Predictive Simulations to Assess Potential Effect of Mining Activities on Groundwater

Resource Document for Environmental Impact Statement

UMore Mining Area
Dakota County, Minnesota

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1.0 Introduction

This report presents the results of predictive simulations conducted to evaluate potential groundwater effects related to proposed sand and gravel mining at the University of Minnesota Outreach, Research, and Experiment Park (UMore Park) property located in Dakota County, Minnesota. The proposed mining and ancillary use area, referred to as the UMore Mining Area (UMA), comprises approximately 1,700 acres in the western one-third of UMore Park (Figure 1) and is the subject of an Environmental Impact Statement (EIS) being prepared by the University of Minnesota. A detailed groundwater assessment has been conducted and the resulting report (Barr, 2009a) describes the geologic and hydrogeologic setting of the UMA.

A calibrated groundwater flow model, based on UMA-specific hydrogeologic and regional data (Barr, 2009a), was used to conduct the simulations. The simulations were performed to evaluate conditions and potential environmental concerns identified in the Scoping Decision Document (SDD) based on comments to the Scoping Environmental Assessment Worksheet (SEAW) prepared by the University (University of Minnesota, 2009a; University of Minnesota, 2009b). Significant contributions to the modeling effort were made by various stakeholders during on-going Technical Advisory Committee meetings sponsored by the University.

Several primary concerns emerged in comments to the SDD with respect to how gravel mining operations may affect groundwater resources. These concerns have been addressed in this report with the following tasks:

1. Assessment of groundwater withdrawals needed to support gravel washing operations and concrete production
2. Simulation of the mine pit-lake that will be created as a result of mining and identification of potential changes to the groundwater flow system resulting from the lake.
3. Evaluation of the effects of mine operations within current and future municipal drinking water supply management areas
4. Model simulation of a potential contaminant release to the aquifer from within the mine areas used for storage of fuels, and other materials that might lead to a spill or other impact to groundwater.

Multiple predictive simulations were conducted for each task. The methods used and results from these simulations are described in the following sections.
2.0 Effect of Mining Operations on the Groundwater Flow System

The proposed mining operations will require a dedicated water supply to support gravel washing, concrete production, and general operational activities at the mine site. Groundwater from the shallow, unconfined, glacial outwash aquifer, and the deeper Prairie du Chien Group aquifer, have been identified as sources that will meet the water needs for the proposed project. Two water supply wells, one in each aquifer, are proposed. The groundwater flow model of the UMore area (Barr, 2009a) was used to simulate the potential effects of pumping these wells.

2.1 Mining Related Water Demand

A conceptual schematic of water consumption for the gravel mining operations is shown on Figure 2. Details regarding mining related water demands are described below.

2.1.1 Wash Operations

The wash process consists of moving mined aggregate along a conveyance system equipped with screens and wash collectors. It is estimated that water will need to be circulated at a rate of several thousand gallons per minute to effectively remove the fine particles from the mined aggregate.

2.1.2 Sustainability

In order to meet the University’s goal of employing sustainable groundwater use at UMore, and working toward the U.S. EPA Region 5 goal of minimizing impacts to water quality and water resources (U.S. EPA 2009), several iterative simulations of groundwater pumping effects were evaluated. The term “sustainable” in the context of the groundwater withdrawal was defined as minimizing the impact to the groundwater resource.

Like any groundwater model, the simulations are able to predict drawdown with significant precision. However, the accuracy of these predictions are constrained by inherent uncertainties in the calibrated model. A sustainable drawdown criteria was established accounting for potential uncertainties in the model predictions. Drawdowns of less than one foot at the UMore property boundary were determined to be sustainable in this context.

Based on input from the mining operator, a starting circulation rate for wash operations of 2500 gpm was proposed. The model was used to simulate this rate and it was found to be theoretically possible to obtain sufficient water volume over time if the pumping were distributed laterally to several pumping wells and
multiple aquifers. This is because much of the water would eventually infiltrate back to the upper water table aquifer and would thus offset drawdown.

However, due to the limited saturated thickness of the outwash aquifer, pumping from the uppermost saturated unit alone would not be able to sustain the initial rate. Placing multiple wells within several aquifer units would be needed, but this would be potentially expensive and could interfere with other groundwater users. The effects of recharging the upper portion of the outwash aquifer would also lag the withdrawals from deeper aquifers; therefore, drawdown from the mining operation would potentially extend far off site before recharge to the lower aquifer units would be able to partially offset the drawdown resulting from pumping at 2,500 gpm. It was concluded that pumping at high rates would likely have significant financial and regulatory concerns regarding well construction, appropriations, and overall energy consumption.

Therefore, engineering controls were considered to reduce the groundwater withdrawal. Construction of one or more clay-lined settlement and recirculation basins was proposed. The ponds would be constructed using clay excavated from the deposits on site and would reduce the seepage rate allowing water to be withdrawn from the outwash aquifer at a much lower rate. The operation would still circulate several thousand gallons per minute of water, but groundwater would only be needed to initially fill the basins and then as makeup water for seepage and evaporation loss from the basin. Because the seepage would be recharging directly to the aquifer being pumped, the infiltration from the basin could partially offset the drawdown due to pumping. Initial results indicated that pumping at lower rates created less drawdown at the site boundary and therefore was deemed a more sustainable pumping scenario than the initial circulation rate of 2,500 gpm.

The sustainable groundwater pumping design criteria was then further evaluated to obtain model input parameters and refine a pumping rate that would be included in the preliminary design plans as described below.

### 2.1.3 Recirculation Basin Water Balance

The settlement basin will be located within the ancillary facilities area near the aggregate processing facilities (Figure 1). It is estimated that the settlement basin will cover a surface area of 200,000 ft² and will be up to 20 ft deep. A clay liner will be constructed to limit the amount of seepage from the basin. The clay liner is assumed to have a hydraulic conductivity of $3.3 \times 10^{-8}$ ft/sec ($1 \times 10^{-6}$ cm/sec) and a minimum thickness of one foot. The actual liner thickness may be greater than one foot, but a unit thickness was assumed for an initial estimate. Based on Darcy’s law, the leakage from the settlement basin through the clay liner can be estimated from the following equation:
\[ q' = K_c \frac{h_w - hae}{L_c} \]

Where: \( q' \) is the flux from the basin per unit area, \( K_c \) is the hydraulic conductivity of the clay liner, \( h_w \) is the depth of the water in the basin, \( hae \) is the air-entry value for the soil below the clay liner, and \( L_c \) is the thickness on the clay liner.

The clay liner offers significant resistance to flow and allows a very low leakage rate. Therefore, the soil below the liner will be unsaturated and have a negative pressure head. Bouwer (2002) states that the air-entry value for the material below the liner is appropriate to use for this negative pressure head. The air-entry value \((hae)\) is estimated as two times the negative pressure head for a soil at the wetting front \((h_w)\) (Bouwer, 2002). A typical \(h_w\) value for a loamy-sand to sandy-loam (the predominate material at settlement basin location) is -0.82 ft (-25 cm) (Bouwer, 2002), giving a \(hae\) value of -1.6 ft (-50 cm).

Using the above equation, it is estimated that the settlement basin will have a leakage on the order of 64 gallons per minute. This is considered to be a conservative estimate for the leakage rate, as it is likely that the hydraulic conductivity of the clay liner will be lower than \(3.3 \times 10^{-8}\) ft/sec \((1 \times 10^{-6}\) cm/sec\), particularly after siltation occurs within the basin as a result of gravel washing.

Water will also be lost from the settlement basin via evaporation. Evaporation from a water body can be estimated using a pan coefficient (Jones, 1992). The pan coefficient is calculated as the ratio of free-water-surface evaporation to observed pan evaporation. Using an average annual pan evaporation of 39 in/yr (University of Minnesota, 2009c) and a pan coefficient of 0.74 (USDA, 1977), leads to an annual potential evaporation loss from the settlement basin of 27 in/yr. This equates to a total loss from the settlement basin due evaporation equivalent to about 6.4 gallons per minute.

The total water loss from the basin, and hence, the amount of makeup water needed to maintain adequate water levels in the settlement basin, is estimated to be 70 gallons per minute (seepage loss plus evaporation loss). While 70 gallons per minute is needed for makeup water, only 6.4 gallons per minute (evaporation) is lost from the groundwater system. The seepage loss from the settlement basin (estimated at 64 gpm) is returned to the groundwater system as induced recharge.

In order to be conservative for modeling purposes, and to account for periods of prolonged drought, stormwater runoff to the settlement basin and direct precipitation onto the basin are not included as a
component of the makeup water. Although construction of a thicker liner would further reduce infiltration, it would come at additional energy and expense of liner construction and pond maintenance for little or no benefit in reducing the potential impact on the resource. Therefore, the initial minimum liner thickness was deemed suitable for a sustainable withdrawal and was retained as an assumption in modeling the seepage and drawdown estimates.

2.1.3.1 Pumping Before Development of Mine Pit-Lake
Makeup water will be supplied by groundwater during the initial phases of gravel mining. An existing test well (PW-C2-202 in Barr, 2009a), screened in the sand and gravel outwash, and located west of the ancillary use facility, is capable of meeting this demand. This well will also be used to initially fill the settlement basin. The maximum capacity of this well is approximately 250 gallons per minute.

2.1.3.2 Pumping After Development of Mine Pit-Lake
Once a mine pit-lake of sufficient size is developed, it is likely that the mine pit-lake will be used as the source of makeup water. This means that a pump will be placed in the mine pit-lake for makeup water and pumping from the well will be reduced or discontinued. Because well PW-C2-202 is located in a future mining area, it will eventually be decommissioned and sealed in accordance with Minnesota Rules Chapter 4725 and Dakota County Ordinance 114.

2.1.4 Concrete Production
Concrete production will also occur in the ancillary use area and will require a water supply separate from the wash water supply. It is estimated that a maximum of 4 million gallons of water per year will be needed for concrete production. To meet this demand, a new well will be drilled. The saturated portion of the outwash near the planned concrete production facility is too thin to meet the projected water demand. Therefore, a new well be set in the Prairie du Chien Group aquifer. This well will operate intermittently on a daily and or seasonal basis at a maximum capacity of 100 to 150 gallons per minute with an assumed annual average pumping rate of 7.6 gallons per minute.

2.2 Simulation of Impacts from Mining Operations
Water demands associated with the gravel mining activities described above were incorporated into the MODFLOW groundwater flow model developed for the UMore Park area (Barr, 2009a) to assess effects of the water withdrawals on the groundwater flow system. For details on model development and calibration see the groundwater assessment report (Barr 2009a).
2.2.1 Description of Simulations

Two simulations were run to assess the effect of mining operations on the groundwater flow system. The first simulation (Mining Simulation 1) assumed that makeup water for gravel washing would be supplied by groundwater pumped from well PW-C2-202 and that there is no mine pit-lake present. The second simulation (Mining Simulation 2) assumed that the mine pit-lake is developed and is the source of water for gravel washing. Simulations were run in steady state. Due to the long term nature of the mining operations (approximately 40 years), steady state simulations are more appropriate and more conservative than transient simulations in assessing impacts. These simulations were set up to assess the effects of mining operations alone. The addition of future municipal water supply wells or other stresses on the aquifer were not included in these simulations. Additional simulations, described in Section 3.0 of this report, include future municipal water supply scenarios and future changes in land use.

2.2.2 Modifications to Groundwater Flow Model to Simulate Pond Seepage and Pumping

Minor changes were made to the groundwater flow model to simulate groundwater flow near the mining site. The following changes are common for Mining Simulations 1 and 2:

- The model grid was refined in the mining area, with the smallest cell size being 12.5 meters by 12.5 meters.
- A well open to the Prairie du Chien Group, needed to supply water for concrete production, was added into the model (layer 5) with a steady state pumping rate of 7.6 gallons per minute to meet the estimated water demand of 4 million gallons a year.
- The return of water to the groundwater system via seepage from the settlement basin was simulated by adding a series of virtual injection wells in layer 1 of the model. This technique allows for a convenient means of simulating seepage to the water table within a discrete area. A total of 122 virtual injection wells were added over the 200,000 ft² settlement basin (one virtual injection well per model cell over the area of the settlement basin). The rate for each injection well was set at 0.52 gallons per minute. The cumulative injection rate of all 122 virtual injection wells was 64 gallons per minute (the estimated seepage rate of the settlement basin).
- Aerial recharge over the settlement basin was reduced to zero. The only infiltration occurring over the settlement basin area would be from basin seepage, which is accounted for with the virtual injection wells.
The following additional change to the groundwater model was made for Mining Simulation 1.

- An existing six inch well, screened in the outwash, and located west of the ancillary use area (well PW-C2-202 in Barr, 2009a), was used to provide makeup water for the gravel washing operation prior to development of a mine pit-lake. This well was added to the model (layers 1 to 3) and the pumping rate was set at 70 gallons per minute (amount of makeup water estimated from above).

The following additional changes to the groundwater model were made for Mining Simulation 2

- The mine pit-lake was simulated with a zone of high hydraulic conductivity (Anderson et al., 2002). The mine pit-lake geometry as presented in the mining plan (Dakota Aggregates, 2009) was used.
- Recharge over the mine pit-lake was calculated as the average precipitation rate plus the calculated runoff volume into the lake.
- An average precipitation of 32.6 in/yr was used based on climatic data for 1975-2003 (the same time period used for the SWB model from Barr, 2009a).
- Surface runoff to the lake was calculated from additional output from a modified version of the SWB recharge model accounting for the change in topography from mining. Surface runoff to the lake equated to an additional 11.2 inches/year of recharge applied to the lake area.
- Evaporation from the lake was incorporated using the Evaporation Package for MODFLOW (McDonald & Harbaugh, 1988; Harbaugh & McDonald, 1996) as a steady state annual value. The average pan evaporation for 1975 to 2003 for St. Paul, MN was 37.3 inches per year (University of Minnesota, 2009c). Using a pan coefficient of 0.74 (USDA, 1977) gives an annual average lake evaporation of 27.4 inches per year.
- Makeup water for gravel washing was assumed to be supplied by the mine pit-lake. Withdrawal from the lake was simulated by adding a well in the middle of the high hydraulic conductivity zone representing the lake. This well was set to pump at 70.1 gallons per minute (amount of makeup water estimated from above).

2.3 Results of Simulated Impacts from Groundwater Pumping
Results from the two simulations show that water demands for mining operations will result in minimal effects on the groundwater flow system (Figures 3 & 4). Mining Simulation 1 shows that minimal regional drawdown in the water table aquifer and minimal reduction in hydraulic head in
deeper aquifers (less than 0.1 ft) is expected to occur from the additional pumping of groundwater prior to the formation of a mine pit-lake. The cone of depression from the pumping will extend slightly beyond the UMA boundary. This drawdown is not significant enough to adversely affect any nearby wells (municipal or private) and is small compared to the drawdown expected due to increases in regional demand (see Section 3).

Seepage from the settlement basin will cause an increase of approximately 0.3 ft in the groundwater level below the basin prior to the formation of a mine pit lake (Figure 5). This seepage helps to offset the drawdown in the water table aquifer. The small increase in water level below the basin will cause a slight divergence in flow near the settlement basin (Figure 5); however, the resulting hydraulic gradient will result in flow that will remain to the northeast.

Mining Simulation 2 shows that the mine pit-lake will reduce the hydraulic gradient in the footprint of the lake to near zero. Where portions of the lake extend in the upgradient direction, water levels in the water table aquifer are predicted to be lowered by as much as 1.5 feet (Figures 3 & 4). Where portions of the lake extend downgradient, water levels in the water table aquifer are predicted to increase by up to 4 feet. Overall, creation of the mine pit-lake will tend to increase groundwater levels due to an increase in recharge to the groundwater system via direct precipitation onto the lake surface and surface-water runoff into the lake. The mine pit-lake will act as a flow-through lake with groundwater entering on the west side and flowing out on the east side. Locally, near the shore of the min pit-lake, groundwater flow directions will change slightly relative to Mining Simulation #1. However, groundwater flow from the site will still be to the northeast toward the Mississippi River (Figure 3).
3.0 Simulation of Future Conditions

Significant increases in projected water demand for communities surrounding UMore Park will likely have adverse effects on the groundwater system over the next several decades (Metropolitan Council, 2009). Future (post-mining) groundwater conditions were simulated to assess how the formation of a mine pit-lake may affect groundwater resources in the future.

3.1 Changes to the Groundwater Flow Model

The groundwater flow model of the UMore Park area (Barr, 2009a) was modified to simulate future conditions. Specifically, concerns were raised in comments to the SEAW regarding the influence of the completed mine pit-lake on the future groundwater flow system. The mining operations are projected to last 30 to 40 years. In order to simulate the effect of the future mine pit-lake on groundwater resources, changes in recharge, the anticipated final configuration of the mine pit-lake, and projected municipal water demand were incorporated into the groundwater flow model to approximate conditions for the year 2050.

3.1.1 Changes in Recharge

As development occurs and land use in the area changes, it is expected that recharge will also change. The Soil Water Balance (SWB) recharge model (see Appendix G of Barr, 2009a) was updated with projected land use for UMore Park (Design Workshop, 2009), Rosemount (Rosemount, 2009), Empire Township, and Coates (Perry, 2009). Topography was adjusted in the mining area based on end use topographic contours presented in the mining operation plan (Dakota Aggregates, 2009). All other inputs to the SWB model (e.g., climate data) remained the same as the SWB simulation presented in Barr (2009a). The recharge calculated with the updated SWB model was then incorporated into the groundwater flow model. To maintain consistency with the original model calibration presented in Barr (2009a) a scaling factor of 1.28 was applied to the estimated year 2050 recharge. Details on how the recharge scaling factor was developed are described in Section 5.7.1.3 of the Groundwater Assessment Report (Barr, 2009a).

Overall, the changes in land use anticipated to occur between the present and 2050 do not significantly change the recharge in the model. The year 2050 SWB model predicts an average increase in recharge of approximately 1.7 percent (0.1 inches per year), which is consistent with similar studies (Barr, 2009b). The overall increase in recharge is attributed primarily to a change from agricultural land use to low-density and single-family residential land use. Low-density
residential land use combined with best management practices for stormwater typically result in less runoff than agricultural land use, thus allowing for more infiltration. Also, compared to agricultural land use, evapotranspiration and soil water capacity is typically less in low-density residential areas due to a shallower plant rooting depth (grass lawns compared to corn or soybeans). These factors increase net recharge (see Dripps and Bradbury, 2007). The year 2050 SWB model predicts that recharge over areas converted from agricultural land use to residential land use will increase 1 to 3 inches per year. This increase is mostly offset by a predicted decrease in recharge in areas of higher intensity development, where recharge is predicted to be less due to the significant increase in impervious surface.

3.1.2 Incorporation of Mine Pit-Lake
The mine pit-lake will be created by gravel extraction below the water table. The mine pit-lake was incorporated into the groundwater flow model using the same methods as described for Mining Simulation 2 in Section 2.2.2 of this report.

3.1.3 Increase in Water Demand
Based on projections from the Metropolitan Council, water demand is expected to increase in the area around UMore Park as population increases. The Metropolitan Council estimates that the annual water demand for Rosemount will increase from 910 million gallons in 2008 to 3.49 billion gallons in 2050 (Ross, 2009). For Empire Township, the Metropolitan Council estimates that the annual water demand will increase from 80 million gallons in 2008 to 518 million gallons in 2050 (Ross, 2009).

No additional demand was included in the Metropolitan Council estimates to account for future water use in UMore Park, and no other published projections or estimates for future UMore Park demand were available to include in the modeling. Adding the incremental pumping for a theoretical future UMore Park population would also require a degree of specificity that is not currently possible (e.g., identification of specific water well locations and service areas) given available information.

The projected increases in water demand described above were incorporated into the groundwater flow model by adding additional high capacity wells. Details on the number of additional wells and projected future pumping rates are presented in Table 1. The well capacities for future wells were based on well capacities of existing wells in the area. Projected short-term peak water demands from the Metropolitan Council were used to determine the number of future wells needed. The annual average water demands were used for determining the pumping rates for the simulations. All future
wells were assumed to be open to the Jordan Sandstone. The locations of additional Rosemont wells were based on the planned locations of future well fields (Barr, 2005; WSB, 2007). Additional Empire Township wells were added to the existing well field.

3.2 Assessment of Mining Related Impacts on Future Groundwater Resources

As anticipated, modeling results show a significant decline in water levels in the Jordan, Prairie du Chien, and Quaternary (glacial outwash) aquifers in the year 2050. A drawdown of up to 15 feet may occur in all these aquifers over the UMA. The decline in water levels is directly attributable to the over fourfold increase in projected municipal water demand and is independent of the proposed mining operations. These results are consistent with conclusions from regional assessments conducted by the Metropolitan Council (2009) and Scott County (Barr, 2009b).

Two simulations were run to assess the incremental effect of the mine pit-lake; one with the mine pit-lake included in the simulation and one without the mine-pit lake. Both simulations included the increased municipal pumping and changes in recharge. A comparison of the two simulations shows that the presence of the mine pit-lake reduces the future drawdown because of increased recharge to the groundwater system. The increase in 2050 water levels with the mine pit-lake is 1 to 2 feet higher than levels in the future simulation where the mine pit-lake is not included (Figure 6).

Groundwater flow from the UMA will be to the northeast towards the Mississippi River under these scenarios (Figure 6).

The projected future drawdown indicates that the water level in the mine pit-lake will be about Elevation 870 MSL, approximately 15 feet below the current water table elevation at this location.
4.0 Drinking Water Supply Management Areas

Another potential environmental issue identified in the SEAW was the location of operations with respect to future municipal Drinking Water Supply Management Areas (DWSMAs). Parts of the UMA are located within the DWSMA for the City of Rosemount (Barr, 2010). A DWSMA is established to help water and land use managers plan development within areas that might conceivably result in an impact to public water supplies. The Minnesota Department of Health allows for mining within a DWSMA; however, guidance and special considerations are offered for mining in portions of a DWSMA where the aquifer is vulnerable (MDH, 2009). Over the course of mining in the UMA, the extents of the DWSMAs for nearby communities are likely to expand due to increased pumping for municipal water supply and the installation of additional wells to meet the future demand. To help plan for mining activities, the estimated extent of the DWSMAs for Rosemount and Empire Township under projected future conditions (approximately year 2050) and aquifer vulnerability in the mining area were evaluated.

4.1 Wellhead Protection Area (WHPA)

A wellhead protection area (WHPA), as defined by Minnesota Statute 103I.005, is “the surface and subsurface area surrounding a well or well field that supplies a public water system, through which contaminants are likely to move toward and reach the well or well field.” Minnesota Rule 4720.5510 defines the minimum time of travel for defining a WHPA as ten years. Depending on local geology and the aquifer used, capture zones are defined by evaluating porous media groundwater flow or a combination of porous media flow and fracture flow. Porous media flow is typically evaluated using a groundwater flow model and fracture flow is typically evaluated using analytic methods developed by the Minnesota Department of Health (MDH, 2005). For the UMore area, estimated future WHPAs are defined using both porous media flow and fracture flow methods.

4.1.1 Future Water Demand

The estimated future WHPAs for both Rosemount and Empire Township were delineated using projected water demands as described in Section 3.1.3 if this report. Coates, located east of the UMA, does not have a municipal water supply system, and does not appear to have current plans to build one, so an estimated future WHPA was not delineated for Coates.
4.1.2 Porous Media Flow Evaluation

The estimated future porous-media-flow capture zones for each well were delineated using a slightly modified version of the groundwater flow model developed for the UMore park area (Barr, 2009a).

4.1.2.1 Modifications to the Groundwater Flow Model

Minor changes were made to the groundwater flow model to accurately simulate future conditions. Additional municipal wells were added to the model and pumping rates were adjusted to represent projected future water demand as described above. The model grid was refined in the vicinity of municipal wells to allow for a more accurate delineation of the porous-media-flow capture zones. The grid cell size was set at 10 x 10 meters around the wells and expands in size to 200 x 200 meters away from the wells. Recharge was adjusted based on future land use changes as described in Section 3.1.1. The mine pit-lake was added to the model as described in Section 2.2.2.

4.1.2.2 Particle Tracking

The estimated future10-year porous-media-flow capture zones were delineated using particle tracking from the groundwater flow model. A total of 800 particles were tracked from each well. Particles were released from 15 vertical points along the open section of each well within the Jordan Sandstone. Porosity values used for the Quaternary sediments, St. Peter Sandstone, Prairie du Chien Group and Jordan Sandstone were 0.25, 0.283, 0.056, and 0.2 respectively (after Norvitch et al., 1974, Schwartz and Zhang, 2003). Particles were tracked backwards in time from each well for ten years. The areas encompassed by the particle traces when viewed in plan view were then outlined to define the porous media capture zones (Figure 7).

4.1.3 Fracture Flow Capture Zones

The Prairie du Chien Group is classified as being highly fractured over much of the Twin Cities Basin and has been shown to be hydraulically connected to the Jordan Sandstone in the UMore Park area (Barr, 2002; Palen, 1990). Because of the hydraulic connection between the two aquifers, MDH rules, in relation to wellhead protection areas, require the delineation of fracture flow capture zones (MDH, 2005).

Estimated future fracture flow capture zones were delineated for all Rosemount and Empire Township municipal wells (current and future) using delineation technique number 4 from MDH guidance (MDH, 2005). Preliminary fixed-radius fracture-flow capture zones for all municipal wells were extended to account for overlap with the fixed radius capture zones of nearby wells as appropriate. The general procedure for accounting for overlapping capture volumes presented in
MDH guidance (MDH, 2005) was followed except the areas of overlap were calculated using geometric functions within ArcGIS rather than using the short and long access of overlap. Calculation of overlap with ArcGIS allows for a more accurate redistribution of the shared volumes and allows for easier calculation when the capture zones of more than two wells overlap. Fixed radius capture zones were then extended up gradient based on the direction of groundwater flow as determined from the groundwater flow model. Composite fracture-flow capture zones were defined by combining the individual components of the fracture flow analysis (Figure 7).

4.1.4 Estimated Drinking Water Supply Management Area (DWSMA)

The estimated future DWSMA encompasses the entire WHPA (capture zones) as described above (Figure 7). A DWSMA must be defined by easily identifiable boundaries such as roads, parcels, or public land survey boundaries. Because roads and parcels in this area are subject to change, the estimated future DWSMA was defined using quarter section boundaries.

4.2 Aquifer Vulnerability and Mining Considerations

Aquifer vulnerability in the proposed mining area was assessed (Figure 8). The Minnesota Department of Health allows mining within a DWSMA; however, they offer guidance and special considerations for mining in areas of a DWSMA were the aquifer is vulnerable (MDH, 2009).

Geologic logs listed in the Minnesota Geological Survey (MGS) County Well Index for wells in the vicinity of the DWSMA along with borehole logs and geologic cross sections for UMore Park (Barr 2009a; ProSource Technologies, 2008) were reviewed and “L scores” were assigned to each well based on the thickness of confining units above the Jordan Sandstone at each well location (see MnDNR (1991) for a discussion of how to determine L scores). L-scores were compared to the surficial geology map from Meyer (2007), the bedrock geology map from Mossler and Tipping (2000), and a map of the extent of till below the water table (Barr 2009a, Figure 16). In general, areas with L-scores less than 1 were assigned an aquifer vulnerability of “high,” areas with L-scores between 1 and 4 were assigned an aquifer vulnerability of “moderate,” and areas with L-scores greater than 4 were assigned an aquifer vulnerability of “low.”

The vulnerability of the aquifer was used to site the ancillary use facility (AUF) that will serve as a storage and production area to support the mining operations. The selected location of the mine-site ancillary facilities is an area where the aquifer is mostly classified as having a low vulnerability due to the underlying glacial till geology. The entire area of the planned ancillary facilities is located entirely outside of the estimated future DWSMA. The AUF will be used to store petroleum, asphalt,
binder cement, and recycled asphalt products (RAP). Therefore, storage of production materials and fluids poses little threat to drinking water supplies.
5.0 Simulation of Hypothetical Release to Aquifer

Mining operations are anticipated to involve the use of two 12,000 gallon above ground, double-walled fuel tanks for fueling on-site equipment that will be located within the AUF. In addition, asphalt cement and RAP will also be stored in the AUF. These areas and the tanks within them will have multiple safeguards against spills and leaks, be subject to routine inspections and testing, and governed by a site specific spill prevention control and countermeasures (SPCC) plan. In addition, they are located atop a thick glacial clay unit that is outside of the vulnerable aquifer area. Therefore, a release of chemicals from the facility is unlikely to affect the underlying aquifers.

Both petroleum fuel and asphalt products contain a mixture of hydrocarbons. Some of these hydrocarbons include polycyclic aromatic hydrocarbons (PAHs) such as benzo(a)pyrene that are found in asphalt products. Other constituents such as benzene, toluene, ethyl benzene, and xylene (BTEX) are commonly found in petroleum. The majority of the other hydrocarbon constituents are either not liquid in the subsurface (asphalt cement, RAP) or are less soluble, less mobile, or less toxic than BTEX.

5.1 Modeling Approach

In evaluating the likely impacts from release, Barr adopted a conservative approach in conducting simulations of a release from the AUF. A petroleum fuel release was selected as a proxy for contaminant releases generally, because the fuel would contain BTEX which includes benzene, a suspected human carcinogen. Also, BTEX was selected to model the fuel release because it is generally more mobile in the environment than other carcinogens such as PAHs including benzo(a)pyrene. Other potential contaminants of concern (such as PAHs, or metals) are typically not very soluble (with the exception of the PAH naphthalene) and tend to be strongly sorbed in the unsaturated zone (Townsend, 1998; Barker, 1998). Therefore, the use of BTEX provides a relatively conservative or “worst case” proxy for evaluation of a hypothetical release of other organic contaminants potentially stored or used at the UMA. PAHs are generally less prone to biodegradation than BTEX compounds, but this difference is minor relative to the lower solubility and mobility of PAHs described above.

As described above in Section 4.3, the entire area of the planned ancillary facilities area is located outside the estimated future DWSMA for the city of Rosemount and is located in an area classified as
having a low vulnerability to aquifer contamination due to the thick sequence (50-150 feet) of both saturated and unsaturated glacial till (see Barr 2009a for a detailed description of the local geology).

The location of the AUF and the use of secondary containment systems significantly limit the potential for contamination to source water aquifers. However, for this simulation, it was assumed that the release of petroleum would bypass the secondary containment systems and remain undiscovered by routine monitoring and inspection, with the free-phase layer of petroleum eventually migrating downward to the water table to act as a constant stationary source for a dissolved phase plume of BTEX. The sorption, attenuation, and biodegradation of the released petroleum in the unsaturated zone are not characterized in this evaluation, although these factors would occur and reduce the amount of petroleum reaching the water table.

For this simulation, it is assumed that the contaminants (BTEX) enter the groundwater system in the uppermost saturated zone (layer 1 of the groundwater flow model). Only the dissolved phase was simulated. The source of the dissolved phase contaminants was assumed to be constant with a concentration equal to the effective solubility of BTEX from diesel fuel in water.

From the source location, the simulated contaminant moves advectively with groundwater, is acted upon by dispersion, is retarded by sorption reactions, and biodegrades as a function of the concentration of the contaminant and oxygen. Retardation slows the movement of the contaminant and biodegradation removes mass from solution, thereby reducing the concentrations over time. The contaminant moves downgradient until it is completely biodegraded.

All of the BTEX compounds can be degraded through naturally occurring microbially-mediated oxidation-reduction (redox) reactions. In these reactions, electrons are transferred from organic contaminants (i.e., BTEX) to electron receptors. Biodegradation of BTEX compounds occurs in both aerobic and anaerobic conditions. Factors that affect the rate of biodegradation include the presence of food sources for the microbes, the presence of electron donors or receptors (other than oxygen), and the pH and organic content of the aquifer. The degradation processes typically involve making simpler compounds from complex compounds through catalyzation by bacteria. For petroleum compounds, aerobic degradation processes use oxygen as the primary electron receptor and occur at much high rates than do the anaerobic degradation processes. For this model only biodegradation from aerobic conditions was considered (i.e., O₂ was the only electron receptor). Other electron receptors, used under anaerobic conditions, such as nitrate, manganese, ferric iron, and carbon dioxide are likely available locally (especially nitrate); however, they were not considered in this
model. Considering only oxygen as an electron receptor and assuming no biodegradation involving other electron receptors is conservative.

Rather than modeling the individual BTEX compounds, BTEX was modeled as a single solute with the characteristics of benzene (the predominant aromatic with the lowest retardation coefficient and highest solubility). A utilization factor of 3.14 was used for the degradation of BTEX in the presence of oxygen (Clement, 1998); meaning 3.14 mg of oxygen is required to degrade 1 mg of BTEX. The utilization factor used is the average for all of the BTEX compounds (Zheng and Bennett, 2002).

The reactive contaminant transport code RT3D (Clement, 1998), developed to aid in the evaluation of natural attenuation, was chosen for this study. RT3D is a modified version of MT3D (Zheng, 1990) capable of simulating multiple species reactivity (i.e., reactivity between oxygen and BTEX). RT3D uses the groundwater flow field as determined by a MODFLOW groundwater flow simulation to solve for solute concentrations within that flow field. The code is capable of simulating the major processes of contaminant transport including: advection, dispersion, diffusion, retardation via sorption, and multiple species chemical reactions.

5.2 Modifications to the Groundwater Flow Model

The MODFLOW groundwater flow model developed for UMore area and described in the groundwater assessment report (Barr, 2009a) was used for the simulation of a hypothetical diesel fuel spill. For details on model development and calibration see the groundwater assessment report (Barr, 2009a). Minor changes were made to the groundwater flow model to accurately simulate the transport of BTEX compounds from a hypothetical spill. The model grid was refined around the area of the hypothetical spill with the smallest cell size being 3.5 meters by 3.5 meters. Pumping for mining operations and induced infiltration from the wash water settlement basin were included as described for Mining Simulation 1 in Section 2.2 of this report.

5.3 Transport Parameters

The following contaminant transport parameters were used in the RT3D transport simulations: longitudinal dispersivity, ratio of horizontal to longitudinal dispersivity, ratio of vertical to longitudinal dispersivity, distribution coefficient ($K_d$), soil bulk density, and porosity. Diffusion was not simulated explicitly as its effect is considered negligible because the flow velocities are much too large to see the effects of diffusion or to differentiate between the effect of diffusion and dispersion (Fetter, 1999).
Longitudinal dispersivity is scale dependent. Based on an empirical model developed by Xu and Eckstein (1995) longitudinal dispersivity was set at 6 meters. Using a general rule of thumb developed by Zheng and Bennett (2002) the transverse dispersivity was set at 0.6 meters (one order of magnitude less than the longitudinal dispersivity) and the vertical dispersivity was set at 0.06 meters (two orders of magnitude less than the longitudinal dispersivity).

A linear sorption isotherm was applied, where the distribution coefficient ($K_d$) was set equal to the slope of the sorption isotherm. $K_d$ can also be described as a function of the organic carbon partition coefficient ($K_{oc}$) and the fraction of organic carbon in the soil ($f_{oc}$)

$$K_d = K_{oc} \times f_{oc}$$

A $K_{oc}$ for benzene of 83 cm$^3$/g was used (MPCA, 2005). The $f_{oc}$ was assumed to be 0.0001, which is on the low end of suggested values for sand (MPCA, 2005). A soil bulk density of 1.787 gm/cm$^3$ was used, based on data presented in the groundwater assessment report (Barr, 2009a).

Porosity values for the Quaternary sediments, St. Peter Sandstone, Prairie du Chien Group, and Jordan Sandstone were assumed to be 0.25, 0.283, 0.056, and 0.2 respectively (Norvitch et al., 1974, Schwartz and Zhang, 2003) The model shows that contaminants do not reach the lower aquifers so porosity values for the lower aquifers do not play a role in the transport simulation.

### 5.4 Source Terms

For BTEX, it was assumed that a continuous source was present at the planned location of fuel storage tanks. In the source zone, the concentration of BTEX at the water table (model layer 1) was set at 2.78 mg/L, which is the effective solubility of total BTEX in water from diesel fuel (EPA, 2007). Initial concentrations of BTEX elsewhere were assumed to be zero as no BTEX compounds are known to be present in the groundwater near the hypothetical release location.

The dissolved oxygen concentration of infiltrating groundwater (recharge) was assumed to be 7 mg/L. Initial dissolved oxygen in the groundwater was set at 6.28 mg/L based on the average dissolved oxygen concentration from nearby monitoring wells (Barr, 2009a).

### 5.5 Results of Simulation of Hypothetical Fuel Release

Results from the simulation show that the BTEX plume migrates approximately 550 feet to the northeast before reaching a static equilibrium after approximately 3 years (Figure 9). The simulation indicates that none of the BTEX constituents migrate laterally off the UMore Park property or
vertically below the outwash/glacial till. Because BTEX is more mobile than typical PAH compounds, the modeling results indicate that PAH compounds would similarly be limited to the UMore Park site.
6.0 References Cited


Dakota Aggregates, LLC. 2009. Proposed UMore Park Nonmetallic Mining Operation, UMore Park, City of Rosemount and Empire Township.


Rifai, H.S., P.B. Bedient, R.C. Borden, and J.F. Haasbeek. 1987. BIOPLUME II – Computer model of two-dimensional transport under the influence of oxygen limited biodegradation in groundwater, user’s manual, Version 1.0, Rice University, Houston, TX.


Tables
Table 1
Projected Future Water Demand and Well Pumping Rates
UMore Mining Area
Dakota County, MN

<table>
<thead>
<tr>
<th>Well</th>
<th>Unique Number</th>
<th>Unique Capacity (gpm)</th>
<th>2008 Water Withdrawal (Mgal)</th>
<th>2050 Projected Water Withdrawal (Mgal)</th>
<th>Pumping Rate Used in Model (m$^3$/day)</th>
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<td>1000$^a$</td>
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Total annual usage (Mgal) 910.4 3,493.0

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<th>Well</th>
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<th>Unique Capacity (gpm)</th>
<th>2008 Water Withdrawal (Mgal)</th>
<th>2050 Projected Water Withdrawal (Mgal)</th>
<th>Pumping Rate Used in Model (m$^3$/day)</th>
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<td>122.0</td>
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</table>

Total annual usage (Mgal) 80.1 518.3

$^a$ Well capacity is estimated
Figures
UMORE PARK AND UMA LOCATION
UMore Mining Area
Dakota County, MN

Source: MnDOT, MN DNR, Dakota County, Barr, SEH, HKGi.
USGS topographic map background downloaded from the U.S.
Department of Agriculture, Natural Resources Conservation Service.

Figure 1
Figure 2

CONCEPTUAL WATER DEMAND FOR GRAVEL MINING OPERATIONS
UMore Mining Area
Dakota County, MN

Makeup Water 70.1 gpm
Evaporation 6.4 gpm
Wash water recirculated > 1000 gpm
Concrete Production 7.6 gpm

Seepage 63.7 gpm
Unsaturated Zone
Saturated Zone

Glacial Outwash Aquifer
Prairie du Chien Group Aquifer

Note: Max capacity approx. 250 gpm.
Makeup water likely to be pumped from pit-lake in later stages of mining.

Note: Max capacity approx. 150 gpm
Figure 3

effect of mining operations on groundwater system: water table aquifer

Simulated change in water level elevations from current conditions due to groundwater pumping related to mining activities, assuming that a mine pit-lake is not present. Wash water is withdrawn from a well open to the sand and gravel outwash. Concrete production water is withdrawn from a well open to the Prairie du Chien Group aquifer. Positive values indicate an increase in water levels from current conditions. Negative values indicate a decrease in water levels from current conditions.

Simulated change in water level elevations from current conditions due to mining activities, assuming the mine pit-lake is fully developed. Wash water is withdrawn from the mine pit-lake. Concrete production water is withdrawn from a well open to the Prairie du Chien Group aquifer. Positive values indicate an increase in water levels from current conditions. Negative values indicate a decrease in water levels from current conditions.
Simulated change in hydraulic head from current conditions due to groundwater pumping related to mining activities, assuming that a mine pit-lake is not present. Wash water is withdrawn from a well open to the sand and gravel outwash. Concrete production water is withdrawn from a well open to the Prairie du Chien Group aquifer. Positive values indicate an increase in hydraulic head from current conditions. Negative values indicate a decrease in hydraulic head from current conditions.

Simulated change in hydraulic head from current conditions due to mining activities, assuming the mine pit-lake is fully developed. Wash water is withdrawn from the mine pit-lake. Concrete production water is withdrawn from a well open to the Prairie du Chien Group aquifer. Positive values indicate an increase in hydraulic head from current conditions. Negative values indicate a decrease in hydraulic head from current conditions.
Figure 5
GROUNDWATER CONTOURS NEAR SETTLEMENT BASIN:
MINING SIMULATION 1
UMore Mining Area
Dakota County, MN

contour interval = 0.1 ft
Simulated future water level elevations with increased municipal water demand, changes in recharge due to land use change, and full development of the mine pit-lake. Arrows indicate the groundwater flow direction.

Comparison of simulated future water level elevations with and without the mine pit-lake. Contours indicate the net difference in simulated future water level elevations attributed to the formation of the mine pit lake. Positive values indicate a net water level rise in feet. Negative values indicate a net water level drop in feet.

Figure 6
SIMULATION OF FUTURE CONDITIONS
UMore Mining Area
Dakota County, MN
Figure 7

SIMULATION OF FUTURE MUNICIPAL WELL CAPTURE ZONES AND DWSMA UMore Mining Area Dakota County, MN

Municipal Supply Wells

- Existing Well
- Future Well
- Estimated Future DWSMA
- UMore Mining Area (UMA)
- Estimated Future Porous Media Capture Zone
- Estimated Future Fracture Flow Capture Zone

Note: Wells denoted with an "R" are Rosemount wells, wells denoted with an "E" are Empire Township wells.
Figure 8
AQUIFER VULNERABILITY
UMore Mining Area
Dakota County, MN
Figure 9

HYPOTHETICAL PETROLEUM RELEASE SIMULATION
UMore Mining Area
Dakota County, MN

Two Months After Release
Six Months After Release
One Year After Release
Two Years After Release
Three Years After Release
Five Years After Release

Total BTEX (mg/L)

0 - 0.2
0.2 - 0.4
0.4 - 0.6
0.6 - 0.8
0.8 - 1.0
1.0 - 1.2
1.2 - 1.4
1.4 - 1.6
1.6 - 1.8
1.8 - 2.0
2.0 - 2.2
2.2 - 2.4
2.4 - 2.6
2.6 - 2.78

UMore Mining Area Boundary (UMA)

Reference Map

Ancillary use and fuel storage location

Feet

0 500 1,000