether any of these approaches could be justified to limit aggregate extraction depends on what the cumulative impact of mining is forecast to be on the river. The impact of UMore on the Vermillion is not substantial. However, no other mine operation is this well studied. Mines closer to the river with greater hydraulic connection are likely to have greater impact.

We suggest that the datasets and models created for UMore be used in a way similar to the cited Canadian studies to test model thermal plume migration and thereby develop an understanding of the sensitivity of Quaternary aquifer where it recharges the Vermillion River. A range of scenarios based on measured properties could be used to estimate thermal plume migration rates in the Quaternary sand and gravel aquifers and determine if current mine setbacks from water bodies are adequate to dissipate heat before it reaches the stream. The impact of a shallow lake contained entirely within the Quaternary aquifer with primarily lateral flow to the river will likely have the most impact. Alternatively, the VRWJPB could adopt a 250m setback based on the modeling done in the Canadian study, however, this is based on their flow rates and gravel properties.

Bibliography

Balaban, N.H.; Hobbs, H.C.. (1990). C-06 Geologic atlas of Dakota County, Minnesota. Minnesota Geological Survey.Retrieved from the University of Minnesota Digital Conservancy, http://hdl.handle.net/11299/58494.

Barr Engineering. 2009. Impacts to Groundwater Supply from Development of the Detailed Area Plan Study Area, Scott County, Minnesota. Prepared for Scott County, Minnesota. February, 2009.

Green, J.A., J.A. Pavlish, R.G. Merritt, and J.L. Leete 2005. Hydraulic Impacts of Quarries and Gravel Pits. Report prepared by the Minnesota Department of Natural Resources, Division of Waters for the Legislative Commission on Minnesota Resources funded by the Minnesota Environment and Natural Resources Trust Fund, 139 pp.

Johnson, M.D., R.S. Adams, A.S. Gowan, K.L. Harris, H.C. Hobbs, C.E. Jennings, A.R. Knaeble, B.A. Lusardi and G.N. Meyer, 2016. Quaternary Lithostratigraphic Units of Minnesota. Minnesota Geological Survey Report of Investigations 68, ISSN 0076-9177.

Markle, Jeffrey M., 2011. Thermal Plume Transport From Sand and Gravel Pits Potential Thermal Impacts on Cool-Water Streams). Electronic Thesis and Dissertation Repository. 360. http://ir.lib.uwo.ca/etd/360

Markle, J.M., and R.A. Schincariol, 2007. Thermal plume transport from sand and gravel pits—Potential thermal impacts on cool water streams. Journal of Hydrology 338, 174-195, doi: 10.1016/j.hydrol.2007.02.031

Markle, J.M., R.A. Schincariol, J.H. Sass, and J.W. Molson, 2006. Characterizing the Two-Dimensional Thermal Conductivity Distribution in a Sand and Gravel Aquifer. Soil Science Society of America Journal 70, 4, 1281-1294. doi:10.21.36/sssaj2005.0293

Smerdon, B.D., C.A. Mendoza and K.J. Devito, 2012. The impact of gravel extraction on groundwater dependent wetlands and lakes in the Boreal Plains, Canada. Environmental Earth Sciences 67, 1249-1259. doi: 10.1007/s12665-012-1568-4

Meyer, G.N.; Mossler, J.H.. (1999). M-102 Primary sources of construction aggregate in the Twin Cities seven-county Metropolitan Area, Minnesota. Minnesota Geological Survey. Retrieved from the University of Minnesota Digital Conservancy, http://hdl.handle.net/11299/57004.

ProSource 2008. Geological Assessment UMore Park Rosemount and Empire Township, Minnesota; Prepared for University of Minnesota, ProSource Technologies, Inc, in association with J.D. Lehr, PA. June 3, 2008.