Groundwater-Flow and Solute-Transport Modeling

Jordan Aggregates EIS

Prepared for
Scott County

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(revised September 2013)

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1.0 Conceptual Hydrogeologic Model

1.1 Purpose and Scope of Numerical Modeling

A numerical groundwater flow model was developed and calibrated for the purpose of evaluating certain potential groundwater impacts that may result from the Jordan Aggregates Proposed Mining Operation in Sand Creek Township, Scott County, Minnesota. This evaluation is in the context of the preparation of an Environmental Impact Statement (EIS), which was required by the Responsible Government Unit (RGU), Scott County. A Scoping Decision Document (SDD) was accepted by Scout County in November 2011. The SDD identified certain groundwater impacts be further evaluated as part of the EIS.

In November 2011, an EIS Work Plan was prepared by Barr Engineering Co. As part of the evaluation of potential groundwater impacts, the following Work Plan elements were identified:

- An aquifer test of the Franconia-Ironton-Galesville (FIG) aquifer is to be conducted by the Proposer for the purposed of evaluating alternative water supply sources and to obtain data to aid in calibrating a groundwater flow model. If necessary, a new FIG aquifer well will be installed to perform this test
- The existing MODFLOW groundwater flow model that was initially developed by Barr Engineering Co. to facilitate review of the Proposers Environmental Assessment Worksheet (EAW) is to be refined. The refinements are to included:
    - Parameterization of hydraulic conductivity values using data from previously performed slug tests;
    - Modification of layer geometries, as necessary, to accommodate new drilling information;
    - Incorporation of local wetlands as discrete features in the model;
    - Calibration of the groundwater model to water levels measured in wells and calibration to aquifer test data.

These data collection and model-refinement efforts are intended to provide a more reliable evaluation of the impact to groundwater of various alternatives. A maximum of three alternatives (the preferred alternative and two additional alternatives) are to be evaluated using the groundwater flow model. Each alternative will be evaluated with respect to:

- Changes in flow path and flow rate of groundwater from the mine pit after flood inundation;
- Changes to the water table;
- Changes to baseflow of Sand Creek;
- Changes in flow direction and potentiometric head in the Jordan Sandstone and the FIG aquifer;
- Identification of well potentially impacted;
- Identification of wetlands impacted, if any, and magnitude of hydrologic impact;
- Potential impacts to future water supplies for the City of Jordan.

1.2 Regional Hydrogeologic Setting

1.2.1 Geologic Setting

Geologic units underneath northern Scott County and throughout the metropolitan area fall into three broad categories: (1) Precambrian volcanic and crystalline rocks; (2) late-Precambrian through Ordovician sedimentary rocks; and (3) Quaternary unconsolidated deposits. The Precambrian volcanic and crystalline rocks generally are not considered major water-bearing units and are at a considerable depth below ground surface in northern Scott County (although they do subcrop in the southwestern part of the County). The late-Precambrian through Ordovician sedimentary rocks make up the major regional aquifers and aquitards in the metropolitan area, and include units such as the Hinckley Sandstone, the Ironton-Galesville sandstone, the Jordan Sandstone, and the Prairie du Chien Group. The Quaternary unconsolidated deposits include glacial outwash, glacial till, and alluvial deposits.

Portions of Iowa, Minnesota, Wisconsin, Illinois, and Missouri were in a depression (called the Ancestral Forest City Basin) covered by a shallow eperic sea in the late-Precambrian (@ 570 million years ago). A northern bay of this sea extended over a syncline in the Precambrian Lake Superior Volcanic rocks into southern Minnesota and western Wisconsin. This bay is called the Hollandale Embayment. The Hollandale Embayment extended from north of Hinckley to the Iowa border, deepening to the south. From the late-Precambrian (@ 570 million years ago) through the Devonian (@ 355 million years ago) the water level in the eperic sea fluctuated causing transgressions (a rising of sea level) and regressions (a dropping of sea level). Depending on the sea level, different sediments were deposited. For example, as the sea level rose, beach sands were deposited (e.g. the

Jordan Sandstone), followed by a deeper water environment were carbonate deposits formed from shell-bearing sea animals (e.g. Prairie du Chien Group).

During this depositional process, additional tectonic activity took place, forming a small basin in the Hollandale Embayment, known as the Twin Cities Basin. Faulting of the existing sedimentary rocks took place during the formation of the Twin Cities Basin.

An extended period without significant deposition took place after the Devonian (@ 355million years ago), as the seas retreated for the last time. If additional deposition did take place, these rocks have been subsequently eroded away. At the beginning of the Quaternary (@ 1.5 million years ago), the great continental ice sheets formed and glaciers moved into the area. The glaciers eroded away all or portions of the upper sedimentary units in many locations. Glacial till was deposited underneath and adjacent to the glaciers. Rivers running from the glaciers deposits sand and gravel (outwash). Ice blocks were left in place to melt as the glaciers retreated. Several glacial advances and retreats took place during the Quaternary.

The glacial rivers incised through the glacial deposits and into the bedrock units as the glaciers retreated. These rivers, and their associated tributaries, changed channel locations upon glacial re-advancement, and subsequent deposits formed buried bedrock valleys. The ancestral Mississippi River and the River Warren (ancestral Minnesota River) incised back into the glacial deposits, forming wide river valleys with alluvial terrace deposits and backwater areas. The River Warren, in particular, contributed to the current landscape in northern Scott County by first incising a very wide river channel (the boundaries of which are denoted by the Minnesota River bluff) and then subsequently filling the channel with alluvial deposits as the River migrated to its approximate current location as the Minnesota River.

1.2.1 Regional Hydrostratigraphic Units

Hydrostratigraphic units are either aquifers (one or more geologic units capable of transmitting usable quantities of water, dominated by horizontal groundwater flow) or aquitards (one or more geologic units of low permeability, dominated by vertical groundwater flow). Hydrostratigraphic units comprise geologic formations of similar hydrogeologic properties. Several geologic units might be combined into a single hydrostratigraphic unit or a geologic formation may be subdivided into a number of aquifers and aquitards.

1.2.1.1 Mt. Simon-Hinckley Aquifer

The Mt. Simon Sandstone and the Hinckley Sandstone are generally not differentiated from one another for hydrogeologic purposes and are considered to function as a single aquifer. The Mt.

Simon-Hinckley aquifer is not as well connected to major rivers and streams in the region (compared to other aquifers of younger formations), principally because the overlying Eau Claire Formation is a substantial and areally extensive aquitard.

Data on groundwater movement in the Mt. Simon-Hinckley aquifer is limited but flow is generally different from the overlying aquifers – flowing northeast to the pumping centers of the central cities area in Hennepin County. The Minnesota DNR has placed a moratorium on usage of the Mt. Simon-Hinckley aquifer in the Twin Cities because of its isolation from the major river systems and its limited recharge areas. There are no high-capacity wells that utilize the Mt. Simon-Hinckley aquifer in Scott County.

1.2.1.2 Eau Claire Formation

The Eau Claire Formation is a substantial confining unit, consisting of 60 to 110 feet of low-hydraulic conductivity siltstone, shale, and silty sandstone. The Eau Clair Formation subcrops beneath glacial deposits in southwestern Scott County (southwest of Prior Lake) and is eroded away in some locations.

1.2.1.3 Ironton-Galesville Aquifer

The Ironton-Galesville aquifer, which consists of the Ironton Sandstone and the Galesville Sandstone, has not been highly utilized in Scott County because sufficient water supplies can typically be obtained from shallower units, such as the Prairie du Chien-Jordan aquifer. Recently, the Ironton-Galesville aquifer (along with the Franconia Formation) has undergone greater evaluation by the Minnesota Geological Survey, particularly in western Hennepin County, where the Prairie du Chien-Jordan aquifer is not present.

In deep bedrock conditions, hydraulic conductivity values typically range from 1.5 to 28 feet per day and average about 10 feet/day (based on specific capacity tests). In shallow bedrock conditions, interconnected fracture systems seem to develop, resulting in average hydraulic conductivity values of about 28 feet/day (Runkel et al., 2003).

1.2.1.4 Franconia Aquifer

The Franconia Formation is often lumped together with Ironton-Galesville Sandstones (as the FIG aquifer) or is lumped together with the overlying St. Lawrence Formation as a regional aquitard. The lower portion of the Franconia Formation is a separating confining layer above the Ironton-Galesville aquifer. Where the Franconia Formation is the first bedrock (below glacial deposits), weathering and fracturing can make it of sufficient productivity that it can be used for water supplies.

1.2.1.5 St. Lawrence Confining Layer

The St. Lawrence Formation is a regional leaky confining layer (aquitard) that separates the Franconia aquifer from the overlying Prairie du Chien-Jordan aquifer. Runkel et al. (2003) describe the St. Lawrence Formation as having low bulk hydraulic conductivity in the vertical direction and can provide confinement. These confining characteristics are present where the St. Lawrence Formation is relatively deep and overlain by the Jordan Sandstone. However, where the St. Lawrence Formation is at shallow depth, interconnecting fractures make the St. Lawrence Formation a relatively high yielding aquifer.

1.2.1.6 Prairie du Chien-Jordan Aquifer

The Prairie du Chien Group and the Jordan Sandstone are typically treated as a single aquifer system in the Twin Cities area; the Prairie du Chien-Jordan Aquifer. The Prairie du Chien-Jordan Aquifer supplies 80 percent of the groundwater pumped in the Twin Cities area, with yields from 85 to 2,765 gpm (Schoenberg, 1990). Groundwater flow in the Jordan Sandstone is primarily intergranular but secondary permeabilities undoubtedly develop due to jointing and differential cementation (Schoenberg, 1990). Groundwater flow in the Prairie du Chien Group is through fractures, joints, and solution features. A small number (perhaps 3 to 5) horizontal fracture zones are responsible for the majority of flow in the Prairie du Chien Group (Runkel et al., 2003).

A tacit assumption that is made when two geologic units are combined into a single aquifer is that there is not a significant head difference between the two units. On a regional basis, this is likely a good assumption; head differences (where available) are relatively insignificant between the two units. However, there is evidence that local differences in head between the two units can develop, especially where pumping is only in the Jordan Sandstone. An example of this phenomenon is in the vicinity of St. Paul Park Well No. 1 and the Marathon Ashland Petroleum Company (formerly Ashland Petroleum) refinery. A pumping and recovery test was performed in the Jordan Sandstone using St. Paul Park Well No. 1 while monitoring at multiple levels in the Prairie du Chien Group and the Jordan Sandstone. A substantial cone of depression developed in the Jordan Sandstone but very little drawdown was observed in the Prairie du Chien Group piezometers (Barr Engineering, 1990). High capacity production wells are also operated in the Jordan Sandstone at the Marathon Ashland refinery with little response in the Prairie du Chien Group. In this area, the two units are distinctly different aquifer systems under hydraulic stresses.

An artificial recharge study on the Prairie du Chien-Jordan Aquifer was conducted by the U.S. Geological Survey in West St. Paul (Reeder, 1976). Reeder (1976) notes that "[a]lthough the Prairie du Chien and the underlying Jordan Sandstone are hydraulically connected, the water levels in the

Prairie du Chien wells are at an altitude of 724 feet (221 m) and in the Jordan well at an altitude of 722 feet (220 m)", thus indicating some differences in hydraulic head. During a pumping test in the Prairie du Chien Group, drawdown in the Prairie du Chien Group was noted to be greater than in the Jordan Sandstone. The study indicates that the two units behave differently even though they are hydraulically connected.

Tipping (1992, unpublished MS Thesis) conducted an isotopic and chemical study of groundwater flow in the Prairie du Chien Group and Jordan Sandstone in northern Scott and Dakota Counties. Tipping (1992, unpublished MS Thesis) found that recharge from the Prairie du Chien Group to the Jordan Sandstone was induced, in part, by high capacity pumping in the Jordan (e.g. Apple Valley). In Apple Valley, a sustained vertical gradient between the two units develops. Different isotopic signatures for the two units also manifest themselves in some locations. Tipping (1992, unpublished MS Thesis) notes that the upper member of the Jordan Sandstone (Coon Valley Member) is typically fine-grained, well-cemented, has a lower conductivity than beds above and below it, and may serve locally as an aquitard.

A study by Runkel et al. (2003) has demonstrated that the lower portion of the Oneota Dolomite is massive, of low permeability, relatively unfractured, and acts as a regional aquitard that separates the permeable portions of the Prairie du Chien Group (the upper part of the Oneota Dolomite and the Shakopee Formation) from the Jordan Sandstone.

1.2.1.6.1 Jordan Sandstone

Many high-capacity wells are completed solely within this unit. The unit is approximately 100 feet thick. The degree of cementation of the Jordan Sandstone varies (Tipping, 1992, unpublished MS thesis). Hydraulic conductivity can vary, depending upon the degree of cementation. Schoenberg (1990) reports a range of horizontal hydraulic conductivity values from 19 to 107 feet/day from field tests.

The Jordan Sandstone subcrops beneath glacial drift and alluvium in major river valleys, which are the primary discharge zones. In these areas, hydraulic head can be expected to be at or slightly above the elevation of the river. Discharge via high-capacity wells is also a significant discharge route. Recharge is primarily through leakage from the overlying Prairie du Chien Group. Flow in the Jordan Sandstone is to the north, where groundwater discharges into the Minnesota River.

1.2.1.6.2 Shakopee Formation and Oneota Dolomite

The basal Oneota Dolomite is a regional confining layer (aquitard) in Scott County and throughout southeastern Minnesota (Runkel et al., 2003). The confining unit is about 40 feet thick and consists

of massive, relatively unfractured dolomite. Packer tests performed by the Minnesota Geological Survey suggested that the unfractured portions of the basal Oneota Dolomite may have hydraulic conductivity values as low as 10-4 feet/day (Robert Tipping, personal communication). There is some fracturing that cuts through the basal Oneota Dolomite – this fracturing provides the means for leakage between the Jordan Sandstone, below, and the Shakopee Formation of the Prairie du Chien Group, above.

The level of hydraulic communication between the Jordan Sandstone and the Shakopee Formation can only be tested with pumping tests using wells completed only within the Jordan Sandstone. A small number of such tests have been performed. The results of these tests indicate a relatively uniform leakage resistance – typically 2,000 to 6,000 days.

Along with the Oneota Dolomite, the Shakopee Formation makes up the Prairie du Chien Group. The areal extent of the Prairie du Chien Group is similar to that of the underlying Jordan Sandstone. Horizontal hydraulic conductivity values are in the same range as those of the Jordan Sandstone.

Flow in the Prairie du Chien Group is dominated by 3 to 5 relatively thin (5 to 10 feet) zones of highly connected horizontal fractures in the Shakopee Formation and the upper part of the Oneota Dolomite (Runkel et al, 2003). Horizontal hydraulic conductivity values within these thin zones can exceed 1,000 feet/day. Between these fracture zones, the hydraulic conductivity is much lower. At a very local scale, these horizontal zones of high flow may not be well connected but regional fractures and joints provide good connection on a more regional basis. This allows the upper part of the Prairie du Chien Group to be treated as a single aquifer system.

Unlike deeper hydrostratigraphic units, the Prairie du Chien Group can be unconfined. Where the drift is thin or absent, the water table resides in the Prairie du Chien Group. Recharge is primarily through leakage from the overlying glacial drift. Discharge is to the glacial drift in the valleys of major rivers.

1.2.1.7 Glacial Drift Aquifer

Glacially deposited sediment can be very complex and unpredictable. In many areas, the existing data will likely be sparse or so complex that the entire thickness of glacial deposits can only be treated as a single aquifer.

At a given location, the Glacial Drift aquifer may contain several interfingering sand-gravel layers with till; however, these discrete zones may not be correlatable over an extended area. The transmissive sediments are therefore considered part of the same aquifer system and are assumed to be hydraulically connected

The Glacial Drift aquifer is in relatively good connection with local streams and lakes. Recharge is primarily by infiltrating precipitation and leakage from perched lakes, such as Prior Lake. Discharge is to streams, lakes, and leakage to underlying aquifers.

In most of Scott County, south of the Minnesota River bluffs, the Glacial Drift Aquifer is thick (over 100 feet thick) but is saturated only near the bottom. The base of the Glacial Drift Aquifer is typically a clayey till layer deposited on top of the Shakopee Formation.

1.2.1.8 Minnesota River Alluvial Systems

Near the Minnesota River, scouring by the glacial River Warren deeply incised the bedrock and filled the valley with mixed alluvial sediments. These valley-fill deposits are typically saturated to within a few feet of the ground surface and are generally highly transmissive. Many small streams and wetlands are surface expressions of the water table. Bedrock aquifer systems discharge into the valley fill deposits, which are hydraulically connected to the Minnesota River.

1.3 Local Hydrogeologic Setting

1.3.1 Hydrostratigraphic Units

Many of the regional hydrostratigraphic units that are described above are also present in the vicinity of the Project Site. However, because the Project Site is situated in the Minnesota River valley, some of the upper bedrock unites have been eroded away by the ancestral River Warren. At the Project Site, all units above the St. Lawrence Formation (including the Prairie du Chien Group and the Jordan Sandstone) are absent. The St. Lawrence Formation is present only in the southern portions of the Project Site – the Franconia Formation is the uppermost bedrock on the northern part of the site. Hydrogeologic cross sections through the Project Site, developed by McCain and Associates, Inc. (2009) are shown on Figure 1-1. The elevation of the bedrock surface varies from approximately 670 feet, msl in the southwest corner of the Project Site to 570 feet, msl at the north end of the Project Site.

The St. Lawrence Formation in the area of the Project Site is characterized by dolomite-cemented, very fine-grained sandstone and siltstone, with some interbeds of shale and dolostone. In full section, the St. Lawrence Formation is 55 to 80 feet but at the Project Site it is about 0 to 20 feet thick.

The Franconia Formation is the uppermost geologic unit that makes up the Franconia-Ironton-Galesville aquifer. The Franconia Formation has recently been renamed the “Tunnel City Group” and the underlying Ironton-Galesville Sandstones are now referred to in the stratigraphic nomenclature as

the “Wonowoc Formation” (these changes were made to be consistent with stratigraphic nomenclature used in Wisconsin). However, for hydrogeologic purposes, the aquifer system continues to be referred to as the “Franconia-Ironton-Galesville aquifer” or “FIG aquifer”. At the Project Site, the Franconia Formation is estimated to be 120 to 140 feet thick and composed primarily of shale. In much of Scott County, the FIG aquifer is a very poor producer of water to wells but where it is the uppermost bedrock, secondary permeability features (primarily pressure relief jointing) makes the FIG aquifer a viable water supply for domestic wells and small community wells.

The uppermost hydrostatigraphic unit (in which the water table is present) is composed of highly permeable sand and gravel deposits, up to 70 feet thick, which are part of river terrace deposits of the Minnesota River. North of the Project Sites, these deposits increase in thickness up to 150 feet within the ancestral stream channel of the glacial River Warren. Area of clay silt loam floodplain deposits up to 20 feet thick are present in the upper horizons of the surficial deposits in lowland areas near Sand Creek and in the area to the northwest of the Project Site between Valley View Drive and the Minnesota River (McCain and Associates, Inc., 2009).

1.3.2 Groundwater Flow Direction

The Minnesota River is the regional discharge zone for all aquifers in the area (with the exception of the deep Mt. Simon-Hinckley aquifer). Therefore, the dominant groundwater flow direction in the aquifer system is northwest, toward the Minnesota River. Based on water-level measurements in piezometers and wells for August 2009 (McCain and Associates, Inc. 2009), the elevation of the water table at the Project Site is approximately 720 feet, msl. The horizontal hydraulic gradient of the water table is approximately 0.0025, which is relatively flat and indicative of a highly transmissive sand-and-gravel surficial aquifer.

The entire Minnesota River valley is an area where deeper groundwater flows both laterally to the Minnesota River and upward from deeper bedrock aquifers to the shallow surficial aquifer (i.e. it is an area dominated by upward vertical hydraulic gradients). These upward vertical gradients become greater near the Minnesota River and underneath the River, groundwater flow can be expected to be nearly vertical and upward. Based on a comparison of static water elevations in the two FIG wells at the Project Site (the Greenhouse Well and the House Well, both situated near the center of the site), there are moderate vertical upward gradients – approximately 0.004 – between the upper FIG aquifer and the water table.

1.3.3 Groundwater Interaction with Sand Creek

In general, streams generally are losing (i.e. stream water flows into the water-table aquifer) in headwater reaches and gaining (i.e. groundwater flows into the stream) near the stream mouth. However, there are several factors that can cause a deviation from this generality: local geologic conditions; seasonal variability; and stream-channel morphology. Stream-flow data for Sand Creek indicates that Sand Creek is a losing reach in the vicinity of the Project Site.

Hydrograph data from stream monitoring reports by Metropolitan Council Environmental Services for 2003 and 2004 show flows at or near zero during base flow conditions along the reach of Sand Creek adjacent to the Project Site, which indicates that Sand Creek receives negligible groundwater inflows in this area. Discharge measurements by the USGS (Mitton et al., 2003) show that the stream flow in Sand Creek changes from 1.8 cubic feet per second (cfs) in downtown Jordan. Further downstream, Sand Creek is expected to become gaining with base flows in the range of 14 cfs (Barr, 2011).

The surface-water elevation of Sand Creek under typical, non-flood conditions is in the range of 724 to 726 feet, msl. Typical water table elevations, as measured by piezoemters and monitoring wells near Sand Creek at the Project Site are approximately 722 to 723 feet, msl. These elevation relationships further indicate that Sand Creek is not a gaining stream along this reach and may naturally be a losing steam. But because the elevations of water table and stream are only a couple of feet different (at most), changes in the elevation of the water table would be expected to have some small change in the amount of stream loss from Sand Creek. For example, if the water table dropped underneath or next to Sand Creek, there would be a change in the moisture content or pore pressures in the sediments which would provide the hydraulic *potential* for increased stream losses. These losses may not be measurable and would only be a factor in the winter when base flow conditions are at their lowest.

1.3.4 Groundwater Interaction with Nearby Wetlands

There are several wetland areas north and northwest of the Project Site, between the Minnesota River and Valley View Road (Figure 1-2). Some of these wetlands have water stage elevations that are above the water table, indicating perching conditions on fine-grained deposits such as silt and clay. There are some wetlands that appear to be surface expressions of the water table, due to their depth. The perched wetlands may provide some recharge to the aquifer system but the amount is negligible compared to the effects of regional upwelling of groundwater in this discharge area. For those wetlands that are surface expressions of the water table, groundwater from the Project Site can be

expected to either discharge, flow under, or flow through the wetlands. These wetlands perform the same function as the Minnesota River – they serve as groundwater discharge features.

1.3.5 Pumping Wells

Twenty four (24) water supply wells have been identified near the Project Site, include 19 domestic wells. Five other wells include: a well owned by the Metropolitan Mosquito Control District; the Juvenile Alternative Facility well; and two wells at the SCALE training facility. Locations of wells near the Project Site are shown on Figure 1-3

The majority of these wells are completed in the surficial aquifer. There are also two wells at a homestead on the Project Site that are completed in the upper FIG aquifer (the Greenhouse Well and the House Well). Two residences in the vicinity recently replaced their surficial aquifer wells with new wells complete in the FIG aquifer.

Domestic wells generally are not pumped frequently or for long duration. For purposes of this study, an average pumping rate of 5 gallons per minute per well was assumed, which is likely higher than the actual use. In the modeling, these wells were found to have an insignificant effect on groundwater flow conditions.

For this evaluation, it was assumed that the non-domestic wells pumped at the following average rates:

- Metropolitan Mosquito Control District Well: 20 gpm
- Juvenile Alternative Facility Well: 40 gpm
- SCALE building water supply Wells: 50 gpm (combined)
- SCALE training exercise Well: 0 gpm

The above rates are similar to those used in the McCain and Associates, Inc. (2009) evaluation for the Jordan Aggregates EAW with one exception – this evaluation assumed that the SCALE training exercise well was only used sparingly. McCain and Associates, Inc. (2009) assumed an average rate of 300 gpm that is not reflective of the average pumping rate of the well. It is the average rate that is the most important factor evaluating effects for this proposed project,

1.3.6 Recharge

Recharge refers to precipitation that infiltrates beneath the root zone and eventually reaches the water table. Recharge rates in the Metro Model 2 were developed using the Soil Water Balance (SWB) model (Westenbroek et al., 2010). These rates were computed on a daily basis over a several year

period and an average valued was computed. The recharge rates vary spatially on a 30 meter by 30 meter grid over the metro area. Parameters that are used to calculated recharge include: daily precipitation; daily temperature (max and min); land use; crop type; and topography. The Metro Model 2's recharge values were used directly in the local model developed for this study.

1.4 Summary of Local Hydrogeologic Conceptual Model

The conceptual hydrogeologic model for the Project Site and surrounding area is depicted schematically in Figure 1-4. The conceptual model identifies those sources and sinks for water, hydrostratigraphic units, and directions of groundwater flow that are considered important to the purpose of the model and this EIS.

2. Groundwater Flow Model Construction and Calibration

2.1 Description of Model Codes

The code (software) used for modeling groundwater flow for this project is the USGS's three-dimensional finite-difference code, MODFLOW (McDonald and Harbaugh, 1988). MODFLOW is capable of simulating steady-state and transient non-uniform groundwater flow in three dimensions. MODFLOW is widely used, well-documented, and is considered the standard tool of the profession.

MODFLOW was selected for use in this project because the Metropolitan Council's Metro Model 2 regional groundwater flow model (Metropolitan Council, 2008) was constructed with MODFLOW. The Metro Model 2, which is based on an extensive collection of geologic and hydrogeologic data from the seven-county metropolitan area including Scott County, was used as the basis for constructing a more local-scale model for this project.Another reason for selecting MODFLOW is that it interfaces with the groundwater particle tracking code, MODPATH (Pollock, 1994) and the solute transport model MT3DMS (Zheng and Wang, 1999).

MODPATH (Pollock, 1994) is a groundwater particle tracking code that is used in conjunction with the MODFLOW solutions. MODPATH is used to delineate the direction and time-of-travel of groundwater in an advective, non-reactive, non-dispersive manner. MT3DMS (Zheng and Wang, 1999) is a widely used solute-transport model, designed to work with MODFLOW. MT3DMS has various technical options for simulating the movement of a reactive or non-reactive solute in groundwater, with various types of chemical reactions and dispersive migration.

2.2 Model Domain and Discretization

The model used for this project was constructed as a local model that was "extracted" from the regional Metro Model 2 through a process called Telescopic Mesh Refinement, or "TMR" (Anderson and Woessner, 1992). The local model boundaries were set at sufficient distance from the mining area that the effects of the model boundary conditions would not affect simulation of mining phases. The TMR procedure was used to extract constant-head boundary conditions from the Metro Model 2.

The Site Model was refined to show more detail than the Metro Model 2. Grid spacing at and near the Site was reduced from 500 x 500 m to 31 x 31 m to allow detailed representation of planned mining features; grid spacing away from the Site was kept at 500 x 500 m. The spatial distribution of hydraulic parameters and recharge and the locations of surface water features were refined using

existing geospatial data, recent aerial photos, and site-specific data. Wells from the Metro Model 2 within the bounds of the Site Model were incorporated and pumping wells near the Project Site were included in the model. The vertical layering of the Metro Model 2 was retained in the local model domain. The local model domain is shown on Figure 2-1.

There are nine layers in the groundwater model. These nine layers are carryovers from the Metro Model 2. Layer 1 is the shallowest hydrostratigraphic unit and Layer 9 is the deepest. The nine layers represent the following units:

Model Layer	Hydrostratigraphic Unit
1	Surficial aquifer (inactive near Minnesota River)
2	Surficial aquifer (inactive near Minnesota River)
3	Prairie du Chien Group (aquifer) - becomes part of the surficial aquifer where eroded away near Minnesota River
4	Jordan Sandstone (aquifer)) - becomes part of the surficial aquifer where eroded away near Minnesota River
5	St. Lawrence Formation (aquitard)) - becomes part of the surficial aquifer where eroded away near Minnesota River
6	Franconia Formation (aquifer)
7	Ironton-Galesville Sandstone (aquifer)
8	Eau Claire Formation (aquitard)
9	Mt. Simon-Hinckley Sandstone (aquifer)

As noted in the above table, near the Minnesota River some of the upper model layers transition from bedrock units to the surficial aquifer because the bedrock units have been eroded away (during glacial flooding) and unconsolidated silts, sand, and gravel have been deposited in their place. Also, because of topographic changes, Layers 1 and 2 (which typically represent the surficial aquifer in other parts of the metro area) are made inactive in the vicinity of the Project Site.

2.3 Parameter Selection and Distribution

The Metro Model 2 has undergone extensive calibration to measured water levels in wells, base flows in streams, and aquifer test results. The values of the resulting hydrogeologic parameters in the Metro Model 2 were retained in the local model. However, four additional hydraulic conductivity zones were added to the local model in the vicinity of the Project Site to reflect information on the hydraulic conductivity of the surficial sand-and-gravel unit obtained from slug

tests and specific capacity tests on-site. Both horizontal and vertical hydraulic conductivity were included as parameters for these zones. Figure 2-2 depicts the locations of these zones. The values of hydraulic conductivity for these zones were arrived at through the model calibration and optimization process.

2.4 Model Calibration and Optimization

2.4.1 Calibration Methodology

Calibration of a model involves adjusting the values of hydrogeologic parameters within expected ranges to achieve a satisfactory match between observed measurements and simulated results. It is not possible to achieve a perfect match between simulation results and measured values but the objective of calibration is to get the best match possible without straying from the conceptual model and the overall understanding of groundwater flow in the area. Because there is always an inherent uncertainty in groundwater models due to an incomplete understanding of subsurface conditions, some difference between observed and simulated conditions must be accepted. The calibration process attempts to find parameter values that fit both the conceptual model for the Project Site and reduce the differences between model results and measured values.

The calibration process used the model-independent inverse optimization code PEST (Doherty, 2009). Pest automatically adjusts the values of selected model parameters within user specified ranges (which limit the range of possible values) until the difference between observed conditions and model-simulated results are minimized in a least-squares sense. The term “inverse” refers to the process of arriving at a calibration by adjusting model parameters. The term “optimization” refers to the calibration process that balances the calibration’s residuals (i.e. difference between observed and simulated values) over all of the observations.

2.4.2 Calibration Targets

The model used groundwater models measured in monitoring wells as calibration targets (i.e. measurements to which the model is calibrated to). All calibration targets were weighted equally. A total of 1,222 groundwater measurements from wells (obtained from the Minnesota Geological Survey’s County Well Index, or “CWI”).

An additional set of calibration targets was used to assign parameter values for hydraulic conductivity zones at the Project Site. These calibration targets included water-level measurements in monitoring wells and maximum drawdown measurements in selected Franconia wells and surficial aquifer monitoring wells during a pumping test of a Franconia well conducted in 2012.

2.4.3 Calibration Results

A plot of measured versus simulated target head values is shown on Figure 2-3 for the entire model domain. The values cluster around a diagonal line that represents a perfect match between observed and simulated values. The model calibration has a root-mean squared error of 7.75 and a residual mean value of 0.07 meters. These calibration statistics indicate a good match between simulated and observed conditions.

For site conditions and simulation of the Franconia well pumping test, simulated water levels were within 0.03 meters of measured water levels at site. Simulated drawdowns from pumping test were within 0.15 meters of observed drawdown in the Franconia observation well and within 0.006 meters in monitoring wells completed in the sand-and-gravel unit at the site.

2.4.4 Simulated Groundwater Flow – Existing Conditions

The calibrated model's simulation of typical groundwater flow direction and water-table elevation for existing conditions (i.e. with current land use and no mining) are shown on Figure 2-4. In this simulation, the Mosquito Control District well, the SCALE facility wells, and the Juvenile Alternative Facility well are pumping at rates previously described. Sand Creek is at its typical non-flood elevation.

The groundwater time of travel from the downgradient perimeter of the proposed mine pit was calculated and is also depicted on Figure 2-4. The effective porosity used in the MODPATH model to calculate time-of-travel from groundwater velocities is assumed to be 0.1. This is a value that is typical of unconsolidated but glacially influenced sand and gravel deposits. The effective porosity is typically lower than the true porosity because of the presence of "dead pores" and retained moisture on the soil-grain surfaces.

The model predicts that Sand Creek is a losing stream along the reach of stream adjacent to the Project Site. Stream losses along this reach are predicted to be 0.16 cubic feet per second (cfs).

3. Simulation of Project Conditions

3.1 Simulated Mine Conditions

Aggregate mining will be performed below the water table by dredging. Within the mining limits sand and gravel will be excavated down to the water table, which is anticipated to be encountered at approximately elevation 720 feet, msl. Based on site topography, the excavation depths will range from 4 to 49 feet. In the center of the site, excavation will extend below the water table to approximately elevation 600 feet, msl or the top of bedrock, should bedrock be encountered above elevation 600 feet. A pond of approximately 36 acres and 115 feet deep will be formed as a result of mining. The water level in the pond will be the surface expression of the water table.

One new well will be installed and completed in the sand-and-gravel unit below the water table to provide water for aggregate washing operations as well as dust control. The exact location of the well will be determined as part of the IUP application and MDNR appropriation permitting processes, however it is expected that the well will be located within the proposed plant processing area.

A ground water appropriation permit will be required for the operation of this wash well. Water usage at the site will vary based on a number of factors including precipitation, rate of aggregate excavation, silt content of aggregate, and product demand. The anticipated annual water requirement for the site is estimated at 500,000 to 2 million gallons (average pumping rate of 1 to 4 gallons per minute) and peak rate water use of 200 gallons per minute (i.e. the wash water well will be operated at a maximum rate of 200 gpm for a short period of time, resulting in an annually averaged rate of 1 to 4 gpm).

During mining, approximately 2,700 tons of sand and gravel will be excavated daily. The removal of the material from the mine has an effect that is similar to pumping water because sand and gravel is taken out and the resulting “void” space is filled by groundwater flowing into the pit. Assuming an approximate bulk density of sand 1.67 tons/m3, and a standard void ratio for sand and gravel of 0.3, approximately 1,134 m3 of solid material will be removed from the mine pit each day. This value of 1,134 m3/day can be thought of as the “pumping rate” due to sand and gravel extraction.

In addition to the removal of sand and gravel, there is removal of water from the pit due to evaporation. The average pan evaporation rate in the Twin Cities metropolitan area for the period 1972 to 2008 is 36.91 inches. During this same period, the average precipitation was 29.41 inches. The difference between evaporation and precipitation (E-P) is 7.5 inches (0.191 meters). This equates

to an average “loss” to the atmosphere of water from the 36 acre (145,687 m2) mine pit of 27,753 m3/year or 76 m3/day (13.9 gallons per minute).

The total average mine water loss due to extraction of aggregate and evaporation is 1,210 m3/day (222 gallons per minute).

The calibrated groundwater flow model was used to simulate the effects of mining on groundwater levels, groundwater flow direction, base flow of Sand Creek, and wetland areas. The hydrogeologic effects of mining were simulated in the following manner:

- The mine pit was simulated using a zone of high hydraulic conductivity (10,000 m/day, compared to the surrounding average hydraulic conductivity value of 11 to 21 m/day), as described by Anderson et al. (2002). This method results in the formation of a flat water table across the water body, with a typical steepening of the hydraulic gradient along the upgradient side of the lake and a flattening of water table on the downgradient side.

- The storage of the mine pit was given a value of 1.0, which is the equivalent of defining the pit as having zero pore space.

- Evaporation and aggregate mining were simulated by placing a fictitious well in the mine pit with a steady-state pumping rate of 1,210 m3/day. Because of the high hydraulic conductivity zone and the storage value of 1.0, the location of the fictitious wells is irrelevant.

- The wash well was located in the sand-and-gravel unit directly northwest of the mine pit, on the Project Site property (recognizing that this well’s final location will be determined during the IUP process). It is unrealistic to assume that the wash well will pump at its maximum capacity (200 gpm) on a continuous basis. As a worst-case condition, a value of 100 gpm continuous operation was assumed.

- Groundwater simulations were performed assuming steady-state conditions. Because the mine will be in operation for many years and steady-state conditions will be attained in a few days, following changes to mining, this is a valid assumption for purposes of this evaluation.

3.2 Predicted Drawdown Effects During Mining

3.2.1 Extent and Magnitude of Drawdown

The model's prediction of the change in the water-table elevation, resulting from the presence of the preferred mine pit (and its water losses) and the presence of the wash well is shown on Figure 3-1. The maximum predicted water-table drawdown (i.e. lowering of the water table compared to existing conditions) is 2.82 feet, which takes place along the southeast edge of the mine pit The model predicts that the water-table elevation will increase (compared to existing conditions) by 0.2 feet at the approximate midpoint of the downgradient perimeter of the mine pit. These results are entirely consistent with expectations for a mine pit, which creates a flat surface expression of

The greatest amount of drawdown beyond the mine area is to the southeast. However, the magnitude of this drawdown is less than about 1.2 feet. To the north and northwest, the maximum predicted drawdown is approximately 0.2 to 0.4 feet. The model predicts that the average drawdown near the wash water well will be approximately 0.8 feet. For deeper hydrostratigraphic units, such as the FIG aquifer, the drawdown is less – the maximum drawdown in the FIG aquifer is 1.13 feet.

3.2.2 Predicted Drawdown in Existing Wells

The model predicts that the mine pit and wash water well will produce a combined drawdown in individual wells that are the following:

Unique Well Number	Predicted Drawdown (feet)
211711	0.18
150106	0.71
216747	0.56
595225	0.37
404675	0.33
510414	0.18
498564	0.20
443648	0.38
760017	0.58
235532	0.29
474684	0.33
271816	0.36
777320	0.30
777297	0.29
[illegible]	[illegible]

None of these drawdown values would be expected to measurably affect the ability for the wells to yield at their current rates.

3.2.3 Effect of Mine Pit Drawdown on Base Flows of Sand Creek

The mine pit results in a drawdown that extend beneath Sand Creek and to areas upgradient of Sand Creek to the southwest. The model predicts that the resulting drawdown will cause an increase in flow from Sand Creek to the shallow aquifer along the stretch of Sand Creek that adjoins the Project Site. In other words, Sand Creek (which is already suspected to be a losing stream along this stretch) will have increased losses to the aquifer from 0.16 cfs (current conditions) to 0.25 cfs (predicted conditions with the preferred mine configuration). The average winter base flow in Sand Creek is approximately 1.8 cfs (Metropolitan Council, 2004). Therefore, the model predicts that the proposed project will result in a potential reduction in base flow of Sand Creek of 0.09 cfs, which may result in an overall winter base flow along this reach of Sand Creek of 1.7 cfs. Sand Creek is suspected to gain considerable base flow (@ 14 cfs) further downstream of the Project Site (Barr, 2011)

3.2.4 Effect of Mine Pit Drawdown on Wetlands

The wetlands that are located in the vicinity of the Project Site are net recipients of groundwater (i.e. groundwater flows from the water-table aquifer into the wetlands). The model predicts that typical inflows into the wetlands total approximately 3.20 cfs. The model predicts that the mine pit and wash water well will result in a net reduction in groundwater inflows into all wetlands of 0.10 cfs – a reduction of about 3 percent. The model does not predict that drawdown induced from mining operations will measurably affect the stage elevation of the wetlands.

3.3 Prediction of Groundwater Time of Travel from Mine Pit

The model's prediction of the water-table elevations and groundwater flow paths from the downgradient perimeter of the mine pit is shown on Figure 3-2. Also shown on this figure is the predicted groundwater time-of-travel from the mine pit.

Overall, the groundwater time-of-travel is slightly reduced along the peripheries of the areas downgradient of the mine pit. The mine's wash water well is predicted to capture most of the pit water in the center portion of the area downgradient of the mine pit. This flow analysis predicts that under typical hydrologic conditions and mine operations, water from the mine pit area will flow in a similar direction to groundwater currently underneath the proposed mine-pit footprint. Under the groundwater flow path simulation, the model predicts that none of the mine pit water will flow to any of the existing wells in the area.

3.4 Predictions of Effects of Mine-Pit Flooding

3.4.1 Simulation Approach

The mine pit area is expected to be inundated with flood water from Sand Creek during some higher flooding conditions. A proposed spillway in the berm will begin to let water into the mine pit area when flood waters in Sand Creek reach elevation 728 feet, msl. Inundated water will flow back into Sand Creek after flood waters begin to recede over the same spillway until an elevation of 728 feet, msl is reached. At that point, flood water will be trapped in the mine pit area and will dissipate through infiltration into the surrounding sand and gravel water-table aquifer.

Flood waters from Sand Creek that are retained in the mine area behind the spillway have the potential to temporarily alter the groundwater flow direction (because of temporarily elevated hydraulic head in the mine pit). The flood waters may also contain contaminants, including water-borne pathogens, that may adversely affect the water quality of the water-table aquifer and could impact nearby wells.

The approach to analyzing the effects of mine-pit flooding is to use the groundwater flow model in a transient simulation, along with the solute transport model MT3DMS (Zheng and Wang, 1999). The following procedures were used:

- The water level in the mine pit was simulated at elevation 728 feet, msl and allowed to reach a steady-state condition. This simulation forms the starting point for a transient simulation.

- A transient simulation is performed in which the water in the mine pit, beginning at elevation 728 feet, msl is allowed to re-equilibrate to a new steady-state condition over time. The model simulates the reduction in the flood water. A storage value of 0.15 is used for the unconsolidated aquifer.

- The flooded mine pit is assigned an initial concentration of 100 in the MT3DMS simulation, signifying that 100 percent of the mine-pit water is flood water. (This value has no relationship to the concentration of any contaminant). As the flood water in the mine pit percolates into the surrounding sand and gravel, MT3DMS track the direction and relative concentration (as a percent) of the flood water.

The flood water is simulated using advective, non-dispersive flow (i.e. dispersion is assumed to be negligible). The flood water is simulated in two ways: (1) as a non-reactive, simulated tracer and (2) with a decay constant that has a half-life of 34.65 days. The latter simulation is intended to examine

the migration of pathogens in the flood water as they migrate through the water-table aquifer. The half-life value was calculated from EPA (2002) for "the longest survival rate for pathogenic viruses", which is typically about 0.02. This indicates a 4-log microbial inactivation in approximately 200 days. Biological inactivation is due to a variety of physical, chemical, and biological processes, including desiccation, denaturation, biochemical antagonism from enzymes, and predation.

3.4.2 Mine-Pit Flooding Migration Predictions

A transient groundwater-flow simulation was performed using the MODFLOW model for the purpose of simulating the dissipation of head that would result from a flood event that inundates the mine pit. The initial condition for this simulation was established by performing a steady-state simulation in which the head in the mine pit was set to elevation 732.5 feet, msl, which is the elevation of the 100-year flood event. Flood waters will recede back through the spillway until they reach the spillway elevation (726 feet, msl). At this elevation, the inundated flood waters are trapped behind the berm and recede by seeping into the ground. Therefore, using an elevation of 732.5 feet, msl is likely an extreme worst-case condition.

The transient simulation was run for a period of 10 years, with 40 time steps and a a time-step multiplier of 1.2. The primary purpose of this transient simulation was to establish the groundwater flow field for the MT3DMS solute transport simulation.

The intent of the MT3DMS solute transport simulation is not to simulate a specific contaminant with a specific initial concentration. Rather, solute-transport modeling was used to track the migration of flood water in the pit as it moved out into the water-table aquifer. The initial concentration in the mine pit was set equal to 100, which represents 100% flood water. The flood water migration in the aquifer is then simulated using advective, non-dispersive and non-reactive transport. These simulations allow for the prediction of the movement of the flood water (i.e. the time-of-travel) as well as the attenuation of the concentration through hydrodynamic processes. The GCG Solver was used in the solute-transport calculations with a transport time step of 0.1 days.

The results of the simulations are shown on Figure 3-3 for the water-table aquifer and on Figure 3-4 for the upper FIG aquifer (time snap shots at one-half, one, two, and five years since flooding). Flood water from the mine pit did not reach the lower FIG aquifer (i.e. the Ironton-Galesville Sandstone – Layer 7) in the simulations. The contours shown in Figures 3-3 and 3-4 represent isolines of equal percentage of flood water – 1%, 5%, 20%, 50%, and 70%.

As shown in Figure 3-3, the migrating flood water moves downgradient (northwest) of the mine pit and spreads out to the southwest and northeast as it migrates. The spreading out of the "plume" of flood water also causes the overall percentage of flood water in the groundwater to decrease. The only water-table (i.e. Quaternary) well that appears to be affected by the migrating flood water is the SCALE well, located northeast of the site, across from Valley View Road. The model predicts that flood water would reach this well in two years at a relative "strength" of 20% of the original flood water.

As shown in Figure 3-4, the relative strength of the flood water that migrates down into the upper Franconia aquifer (Layer 6 in the model) is approximately 5% of the original flood water (or less). None of the wells completed in the FIG aquifer near the Project Site are predicted to receive flood-impacted groundwater.

3.5 Evaluation of Alternative FIG Aquifer Water Supply

A FIG aquifer well was evaluated as a possible mitigation alternative for wells that might be impacted by mining activities. The groundwater flow and solute-transport modeling predicts that the yields of the wells in the area will not be affected by mining activities. The only potentially adverse effect that was identified was potential contamination of the SCALE well(s) by flood water that inundates the mine pit and then migrates into the water-table aquifer.

The FIG aquifer's ability to yield water was evaluated through a pumping test conducted by Carlson-McCain Inc. in early 2012 and analyzed by Barr Engineering Co. A memorandum, summarizing the results of the analyses is included as Attachment A to this report. The drawdown data from this test were used in the calibration of the groundwater model. The arithmetic mean value for the hydraulic conductivity of the FIG aquifer was calculated to be 14 ft/day (4.2 m/day). This value was also incorporated into the groundwater flow model.

The hydraulic conductivity of the FIG aquifer (14 ft/day) suggests that this unit should be sufficiently transmissive to supply usable quantities of water for private residential wells, lower demand commercial wells, and small community water-supply wells. It is less likely to be able to yield at sufficient rates to be used as a municipal water supply.

A well, completed in the lower portion of the FIG aquifer (i.e. the Ironton-Galesville Sandstone – Layer 7 in the model), was evaluated at a location in the northeast portion of the mine site, shown on Figure 3-5. The well was assumed to be pumped continuously at 150 gpm. This rate should be

sufficient to supply the SCALES facility with its water needs as well as other potential water users in the vicinity of the Project Site.

A “worst case” evaluation was performed on this well by evaluating the potential for the well to pump migrating flood water from the mine pit without the benefit of biological inactivation. MT3DMS was used to simulate the migration of flood waters through the aquifer units and to predict the percentage of flood water that would be pumped by this hypothetical well. A plot of the percent of flood water predicted to be pumped by this well is shown on Figure 3-5. The maximum percent of flood water pumped by this well is predicted to be 0.7% and is predicted to take place approximately one-half year after a flood event. Based on these results, a FIG well installed at this location and completed in the Ironton-Galesville Sandstone should be able to provide water that is not adversely impacted by flood or mining activities.

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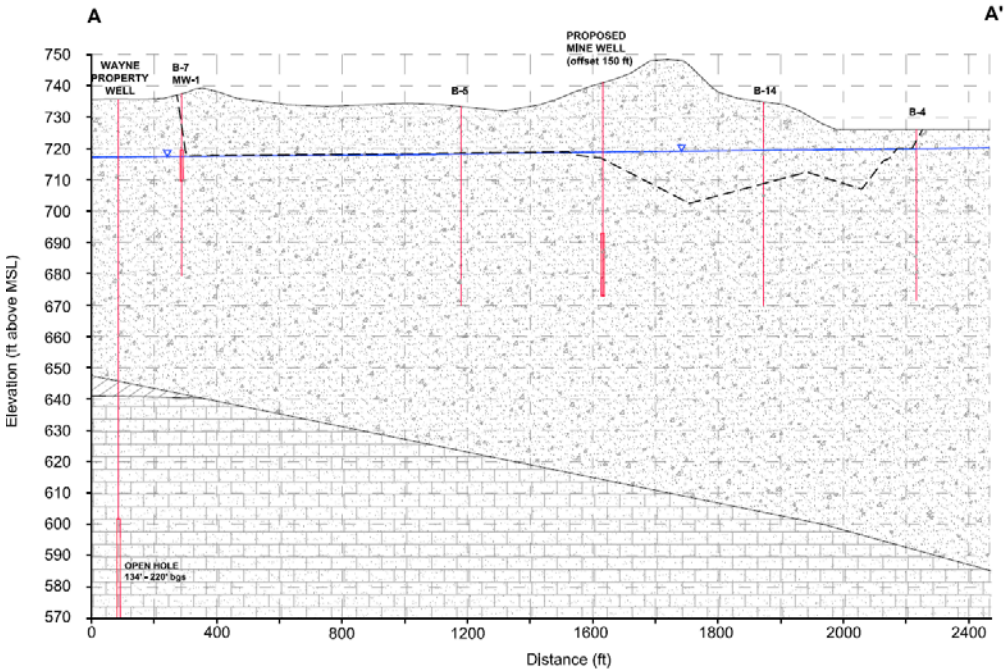
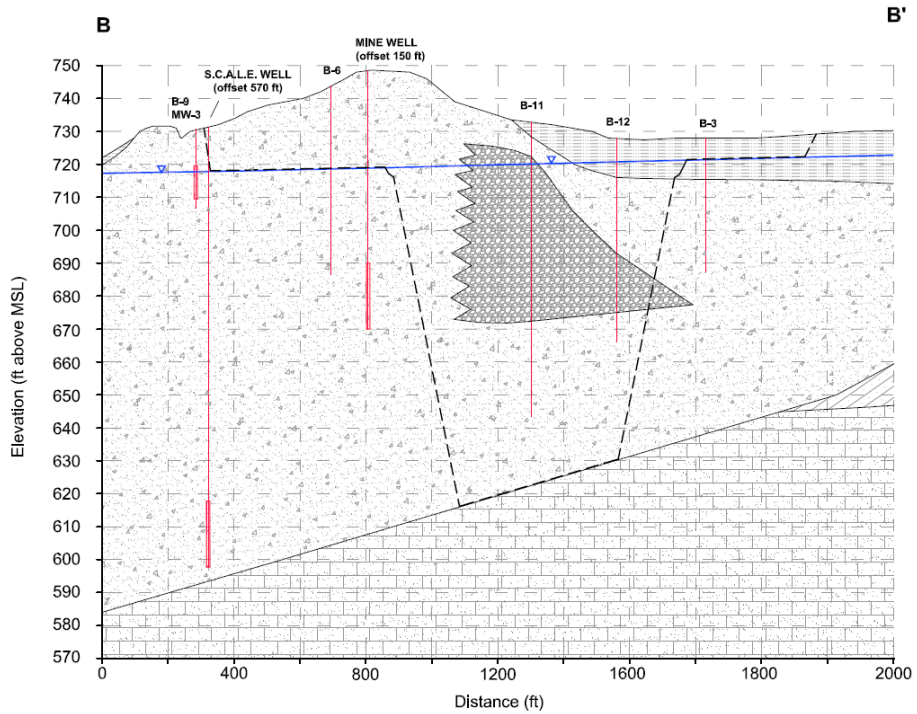
Figures





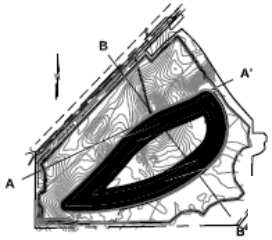
LEGEND

- SCREENED INTERVAL
- STATIC WATER ELEVATION (8-26-09)
- PROPOSED MINE EXCAVATION DEPTH
- UNCONSOLIDATED SILT AND CLAY; FLOODPLAIN ALLUVIUM
- UNCONSOLIDATED SAND & GRAVEL
- FINE TO COARSE GRAVEL
- ST. LAWRENCE FORMATION; FINE SANDSTONE/SILTSTONE
- FRANCONIA FORMATION; SANDSTONE/SILTSTONE/SHALE

NOTES:

1) VERTICAL EXAGGERATION = 10X
2) BORING LOCATIONS OFFSET 20 TO 130 FEET FROM SECTION LINE
3) BEDROCK SURFACE ELEVATION OBTAINED FROM SCOTT COUNTY GEOLOGIC ATLAS

CROSS-SECTION LOCATIONS

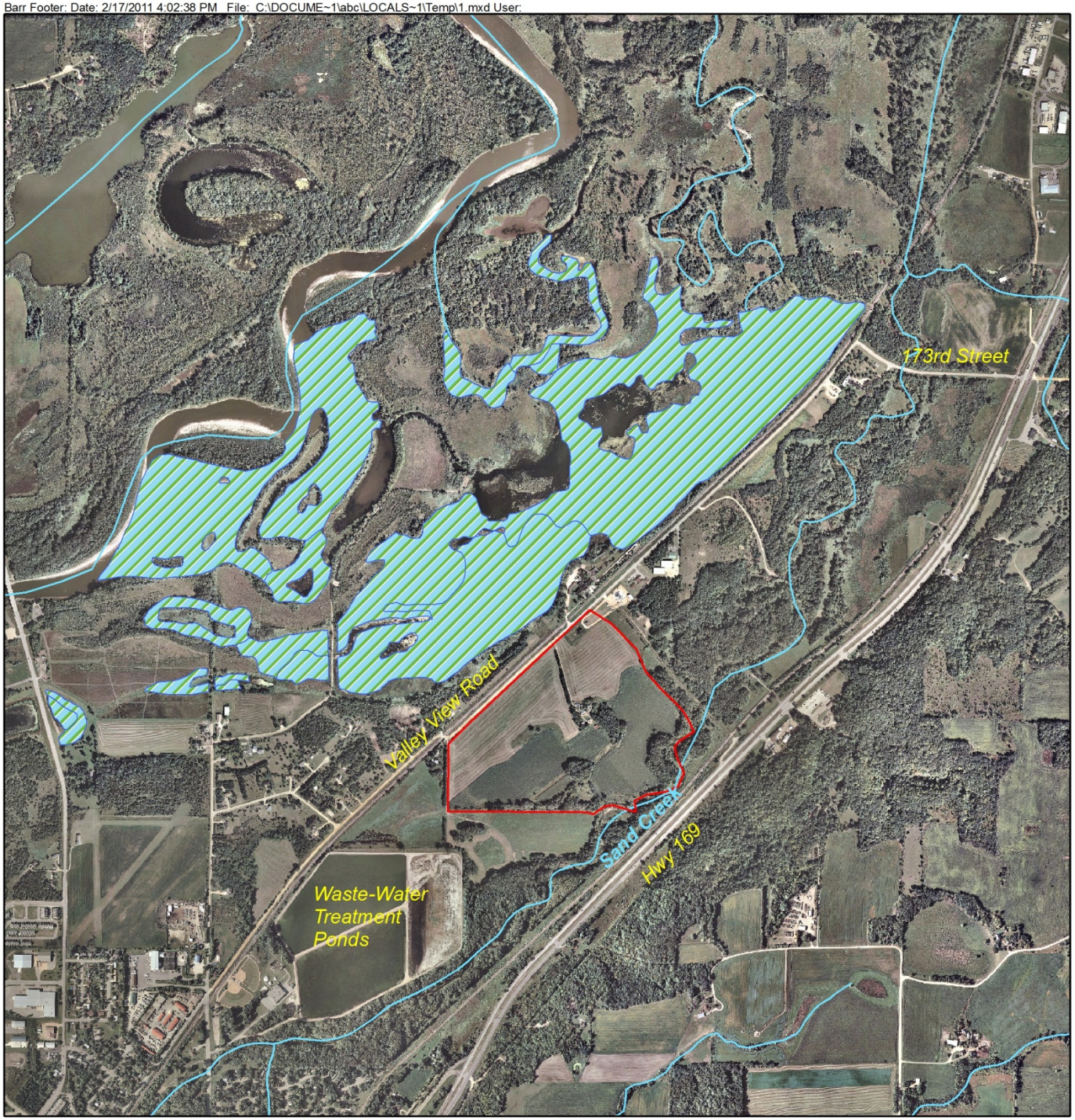


Cross Sections from McCain and Associates, Inc. (2009), updated in 2012

Figure 1-1

GEOLOGIC CROSS SECTIONS THROUGH MINE SITE
Jordan Aggregates EIS
Scott County, Minnesota

Barr Footer: Date: 2/17/2011 4:02:38 PM File: C:\DOCUME~1\abc\LOCALS~1\Temp\1.mxd User:



EXPLANATION

Potential Groundwater-Influenced Wetlands

Mine Site

N

Miles

0.5 0

Figure 1-2

POTENTIAL GROUNDWATER-INFLUENCED WETLANDS
Jordan Aggregates EIS
Scott County, Minnesota

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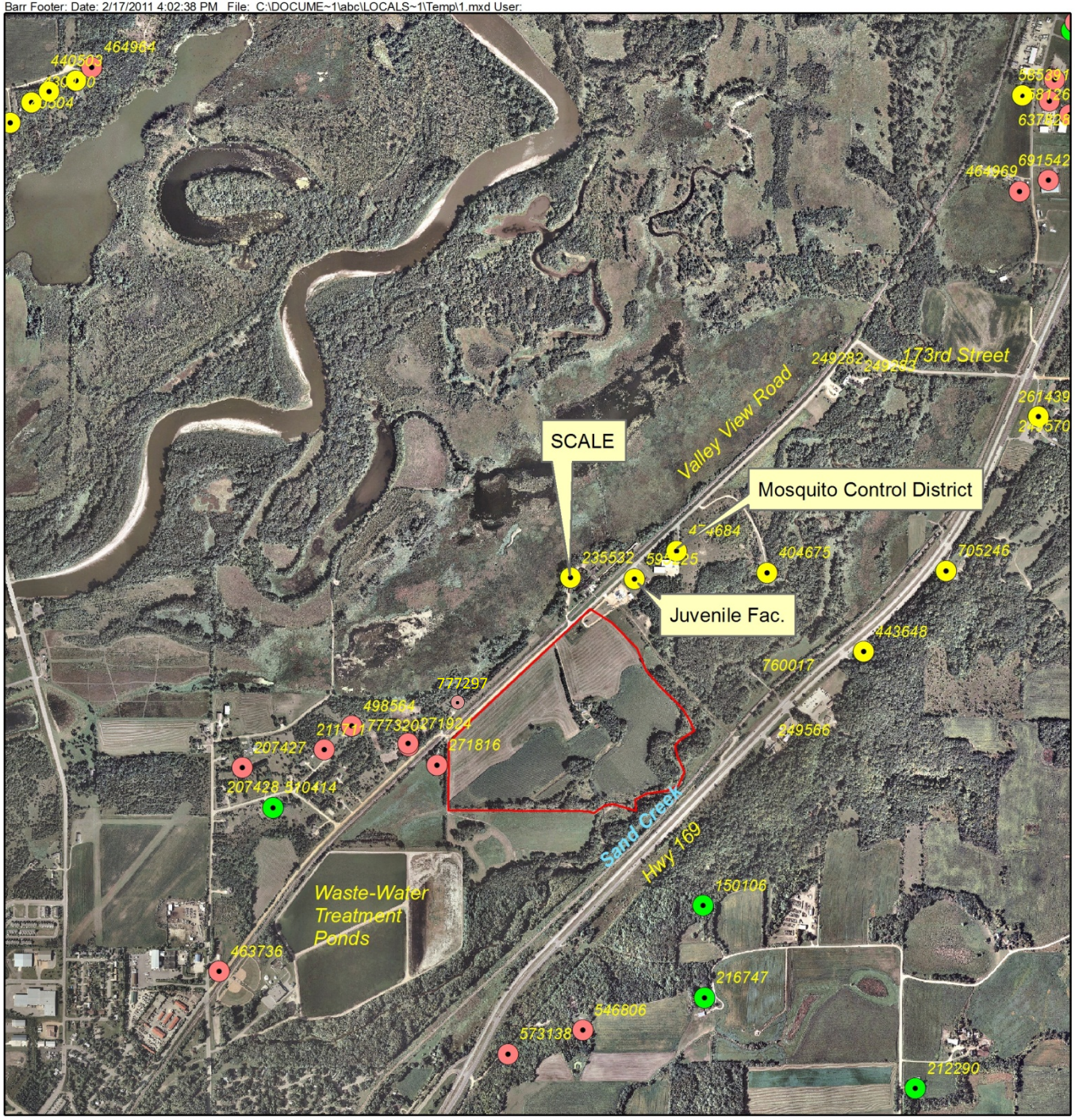

EXPLANATION

Local Wells

AQUIFER

- Quaternary
- Jordan Sandstone
- St. Lawrence Fm.
- FIG Aquifer
- Mt. Simon Aquifer
- Mine Site

N

Miles

0.5 0

Figure 1-3

SUPPLY WELLS IN PROJECT AREA
Jordan Aggregates EIS
Scott County, Minnesota

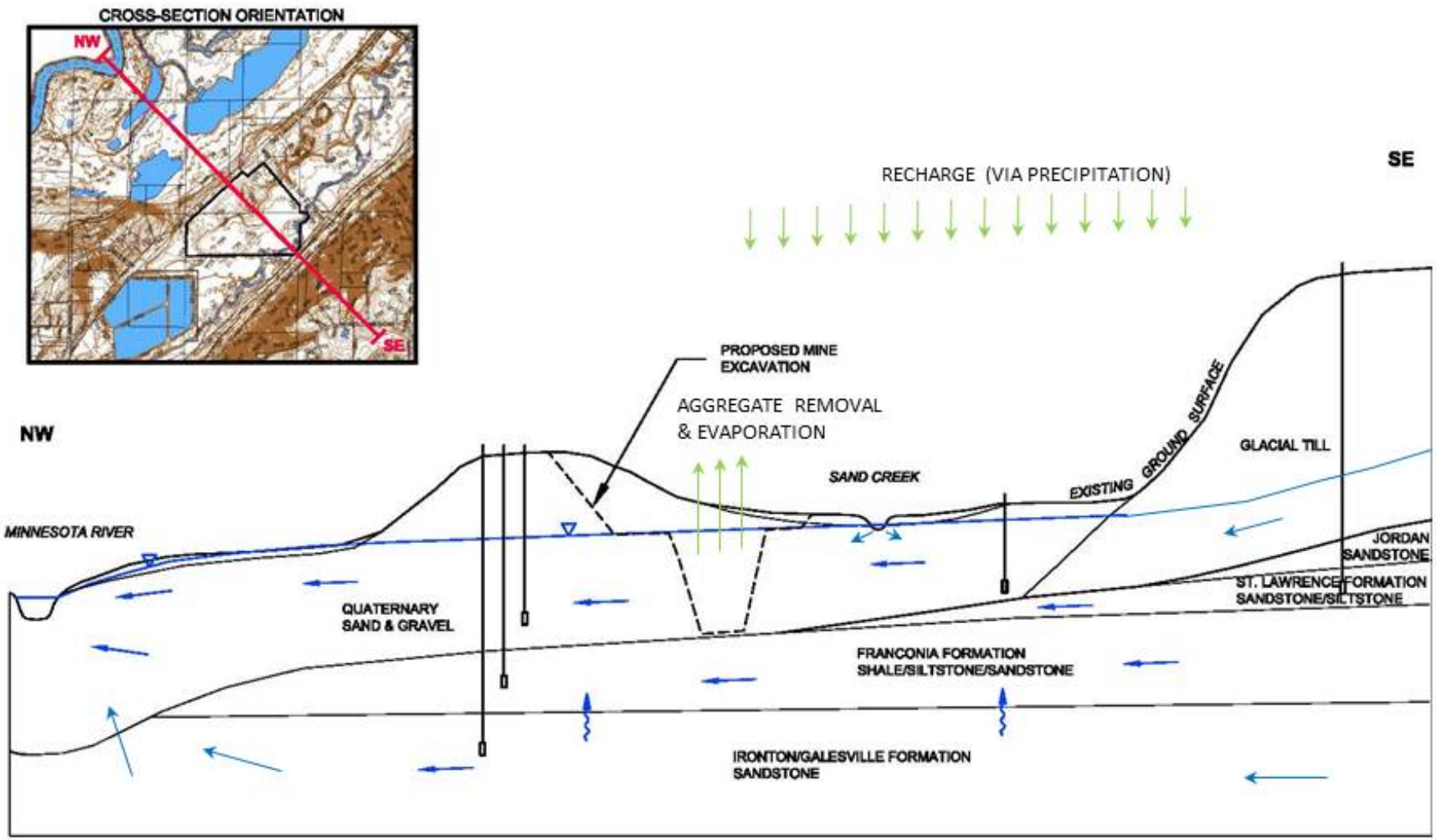

Figure 1-4

Modified from McCain and Associates, Inc. (2009)

CONCEPTUAL HYDROGEOLOGIC CROSS SECTION THROUGH MINE SITE
Jordan Aggregates EIS
Scott County, Minnesota

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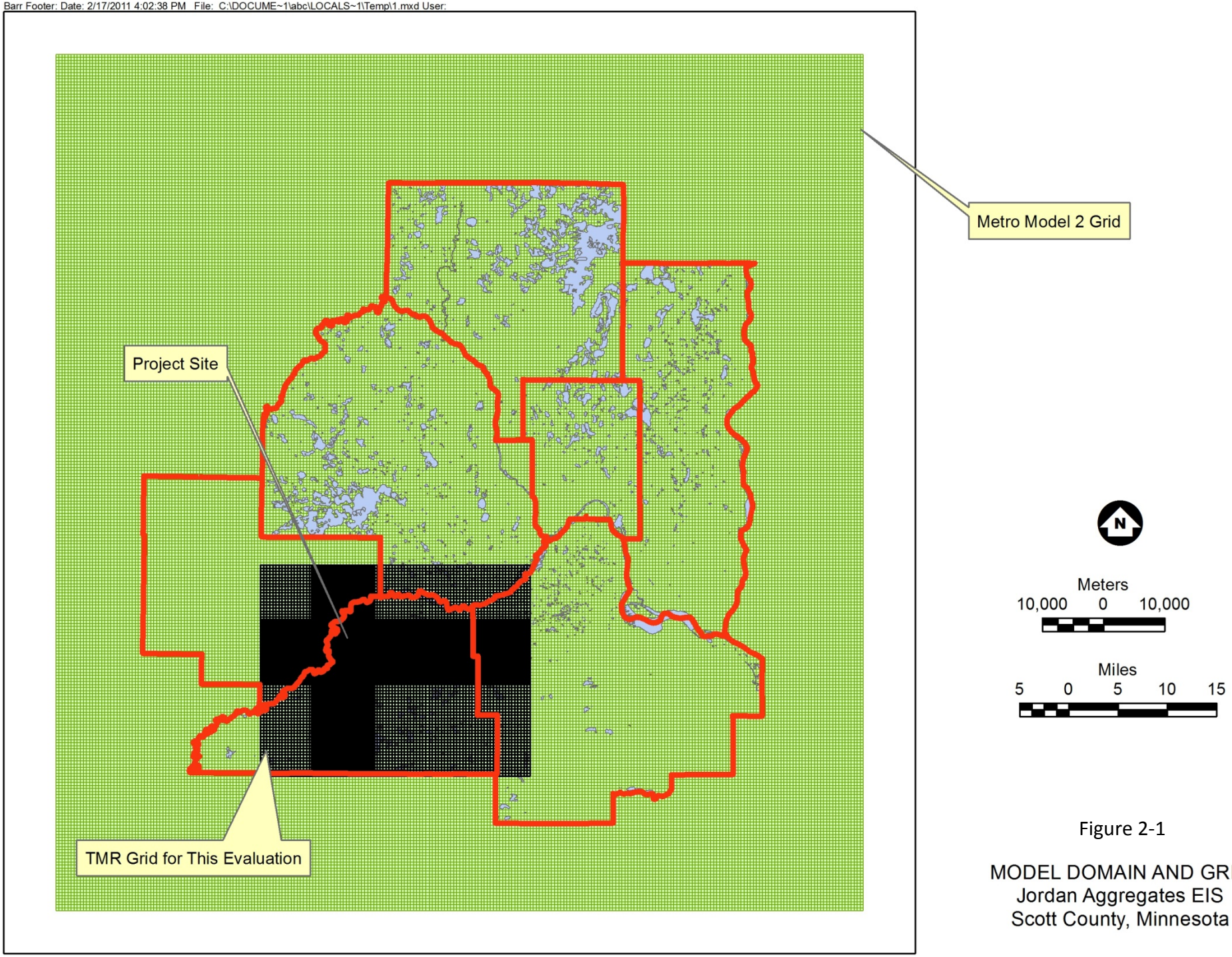

Figure 2-1

MODEL DOMAIN AND GRID
Jordan Aggregates EIS
Scott County, Minnesota

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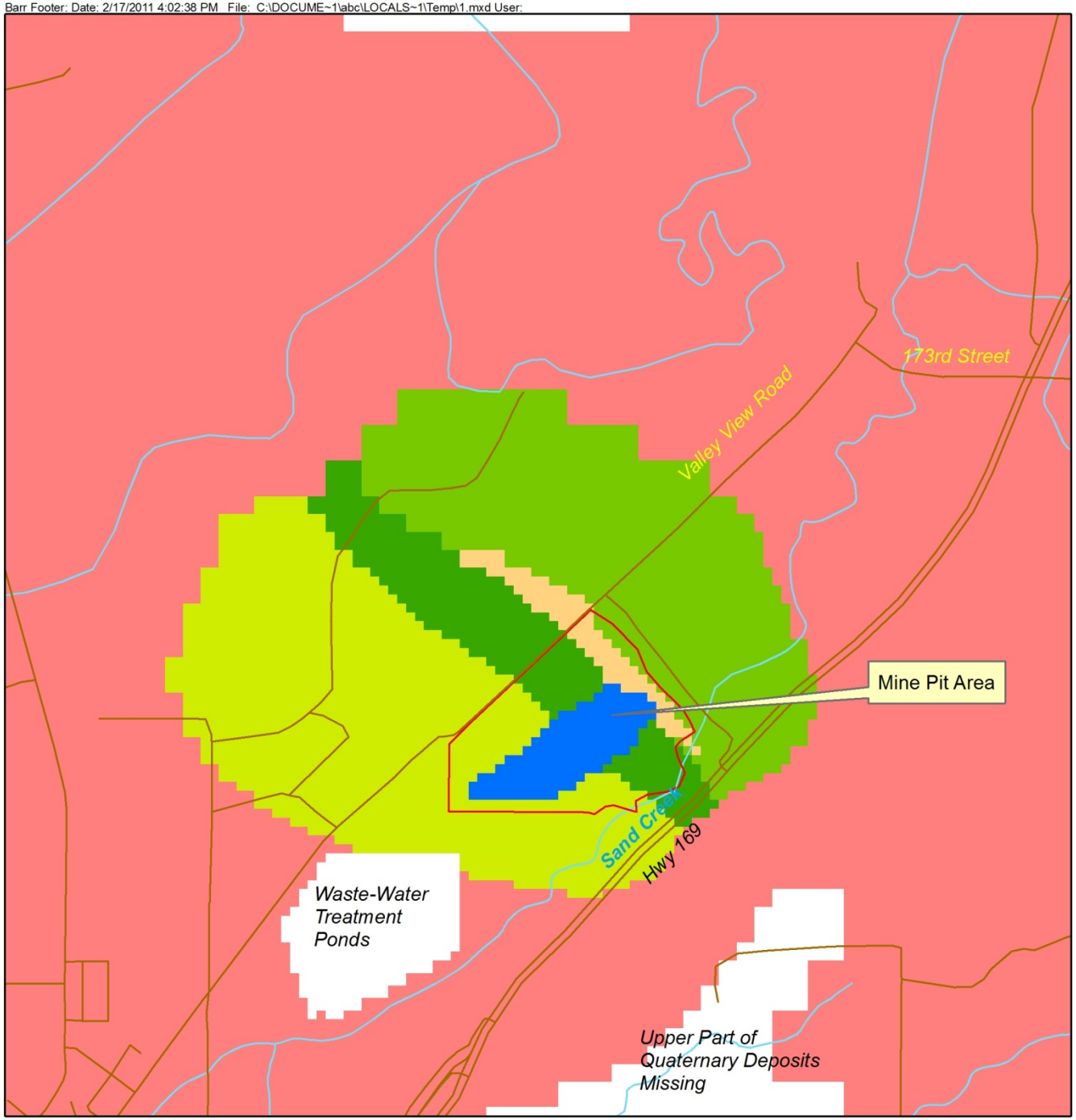


EXPLANATION

Mine Site

k

Horizontal Hydraulic Conductivity (m/d)

- 11
- 19
- 29
- 30.2
- 45
- 10000

N

Miles

0.5 0

Figure 2-2

HYDRAULIC CONDUCTIVITY IN MODEL FOR SURFICIAL QUATRNARY DEPOSITS

Jordan Aggregates EIS
Scott County, Minnesota

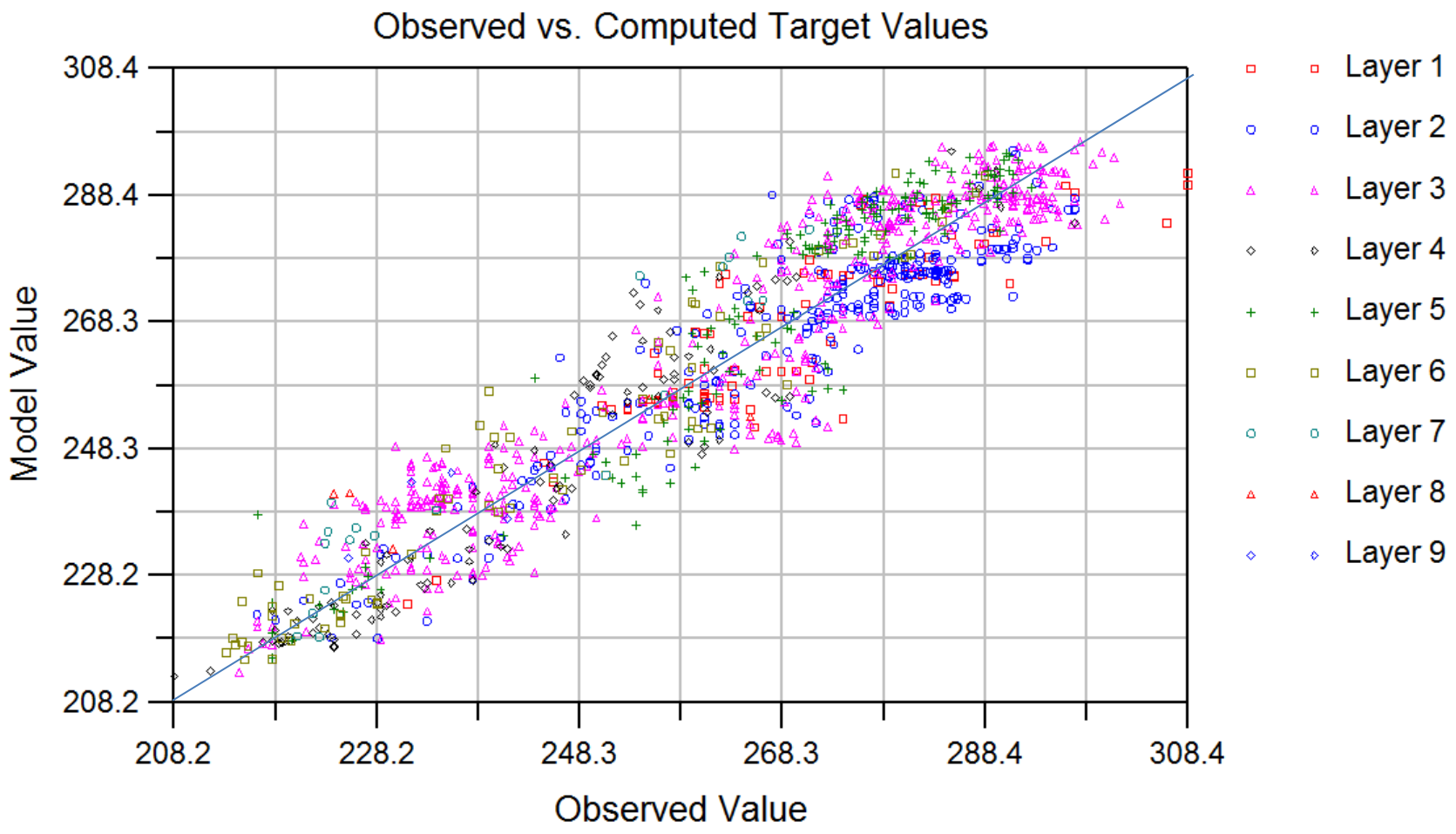
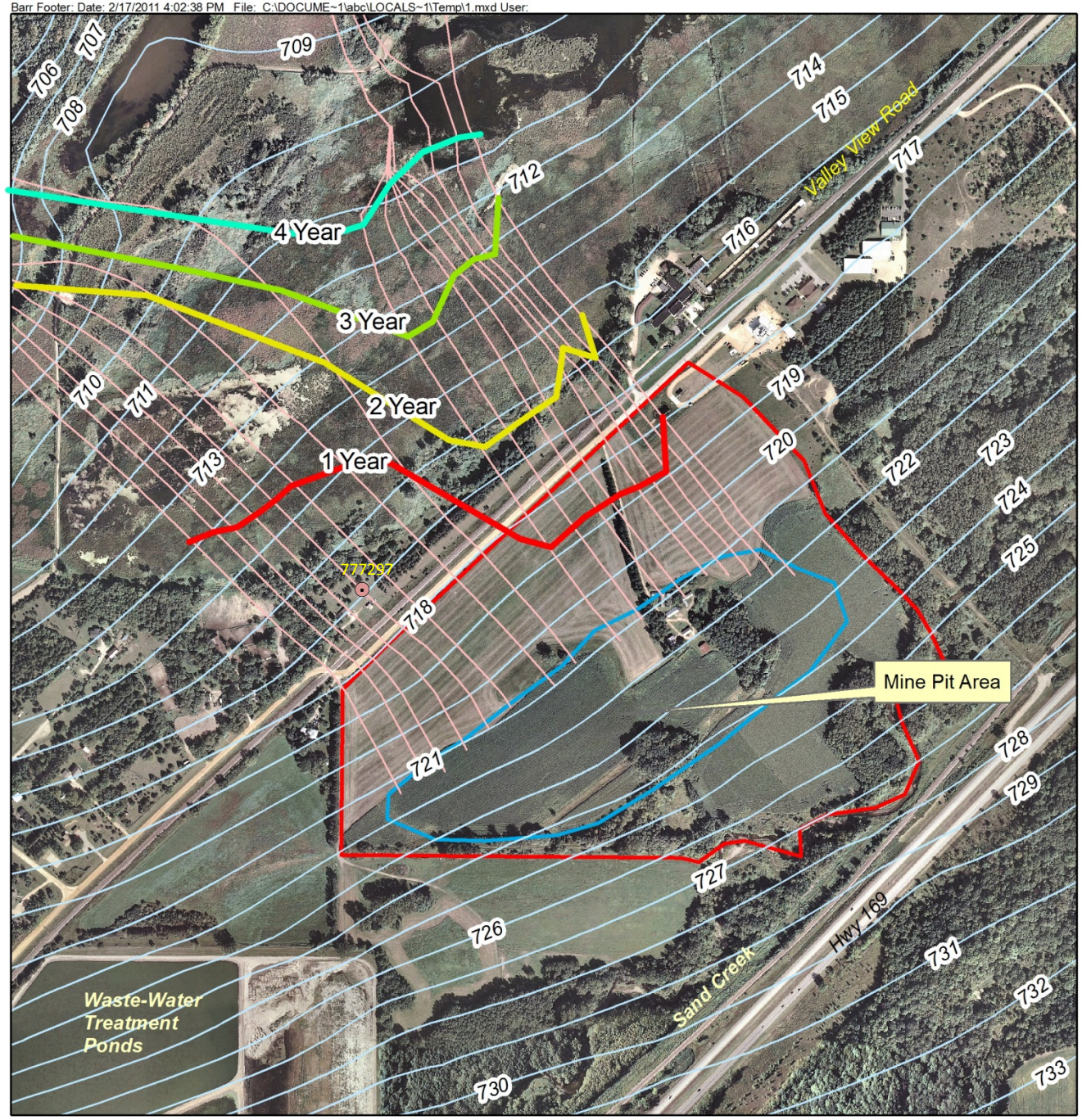


Figure 2-3

PLOT OF SIMULATED AND
OBSERVED CALIBRATION TARGETS
Jordan Aggregates EIS
Scott County, Minnesota

Barr Footer: Date: 2/17/2011 4:02:38 PM File: C:\DOCUME~1\abc\LOCALS~1\Temp\1.mxd User:



Time of Travel of Groundwater Flow Shown in Years from Downgradient Edge of Mine Pit Perimeter

EXPLANATION

- Water Table Elevation (ft, MSL)
- Groundwater Flow Paths
- Proposed Mine Pit Perimeter
- Mine Site

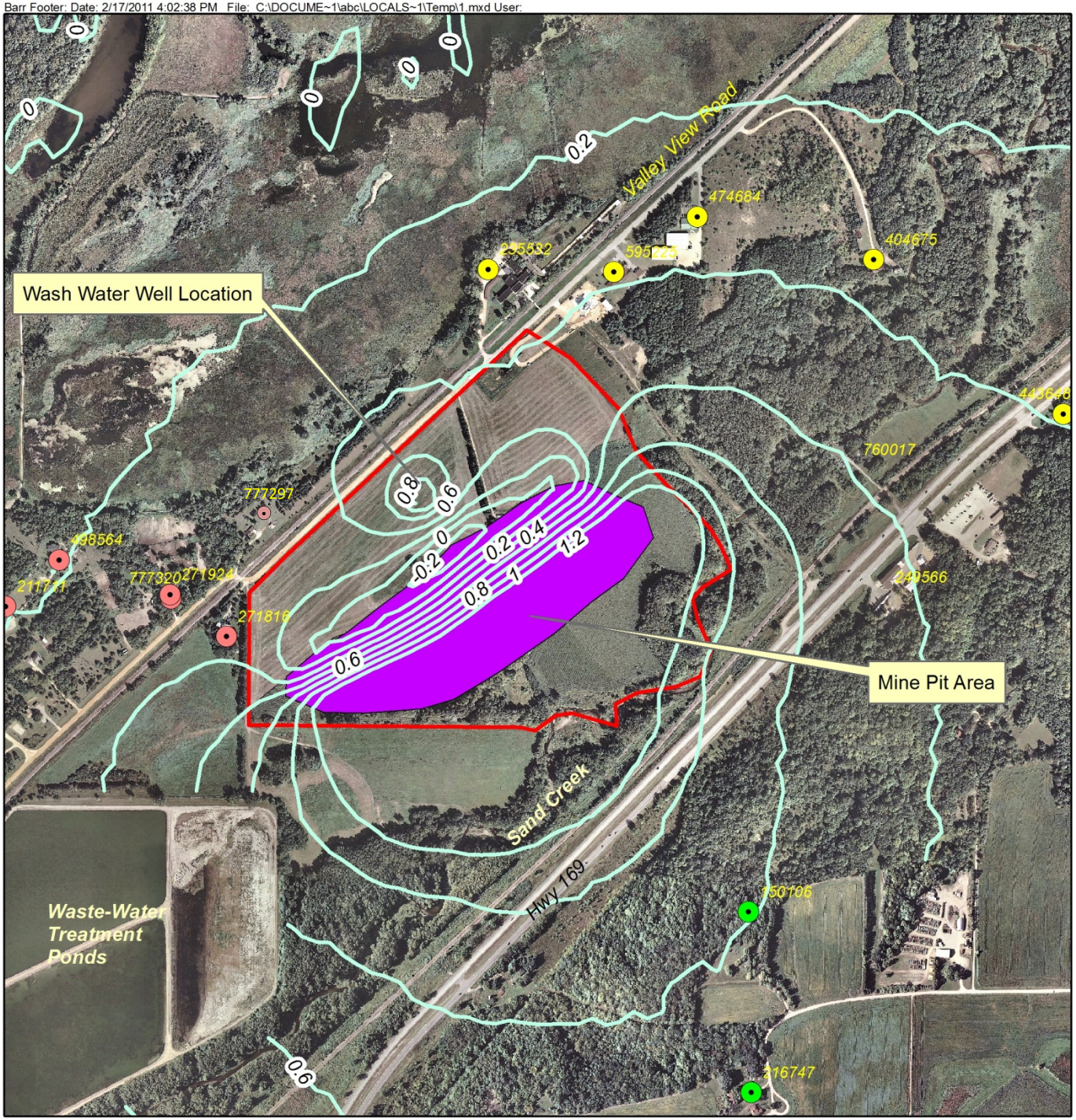
Contour Interval = 1 ft

Miles
0.1 0

Figure 2-4

EXISTING CONDITIONS:
MODELED WATER TABLE
ELEVATION AND GROUNDWATER
FLOW PATHS (WITH TIME-OF-TRAVEL)
Jordan Aggregates EIS
Scott County, Minnesota

Barr Footer: Date: 2/17/2011 4:02:38 PM File: C:\DOCUME~1\abc\LOCALS~1\Temp\1.mxd User:



EXPLANATION

Predicted Drawdown (ft)

Proposed Mine Pit

Mine Site

Local Wells

AQUIFER

- Quaternary
- Jordan Sandstone
- St. Lawrence Fm.
- FIG Aquifer
- Mt. Simon Aquifer

Contour Interval = 0.2 feet

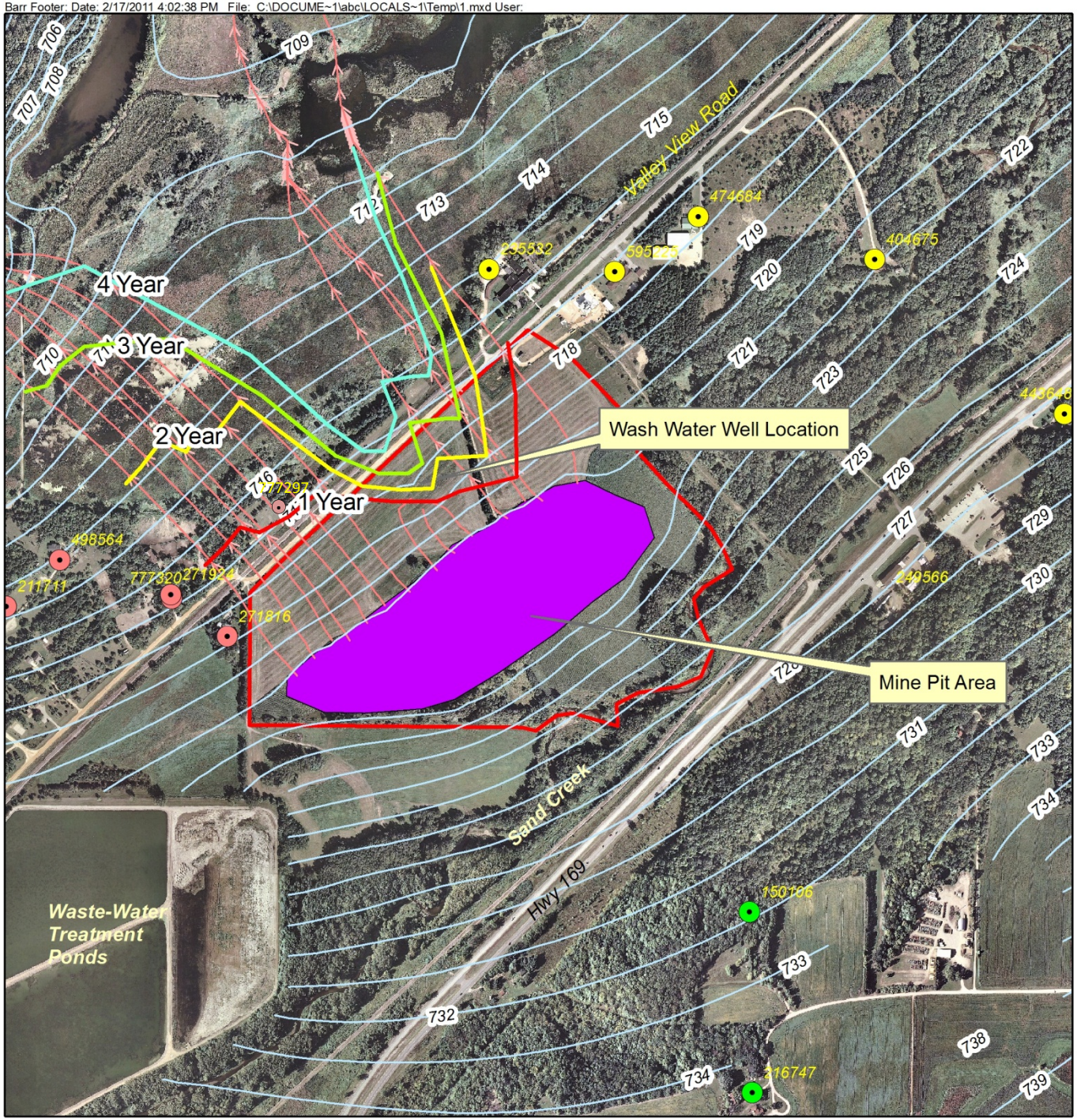
Miles

0.2 0

Figure 3-1

PREFERRED MINE PIT
PREDICTED WATER-TABLE
DRAWDOWN
Jordan Aggregates EIS
Scott County, Minnesota

Barr Footer: Date: 2/17/2011 4:02:38 PM File: C:\DOCUME~1\abc\LOCALS~1\Temp\1.mxd User:



EXPLANATION

- Predicted Water Table (ft, MSL)
- Predicted Groundwater Flow Paths
- Proposed Mine Pit
- Mine Site

Local Wells

AQUIFER

- Quaternary
- Jordan Sandstone
- St. Lawrence Fm.
- FIG Aquifer
- Mt. Simon Aquifer

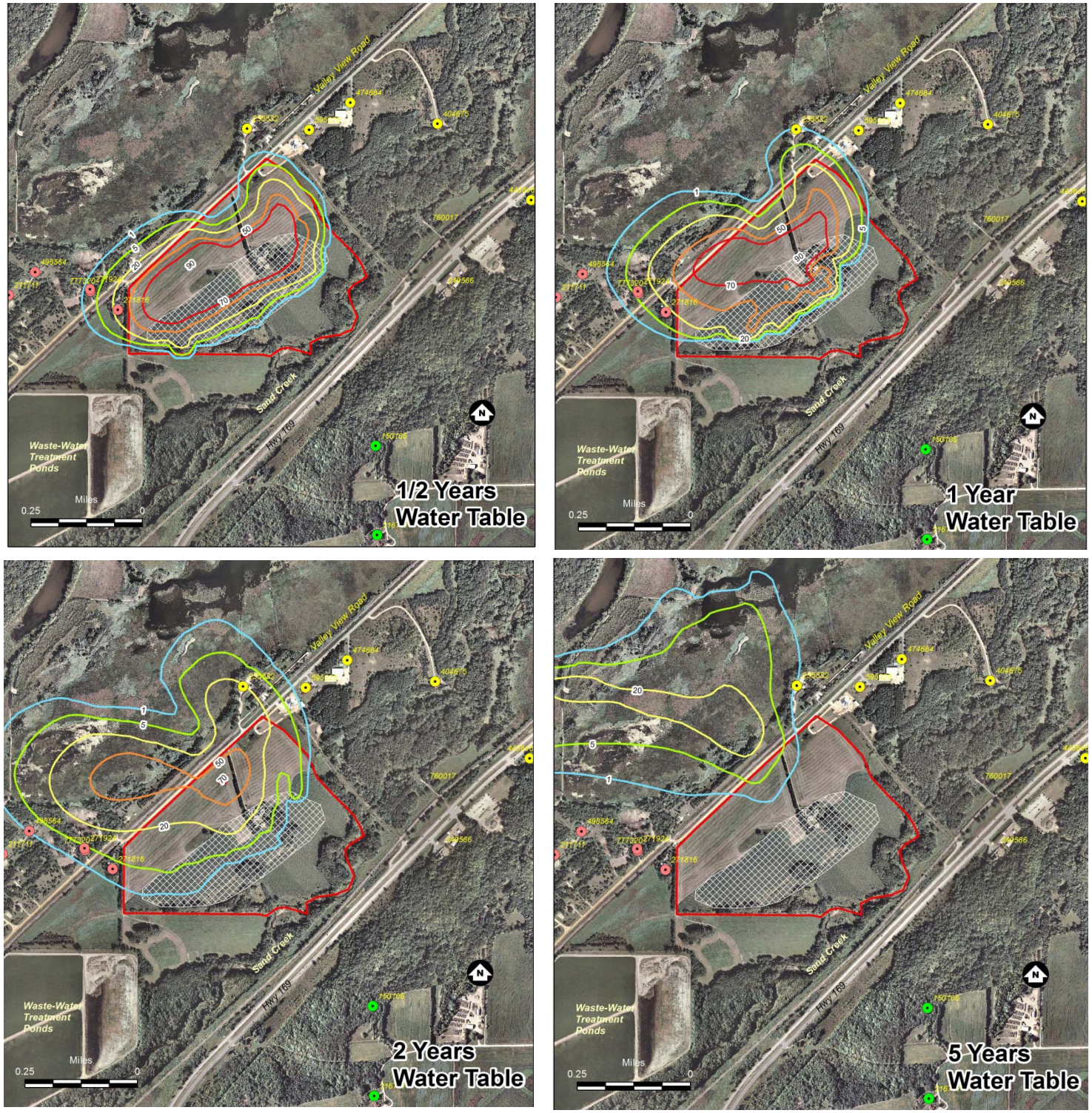
Contour Interval = 1 ft

Miles

0.25 0

Figure 3-2

PREFERRED MINE PIT: MODELD WATER-TABLE ELEVATIONS AND GROUNDWATER FLOW PATHS (WITH TIME OF TRAVEL)
Jordan Aggregates EIS
Scott County, Minnesota



EXPLANATION

Local Wells

AQUIFER

- Quaternary
- Jordan Sandstone
- St. Lawrence Fm.
- FIG Aquifer
- Mt. Simon Aquifer

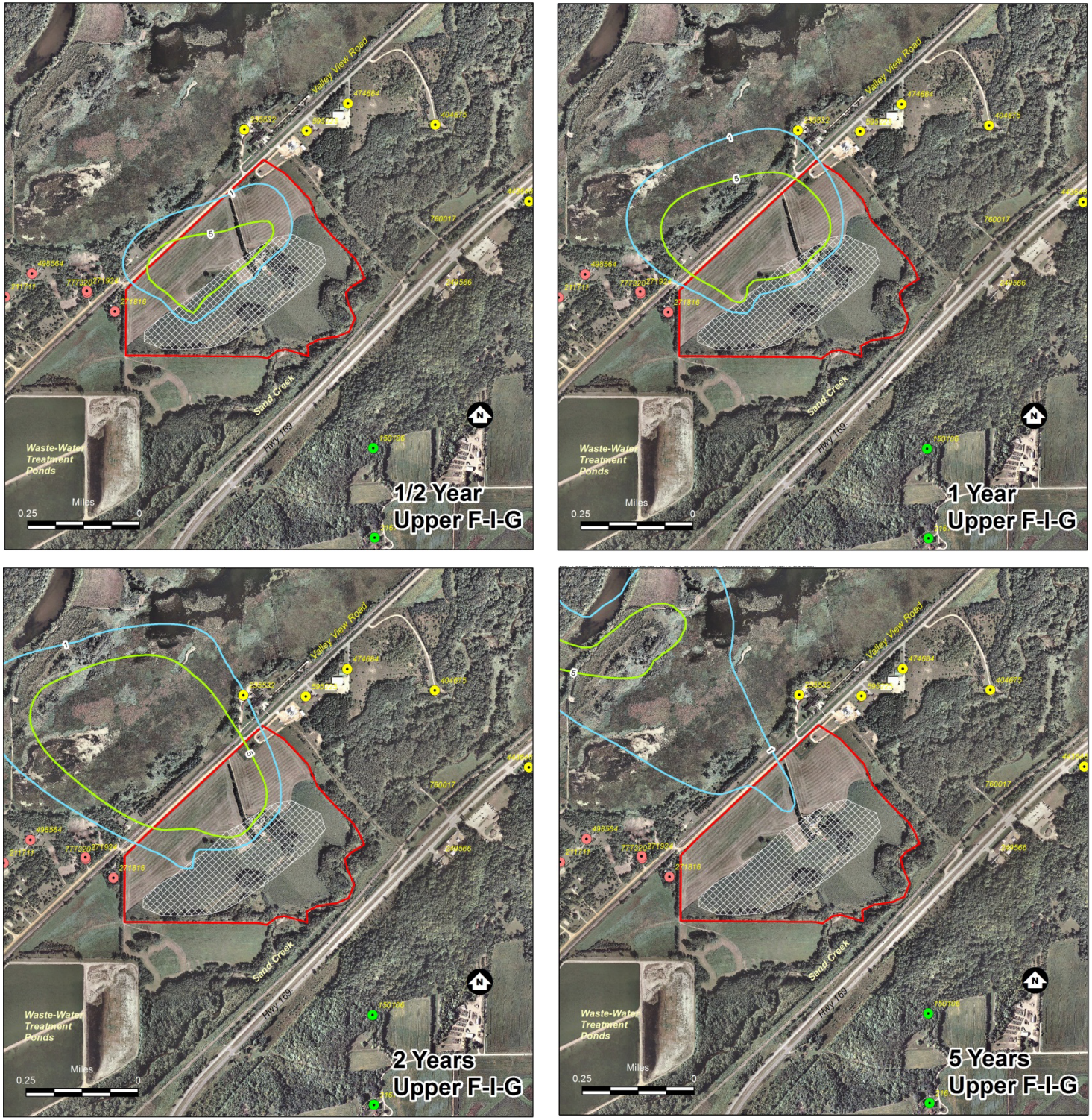
Percent of Flood Water

- 1
- 5
- 20
- 50
- 70

Contours represent the predicted percent of flood water from the mine pit that is present in the groundwater after the specified year(s) since flooding took place

Figure 3-5

PREDICTED PERCENTAGE OF FLOOD WATER IN WATER-TABLE AQUIFER: NON-REACTIVE SOLUTE SIMULATION
Jordan Aggregates EIS
Scott County, Minnesota

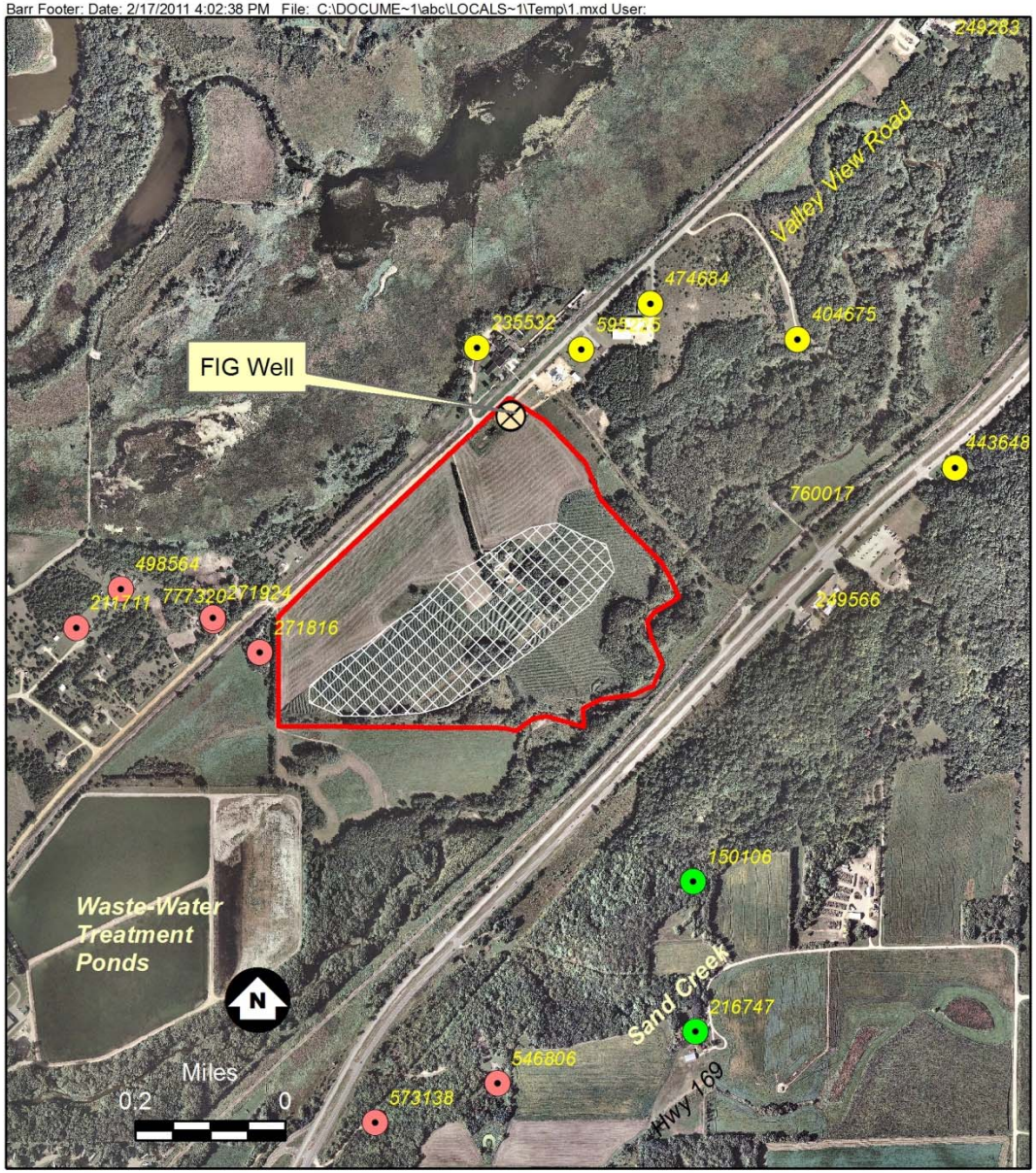


Contours represent the predicted percent of flood water from the mine pit that is present in the groundwater after the specified year(s) since flooding took place

Figure 3-4

PREDICTED PERCENTAGE OF FLOOD WATER IN UPPER FIG AQUIFER: NON-REACTIVE SOLUTE SIMULATION
Jordan Aggregates EIS
Scott County, Minnesota

Barr Footer: Date: 2/17/2011 4:02:38 PM File: C:\DOCUME~1\abc\LOCALS~1\Temp\1.mxd User:



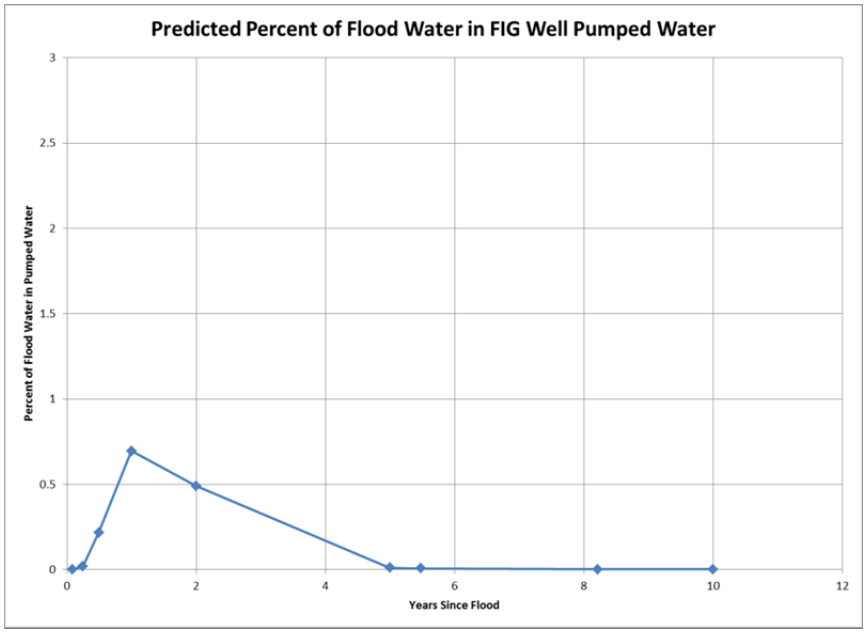


Figure 3-5

LOCATION OF POTENTIAL FUTURE FIG AQUIFER WELL AND PREDICTED MAXIMUM PERCENT OF FLOOD WATER PUMPED BY WELL
Jordan Aggregates EIS
Scott County, Minnesota

Attachment A

Jordan Aggregates Pumping Test Analysis

Technical Memorandum

To: Jordan Aggregates EIS File
From: Adam Janzen
Subject: Jordan Aggregates Pumping Test Analysis
Date: 3/16/2012
Project: 23/70-1010

Introduction

This memorandum details the analysis of pumping test data collected from February 13, 2012 through February 17, 2012 during a pumping test conducted by Carlson-McCain, Inc. at the proposed Jordan Aggregates mine site in Sand Creek Township, MN. The drawdown data from the test pumping well have been analyzed using conventional analytical methods to obtain estimates of hydraulic conductivity for the Franconia shale formation.

Site Description

The proposed Jordan Aggregate mine site is located at 17825 Valley View Drive, Sand Creek Township, Scott County, Minnesota. Eight wells are located on the site, as shown in the site map in Figure 1. The "Greenhouse Well" (Unique #207419) was used as the pumping well for the test, and water levels were monitored in the "House Well" (Unique #207418) and monitoring well MW-3 (Unique #767638). The Greenhouse Well and the House Well are both completed in the Franconia shale, while the remaining monitoring wells and piezometers are completed in the shallower sand and gravel deposits. Figures 2 and 3 show the assumed stratigraphy, derived from the well logs for the Greenhouse Well and the House Well obtained from the Minnesota Department of Health's (MDH) County Well Index (MDH, 2007). Water levels in Figures 2 and 3 are from the manual measurements collected before and during the pumping test presented in Table 1. The water level in monitoring well MW-3 (assumed to be a water-table well) was used as the water table elevation. The stratigraphy in Figure 2 was used in the analysis of the Greenhouse Well data, while the stratigraphy in Figure 3 was assumed for the House Well analysis.

Data Filtering

The raw water level data for the Greenhouse Well and the House Well and the pumping rates in the Greenhouse Well (in gallons per minute) are shown in Figures 3 and 4. Figure 3 shows the entire monitoring period, while Figure 4 focuses on only the first six hours of testing. Note that "sensor depth" refers to the depth of the sensor below the water level in the well, not the absolute depth of the sensor relative to the ground surface or top of casing. As shown on Figure 4, it appears the initial attempt at the pumping test on 2/13/2012 was aborted when rapid drawdown indicated that the pressure sensor was located too shallow in the well. The pump was shut off at 11:07 on 2/13/2012, and then restarted at 11:21 the same day after the sensor was lowered approximately 30 feet. Table 2 defines the four pumping periods of the test; the initial aborted test is not included here or in the analysis.

As seen in Figure 4 between 13:00 and 14:00 on 2/13/2012, there is a spike in the sensor depth data for the House Well. This single point was assumed to be an outlier and was removed from the dataset.

The data for the Greenhouse Well and the House Well both show sudden increases in sensor depth during the late morning hours on 2/15/2012, as shown in Figure 3. The reasons for these abrupt changes are unknown, as the pumping rate remained constant during this time and the sensors were not moved. Lacking a justifiable basis for applying an offset to a large portion of the data, no attempt was made to remove the jumps from the dataset.

Drawdown Calculation

Drawdown data is required for the analysis. Drawdowns for the House Well were calculated using the sensor depth at the beginning of the data record as the reference value. As noted earlier, the sensor in the Greenhouse Well was moved deeper after the aborted first test. Sensor depth data indicate that the water level was still rising in the Greenhouse Well when the pump was restarted; the level rose approximately 0.1 foot in the 5 minutes before turning on the pump. Since no additional information was provided as to the absolute depth of the sensor relative to the ground surface or top of casing, the measured sensor depth below the water level when the pump was restarted was used as the reference to calculate the pumping well drawdowns. Figure 5 shows the drawdown data for both wells.

Data Analysis

The drawdown data were analyzed using AQTESOLV version 4.5 Professional (Hydrosolv, 2007). Conventional analytical methods for pumping test analysis plot drawdown versus time on a log-log or semilog plot and adjust parameters such as the transmissivity (vertically integrated hydraulic conductivity) and the storage coefficient until an optimum fit between a theoretical type curve and the observed data is obtained. Summary reports and curve fitting plots from the AQTESOLV analysis are included as Attachment A.

Both confined and leaky confined analyses were performed. The confined analyses assume no leakage from the sand and gravel into the Franconia, and are thus expected to provide an upper bound on the hydraulic conductivity of the Franconia. The leaky analyses allow vertical flow through the sand and gravel unit into the Franconia. It has been assumed that the bottom of the Franconia is a no-flow boundary, and that there is a constant-head boundary at the top of the sand and gravel unit. This constant-head boundary represents the water table in the sand and gravel unit, though its position is fixed. Since in reality the water table elevation may decrease due to leakage and thus reduce the vertical gradient, the vertical hydraulic conductivity of the sand and gravel may be underestimated by using the constant-head boundary to approximate the water table.

Greenhouse Well Analysis

Estimates of hydraulic conductivity for the Franconia shale and the overlying sand and gravel unit from the analysis of the Greenhouse Well drawdown data are summarized in Table 3.

An initial estimate of hydraulic conductivity for the Franconia shale was obtained using the Papadopulos-Cooper (1967) solution for a large-diameter well pumping in a confined formation. This solution includes a correction for wellbore storage, which affects the drawdown in the pumping well at early times. Fitting the Papadopulos-Cooper solution to the data gave an estimate of 22 feet per day (ft/day) for hydraulic conductivity.

The leaky analysis used the Moench (1985) solution for a large-diameter well in a leaky confined aquifer. The appropriate boundary conditions (constant-head above the aquitard, no-flow below the aquifer) are represented by Case 3 of the Moench solution. Analysis of the entire drawdown dataset gave estimates of

15 ft/day and 0.0002 ft/day for the Franconia and sand and gravel hydraulic conductivities, respectively. As seen in the plot from this analysis in Attachment A, the Moench type curve fits the late time data better than the early time data. The earlier time data were then analyzed separately and sequentially, starting with the first pumping period, followed by the first two pumping periods, and so on. The recovery data alone were also analyzed using the Moench solution; this is known as residual drawdown analysis. The estimated hydraulic conductivities for the Franconia were in a relatively tight range of 8-22 ft/day, while the sand and gravel conductivities were much more variable, ranging from 0.0002-10 ft/day.

House Well Analysis

Estimates of hydraulic conductivity for the Franconia shale and the overlying sand and gravel unit from the analysis of the House Well drawdown data are summarized in Table 4.

Analysis of the House Well data followed a similar procedure as that for the Greenhouse Well data. The initial confined estimate of Franconia hydraulic conductivity using the Papadopulos-Cooper solution was 1500 ft/day, much higher than any value from the Greenhouse Well analysis. The leaky analysis using the Moench solution proceeded in the same fashion as for the Greenhouse Well, sequentially analyzing the pumping data in sections. The hydraulic conductivity estimates for the Franconia were consistently much larger than those obtained from the Greenhouse Well analysis, with the exception of the recovery analysis, which at 12 ft/day was in the same range as the Greenhouse Well conductivities. Sand and gravel conductivities also tended to be larger, with the exception of the minimum value of 1×10^{-8} ft/day.

Discussion of Results

The estimated hydraulic conductivities for the Franconia shale from the House Well analysis seem much too high for a shale formation. The expected range of hydraulic conductivity for the Franconia shale in particular is 5-30 ft/day, which is consistent with the estimates from the Greenhouse Well analysis. Estimates of hydraulic conductivity from analysis of recovery data are often more reliable than those derived from pumping data because the rate is assured to be constant (at zero) and frictional losses from pumping the well will not affect the solution. The Franconia hydraulic conductivities estimated from the recovery data from both the Greenhouse Well and the House Well are consistent, lending more support to the conclusion that the House Well pumping analysis is not believable. Typically analysis of the observation well data is preferred over the pumping well data because the estimated parameters will be

averaged over a larger volume of the aquifer and the influence of well losses will be less significant, but in this case the pumping well data appear to be more reliable.

Summary

Analysis of the drawdown data from the Greenhouse Well resulted in a range of estimated hydraulic conductivities from 8-22 ft/day, with an arithmetic average of 14 ft/day. The vertical hydraulic conductivity of the sand and gravel was less reliably estimated from this analysis: a wide range of 0.0002 to 10 ft/day. Analysis of the House Well data gave considerably higher estimates from of 12-1600 ft/day (740 ft/day average) for the Franconia. The estimated vertical hydraulic conductivity of the sand and gravel ranged from 1×10^{-8} ft/day to 20 ft/day. The Franconia estimates from the Greenhouse Well analysis are assumed to be more accurate and reliable, and fall within the expected range for this unit.

References

Carlson-McCain, Inc. (2012). Personal communication between Nick Bonow of Carlson McCain, Inc. and Ray Wuolo of Barr Engineering, March 1, 2012.

Hydrosolv, Inc. (2007). AQTESOLV for Windows, User's Guide.

Minnesota Department of Health (2007). County Well Index Online. Accessed from http://www.health.state.mn.us/divs/eh/cwi/.

Moench, A.F. (1985). Transient flow to a large-diameter well in an aquifer with storative semiconfining layers. *Water Resources Research*, vol. 21, no. 8, pp. 1121-1131.

Papadopulos, I.S. and H.H. Cooper (1967). Drawdown in a well of large diameter. *Water Resources Research*, vol. 3, no. 1, pp. 241-244.

Theis, C.V. (1935). The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using groundwater storage. *Am. Geophys. Union Trans.*, vol. 16, pp. 519-524.

Table 1: Manual water level measurements before and during the pumping test. (Carlson-McCain, 2012).

Well	Location (Scott Co. Coords.)		Top of Riser Elevation (ft MSL)	Depth to Water (bTOR)	Water Elevation (ft MSL)	Date	Time
	Northing (ft)	Easting (ft)					
MW-1	178937	420391	741.45	23.6	717.85	2/13/2012	9:03 AM
MW-2	179410	420894	732.12	14.65	717.47	2/13/2012	8:55 AM
MW-3	179934	421449	731.99	13.9	718.09	2/13/2012	8:01 AM
MW-4	180263	422291	740.19	21.17	719.02	2/13/2012	12:04 PM
PZ-1	178315	421990	729.66	8.06	721.60	2/13/2012	12:24 PM
PZ-2	179215	423045	728.63	7.12	721.51	2/13/2012	12:17 PM
House Well	179124	421913	734.86	15.14	719.72	2/13/2012	9:49 AM
Greenhouse Well	179419	421854	746.76	27.03	719.73	2/13/2012	10:20 AM

Table 2: Pumping rates for the Greenhouse Well

Date and Time	Elapsed Time (s)	Pumping Rate (gpm)
2/13/2012 11:21:54	0	43
2/13/2012 11:32:49	655	47
2/13/2012 12:38:49	4615	52
2/13/2012 13:21:06	7152	57
2/16/2012 08:41:00	249546	0

Table 3: Summary of hydraulic conductivity estimates from analysis of Greenhouse Well pumping test data.

Data Used	Analysis Method	Franconia Kx (ft/day)	Sand & Gravel Kz (ft/day)
All pumping + recovery	Papadopulos-Cooper	22	N/A
All pumping + recovery	Moench (Case 3)	15	0.0002
First pumping period only	Moench (Case 3)	16	0.02
First two pumping periods	Moench (Case 3)	9	10
First three pumping periods	Moench (Case 3)	15	0.0005
All pumping only	Moench (Case 3)	8	4
Recovery Only	Moench (Case 3)	15	0.0009

Table 4: Summary of hydraulic conductivity estimates from analysis of House Well pumping test data.

Data Used	Analysis Method	Franconia Kx (ft/day)	Sand & Gravel Kz (ft/day)
All pumping + recovery	Papadopulos-Cooper	1500	N/A
All pumping + recovery	Moench (Case 3)	520	9
First pumping period only	Moench (Case 3)	1600	1e-8
First two pumping periods	Moench (Case 3)	325	14
First three pumping periods	Moench (Case 3)	1000	2
All pumping only	Moench (Case 3)	240	20
Recovery Only	Moench (Case 3)	12	12

Barr Footer: Date: 3/16/2012 8:23:38 AM File: I:\Projects\2370\1010\Maps\Pumping Test Figures\Figure_1_Site_Map.mxd User: AKJ

Imagery: 2003

Well

Property Line

Meters

50 0 50 100

Feet

100 0 100 200 300 400

BARR

Figure 1

SITE MAP
Proposed Mine Site
Jordan Aggregates, LLC
Sand Creek Township, MN

BARR

MINNEAPOLIS, MINNESOTA - HIBBING, MINNESOTA
DULUTH, MINNESOTA
ANN ARBOR, MICHIGAN - JEFFERSON CITY, MISSOURI

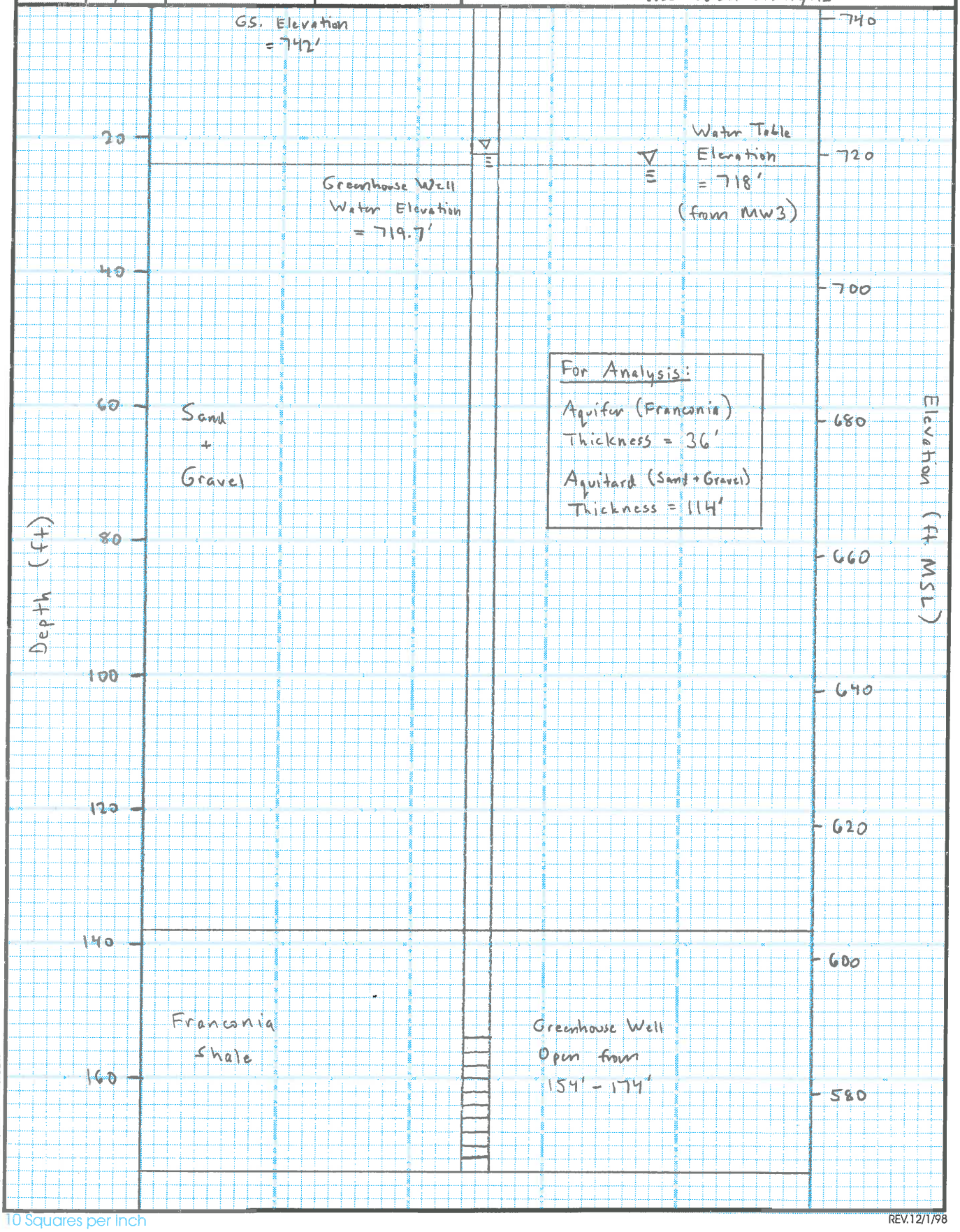
COMPUTED	CHECKED	SUBMITTED
BY AKJ	BY	TO
DATE 3/15/12	DATE	DATE

DATE 3/15/2012 SHEET NO. 1/1

PROJECT NAME Jordan Aggregates

PROJECT NUMBER 23/70-1010

SUBJECT Figure 2: Assumed Stratigraphy
Greenhouse Well Analysis



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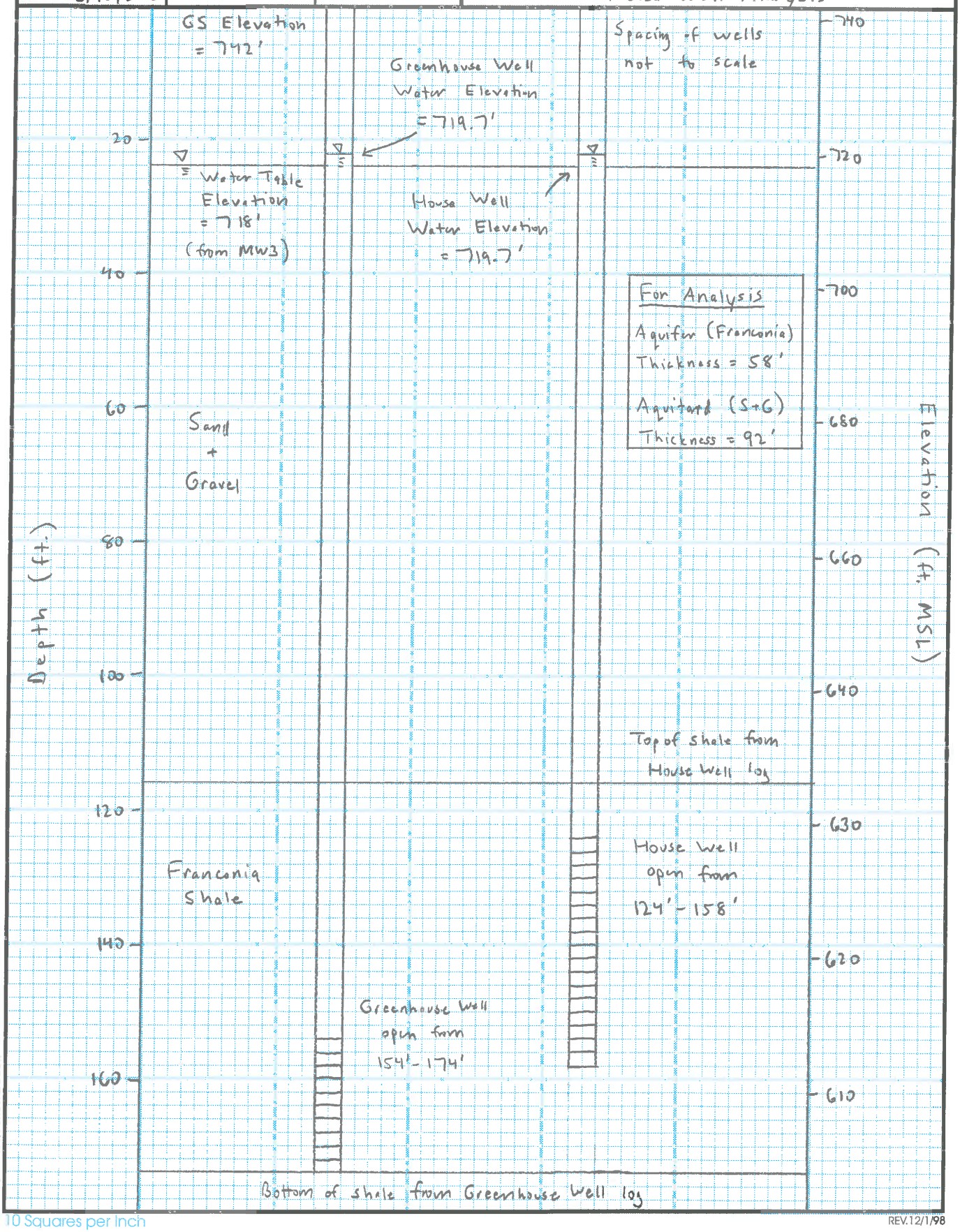
10 Squares per Inch

REV.12/1/98

BARR	MINNEAPOLIS, MINNESOTA - HIBBING, MINNESOTA DULUTH, MINNESOTA ANN ARBOR, MICHIGAN - JEFFERSON CITY, MISSOURI	DATE 3/16/2012	SHEET NO. 1/1
		PROJECT NAME Jordan Aggregates	
COMPUTED	CHECKED	SUBMITTED	PROJECT NUMBER 23/70-1010
BY AKJ	BY	TO	SUBJECT Figure 3: Assumed Stratigraphy House Well Analysis
DATE 3/16/2012	DATE	DATE	



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10 Squares per Inch

REV.12/1/98

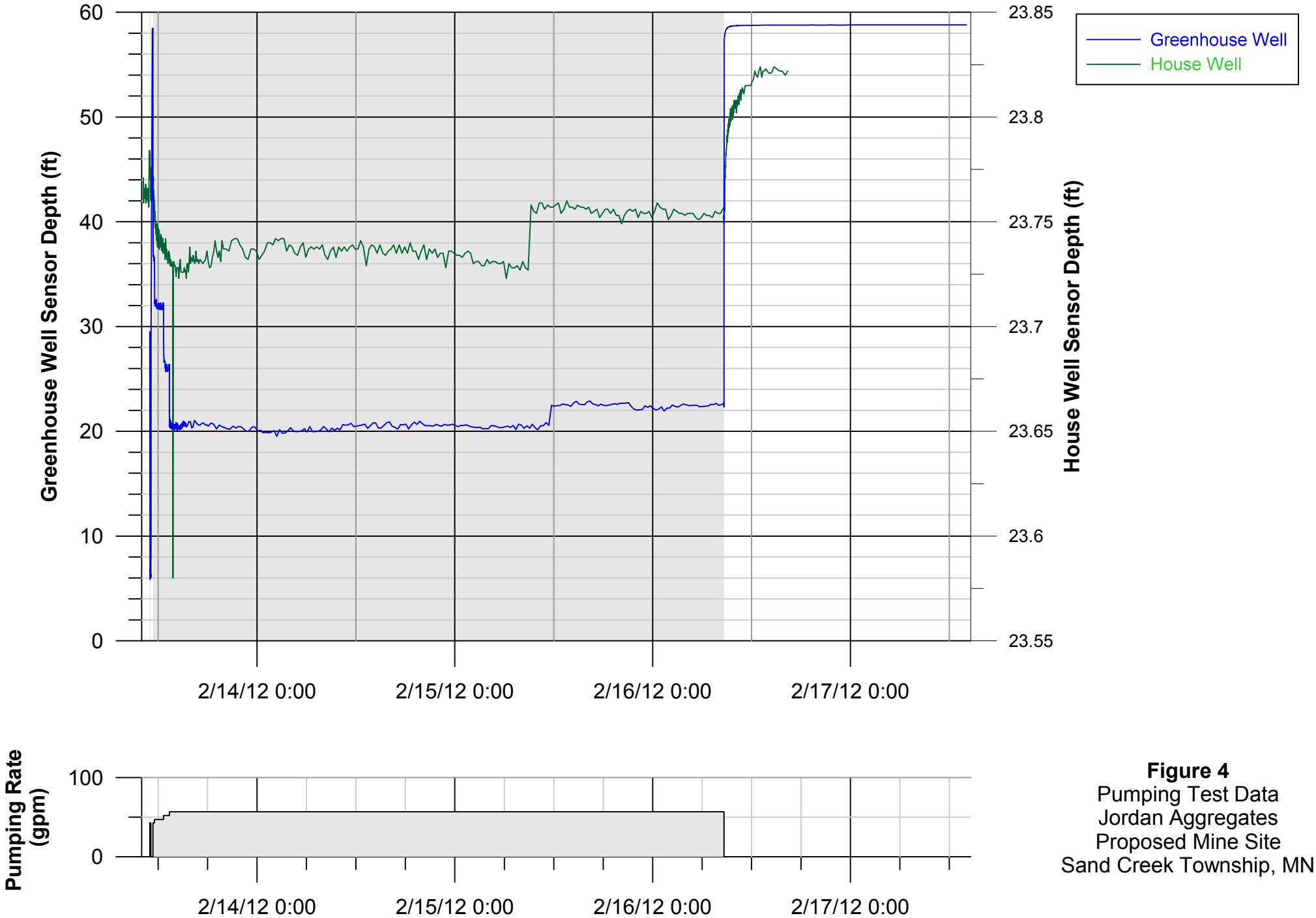

Figure 4
Pumping Test Data
Jordan Aggregates
Proposed Mine Site
Sand Creek Township, MN

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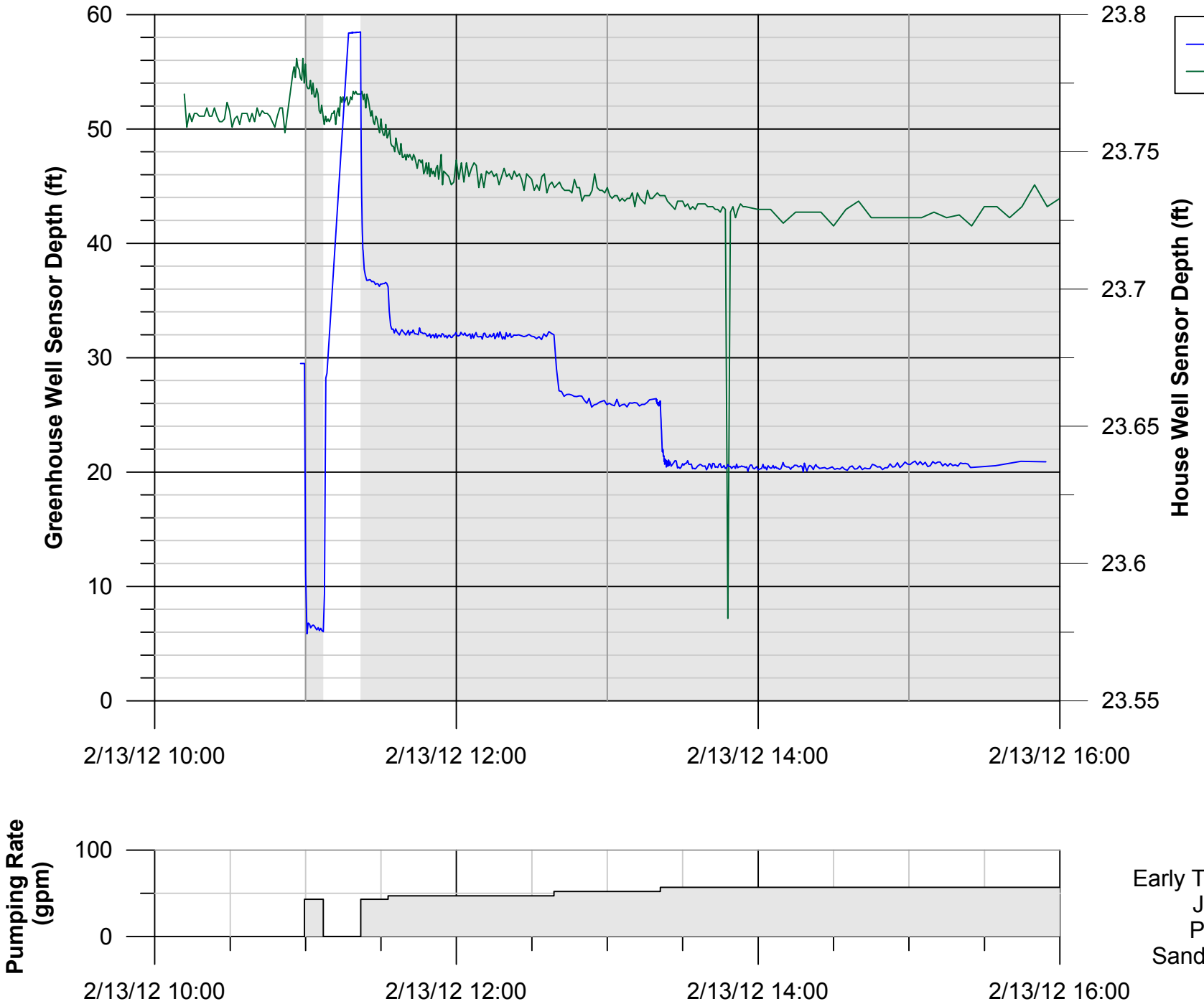

Figure 5
Early Time Pumping Test Data
Jordan Aggregates
Proposed Mine Site
Sand Creek Township, MN

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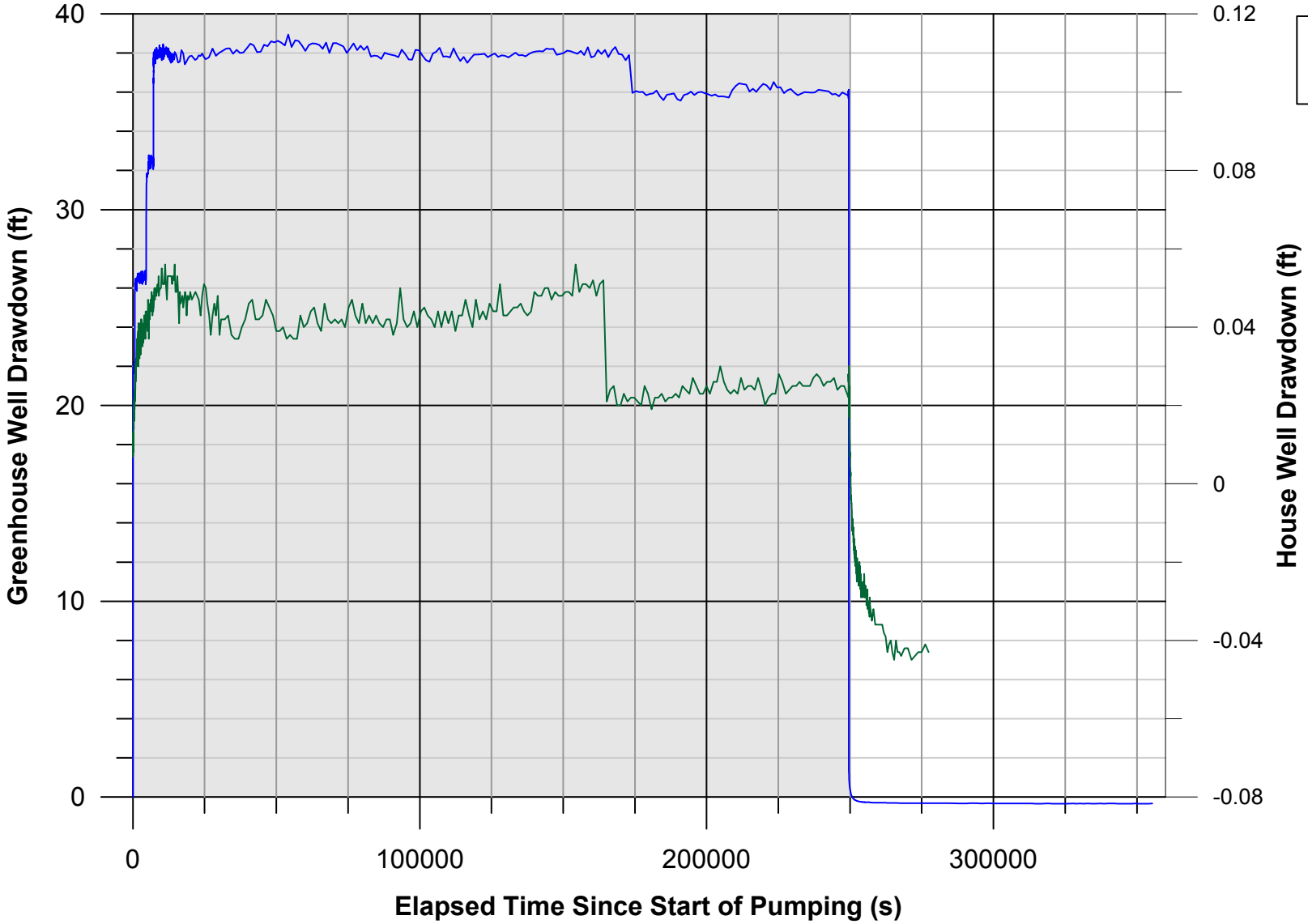

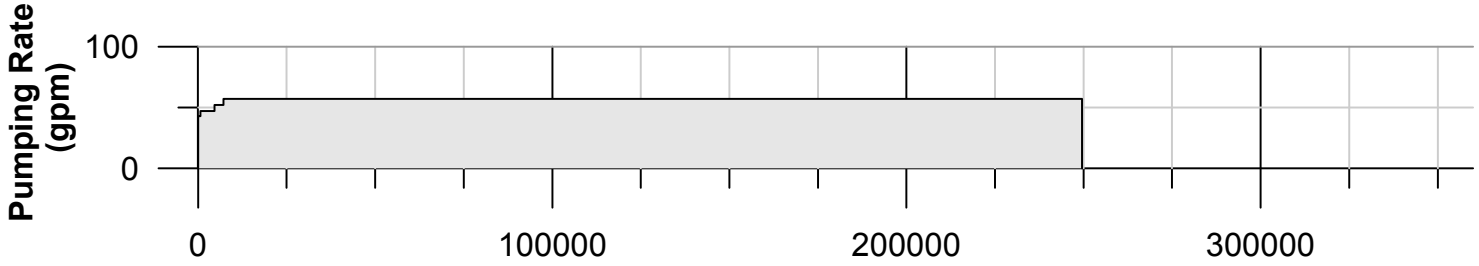

Figure 6
Drawdown Data
Jordan Aggregates
Proposed Mine Site
Sand Creek Township, MN

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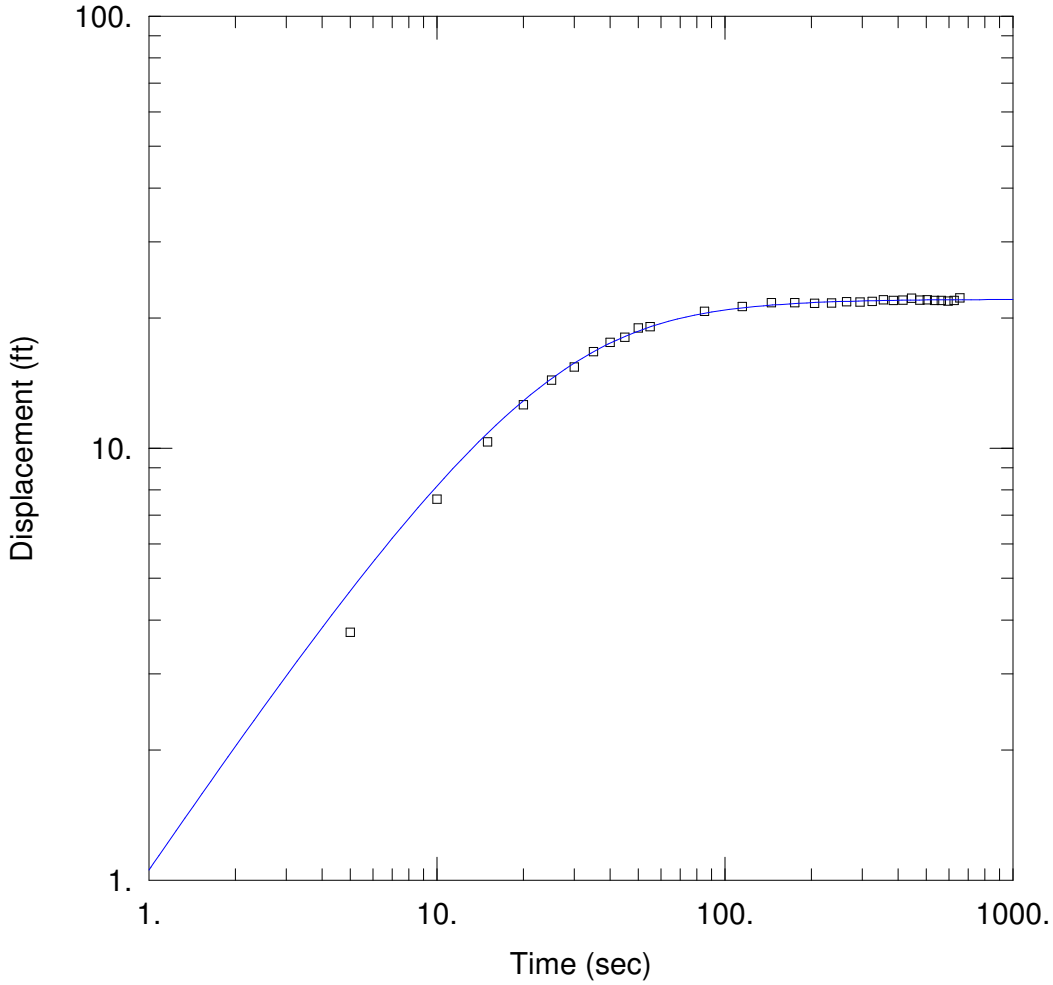


WELL TEST ANALYSIS

Data Set: P:\...\pumping_well_leaky_Moench_1.aqt
Date: 03/16/12 Time: 13:41:18

PROJECT INFORMATION

Company: Barr Engineering
Client: Jordan Aggregates
Project: 23/70-1010
Location: Sand Creek Township, MN
Test Well: Pumping Well
Test Date: 02/13/2012

AQUIFER DATA

Saturated Thickness: 36. ft
Anisotropy Ratio (Kz/Kr): 0.1
Aquitard Thickness (b'): 114. ft
Aquitard Thickness (b"): 1. ft

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
Pumping Well	179419	421854

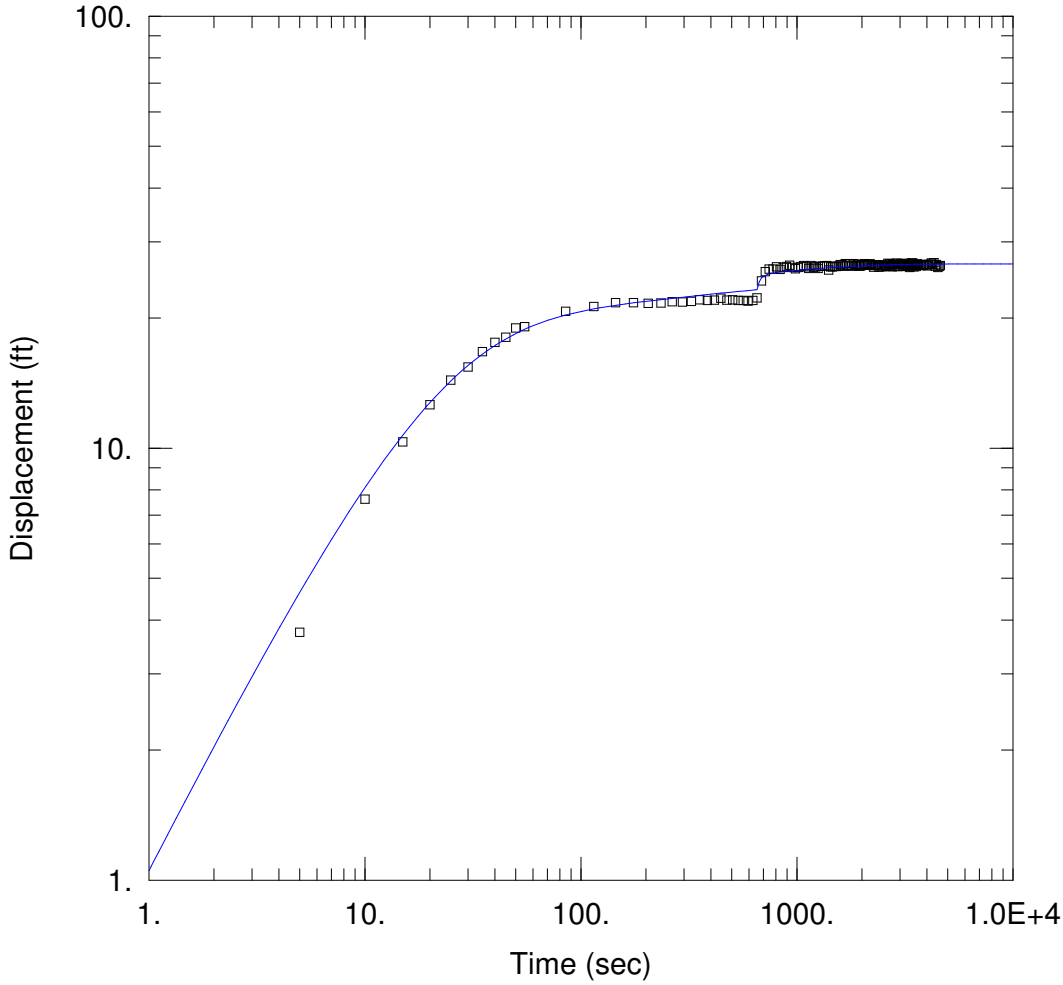
Observation Wells

Well Name	X (ft)	Y (ft)
▫ Pumping Well	179419	421854

SOLUTION

Aquifer Model: Leaky
Solution Method: Moench (Case 3)

T = 566.7 ft^2/day
S = 3.063E-7
r/B' = 8.452E-5
ß' = 1.0E-5
r/B" = 0.
ß" = 0.
Sw = 0.
r(w) = 0.167 ft
r(c) = 0.167 ft



WELL TEST ANALYSIS

Data Set: P:\...\pumping_well_leaky_Moench_2.aqt
Date: 03/16/12 Time: 13:42:31

PROJECT INFORMATION

Company: Barr Engineering
Client: Jordan Aggregates
Project: 23/70-1010
Location: Sand Creek Township, MN
Test Well: Pumping Well
Test Date: 02/13/2012

AQUIFER DATA

Saturated Thickness: 36. ft
Anisotropy Ratio (Kz/Kr): 0.1
Aquitard Thickness (b'): 114. ft
Aquitard Thickness (b"): 1. ft

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
Pumping Well	179419	421854

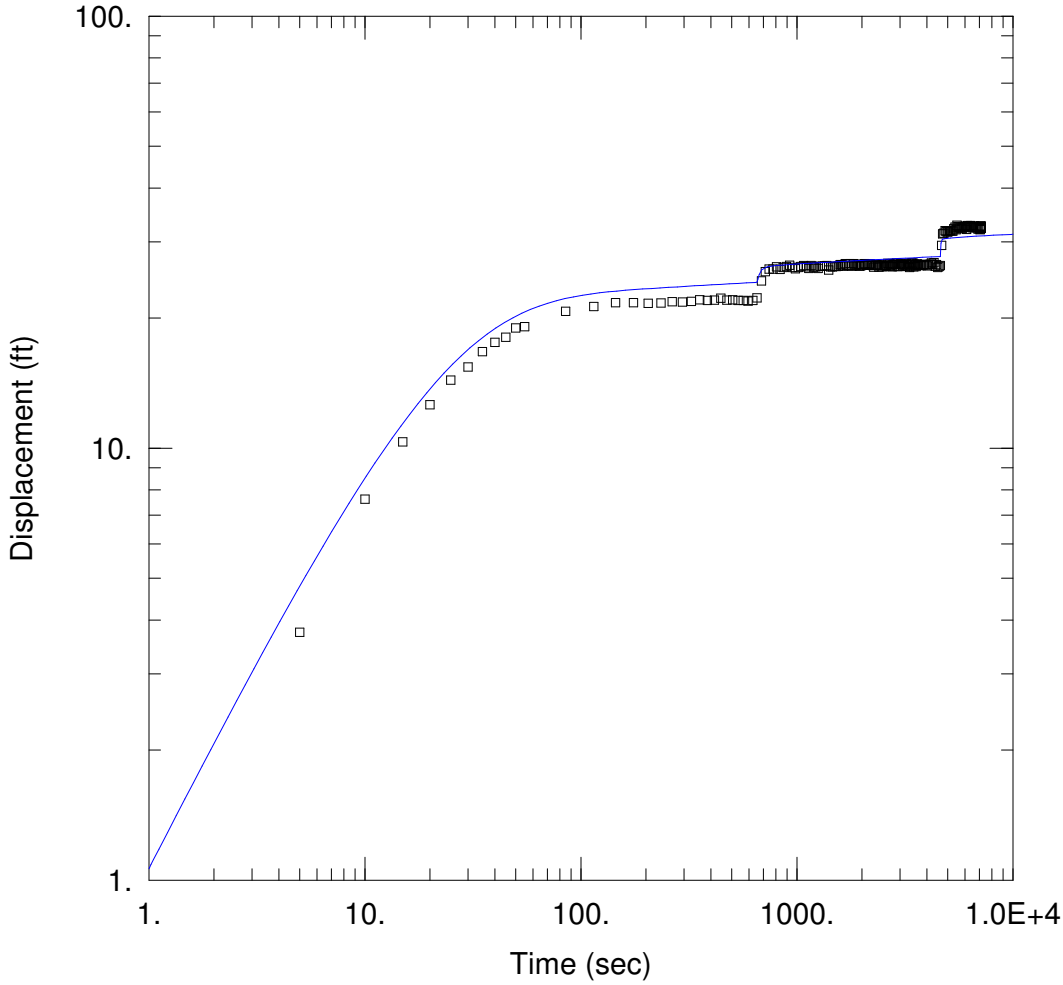
Observation Wells

Well Name	X (ft)	Y (ft)
▫ Pumping Well	179419	421854

SOLUTION

Aquifer Model: Leaky
Solution Method: Moench (Case 3)

T = 323.3 ft^2/day
S = 4.342E-5
r/B' = 0.002814
ß' = 0.006231
r/B" = 0.
ß" = 0.
Sw = 0.
r(w) = 0.167 ft
r(c) = 0.167 ft



WELL TEST ANALYSIS

Data Set: P:\...\pumping_well_leaky_Moench_3.aqt
Date: 03/16/12 Time: 13:44:14

PROJECT INFORMATION

Company: Barr Engineering
Client: Jordan Aggregates
Project: 23/70-1010
Location: Sand Creek Township, MN
Test Well: Pumping Well
Test Date: 02/13/2012

AQUIFER DATA

Saturated Thickness: 36. ft
Anisotropy Ratio (Kz/Kr): 0.1
Aquitard Thickness (b'): 114. ft
Aquitard Thickness (b"): 1. ft

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
Pumping Well	179419	421854

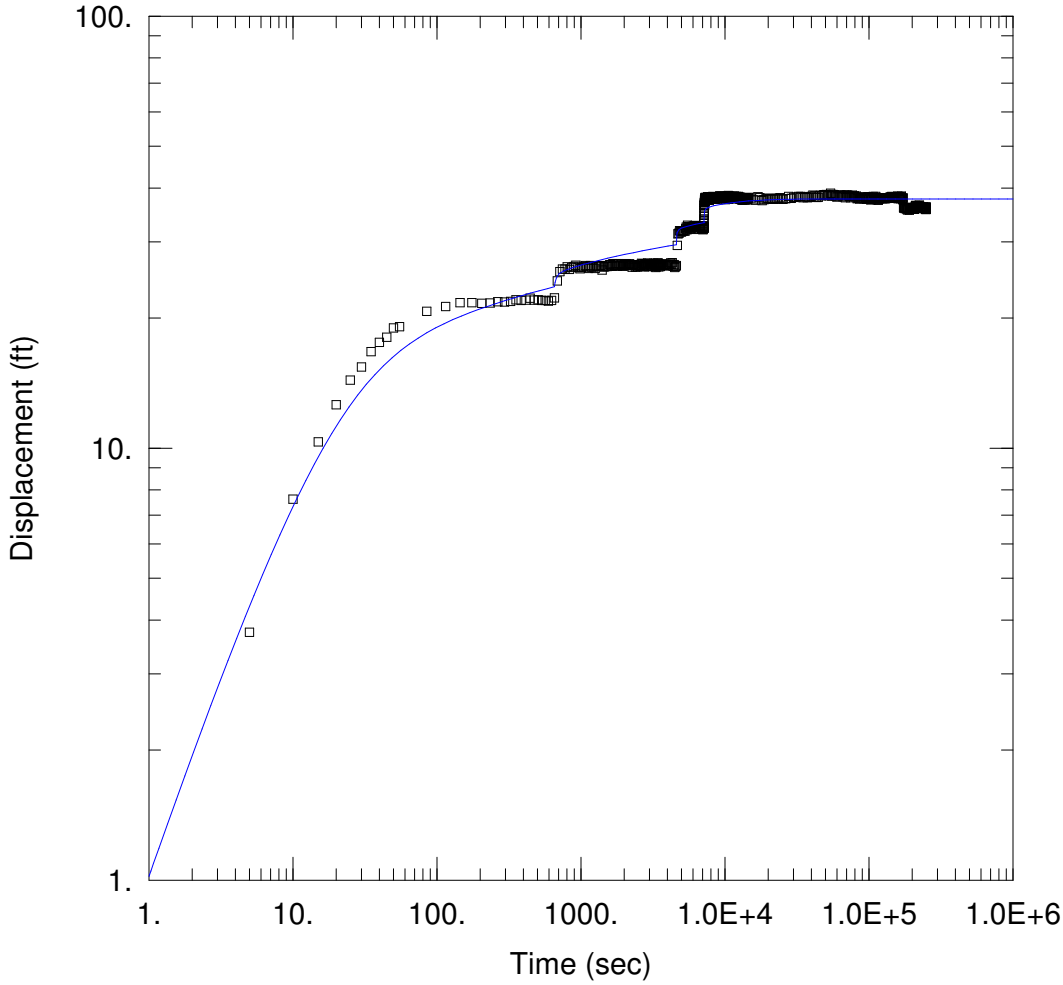
Observation Wells

Well Name	X (ft)	Y (ft)
▫ Pumping Well	179419	421854

SOLUTION

Aquifer Model: Leaky
Solution Method: Moench (Case 3)

T = 543.2 ft^2/day
S = 8.425E-10
r/B' = 1.514E-5
ß' = 0.0003667
r/B" = 0.
ß" = 0.
Sw = 0.
r(w) = 0.167 ft
r(c) = 0.167 ft



WELL TEST ANALYSIS

Data Set: P:\...\pumping_well_leaky_Moench_4.aqt
Date: 03/16/12 Time: 13:45:47

PROJECT INFORMATION

Company: Barr Engineering
Client: Jordan Aggregates
Project: 23/70-1010
Location: Sand Creek Township, MN
Test Well: Pumping Well
Test Date: 02/13/2012

AQUIFER DATA

Saturated Thickness: 36. ft
Anisotropy Ratio (Kz/Kr): 0.1
Aquitard Thickness (b'): 114. ft
Aquitard Thickness (b"): 1. ft

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
Pumping Well	179419	421854

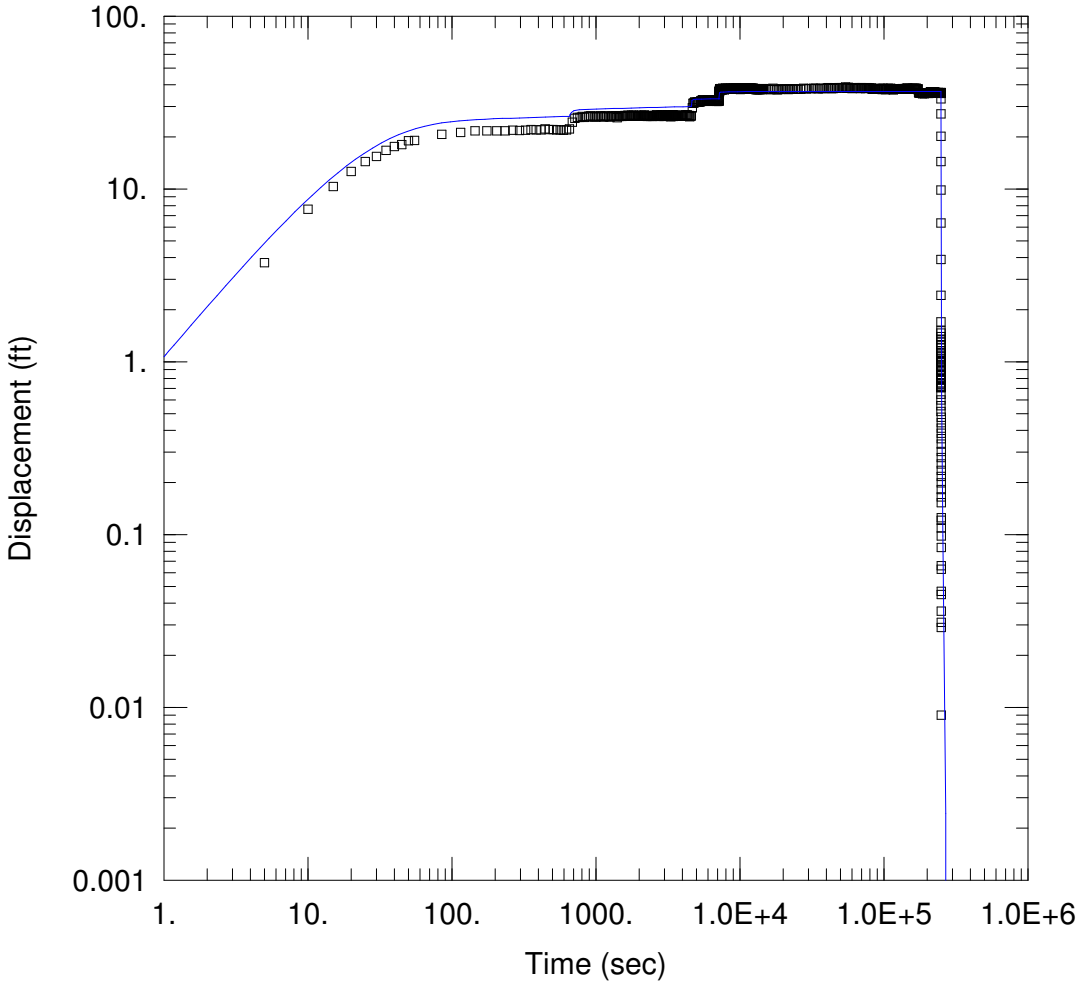
Observation Wells

Well Name	X (ft)	Y (ft)
▫ Pumping Well	179419	421854

SOLUTION

Aquifer Model: Leaky
Solution Method: Moench (Case 3)

T = 298.3 ft^2/day
S = 0.002742
r/B' = 0.001777
ß' = 0.0005132
r/B" = 0.
ß" = 0.
Sw = 0.
r(w) = 0.167 ft
r(c) = 0.167 ft



WELL TEST ANALYSIS

Data Set: P:\...\pumping_well_leaky_Moench_all.aqt
Date: 03/16/12 Time: 13:32:54

PROJECT INFORMATION

Company: Barr Engineering
Client: Jordan Aggregates
Project: 23/70-1010
Location: Sand Creek Township, MN
Test Well: Pumping Well
Test Date: 02/13/2012

AQUIFER DATA

Saturated Thickness: 36. ft
Anisotropy Ratio (Kz/Kr): 0.1
Aquitard Thickness (b'): 114. ft
Aquitard Thickness (b"): 1. ft

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
Pumping Well	179419	421854

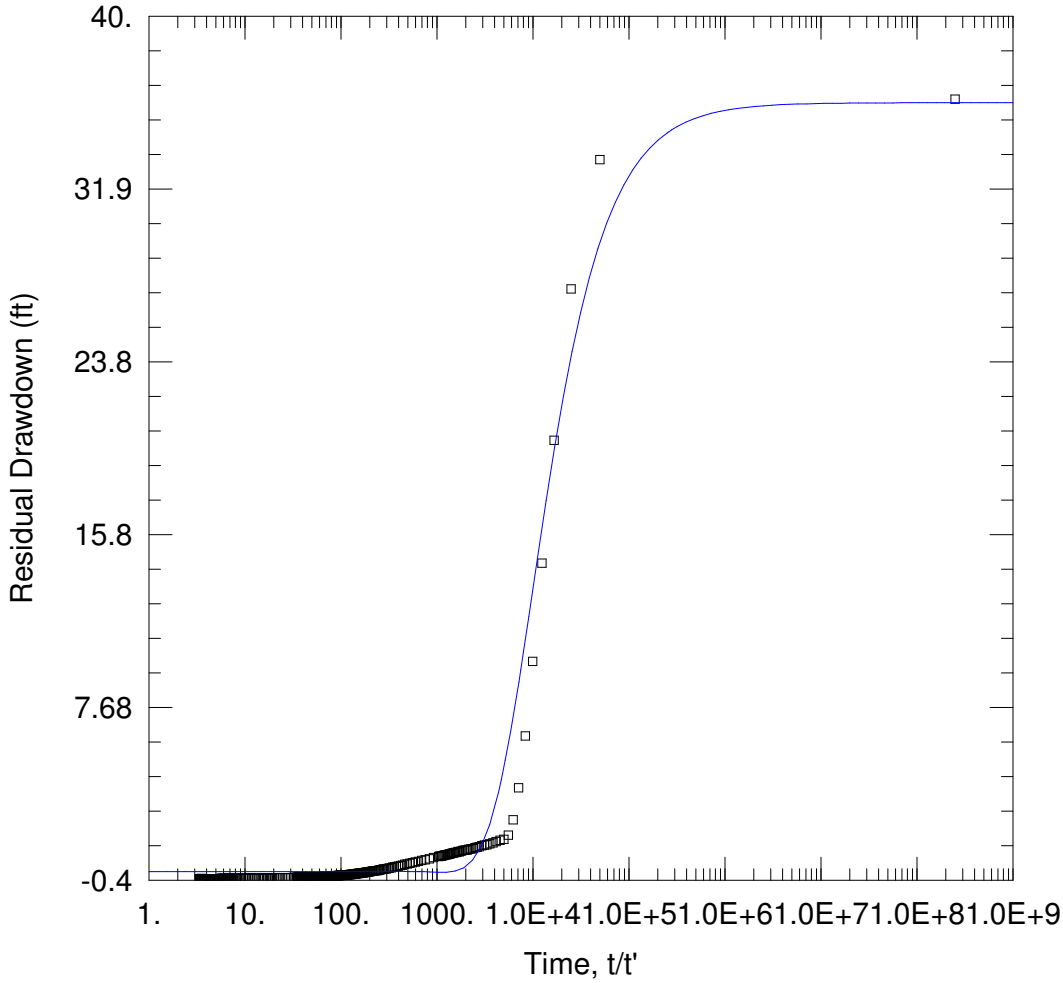
Observation Wells

Well Name	X (ft)	Y (ft)
▫ Pumping Well	179419	421854

SOLUTION

Aquifer Model: Leaky
Solution Method: Moench (Case 3)

T = 554. ft^2/day
S = 1.0E-10
r/B' = 1.0E-5
ß' = 0.0001245
r/B" = 0.
ß" = 0.
Sw = 0.
r(w) = 0.167 ft
r(c) = 0.167 ft



WELL TEST ANALYSIS

Data Set: P:\...\pumping_well_leaky_Moench_recovery.aqt
Date: 03/16/12 Time: 13:39:41

PROJECT INFORMATION

Company: Barr Engineering
Client: Jordan Aggregates
Project: 23/70-1010
Location: Sand Creek Township, MN
Test Well: Pumping Well
Test Date: 02/13/2012

AQUIFER DATA

Saturated Thickness: 36. ft
Anisotropy Ratio (Kz/Kr): 0.1
Aquitard Thickness (b'): 114. ft
Aquitard Thickness (b"): 1. ft

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
Pumping Well	179419	421854

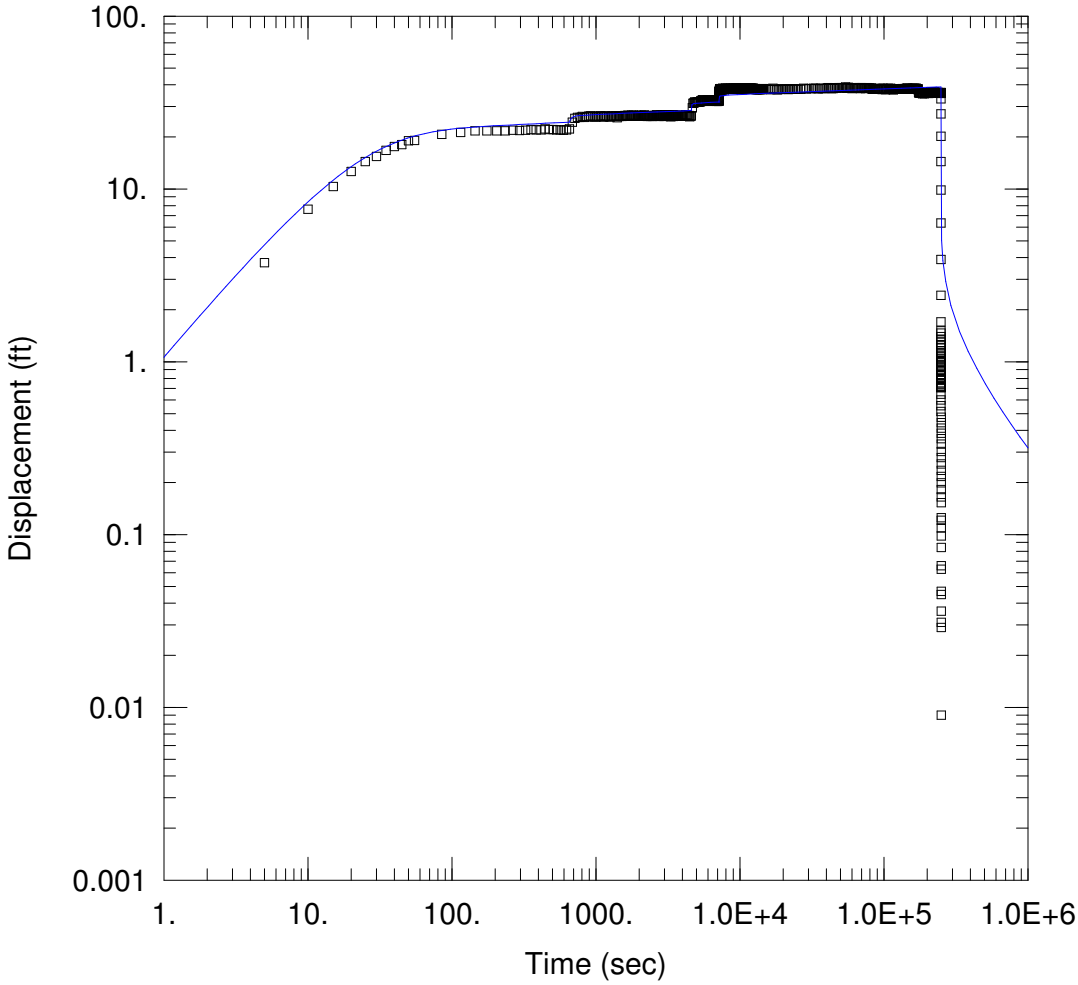
Observation Wells

Well Name	X (ft)	Y (ft)
▫ Pumping Well	179419	421854

SOLUTION

Aquifer Model: Leaky
Solution Method: Moench (Case 3)

T = 530.9 ft^2/day
S = 9.613E-11
r/B' = 2.014E-5
ß' = 1.0E-5
r/B" = 0.
ß" = 0.
Sw = 0.
r(w) = 0.167 ft
r(c) = 0.167 ft



WELL TEST ANALYSIS

Data Set: P:\...\pumping_well_PapCoop.aqt
Date: 03/16/12 Time: 13:32:01

PROJECT INFORMATION

Company: Barr Engineering
Client: Jordan Aggregates
Project: 23/70-1010
Location: Sand Creek Township, MN
Test Well: Pumping Well
Test Date: 02/13/2012

AQUIFER DATA

Saturated Thickness: 36. ft Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
Pumping Well	179419	421854

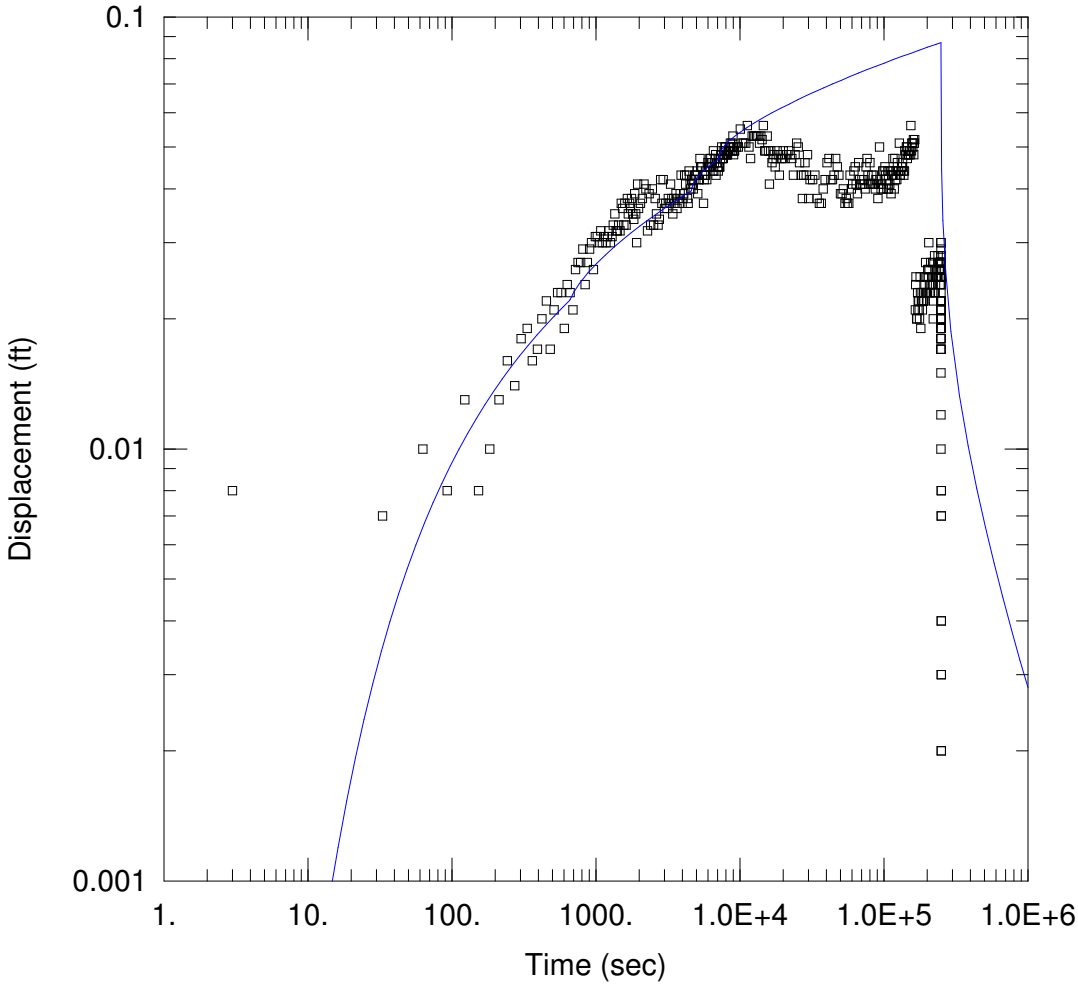
Observation Wells

Well Name	X (ft)	Y (ft)
▫ Pumping Well	179419	421854

SOLUTION

Aquifer Model: Confined Solution Method: Papadopulos-Cooper

T = 788.4 ft^2/day S = 1.0E-10
r(w) = 0.167 ft r(c) = 0.167 ft



WELL TEST ANALYSIS

Data Set: P:\...\house_well_PapCoop.aqt
Date: 03/16/12 Time: 15:41:50

PROJECT INFORMATION

Company: Barr Engineering
Client: Jordan Aggregates
Project: 23/70-1010
Location: Sand Creek Township, MN
Test Well: Pumping Well
Test Date: 02/13/2012

AQUIFER DATA

Saturated Thickness: 58. ft Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
Pumping Well	179419	421854

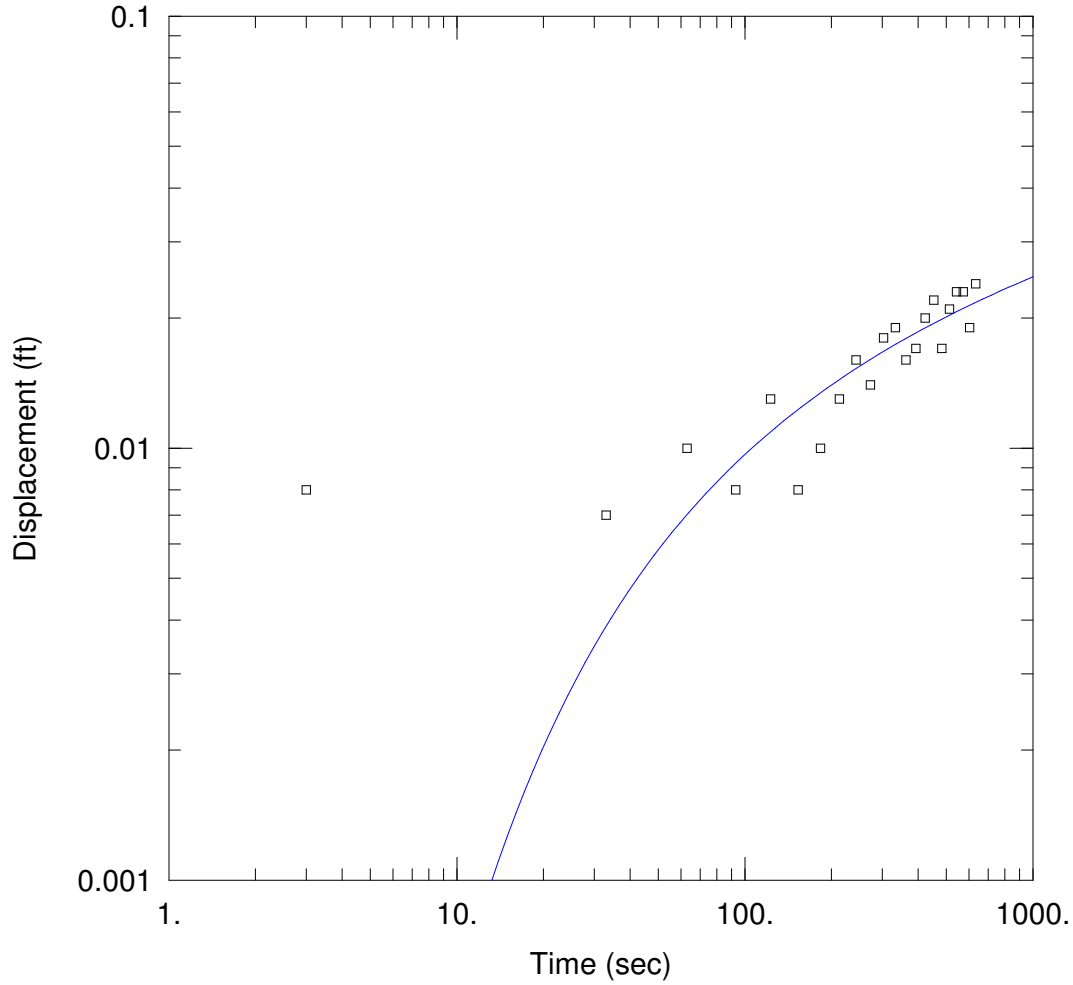
Observation Wells

Well Name	X (ft)	Y (ft)
▫ House Well	179124	421913

SOLUTION

Aquifer Model: Confined Solution Method: Papadopulos-Cooper

T = 8.908E+4 ft^2/day S = 0.0008737
r(w) = 0.167 ft r(c) = 0.167 ft



WELL TEST ANALYSIS

Data Set: P:\...\house_well_Moench_1.aqt
Date: 03/16/12 Time: 14:01:05

PROJECT INFORMATION

Company: Barr Engineering
Client: Jordan Aggregates
Project: 23/70-1010
Location: Sand Creek Township, MN
Test Well: Pumping Well
Test Date: 02/13/2012

AQUIFER DATA

Saturated Thickness: 58. ft
Anisotropy Ratio (Kz/Kr): 0.1
Aquitard Thickness (b'): 92. ft
Aquitard Thickness (b"): 1. ft

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
Pumping Well	179419	421854

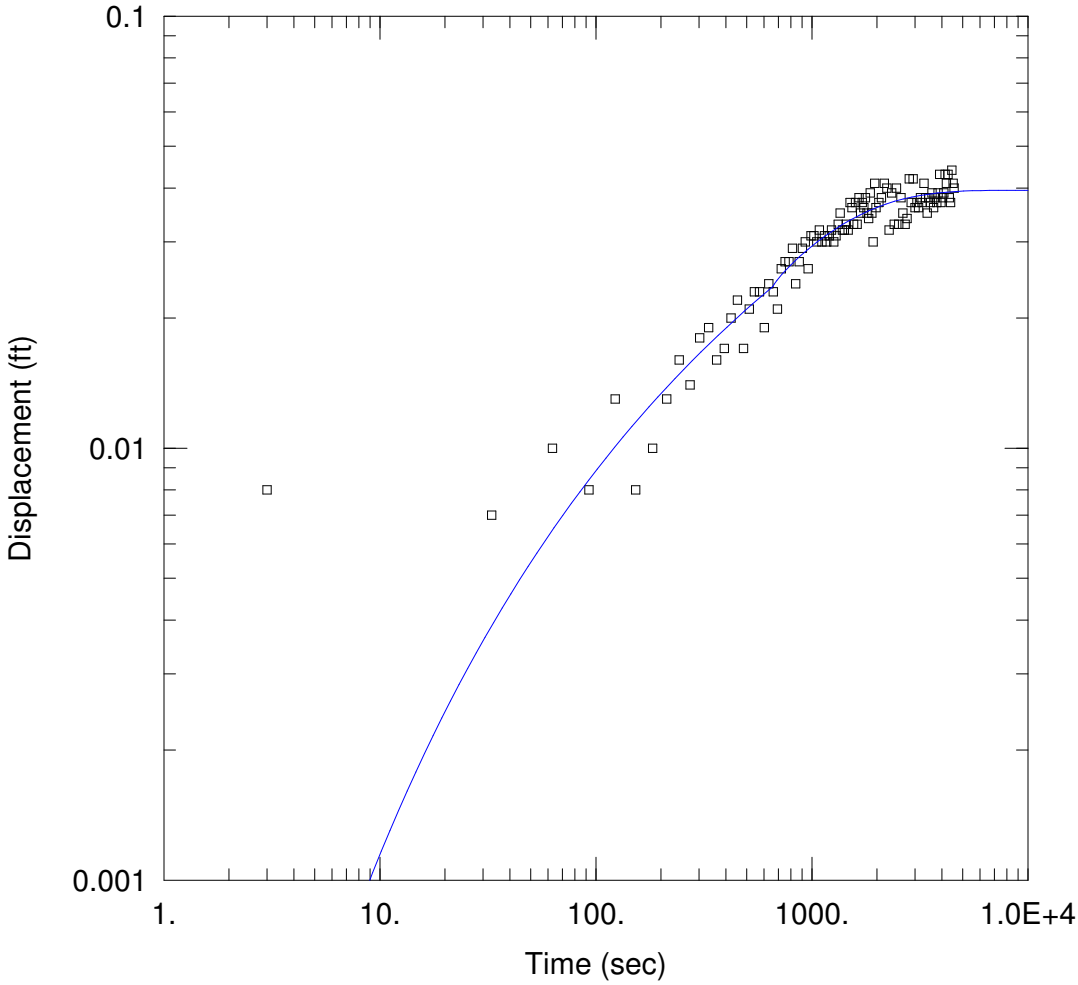
Observation Wells

Well Name	X (ft)	Y (ft)
▫ House Well	179124	421913

SOLUTION

Aquifer Model: Leaky
Solution Method: Moench (Case 3)

T = 9.331E+4 ft^2/day
S = 0.0007997
r/B' = 1.0E-5
ß' = 1.0E-5
r/B" = 0.
ß" = 0.
Sw = 0.
r(w) = 0.167 ft
r(c) = 0.167 ft



WELL TEST ANALYSIS

Data Set: P:\...\house_well_Moench_2.aqt
Date: 03/16/12 Time: 14:00:03

PROJECT INFORMATION

Company: Barr Engineering
Client: Jordan Aggregates
Project: 23/70-1010
Location: Sand Creek Township, MN
Test Well: Pumping Well
Test Date: 02/13/2012

AQUIFER DATA

Saturated Thickness: 58. ft
Anisotropy Ratio (Kz/Kr): 0.1
Aquitard Thickness (b'): 92. ft
Aquitard Thickness (b"): 1. ft

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
Pumping Well	179419	421854

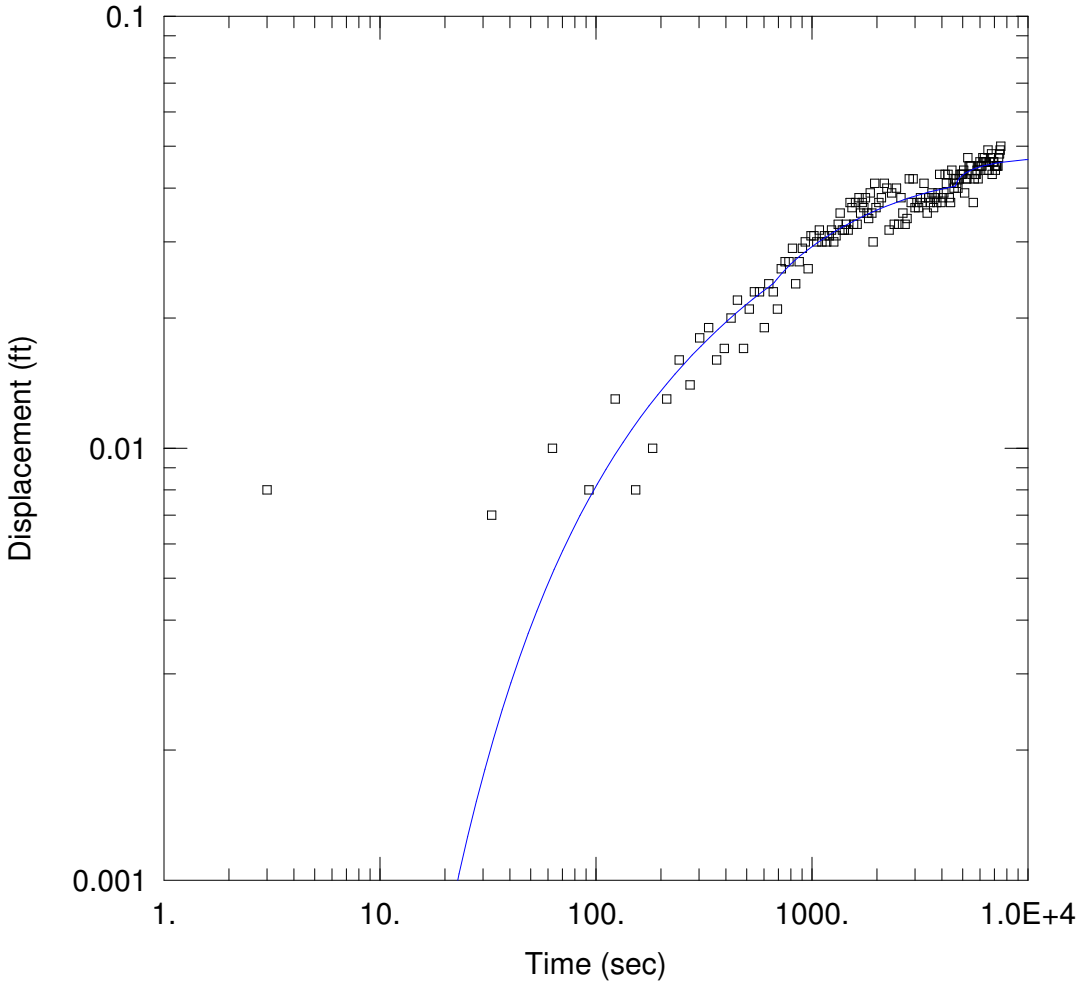
Observation Wells

Well Name	X (ft)	Y (ft)
▫ House Well	179124	421913

SOLUTION

Aquifer Model: Leaky
Solution Method: Moench (Case 3)

T = 1.885E+4 ft^2/day
S = 2.634E-6
r/B' = 0.8588
ß' = 10.
r/B" = 0.
ß" = 0.
Sw = 0.
r(w) = 0.167 ft
r(c) = 0.167 ft



WELL TEST ANALYSIS

Data Set: P:\...\house_well_Moench_3.aqt
Date: 03/16/12 Time: 13:59:00

PROJECT INFORMATION

Company: Barr Engineering
Client: Jordan Aggregates
Project: 23/70-1010
Location: Sand Creek Township, MN
Test Well: Pumping Well
Test Date: 02/13/2012

AQUIFER DATA

Saturated Thickness: 58. ft
Anisotropy Ratio (Kz/Kr): 0.1
Aquitard Thickness (b'): 92. ft
Aquitard Thickness (b"): 1. ft

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
Pumping Well	179419	421854

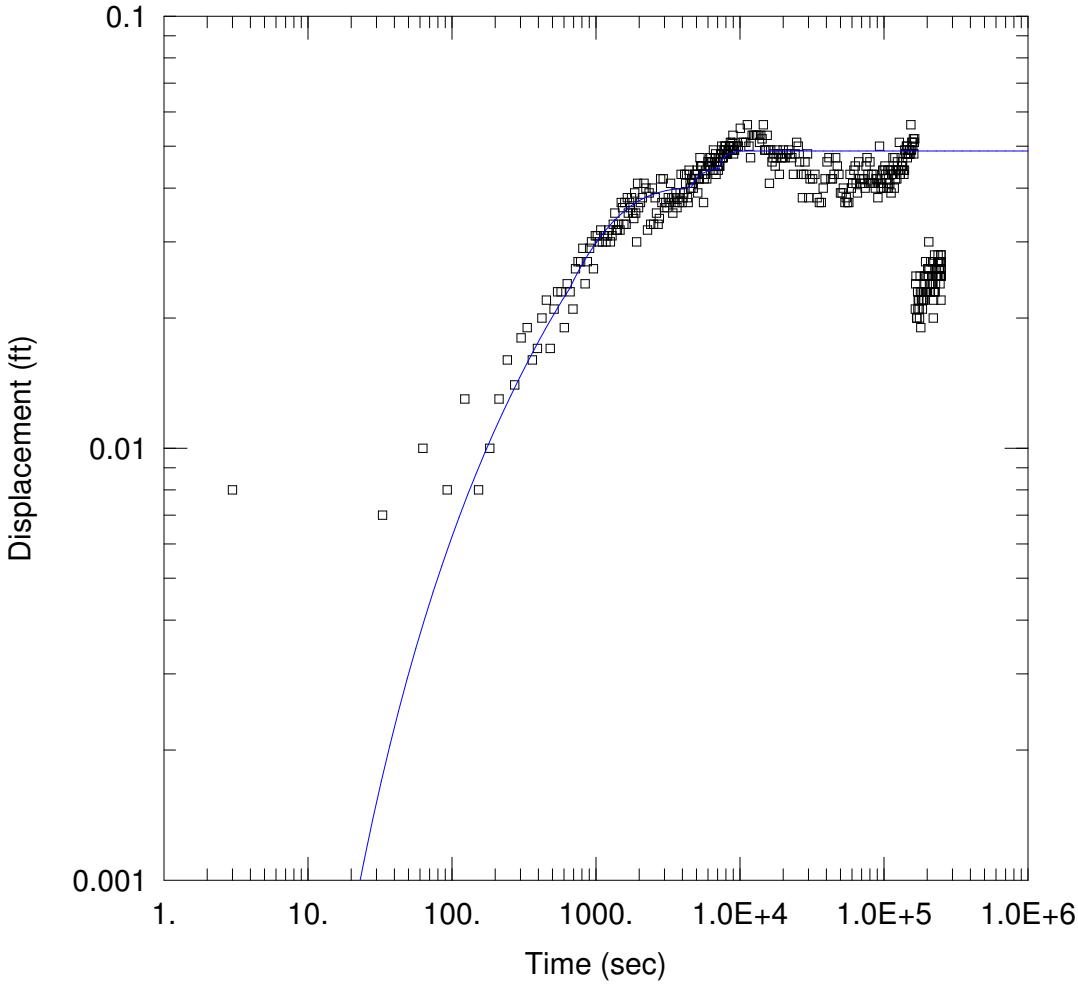
Observation Wells

Well Name	X (ft)	Y (ft)
▫ House Well	179124	421913

SOLUTION

Aquifer Model: Leaky
Solution Method: Moench (Case 3)

T = 5.895E+4 ft^2/day
S = 0.001049
r/B' = 0.2029
ß' = 0.03515
r/B" = 0.
ß" = 0.
Sw = 0.
r(w) = 0.167 ft
r(c) = 0.167 ft



WELL TEST ANALYSIS

Data Set: P:\...\house_well_Moench_4.aqt
Date: 03/16/12 Time: 14:02:57

PROJECT INFORMATION

Company: Barr Engineering
Client: Jordan Aggregates
Project: 23/70-1010
Location: Sand Creek Township, MN
Test Well: Pumping Well
Test Date: 02/13/2012

AQUIFER DATA

Saturated Thickness: 58. ft
Anisotropy Ratio (Kz/Kr): 0.1
Aquitard Thickness (b'): 92. ft
Aquitard Thickness (b"): 1. ft

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
Pumping Well	179419	421854

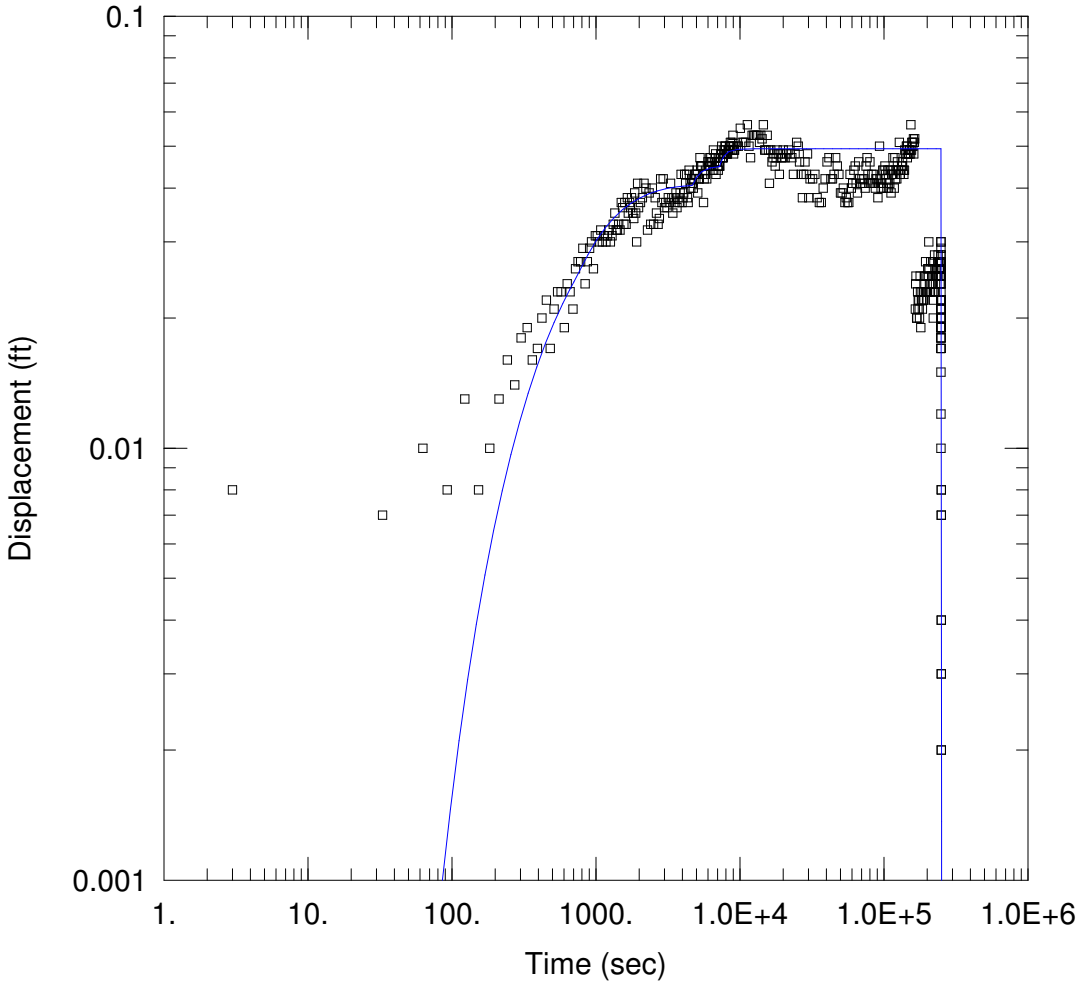
Observation Wells

Well Name	X (ft)	Y (ft)
▫ House Well	179124	421913

SOLUTION

Aquifer Model: Leaky
Solution Method: Moench (Case 3)

T = 1.177E+4 ft^2/day
S = 8.305E-5
r/B' = 1.177
ß' = 2.283
r/B" = 0.
ß" = 0.
Sw = 0.
r(w) = 0.167 ft
r(c) = 0.167 ft



WELL TEST ANALYSIS

Data Set: P:\...\house_well_Moench_all.aqt
Date: 03/16/12 Time: 14:04:44

PROJECT INFORMATION

Company: Barr Engineering
Client: Jordan Aggregates
Project: 23/70-1010
Location: Sand Creek Township, MN
Test Well: Pumping Well
Test Date: 02/13/2012

AQUIFER DATA

Saturated Thickness: 58. ft
Anisotropy Ratio (Kz/Kr): 0.1
Aquitard Thickness (b'): 92. ft
Aquitard Thickness (b"): 1. ft

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
Pumping Well	179419	421854

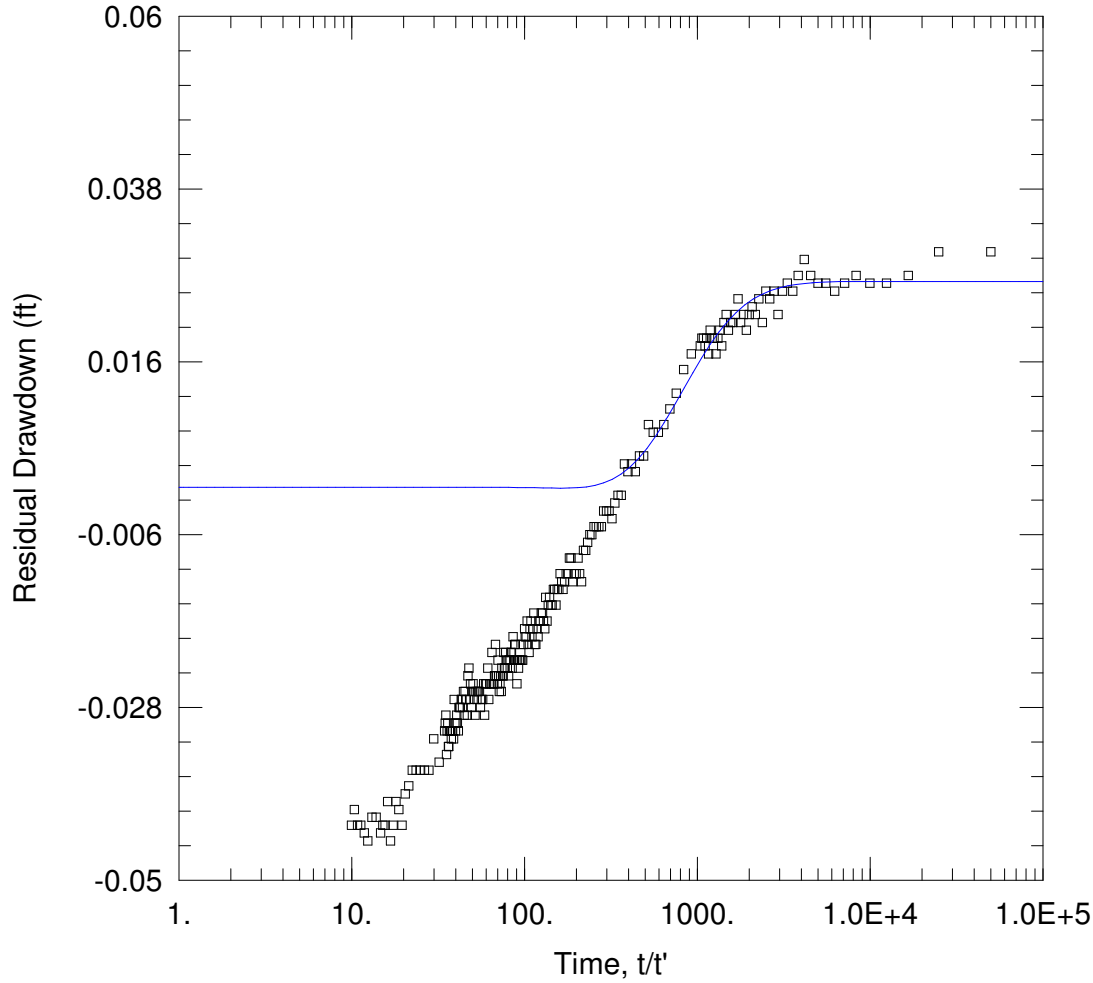
Observation Wells

Well Name	X (ft)	Y (ft)
▫ House Well	179124	421913

SOLUTION

Aquifer Model: Leaky
Solution Method: Moench (Case 3)

T = 1.884E+4 ft^2/day
S = 0.001944
r/B' = 0.8405
ß' = 8.028E-5
r/B" = 0.
ß" = 0.
Sw = 0.
r(w) = 0.167 ft
r(c) = 0.167 ft



WELL TEST ANALYSIS

Data Set: P:\...\house_well_Moench_recovery.aqt
Date: 03/16/12 Time: 14:05:51

PROJECT INFORMATION

Company: Barr Engineering
Client: Jordan Aggregates
Project: 23/70-1010
Location: Sand Creek Township, MN
Test Well: Pumping Well
Test Date: 02/13/2012

AQUIFER DATA

Saturated Thickness: 58. ft
Anisotropy Ratio (Kz/Kr): 0.1
Aquitard Thickness (b'): 92. ft
Aquitard Thickness (b"): 1. ft

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
Pumping Well	179419	421854

Observation Wells

Well Name	X (ft)	Y (ft)
▫ House Well	179124	421913

SOLUTION

Aquifer Model: Leaky
Solution Method: Moench (Case 3)

T = 696.1 ft^2/day
S = 3.449E-5
r/B' = 4.058
ß' = 3.95
r/B" = 0.
ß" = 0.
Sw = 0.
r(w) = 0.167 ft
r(c) = 0.167 ft

From: Nick Bonow [mailto:nbonow@carlsonmccain.com]
Sent: Thursday, October 03, 2013 5:07 PM
To: Ray Wuolo
Cc: 'AFrechette@co.scott.mn.us'; Sedlacek, Kate; John McCain; gduffy@MMBLawFirm.com; mduffy@MMBLawFirm.com; Steve Hentges
Subject: RE: modeling results; monitoring plan

Ray, could you please provide feedback on the following issues:

Throughout the FEIS it is noted that the mine will be excavated down to bedrock. This is incorrect; in my July 10th letter to the County I stated that the revised mine plan will terminate the pond excavation at an elevation of 640 feet, leaving approximately 10 to 30 feet of buffer between the bottom of the proposed excavation and the top of the FIG aquifer. This revision was also discussed at our meeting with the County on July 19th. Could you please clarify whether this design change was incorporated into the model? I noticed that Figure 3-11 of the FEIS and Figure 3-6 of the DEIS v.3 appear to be exactly the same, which would indicate that the change was not incorporated into the model. Also, the final paragraph on page 58 states the model was run with a pit depth of 120 feet, which would again indicate that the change was not incorporated. However, Figure 3-12 shows the mine pit stopping short of the bedrock. The whole purpose of stopping short of the design modification was to provide additional protection for the FIG, but the model doesn't seem to reflect that.

Regarding monitoring and mitigation – I don't think that conducting monitoring in the lower FIG from the get-go is warranted. The model predicted that flood water would not reach the lower FIG, and that even under the worst-case scenario (including mining down to bedrock, which we are not doing) a well completed in the lower FIG should be able to provide water that is not adversely impacted by flood or mining activities. Plus, when the pond is shallow, there's really no risk to the FIG. I think a better approach would be to monitor the pond (depth-integrated), the water table wells, and the deeper surficial aquifer well during the initial development of the mine when the pond is shallow. If the pond does not show very much mixing and/or the deeper surficial aquifer well does not show any impact from flood water then it would be safe to say that there will not be any exceedences in the FIG either and we do not need to monitor the FIG wells. If the deeper surficial aquifer well shows impacts, then we would begin monitoring the FIG wells. If the FIG wells become impacted we would provide mitigation in the form of point-of-use water treatment. If there are no impacts for a period of two years after the pond reaches terminal depth, then monitoring of the FIG wells would cease.

Please let me know if you would like to discuss this further.

Thanks

Nick Bonow
Carlson McCain, Inc.

From: Ray Wuolo <RWuolo@barr.com>
Sent: Friday, October 04, 2013 10:54 AM
To: 'Nick Bonow'
Cc: Frechette, Al; Sedlacek, Kate; John McCain; gduffy@MMBLawFirm.com; mduffy@MMBLawFirm.com; Steve Hentges
Subject: RE: modeling results; monitoring plan

Nick,

Thank you for sending the questions via email so that we can be clear about your concerns and the response.

As I explained to you when you originally proposed changing the depth of the mine in June, from a hydraulic standpoint, based on my experience I do not believe that a 10 to 30 foot buffer between the bottom of the pit and the FIG would have a significant effect on the overall results because the vertical driving head in the pit during the flood is going to likely result in vertical flow paths down to the bottom of the unconsolidated deposits and the time for the head in and around the pit to dissipate to pre-flood
conditions will be several weeks. The vertical anisotropy in unconsolidated sediments is typically assumed to be very low compared to bedrock units with lithofacies bedding planes. This is the same reason why sheet-pile and slurry walls that do not fully penetrate a permeable layer and key into a lower permeability layer are essentially ineffective (see attached article I wrote about his topic in 2000 – this is a pumping scenario but the resulting conclusion that the value of vertical anisotropy is very important is salient to the points in question)

The model was not modified at this late stage in the process to include a pit that has a bottom that is 10-30 feet shallower than originally proposed. To do so would be a costly, time-consuming process. This model (and all flow models) employ the Dupuit-Forscheimer assumption – i.e. the layer in the model that includes the lower unconsolidated unit must assume fully penetrating features. An additional layer could be put into the model to simulate this recently proposed change. However, the model would then require recalibration before re-simulating all of the various conditions/scenarios. If it was decided to modify the model in such a manner, I would also recommend to the County that an additional pumping test be conducted in order to collect data on the vertical hydraulic conductivity of the unconsolidated sediments between the top of bedrock and the new proposed bottom pit level as this data would now be pertinent to the model's predictions. This test will necessitate the installation of a pumping well with a short (< 5 ft) screen at the top of bedrock and two piezometers with 2-foot screens at about 10 and 30 feet above the bedrock. The test could then be performed and analyzing using the method of Moench to estimate the vertical anisotropy. This data could then be used in the model. I would also propose including vertical and lateral dispersion into the model (dispersion was not assumed in the current simulations) and it might be prudent to collect site-specific data. As you know, dispersion causes deviation in solute migration from the predicted groundwater flow paths.

I also explained that while such a change in pit bottom elevation may be perceived as a more acceptable design, it wouldn't likely eliminate the need for monitoring the FIG aquifer. MDH commented on the need for a downgradient monitoring well in the FIG aquifer.

This model, like all models, has inherent uncertainty and the results are intended to be a guide to the proposer, the RGU, and the public as to what will likely take place. But the results cannot be a substitute for monitoring, especially when there is substantial uncertainty. The model used for this EIS, like all models, has assumptions – assumptions in hydrogeologic parameters and assumptions in circumstances that have yet to occur because the pit currently does not exist to test some of the assumptions. Some of these assumptions might be eliminated or otherwise reduced in range with the

collection of various types of site-specific data (e.g., data on vertical anisotropy etc.). Some of the data collection activities have reduced the range of assumptions (e.g., the pumping test in the FIG provided values on the anisotropy of the upper FIG). But even with a lot more site-specific data, monitoring will still be necessary because many questions will not be fully answered, such as: (1) Will flood water displace existing pit water? (2) Will flood water mix or stratify in the pit? (3) What will be in the flood water? (4) Will there be microbes or other organic constituents that will degrade as pit water migrates? (5) Will pit water migrate into the upper bedrock? (6) What will be the effect of groundwater migrating from upgradient be on downgradient groundwater chemistry? Monitoring can answer these questions with a much higher degree of certainty than any amount of modeling. There are not any good analogies (i.e. similar mine pits that are regularly flooded by streams) to help us narrow down what is going to happen in this case. Modeling is necessary because the EIS process requires that the effects of the project on affected environments be estimated. The modeling results suggest where to monitor (and where monitoring need not take place) but it is not a substitute for obtaining data on what actually will take place in the future. A much greater understanding of the long-term effects of flooding of the mine pit will be obtained through monitoring than can be achieved by modeling. For over 25 years, I have been a strong proponent of using models to evaluate groundwater problems because these are complex systems and properly posed models are useful tools. But I understand the limitations of models and their predictive uncertainty and I would never advocate for using models as a substitute for monitoring. For example, I would probably not advise a client of mine to spend lots of money to further refine a model when the likely outcome of that refinement would be model predictions that don't result in substantial benefits. Monitoring during and after pit flooding may show that many of the assumptions in the model (and predictions that resulted from those assumptions) are conservative and future monitoring can be curtailed or otherwise modified. Having such data on hand will be the best argument for changing future monitoring.

Ray Wuolo

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