Groundwater Assessment Work Plan
Resource Document for Environmental Impact Statement

UMore Mining Area
Dakota County, Minnesota

Prepared for
University of Minnesota

November 11, 2008

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List of Acronyms

AOC	Area of Concern
bgs	Below ground surface
EAW	Environmental Assessment Worksheet
EIS	Environmental Impact Statement
FSI	Focused Site Investigation
GOW	Gopher Ordinance Works
MPCA	Minnesota Pollution Control Agency
msl	Mean sea level
TMR	Telescopic Mesh Refinement
UMA	UMore Mining Area
UMore Park	University of Minnesota Outreach, Research and Experimentation Park
USACE	U.S. Army Corps of Engineers

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Executive Summary

The University of Minnesota (University) is proposing to open new aggregate mines and ancillary operations at the University of Minnesota Outreach, Research, and Experimentation (UMore) Park property located in the City of Rosemount and Empire Township, Minnesota. The mining will occur within a portion of UMore Park as shown in Figure 1. The mining area, hereafter referred to as the "UMore Mining Area" or UMA, encompasses approximately 1,765 acres of the western one-third of UMore Park (Figure 2). Mining operations and practices are intended to be similar to practices at existing aggregate mines adjacent to and near the UMA.

The University is preparing an Environmental Impact Statement that will address potential environmental impacts that may result from mining and ancillary operations. In order to assess potential impacts to groundwater, basic information on the geology and groundwater flow system is needed. The goal of this Groundwater Assessment (Assessment) is to collect these data and compile a groundwater flow model that will serve as a tool to aid in evaluating potential mining effects on the groundwater flow system.

Currently available information (including regional groundwater flow models) suggest that the direction of groundwater flow under the UMA is largely northeast toward the Mississippi River. Based on the coarse nature of the gravel deposits that exist under the UMA (ProSource 2008), the aquifer is likely a highly productive groundwater resource. However, there is currently no site-wide monitoring well network that can provide a thorough assessment of current conditions. Also, there is insufficient geologic detail incorporated into the existing regional flow models at the scale of the site to allow prediction of future stressors (e.g., pumping wash water for mine operations). Therefore, more data are needed to more accurately simulate the pre- and post-mining conditions under the vicinity of the UMA and the entire UMore Park area.

This work plan summarizes the current understanding of geologic and hydrogeologic conditions into a preliminary conceptual model and proposes a field data collection program intended to address the gaps in the conceptual model. The data collection tasks will include:

- Installation of 5 pilot borings to assess geologic conditions and guide final selection of well locations.

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- Construction of 16 monitoring wells including three nested locations that will include pumping wells for aquifer testing.

- Collection of baseline monitoring data including water level, temperature, and several general chemistry parameters from within the UMA.

Because the aquifers potentially affected by mining extend well beyond the UMA boundaries, the scope of this Assessment necessarily includes collection of data from wells outside of the UMA, including portions of UMore Park and the surrounding area.

The data collected will be used to construct a more detailed groundwater flow model that will be calibrated to the scale of the UMA and vicinity. This model will then serve as a tool to test various hypotheses regarding potential impacts from the mining and reclamation plan on surrounding groundwater and surface water resources, and to develop mitigation where appropriate. For example, the model may be used to evaluate changes in groundwater flow patterns and temperature within the aquifer as a result of the mining.

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1.0 Introduction

This document presents the Groundwater Assessment (Assessment) Work Plan (Plan) for the Environmental Impact Statement (EIS) being prepared by the University of Minnesota (University) for the proposed mining area at the University of Minnesota Outreach, Research and Experiment Park (UMore Park) Property (Figure 1). The UMore Mining Area (UMA) includes approximately the western one-third of the UMore Park Property, as shown on Figure 2. The UMA is that portion of the UMore Park Property that is proposed for development of gravel mining and ancillary activities, and will be the subject of the EIS.

This Plan has been prepared as a resource document to support the EIS scoping process and will be included in the Scoping Environmental Assessment Worksheet (EAW). The EIS is intended to address the potential for significant environmental impacts and identify mitigative measures resulting from the proposed mining activities.

In the context of mining, groundwater is both part of the mined media, and an important tool for washing and separating the aggregate product. Changes to groundwater that occur within the mine footprint can also move with groundwater and be conveyed to other areas. For this reason, understanding of the groundwater flow system is integral to evaluating and resolving potential effects of mining on groundwater. Even though all of the questions that might be raised regarding gravel mining impacts on groundwater cannot be anticipated at this time, it is clear that a robust groundwater flow and transport model will be a valuable tool in assessing potential alternatives and mitigative measures within the mined area.

This Plan describes the data collection activities that are needed to characterize the groundwater flow system the UMA and develop a groundwater flow model that could be used to evaluate alternatives and/or potential mitigation measures. However, because the underlying hydrogeologic elements of the flow system depend on aquifer characteristics that can vary over thousands of acres, this Assessment includes collection of groundwater data from beyond the boundaries of the UMA and UMore Park.

1.1 Purpose

The purposes of the Groundwater Assessment Work Plan are to:

- Characterize the existing geologic and hydrogeologic data within the vicinity of the UMA.

- Develop a conceptual hydrogeologic model based on current subsurface information.
- Identify the general objectives and data needs of the groundwater flow model needed for the EIS.
- Identify data gaps to be addressed during the Assessment and/or during other concurrent subsurface investigation activities being performed to assess the UMA.
- Describe the methods and means by which the data will be collected.
- Provide a description of the groundwater flow model to be used in simulating pre- and post-mining aquifer conditions, predict potential impacts, and assess mitigative measures.

1.2 Scope of Groundwater Assessment

The following scope of work will be performed during the Assessment:

- Install approximately 16 borings, including 13 monitoring wells and three pumping test wells, in accordance with Minnesota Department of Health and Dakota County ordinances.
- Log and classify soils in the field based on soil samples collected from the borings.
- Develop, survey, and document well construction data at each well location.
- Conduct aquifer tests on each of the three pumping wells.
- Collect baseline groundwater quality samples and field parameters from monitoring wells within the UMA.
- Modify, refine and calibrate the existing regional groundwater flow model to allow predictions at the scale of the UMA. The groundwater flow model will be used to simulate future water levels and thermal transport in and around the mined areas at full mining development.
- Prepare a summary report on the Assessment findings for incorporation into the EIS.

1.3 Concurrent Investigations

This Assessment is intended to characterize overall groundwater flow conditions. It is not intended to investigate any specific current or former areas of suspected environmental impacts. Several additional investigations are being conducted concurrently by the University and others to address potential environmental impacts and other issues.

These investigations include a Phase II Investigation of potential past within the UMA. The Phase II Investigation is focused on addressing these areas prior to mining or within the context of mining activities. The work will be performed in cooperation with the Minnesota Pollution Control Agency (MPCA) and in accordance with applicable rules and guidance. Other studies being conducted by the University include investigation of natural and cultural resources within the UMA pursuant to the EIS.

The U.S. Army Corps of Engineers (USACE) is conducting an investigation of environmental impacts associated with the former Gopher Ordnance Works (GOW) located primarily in the eastern portions of the UMore Park property. Although some GOW-related activities occurred within the UMA, it is assumed that the USACE will remain the primary party engaged in the investigation and remediation of GOW-related areas located within and outside the UMA.

1.4 Preliminary Discussion of Scope and Potential Impacts from Mining

For the purpose of this Assessment, it is assumed that the mining project will generally consist of the following elements at full development:

- Removal of topsoil and sand-and-gravel deposits to an average approximate depth of up to about 75 feet (typical) below the current ground surface elevation in the gray shaded areas shown on Figure 3;
- Dragline excavation of sand and gravel to average approximate depth of up to 150 feet below the ground surface within portions of the yellow-shaded areas depicted on Figure 3. Excavation depth would be about 10 to 70 feet below the water table in these areas depending on bedrock elevation;
- Installation and periodic operation of a single 500 gallon per minute (gpm) well that would be screened within the glacial outwash aquifer for use in gravel washing operations;
- Following mining, the UMA will be reclaimed with native soil and topsoil; the mine pits excavated below the water table will remain as manmade lakes.

1.4.1 Potential Impacts

It is anticipated that the potential impacts that will be assessed by the groundwater flow model will include:

- Potential changes in groundwater levels and flow directions that may affect surrounding wells, streams, and wetlands (if present);
- Potential changes in groundwater temperature reaching surrounding wells, streams and wetlands (if present).
- Other impacts that may be defined in the Scoping Decision Document for the EIS.

Although the model may or may not show a potential impact to one or more resources, the evaluation of the actual nature of these potential impacts on the resource is beyond the scope of this Assessment. Such an evaluation, if necessary, will be provided as part of the scope of the EIS.

1.5 Plan Organization

The remainder of this Plan consists of the following sections:

- Section 2 summarizes the available background information and includes a conceptual model that describes the current understanding of groundwater flow in the area. It also describes the data gaps that need to be addressed so that a project- and scale-appropriate groundwater flow model can be developed.
- Section 3 provides a description of the specific tasks that will be performed to collect the data needed to address the data gaps and to provide additional calibration targets for the groundwater flow model.
- Section 4 provides a description of the groundwater flow model development and the approach that will be used to simulate groundwater flow and thermal transport in the aquifer.
- Section 5 provides a summary of the Plan and a schedule for completion.

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2.0 Background Information

2.1 Previous Investigations and Data Sources

Numerous investigations have been conducted to evaluate environmental conditions at UMore Park, including the UMA. These investigations have primarily focused on assessing the magnitude of environmental impacts from the former Gopher Ordnance Works (GOW) and Post-GOW operations on near-surface soils and groundwater. The investigations that included an evaluation of groundwater conditions and other significant groundwater data sources are discussed below.

2.1.1 Draft – Final Focused Site Inspection Report (Bay West, 2008)

The Focused Site Inspection (FSI) effort included sampling groundwater at a number of GOW Areas of Concern (AOCs) with direct-push boreholes. Groundwater-level data were collected and water-quality samples were submitted for laboratory analysis of AOC-specific contaminants of concern.

Although a groundwater flow (i.e., piezometric contour) map was not produced as part of the FSI effort, the measurements of the depth to groundwater allow for an approximation of water table elevations in the vicinity of the AOCs. The estimated water table elevations from the FSI report are tabulated and selected water table elevations are shown on an UMore Park site map in Appendix A.

Estimated groundwater elevations vary from 904 feet above mean sea level (msl) at AOC#5 (located on the east side of the UMA) to less than 860 feet msl at AOC #7 (located on the eastern side of UMore Park). The difference in groundwater elevations between the observations provided in the FSI suggests groundwater is flowing from southwest to northeast. However, based on slow well recovery and the presence of a four foot thick clay layer observed over the screened interval, Bay West interpreted the groundwater encountered at AOC#5 to be perched above the required water table.

2.1.2 Geological Assessment (ProSource, 2008)

The Geological Assessment entailed a phased drilling program that identified the vertical and horizontal extent of economic aggregate resources at UMore Park. Over 650 borings were advanced to depths of at least 25 feet. A subset of these borings was advanced below the water table and to bedrock. In general, the objective of the study was an economic characterization of the aggregate deposits. The study was not intended to collect environmental data, provide detailed information on the glacial stratigraphy, or describe aquifer properties that are the focus of this Plan.

The field methods were designed to collect soil samples that were representative of 10- to 20-foot long subsurface intervals from each borehole. The data collected from each borehole included borehole location, ground surface elevation, lithologic classification, deposit thicknesses, estimated depth to water, grain size distribution, and a geologic interpretation. These data were entered into a database for future use. The lithologic classifications from the geologic assessment were used to develop cross sections discussed in Section 2.3 of this Plan.

A table summarizing soil boring locations, ground surface elevations, borehole depths, and estimated (non-equilibrium) water table elevations from boreholes is included in Appendix B. The complete report is available at: http://www.umorepark.umn.edu/Gravel_Resources_and_Assessment.

As shown in Appendix B, the estimated water table elevations generally range from greater than 900 feet msl in the southwest corner of UMore Park to less than 850 feet msl at the eastern UMore Park boundary and generally indicate flow toward the northeast

2.1.3 Regional Groundwater and the Metropolitan Council's "Metro Model"

The groundwater flow modeling efforts conducted under this Assessment will be based on the existing regional calibrated groundwater flow model known as the Metro Model. Use of this model will reduce the amount of effort required to characterize the general groundwater conditions in the area around the UMA. Details of the Metro Model are provided at: http://www.metrocouncil.org/environment/WaterSupply/metrogroundwatermodel.htm.

A summary of the model and its general limitations are described below.

General Description of Groundwater Flow Models

Groundwater models are tools that can help improve our understanding of aquifer behavior. A numerical groundwater flow model is the mathematical representation of groundwater flow in aquifers and aquitards using a computer to speed calculations and allow easier visualization of the results. Using specially developed software codes, the computer simulates the behavior of aquifers over time and space by applying the basic laws of physics governing groundwater flow and the physical properties of the aquifer, recharge, pumping, interaction with rivers, or other phenomenon. Regional groundwater flow models incorporate the overall flow field and describe the basic directions of groundwater flow and interaction of groundwater with major discharge areas such as the Mississippi and Vermillion Rivers.

The Metro Groundwater Model

The Metropolitan Council's new "Metro Model," is a finite-difference, three-dimensional groundwater model of major aquifers and aquitards in the Seven County Metropolitan Area that was developed in MODFLOW (Harbaugh and McDonald, 1996) computer code. The model was constructed and calibrated by Barr Engineering Company for the Metropolitan Council as part of a regional water supply planning effort by the Metropolitan Council for the greater Twin Cities metropolitan area. Model layer input is included in Appendix C. The modeling data and files are publicly available and build upon previous regional modeling efforts, including updated calibration and incorporation of new databases and resources. This model provides a starting point for modeling of the UMA, particularly in terms of characterizing bedrock flow conditions. Current model output for the UMA and the surrounding area is shown on Figure 3 and indicates that flow is to the northeast toward the Mississippi River.

Model Interpretation and Limitations

Because the model is calibrated to field data from pumping tests conducted in bedrock wells in Rosemount and other water supply wells in the vicinity, it is likely that the regional model includes sufficient detail on the bedrock flow system. This assumption is supported by the tendency of bedrock units to have laterally consistent geometry and aquifer properties.

However, there is likely to be significantly less lateral continuity with respect to geometry and aquifer properties within the glacial deposits that comprise the uppermost portions of the saturated aquifer, represented in the model by layers 1 and 2 (Appendix C). For example, Figure 4 shows that modeled hydrology (water levels) indicate groundwater flow is toward the Mississippi River located northeast of the UMA. Generally, the model elevations appear to provide a relatively close match to actual heads for several bedrock wells in the area as indicated by the head residual values shown on Figure 4. It should be noted that the residuals vary from +/- 1 to 2 meters in the upgradient (southwest) side of the model to +/- over 7 meters in the north and west side of the UMore Park portion of the model.

The larger deviation in modeled versus observed heads in the northern portion of the UMore Park suggests that t details near the center of the model are missing; thus resulting in increased error within the modeled head values. The model currently includes only limited information from the upper portion of the saturated zone. Therefore, the modeled head error may be related, in part, to site-specific geologic conditions that are not represented within the model domain. Additional discretization of hydraulic properties may be needed within the uppermost model layers. Additional layers may also need to be added, based on actual site geology if laterally continuous units are encountered in the glacial deposits.

A major limitation of the current regional model is that the resolution is limited by the current grid size of 500 x 500 meters. This grid size does not include much specific information about the UMA and vicinity. To overcome this limitation and add detail to the shape and properties of the existing aquifer and the configuration of the mining lakes, the model grid will need to be refined. Additional detail on cell refinement and modeling approach is included in Section 4.

2.1.4 Empire Township Sand and Gravel Mining and Accessory Uses Area

The Empire Township Sand and Gravel Mining and Accessory Uses Area (Empire Mining Area), located southwest of the UMA (Appendix D, Exhibit 1B), has been permitted for aggregate mining operations by a consortium of mine operators and landowners. The mine permitting process included the preparation of a Scoping EAW (Bolton & Menk, Inc., 2003) and an EIS (Bolton & Menk, Inc., 2005). To satisfy ensuing permitting requirements, a Groundwater Impact Study (GI Study) was developed to provide analysis of reasonable worst-case groundwater impacts in the Empire Mining Area and to identify options to remedy those impacts (URS, 2005). The GI Study summarized the existing hydrogeologic conditions at the site, the groundwater flow model development and calibration, and the mining impacts analysis and mitigation options. Below is a summary of the pertinent data from the GI Study report.

Geologic Setting

Similar to the UMA, the geologic units within the Empire Mining Area consist of unconsolidated glacial deposits overlying sedimentary Paleozoic bedrock units. The glacial deposits consist primarily of sand and gravel textured outwash and Superior till with lesser amount of Des Moines and pre-late Wisconsin till deposits present locally. The glacial deposits display a complex stratigraphy of interfingering sand-gravel layers with till. The uppermost bedrock units include Platteville and Glenwood Formations (isolated remnants), St. Peter Sandstone, Prairie du Chien Group, and the Jordan Sandstone.

Groundwater Occurrence and Flow

Within the Empire Mining Area, depth to groundwater is generally 20 to 50 feet below ground surface. Pre-mining water levels were reported to be stable, exhibiting annual fluctuations on the order of 4 feet. Horizontal hydraulic gradients are approximately 0.002 feet/feet and reportedly do not vary substantially throughout the site. Areal groundwater recharge is anticipated to occur throughout the area as a result of infiltration of surface water.

As discussed in the GI report and demonstrated by simulated water table contours (Appendix D, Figure 2-1; Barr, 2007) a groundwater flow divide is suspected to be present within the Empire Mining Area (south of the UMA). South of the divide, groundwater flows to the southeast and discharges to the Vermillion River and associated tributaries. North of the divide, groundwater flows to the northeast towards UMore Park and ultimately discharges to the Mississippi River.

Using the average hydraulic gradient (0.002 ft/ft), the range of hydraulic conductivity values cited for the outwash (which range from 8 to 61 feet per day in alluvium) in the GI Study, and an effective porosity value of 25%, average linear groundwater velocity within the outwash at the Empire Mining Area is estimated to range from approximately 23 to 180 feet per year. It should be noted that the hydraulic conductivity values used above are derived from model calibration, rather than actual field measured values.

2.1.5 Other Groundwater and Information Sources

Other sources of groundwater data at UMore Park include depth to groundwater measurements collected in various monitoring wells installed at or near UMore Park, water level elevation information from the County Well Index (CWI) and Dakota County, and details from the City of Rosemount Wellhead and Source Water Protection Plan (Barr 2003). These data are summarized in Appendix E and described briefly below.

In general, the data available are insufficient to characterize current groundwater flow across the UMA and surrounding area. However, the data available does suggest that the groundwater flow in the uppermost glacial (Quaternary) aquifer generally matches the regional model flow direction to the northeast. As shown by the Vermillion River watershed map (Appendix E), drainage from the southern portion of the UMA flows toward the Vermillion River. It is unclear from the available groundwater data whether groundwater flow coincides with surface water flow in this area.

Appendix E contains a summary of the existing wells that have been tentatively identified within the UMore Park and vicinity. Several criteria were applied to identify wells that will be suitable for inclusion in the monitoring network for the UMA as described in Section 3. In general, the location, construction, and access to a particular well was considered in identifying which wells will be used for monitoring during this Assessment.

As shown in Appendix E, the UMA is not currently within any Wellhead Protection Areas (WHPAs) and Drinking Water Supply Management Areas (DWSMAs) for the City of Rosemount. The placement of new water supply wells may potentially affect future groundwater flow patterns. This information will be evaluated as part of the groundwater flow modeling described in Section 4.

2.2 Climate and Hydrology

UMore Park is located within Dakota County, Minnesota, approximately 25 miles southeast of the Twin Cities. The average daily maximum temperatures range from 23 to 83 degrees Fahrenheit and average annual precipitation is approximately 32.5 inches (NOAA, 2008).

Within the UMA, the ground surface generally slopes from west to east from approximately 950 msl to 940 feet msl (USGS, 1974). The predominant surface water drainage direction is to the southeast; however, a number of shallow, closed contour basins and road ditches receive and/or transmit surface water runoff. Surface water bodies in the vicinity of the UMA include the Vermillion River, located approximately five miles south of the UMA, and the Mississippi River, which is located approximately 6 miles northeast of the center of UMA.

Recharge to the groundwater system primarily results from precipitation as it infiltrates through the soil or leaks downward from wetlands. Estimated average annual recharge rates in the vicinity of UMore Park vary from approximately four to ten inches (USGS, 2007) but are likely greater in wetland areas and storm water retention basins.

2.3 Geologic Setting

The discussion below addresses conditions in the vicinity of the larger UMore Park area because the characterization of the groundwater flow field will need to include information for the area beyond the UMA for modeling to adequately address mining and post-mining conditions.

2.3.1 Bedrock Stratigraphy

The geology at UMore Park consists of 25 to over 160 feet of unconsolidated glacial deposits overlying an erosional Paleozoic bedrock surface (ProSource, 2008). Based on the Dakota County Geologic Atlas (MGS, 1990), the uppermost bedrock units in the study area include the St. Peter Formation Sandstone and the Prairie Du Chien Group (dolomite). The uppermost geologic units within the UMA are shown on the stratigraphic column in Figure 5.

The Prairie Du Chien Group and the underlying Jordan Sandstone together comprise the primary aquifer locally used for domestic water supply and crop irrigation. Paleozoic bedrock units beneath the Jordan Sandstone include the St. Lawrence Formation (an aquitard or confining layer), the Franconia Formation, and the Ironton-Galesville Sandstones (regional aquifers), the Eau Claire Formation (a regional confining unit), and Mount Simon-Hinckley Sandstone (the deepest regional aquifer).

As shown on Figure 6, the bedrock topography at UMore Park is dominated by a northeast trending bedrock valley in the center portion of the UMA that was incised prior to the Late Wisconsin era (MGS, 1990). The bedrock topography shown on Figure 6 is an approximation based on widely spaced data. Recent investigations (ProSource, 2008) indicate that Figure 6 reflects general bedrock topographic patterns; however the ProSource data indicate that the bedrock map will need to be revised to more accurately reflect conditions at the UMA.

2.3.2 Glacial Stratigraphy

Numerous continental ice sheets have advanced into Dakota County during the past two million years (MGS, 1990). The surficial soils are relatively thin across the site (<10 feet thick) and are derived from loess (wind blown silt) or consist of localized fill associated with post-settlement development. The underlying glacial deposits above bedrock consist primarily of sand and gravel associated with the Rosemount Outwash Plain. Melt water runoff transported sediment from the northwest, where the St. Croix Moraine exists today, to the southeast where it was deposited on the outwash plain. These deposits were formed with sediment transported by glacial melt water associated with the Late Wisconsin era Superior Lobe glaciation. The outwash is comprised primarily of sand and gravel of varying grain sizes with fine-grained fractions (passing No. 200 sieve) generally below five percent by weight. The outwash exhibits a thickness of over 150 feet within the upper reach of the bedrock valley located in the UMA as shown on Figure 6. An older, pre-Late Wisconsin era outwash deposit was identified within the UMA (ProSource, 2008) and is differentiated from the Superior Lobe outwash by its lower gravel content and the presence of iron mottling.

Glacial till and lacustrine (lake) deposits are located within and above the outwash. The till consists of mixed gravel, sand, silt, and clay and is typically yellowish brown to gray in color. The lacustrine units are typically fine-grained with higher clay content. The till and lacustrine deposits range in thickness from a few feet to tens of feet and exhibit lateral continuity on the order of a half-mile in the west central portion of UMore Park (Figures 7, 8, and 9).

2.4 Hydrogeology

Depth to groundwater varies from approximately 50 feet bgs in the southwest to 100 feet bgs in the northeast portions of UMore Park. The water table surface is within outwash or till deposits across UMore Park with the exception of the southeast corner where St. Peter Sandstone is present near the ground surface (Appendix B). Where the water table is positioned within the outwash or St. Peter Formation sandstone, groundwater flows occurs under generally unconfined conditions. Confined groundwater flow in outwash is likely where overlying till or lacustrine deposits are present at or beneath the water table. The extent of the confined groundwater flow conditions is currently not well known; however, confined conditions are suspected to be present in the west central and eastern portions of UMore Park, based on the apparent presence of fine-grained deposits in these areas.

Based on preliminary output from the Metro Model (Figure 4), the direction of groundwater flow within the outwash and underlying aquifers is likely to the northeast towards the Mississippi River. The Vermillion River located south of the site is a gaining reach (i.e., groundwater discharges to the river) with groundwater elevations approximately 25 feet below those at UMore Park (Bolton & Menk, 2005). Therefore, a groundwater flow divide is inferred near the southern boundary of UMore Park.

2.5 Preliminary Groundwater Flow System Conceptual Model

Groundwater elevation and geologic data have been assessed by evaluating the existing wells, modeling results, and by creating numerous cross sections from aggregate resource data and information included in Appendices A through D. The preliminary conceptual model presented below is based on a review of this site-specific information and publicly available information sources. This information is summarized in the conceptual cross sections shown on Figures 7 through 9. This preliminary conceptual model will be discussed in the following sections.

2.5.1 Hydrostratigraphy

The thick deposit of sand and gravel present within UMore Park was deposited as a proglacial outwash plain that received melt water runoff from the Superior Lobe ice margin. The fine-grained units within the outwash deposit, such as till or lacustrine deposits, likely represent minor Late Wisconsin era or older ice advances, re-deposited blocks of till/lacustrine soils, or low-energy fluvial deposits that were placed during outwash plain deposition. Due to the temporal and spatial variation typical of this depositional environment, the fine-grained till and lacustrine deposits are expected to exhibit changes in elevation, thickness, and continuity throughout the UMA. In contrast to the glacial deposits, the bedrock units (except for the St. Peter Sandstone) are expected to be relatively homogenous and laterally continuous beneath UMore Park. Because potential impacts from mining are unlikely to influence the deep bedrock portions of the groundwater flow system, the primary zone of interest is the outwash and uppermost saturated aquifer units above the Prairie du Chien Group.

2.5.2 Groundwater Recharge

Groundwater recharge is anticipated to take place primarily at and upgradient (west/southwest) of the UMA. Where closed contour land surface depressions and road ditches are present, directed recharge likely takes place but, due to the depth to groundwater and permeable nature of the outwash, significant water table mounding is unlikely to develop under those areas.

2.5.3 Groundwater Flow and Hydraulic Conductivity

The uppermost saturated unit occurs mainly within the outwash sand and gravel. The entire outwash sequence is assumed to be continuously saturated with depth. Horizontal groundwater flow is anticipated to be within the unconfined outwash unit and underlying bedrock units in a northeasterly direction. Although horizontal flow is likely predominant, vertical hydraulic gradients may result in localized downward flow potentials, particularly in areas where fine-grained deposits impede horizontal groundwater movement.

No site-specific aquifer tests have yet been conducted in the UMA. However, hydraulic conductivity of the fine-grained deposits (silt and clay) likely range from approximately 10^{-4} to 10^{-1} feet per day. The hydraulic conductivity of the coarser outwash likely ranges from 10^{-1} to 10^{2} feet per day based on standard nomagraphs (Freeze and Cherry, 1979. p 29).

2.5.4 Groundwater Discharge

Regional groundwater discharge from bedrock units is expected to take place into the buried bedrock valley that is located east of UMore Park (Figure 6) and into the alluvium within the modern day Mississippi River valley. Groundwater flow in bedrock (below the outwash) is incorporated by the Metro Model based upon calibration with observed hydraulic heads.

2.6 Groundwater Flow System Data Gap Summary

The primary data gaps related to understanding groundwater flow and the potential affects of aggregate mining at UMore Park are described below.

2.6.1 Geology and Aquifer Properties

The distribution and hydrogeologic properties of the primary hydrostratigraphic units (outwash, till, lacustrine) largely determine the characteristics of groundwater flow characteristics in the upper saturated portions of UMore Park. The determination of the vertical and horizontal extent of these hydrostratigraphic units will provide the physical framework of the hydrogeologic system and serve as the basis for developing a reliable groundwater flow model. Furthermore, incorporating the hydrogeologic properties of each unit into the groundwater flow model will streamline the calibration effort and result in more defensible groundwater model simulations used to predict the future impacts of the proposed mining operations.

Currently there is a major gap in the understanding of the till complex near the eastern edge of the UMA (central portion of the UMore Park). As shown on Figures 7 through 9, a till surface has been documented in shallow borings (ProSource 2008). However, no detailed borings have penetrated into the till unit. A single well log in this area (UID#207605 on Figure 8) suggests fine-grained till extends to bedrock. The detail and drilling method indicated on the drillers log suggests that this information may not be representative of the stratigraphy in this area. In addition, the Metro Model (Figure 4) has shown residual head deviations downgradient of the central till area. This may suggest that vertical gradients present in this area result from groundwater flow around or below the till unit.

Additional data gaps include the overall configuration of the bedrock topography and the nature of the glacial units directly abutting bedrock topographic highs. Where fine-grained units mantle bedrock, there is some potential for locally confined hydrogeologic conditions which need to be included in the model.

Previous investigations have not focused on collection of aquifer hydraulic properties resulting in a lack of data on hydraulic conductivity values, particularly within the UMA.

2.6.2 Groundwater Flow

No site-wide groundwater monitoring well network exists within the UMA or the larger UMore Park. There are only isolated wells screened over a variety of saturated units and intervals. Although monitoring data exists for many of these wells, the events were spread out over a period of years. There are also gaps in the information regarding the lateral and vertical placement of wells.

The horizontal hydraulic head distribution, vertical gradients, and groundwater interaction with surface water bodies within the UMA constitute the primary data gaps related to groundwater flow. By determining the distribution of horizontal hydraulic head across UMore Park, area-wide groundwater flow maps will be produced and will provide a clearer understanding of the directions of groundwater flow. Determining vertical hydraulic gradients within the UMA will provide data that will be used to predict thermal plume migration from future mine pits and will provide data to assess the hydraulic relationship between the outwash and underlying bedrock.

To predict the impacts that mining may have on groundwater and nearby surface water resources, the data gaps described above will be addressed by the proposed scope of work detailed in the following section.

3.0 Investigation Overview

3.1 Technical Approach Summary

The investigation will be conducted in a phased approach to allow for the efficient collection of the geologic and hydrogeologic data needed to refine the conceptual model and refine and calibrate the groundwater flow model. The initial phase will involve the placement of a series of pilot soil borings that will provide information that will better define the vertical and horizontal extent of the primary hydrostratigraphic units. The pilot borings are initial borings that help define the geologic strata in targeted areas prior to well installation. They will also serve to verify that the locations selected for aquifer testing will be representative of aquifer conditions appropriate for refining the groundwater flow model.

The second phase of the investigation will include the installation and testing of a network of monitoring wells that will allow collection of baseline monitoring data, assess hydraulic gradients and aquifer properties. The monitoring data will be collected from wells across the UMore Park area, but the pumping tests will focus on locations within the UMA.

Once the data has been collected it will be incorporated into the conceptual model. The revised conceptual model will then serve as the basis for the updated groundwater flow model. The model will then be calibrated to the observed data and used to run predictive simulations based on conceptual post-mining conditions. The post-mining conditions used for these simulations will be defined in the Scoping Decision Document that will be prepared prior to the initiation of the EIS.

3.2 Investigation Field Tasks

The primary components of the field investigation include:

- Pilot boring advancement
- Detailed geologic description and classification
- Well installation and development
- Hydraulic head (water level) monitoring
- Water quality monitoring

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- Aquifer testing

The subsections below provide an overview of the primary components of the investigation. Technical specifications and specific field methodologies are included in Appendix F.

3.2.1 Pilot Boring Advancement and Sample Logging

The proposed pilot boring/well locations are shown on Figure 10. The boring locations have been selected to address gaps in the conceptual model as discussed in Section 2. Due to the large size of the Assessment project area, naming conventions for wells and borings include a grid coordinate indicator for rapid well location. The grid coordinate corresponds to the map coordinate key shown on Figure 10. See Appendix G for a map showing the proposed pilot boring/well locations relative to GOW features.

Pilot soil borings will be advanced at each planned well location prior to well installation. Soil samples will be collected continuously from the ground surface to the top of bedrock and described in the field for characterization purposes. Each sample will be logged in the field in accordance with ASTM D 2488. The soil descriptions will be used to develop hydrostratigraphic cross sections in the field and to verify planned well screen intervals. A subset of the soil samples will be retained for laboratory geotechnical tests. At least one geotechnical sample will be retained for each major hydrostratigraphic unit encountered during the Assessment. Coarse grained samples will be tested for sieve tests. Core sections of fine-grained samples will be tested for falling head permeability tests.

3.2.2 Well Installation and Development

Monitoring and pumping well installation will occur after the pilot borings have been completed. Proposed well locations are shown on Figure 10. Construction details are summarized on Table 1 which also indicates the specific monitoring or testing purpose for each well. All wells will be installed by a licensed well contractor in accordance with Minnesota Rules Chapter 4725 and Dakota County Ordinance. Unless subsurface conditions dictate otherwise, well borings will be blind drilled in a separate hole and installed adjacent to the pilot boring location. Pilot boreholes not completed as monitoring wells will be sealed in accordance with Minnesota Rules Chapter 4725.

The monitoring and pumping wells will be screened to monitor hydraulic head and water quality in the uppermost saturated aquifer. Based on the current conceptual model, the uppermost saturated aquifer occurs within the outwash and erosional remnants of the St. Peter Sandstone.

In the event that a thick confining layer (e.g., composed of till or lacustrine deposit) or shallow bedrock is encountered in a pilot boring, the boring location will be evaluated to determine if an additional boring is needed to select the appropriate monitoring location and screened interval. Final determination of well locations and screened intervals will be made in the field in consultation with the University of Minnesota.

A total of approximately 16 new wells are currently planned for installation during the Assessment. It is anticipated that3 locations will include nested well set (each nest will consist of two adjacent wells screened at the top and base of the glacial deposits) that will be used to monitor vertical gradients. The lowermost well at these locations will be a larger diameter (approximately 4 inch) well to accommodate a submersible pump for aquifer testing. After testing, these wells will be used for measuring vertical gradients between the water table and the lower portions of the aquifer. Additional wells screened at intermediate depth intervals may be necessary at some locations depending on the subsurface conditions encountered during the pilot boring phase.

After installation, each well will be developed by a combination of surging and pumping to remove fines from the well screen and ensure that an adequate hydraulic connection exists between the well screen and the formation. The north side of the top of riser for each well will be surveyed to the nearest 0.01 of a foot. Surveying and well development methods are described in Appendix F.

3.2.3 Water Level Monitoring

Water levels will be measured in each network well on a semimonthly (twice per month) basis for the duration of the Assessment. Water levels will be collected with an electronic water level indicator. The water levels will be used to determine groundwater elevations and site-wide groundwater flow direction.

In addition to the new wells, the existing wells listed in Table 2 will be used to supplement the groundwater elevation data set provided access is permitted by the well/property owner. Appendix E includes a technical memorandum describing how the existing wells were identified and selected for possible inclusion into the monitoring network.

3.2.4 Water Quality Monitoring

Two groundwater monitoring events spaced approximately 60 days apart will be conducted as part of the investigation. During each groundwater monitoring event, each of the newly installed network wells will be sampled for major cations and anions to determine baseline groundwater water quality conditions. Parameters will include field parameters (temperature, conductivity, and pH, and reduction/oxidization potential), and general ion parameters (aluminum, calcium, magnesium, iron, manganese, sodium, potassium, chloride, bicarbonate, fluoride, sulfate, phosphate, nitrates, ammonia, Total Organic Carbon, and Total Dissolved Solids). The groundwater samples will be analyzed by Legend Technical Services located in St. Paul, Minnesota using standard EPA Methods as described in Appendix F. The field parameters general chemistry will be used to characterize the groundwater flow system and identify the chemical signature of groundwater in various portions of the aquifer.

3.2.5 Aquifer Testing

Aquifer testing will be conducted to assess the hydraulic characteristics of the outwash unit beneath the UMA. The aquifer testing efforts will focus on the outwash in the UMA and are based on the following assumptions:

- Bedrock flow conditions are adequately well characterized by the data used in the Metro Model. Therefore, no additional aquifer testing will be conducted in the bedrock units below the UMA.
- The properties of the outwash remaining below the mined outwash and outside of the UMA will be most determinate of post-mining groundwater flow and thermal plume migration.
- Shorter duration pumping tests from multiple locations around the UMA are likely to be more useful in characterizing aquifer properties than a single, longer duration (e.g., 72-hour or greater) aquifer tests because of the limited extent of hydraulic response resulting from the expected high transmissivity of the deposit.

Based on these assumptions, it is proposed that aquifer test data will be collected from multiple well locations throughout the UMA. Limited duration (8-hour) aquifer tests will be conducted at three locations around the UMA. In general the pumping well will be screened at the base of the aquifer. Each aquifer test will be conducted with a pumping well and a minimum of one observation well. Water levels in the pumping and monitoring wells will be recorded with a pressure transducer during pumping and recovery phases of the tests. Additionally, water levels in selected existing bedrock wells will be monitored during the aquifer tests.

The approach of using multiple limited duration tests provides the opportunity to evaluate the spatial variability of aquifer parameters around the UMA. Data analysis will be analyzed using Aqtesolv Pro (Hydrosolve, 2007) and will employ an analytic method appropriate for the test conditions.

4.0 Groundwater Flow Model Development

4.1 Purpose and Objectives

The purpose of the groundwater model will be to:

- Allow a means to test the conceptual model of groundwater flow within and around the UMA.
- Provide critical groundwater terms for input into surface water models being prepared for the EIS.
- Test hypotheses regarding potential impacts that may result from the proposed mining development, as well as possible solutions to inferred impacts. Examples of specific questions to be answered include: Will mining change the groundwater flow regime? Will temperature increases related to mining affect groundwater discharge areas such as the Vermillion River? If there are temperature impacts, will increasing or decreasing the depths of the lakes mitigate the potential impact?

The groundwater model will meet the following objectives:

- Include a simplified, but robust, representation of the essential hydrostratigraphic details described by the conceptual model.
- Reasonably portray observed heads and simulate gradients that are consistent with the available information.
- Appropriately simulate the surface water groundwater interface and groundwater flow so that the potential effects of groundwater temperature changes from mine pit lakes and the potential impact to the Vermillion River can be evaluated.
- Incorporate reasonably ascertainable information on anticipated pumping conditions resulting from municipal and commercial withdrawals in the vicinity of the UMA.
- Predict the transport of water quality parameters that may hypothetically originate from mine operations and/or simulate changes induced by mining on existing known sources of contamination (if any are identified in the UMA).
- Predict the effects of groundwater extraction for gravel washing on other aquifer users and municipal wells.

4.2 Flow Model

4.2.1 Hydrologic Models

Several modeling programs will be used in the development of the flow model. Groundwater simulations will be performed using MODFLOW (Harbaugh and McDonald, 1996), using the graphical user interface Groundwater Vistas (Environmental Simulations, Inc., 2004). Recharge to the groundwater model will be calculated using the Surface Water Balance (SWB) code (Dripps and Bradbury, 2007), which accounts for soil type, land use, topography, and climatic variation. The flow model will be calibrated to site data using the model-independent automated optimization code PEST (Watermark, 2005). The primary groundwater modeling software is described in the sections below.

MODFLOW

MODFLOW was developed by the U.S. Geological Survey and is in the public domain. It is a widely used and accepted groundwater flow code for characterizing flow in porous, saturated media. MODFLOW simulates three-dimensional, steady-state and transient groundwater flow in saturated media using finite-difference approximations of the differential equation of groundwater flow:

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)-W=S_s\frac{\partial h}{\partial t}$$

Where:

K_{xx}, K_{yy}, and K_{zz}: three principal directions of the hydraulic conductivity tensor
W: sources and sinks
S_s: specific storage
h: hydraulic head
t: time

For steady-state simulations, the partial derivative of head with respect to time is zero and the right side of Laplace's equation, above, equals zero.

Groundwater Vistas

The MODFLOW model will be developed using the graphical user interface (GUI) Groundwater Vistas (ver. 4.09 Build 3; Environmental Simulations, Inc., 2004).

Soil Water Balance (SWB) Model

The SWB code calculates components of the water balance on a daily basis, based on a modified version of the Thornthwaite-Mather soil moisture balance approach. Data requirements include a number of the following commonly available tabular and gridded data types: (1) precipitation and temperature; (2) land use classification; (3) hydrologic soil group; (4) flow direction; and (5) soil water capacity. Recharge is calculated separately for each grid cell in the model domain. Sources and sinks of water within each grid cell are determined based on the input climate data and landscape characteristics. Recharge is calculated as the difference between the change in soil moisture and these sources and sinks. For a detailed description of the SWB model see Westenbroek and others, 2008 (in editorial review as of May 1, 2008).

Inverse Optimization and PEST Calibration

The MODFLOW model will be calibrated through a series of automated inverse optimization procedures using the model-independent parameter estimation software PEST2000 (Watermark Numerical Computing; 1999, 2005). Automated inverse optimization is a method for minimizing the difference between simulated results and observations (the residual or objective function) in a least-squares sense by numerically solving for the derivative (and hence, the minimum) of this objective function. Using PEST involves making some choices on which parameters (e.g., hydraulic conductivity zones, recharge zones, etc.) will be allowed to vary, the maximum and minimum values in which the parameter values could be varied, and initial estimates for the parameter values.

4.2.2 Model Construction

Model domain and perimeter boundary conditions will be extracted from the Metro Model using Telescoping Mesh Refinement (TMR). The horizontal model grid will be refined around key features such as pit lakes and municipal pumping wells. It will have a maximum horizontal grid block size of approximately 200 meters. Initial zonation and parameter values will be identical to those in the Metro Model and will then be refined as necessary based on borehole and pumping test data. Pumping test data will be analyzed using AQTESOLV (Hydrosolve, 2000) in conjunction with conceptual geologic cross sections to determine values for horizontal and vertical hydraulic conductivity values and other aquifer properties.

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All layers from the Metro Model will be included in the groundwater flow model. Additional layers will be added as needed in the unconsolidated zone to more model the water table, surface water features such as mine pit lakes, and provide a numerically stable flow model for temperature and solute transport modeling. Mine pit lakes will be modeled using hydraulic conductivity zones and/or the MODFLOW Lake package. The Vermillion River will be simulated using the MODFLOW River package, which permits modeling of river baseflow. Baseflow and profiling data on the Vermillion River from Dakota County will be used as appropriate.

4.2.3 Model Calibration

When a reasonable flow regime has been achieved through manual calibration, PEST will be used to optimize the model's calibration. The model will be calibrated to water levels in monitoring wells and, if appropriate, other field data. The calibrated model will then be coupled to the regional Metro Model, which will permit simulation of a wider range of conditions.

4.2.4 Forward Simulations

Forward models runs will simulate development of the mining project as a series of steps. Each step will simulate sequential conditions that represent further advancement of mining pit lakes. Modeled hydrogeologic conditions at the end of one timestep will determine conditions at the beginning of the next timestep. The final timestep will represent hydrogeologic conditions at full development.

4.3 Transport Modeling

4.3.1 Particle Tracking

The MODPATH (Pollack, 1994) particle-tracking package will be used to predict the groundwater flowpath and destination of selected chemical parameters. MODPATH operates as an independent extension of MODFLOW. MODFLOW calculates the flux between cells in the aquifer, and MODPATH utilizes the MODFLOW output files to calculate the velocity-vector field for each aquifer cell. After the velocity vectors have been calculated, the path of particles within and between cells can be determined. In addition, groundwater travel times can be predicted. If MODPATH analysis indicates that resources are vulnerable to impacts, additional contaminant transport modeling (described in Section 4.3.2) can be conducted, as warranted by hydrogeologic conditions.

4.3.2 Solute Transport

If needed, a contaminant-transport package will be selected based on the results of fieldwork and preliminary MODFLOW and MODPATH screening. Although a contaminant transport code will not be selected until more is known about the site, MT3D (Zheng, 1990; 1979) is a possible candidate since it provides the basis for the SEAWAT thermal modeling code described below. Because MT3D allows the user to choose from multiple solution algorithms for both dispersion and advection, it is adaptable to a wide variety of problems.

MT3D solves the three-dimensional advection-dispersion equation for contaminant transport in groundwater, shown below:

$$\left[\frac{\partial}{\partial x}\left(D_x \frac{\partial C}{\partial x}\right)+\frac{\partial}{\partial y}\left(D_y \frac{\partial C}{\partial y}\right)+\frac{\partial}{\partial z}\left(D_z \frac{\partial C}{\partial z}\right)\right]-\left[\frac{\partial}{\partial x}(v_x C)+\frac{\partial}{\partial y}(v_y C)+\frac{\partial}{\partial z}(v_z C)\right]=\frac{\partial C}{\partial t}$$

Where:

D_x, D_y, and D_z: three principal directions of the dispersion tensor

C: concentration

v_x, v_y, v_z,: particle velocity

t: time

4.3.3 Thermal Transport Modeling

SEAWAT (Langevin et al., 2008) will be used to evaluate potential impacts of temperature change at mine pit lakes on the Vermillion River and downgradient resources. SEAWAT couples MODFLOW and MT3D to solve saturated variable-density problems. Heat conduction is mathematically represented similar to solute diffusion; therefore temperature may be modeled as if it were a chemical species in MT3D. Information available from studies on the Vermillion River (Appendix E) and recent research on the influence of shallow groundwater on recharge will be incorporated into the modeling effort (Herb et al 2007).

5.0 Summary and Schedule

The overall objective of this Assessment is to develop a reasonable conceptual site model and a defensible groundwater flow model. The flow model will be used as a tool for the EIS to evaluate the potential impacts of the proposed sand and gravel mining on groundwater resources and receptors to evaluate alternatives and mitigation of likely impacts.

5.1 Plan Summary

As detailed in this Work Plan, existing hydrogeologic data are sparse and the preliminary conceptual model has significant data gaps relating to the vertical and lateral extent of primary hydrostratigraphic units, the horizontal and vertical hydraulic gradients, and groundwater interaction with surface water bodies at and in the vicinity of the UMA and UMore Park as a whole.

The following tasks will be completed during the Assessment:

- Pilot borehole advancement
- Detailed soil description and geologic interpretation
- Well installation
- Aquifer testing
- Hydraulic head measurement and baseline groundwater quality monitoring
- Groundwater flow modeling
- Completion of a Groundwater Assessment Report

5.2 Reporting

The results of the Assessment will be summarized into a Groundwater Assessment Report. The report will include the results of the investigation, describe significant deviations from this Plan and provide tabular and graphical summaries of the Assessment findings.

5.3 Schedule

The data collection tasks will begin upon receiving stakeholder approval of this Plan. After authorization to proceed, it is anticipated that the pilot boring advancement, well installation, and aquifer testing tasks will take approximately two months to complete. Development of the groundwater flow model will begin after data collection and is anticipated to require approximately 40 to 60 days. The results of the investigation and groundwater flow modeling work will be summarized in a draft Groundwater Assessment Report that will be submitted to the University as part of the draft EIS by mid-2009.

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