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Technical Memorandum

To: John Adams, ERM; Mike Liljegren, MDNR

From: Jeré Mohr and Jon Aspie, Barr Engineering

Subject: Comparison of Hydrogeologic Setting – Canisteo Pit, Minntac Mine near Kinney, and NorthMet Mine Site

Date: May 22, 2011

Project: 23690862

This memo was prepared in response to the Wetland IAP group's request to provide a comparison between the geologic and hydrogeologic settings at the NorthMet Mine Site and the two sites proposed as analogs for evaluating potential indirect wetland impacts associated with the NorthMet Project. This memo and attached Table 1 present a summary of information on the analog sites and Mine Site.

Mine Site

The regional geologic setting in the vicinity of the Mine Site consists of unconsolidated surficial deposits overlying bedrock of the Duluth Complex, Virginia Formation, and Biwabik Iron Formation. The unconsolidated surficial deposits dominantly consist of four major till units and associated glaciofluvial sediments deposited during advancement and subsequent melting of the Rainy Lobe of the Laurentide tide ice sheet that advanced from the northeast. The four major till units include (in stratigraphic order from bottom to top): a basal unit, a boulder till unit, a brown silty till unit, and a surficial till unit (Winter et al., 1973). A map of surficial geology in the vicinity of the Mine Site is shown on Figure 1.

The ore body of interest is present within the Duluth Complex. The proposed pit will intersect bedrock of the Duluth Complex and the Virginia Formation. Virginia Formation rock will be exposed along the north wall of the pit. The Biwabik Iron Formation will not be intersected by mining.

Unconsolidated deposits observed during site-specific investigations at the Mine Site are relatively heterogeneous and range from very dense clay to well-sorted sand, although predominantly sandy deposits are relatively uncommon. The unconsolidated material at the Mine Site can generally be subdivided into two till units, peat deposits in topographic lows, scattered topsoil and/or alluvium, and a

clayey till unit that does not appear to be continuous across the site. Depth to bedrock across the property averages less than 14 feet, and ranges from 0 to 59 feet (PolyMet, 2010). A map showing unconsolidated thickness based on PolyMet drillhole data is included as Figure 2. Bedrock outcrops are present across the area which may hydraulically separate different areas of the surficial deposits (Siegel and Ericson, 1980).

Hydraulic properties of bedrock and unconsolidated deposits have been measured at the site by conducting aquifer tests:

- The hydraulic conductivity of the unconsolidated deposits ranged from 0.012 to 31 feet per day (ft/day) (Barr, 2006a). Published estimates of the hydraulic conductivity values of the unconsolidated deposits range from 0.1 to 30 ft/day (Siegel and Erickson, 1980).
- The hydraulic conductivity of bedrock of the Duluth Complex ranged from 0.00026 to 0.041 ft/day as measured by single well tests conducted in boreholes (Barr, 2006b).
- The hydraulic conductivity of bedrock of the Virginia Formation ranged from 0.0024 to 1.0 ft/day as measured by conducting four pumping tests (Barr, 2006b).
- Data collected during a 30 day pumping test at P-2 showed a small amount of drawdown at the nearest deep wetland piezometer, but no detectable drawdown at other water table or deep wetland piezometers, indicating that the connection between the bedrock aquifer and surficial aquifer may be relatively weak (Barr, 2007).

Canisteo Mine Pit

The regional geologic setting in the vicinity of the Canisteo Pit near Bovey, Minnesota consists of unconsolidated surficial deposits overlying bedrock of the Virginia Formation, Biwabik Iron Formation, Pokegama Quartzite, and granitic rock of the Giants Range. Cretaceous sandstones are also present in the area. The Biwabik Iron Formation was the only bedrock formation exposed in the Canisteo Pit.

The unconsolidated surficial deposits consist of three major morainal till units and associated glaciofluvial outwash deposits deposited during the advancement and subsequent melting of the Des Moines Lobe that advanced from the north and west. The three major till units consist of a basal till, middle boulder till, and upper surficial till. Glaciofluvial outwash deposits lie stratigraphically between the surficial and boulder till, and often between the boulder till and basal till or bedrock. Surficial geology in the site area is shown on Figure 3.

The basal till is found mainly in the southern portion of the area. The boulder till tends to be the thickest unit in the area. The surficial till is generally less than 30 feet thick in the area. Glaciofluvial outwash deposits in the region are often greater than 50 feet thick and sometimes greater than 100 feet thick. Overall the thickness of the unconsolidated sediments in the vicinity of the Canisteo Pit ranges from 50 to 100 feet (Oakes and Bidwell, 1968). Bedrock does not outcrop in the vicinity of the Canisteo Pit. A map showing the depth to bedrock in the vicinity is included as Figure 4.

Hydraulic properties of the bedrock and unconsolidated deposits presented in USGS Water-Resources Investigations Report 02-4198 (Jones, 2002):

- The hydraulic conductivities of the unconsolidated deposits ranged from 0.01 to 121 ft/day.
- A bedrock hydraulic conductivity value of 0.007 ft/day was used in a groundwater model and appears to be an average value for all bedrock types in the area.
- Hydraulic conductivity values of the Biwabik Iron Formation have been estimated at 0.2 to 16 ft/day (Siegel and Ericson, 1980; Driscoll, 1986).

The closest surface water feature to the Canisteo Pit near Bovey is Trout Lake, located less than 1 mile south of the pit. Trout Lake is likely in hydraulic communication with the unconsolidated aquifer and would act as a hydraulic boundary that could limit the influence of changes in pit water level in this area. There are no other major surface water features located within close proximity of the pit that would be expected to significantly influence the area of influence of the pit.

Minntac Mine near Kinney, MN

The regional geologic setting of the Minntac Mine area near Kinney, Minnesota consists of unconsolidated surficial deposits overlying bedrock of the Virginia Formation, Biwabik Iron Formation, Pokegama Quartzite, and granitic rock of the Giants Range (Cotter, Young, Petri, and Prior, 1965). The Biwabik Iron Formation was the only bedrock formation exposed at the Minntac Mine.

The unconsolidated surficial deposits consist of two major till units and associated fluvial outwash deposited during the advancement and subsequent melting of the Rainy Lobe that advanced from the northeast (Hobbs and Goebel, 1982). Surficial geology in the area is shown on Figure 5. The surficial till is a reddish-brown clayey till (Lindstrom, Ericson, Broussard, and Hult, 1979), and the basal till is a gray

boulder till. Sand and gravel deposits are present between the till units in areas (Cotter, Young, Petri, and Prior, 1965). The thickness of the unconsolidated deposits near Kinney is 20 to 100 feet and the depth to bedrock at the location of the Kinney municipal well is 67 feet (Cotter, Young, Petri, and Prior, 1965). A map showing the depth to bedrock in the vicinity is shown on Figure 6. The unconsolidated surficial deposits are continuous in the vicinity of Kinney, but bedrock outcrops near the Laurentian Divide approximately 2 miles to the north.

Hydraulic properties of the bedrock and unconsolidated deposits in the Kinney area are estimated as follows:

- The hydraulic conductivity of the unconsolidated deposits was estimated to be 425 ft/day based on the specific capacity of the well (Cotter, Young, Petri, and Prior, 1965; Driscoll, 1986). This estimated value is likely representative of localized outwash deposits, rather than the properties of the surficial deposits in this area as a whole.
- Hydraulic conductivity values of the Biwabik Iron Formation have been estimated at 0.2 to 16 ft/day (Siegel and Ericson, 1980; Driscoll, 1986).

Kinney Lake and Yates Lake are located approximately ½-mile south of the Minntac Pit in the Kinney area. These lakes are likely in hydraulic communication with the unconsolidated aquifer and would act as hydraulic boundaries that could locally limit the influence of changes in pit water level in this area. Several pit lakes within abandoned mine pits are also located in the area. The degree of connection between the pit lakes and the unconsolidated aquifer is not known, but if they are in communication with the surficial aquifer, they would likely act as hydraulic barriers. There are no other major surface water features located within close proximity of the pit that would be expected to significantly influence the area of influence of the pit.

Conclusions/Recommendations

Based on the information reviewed for this memo, the geologic and hydrogeologic settings of the Mine Site are relatively similar to the Canisteo and Minntac sites, which are proposed as analog sites for evaluating potential indirect wetland impacts. Because of the similarities between the sites, it is appropriate to use information from the analog sites to evaluate the potential for indirect wetland impacts at the Mine Site in a semi-quantitative sense. In general, the three sites consist of a thin veneer of heterogeneous unconsolidated deposits underlain by fractured bedrock. At all three sites, the degree of

hydraulic connection between the unconsolidated deposits and the bedrock is likely highly spatially variable.

The primary differences between the analog sites and the Mine Site appear to be related to bedrock hydraulic conductivity, the thickness and continuity of unconsolidated deposits, and the depths of the mine pits. The presence of the Partridge River within relatively close proximity to the NorthMet pit will also affect the propagation of drawdown in the surficial aquifer compared to drawdowns observed at the analog sites.

The differences in bedrock properties between the sites will likely translate into some differences in the shape and size of the cone of depression within the bedrock. The Biwabik Iron Formation generally has a higher hydraulic conductivity than the Duluth Complex and Virginia Formation. However, indirect impacts to wetlands would be largely driven by the degree of connection between the bedrock and the unconsolidated deposits. There is no information to suggest that the nature of this connection is substantially different at the Mine Site compared with the proposed analog sites.

The unconsolidated deposits at the analog sites (especially the Canisteo site) are generally thicker and more continuous than at the Mine Site. There are many factors that control the shape and size of the area of drawdown (or rebound) within the surficial deposits; however, it is likely that area of influence would be more continuous at the analog sites compared with the Mine Site. Due to the thin, discontinuous nature of the surficial deposits at the Mine Site, areas of drawdown are expected to be more localized. Bedrock outcrops present in the vicinity of the Mine Site likely act as barriers to flow in the unconsolidated aquifer, which may act to limit the area of influence of the pit. No outcrops are present in the vicinity of the Canisteo Pit and outcrops are less frequent at the Minntac site compared with the Mine Site.

The greater depth of the proposed NorthMet pits is not likely to have a significant influence on the potential for indirect wetland impacts. Fractures and joints are more extensive in the upper 200 to 300 feet of the Duluth Complex (Siegel and Ericson, 1980), a similar depth to the Canisteo and Minntac pits. While deeper fractures and joints may be encountered in the NorthMet pits, there is a low likelihood that they would have a direct hydraulic connection to the unconsolidated deposits.

The Partridge River in the vicinity of the Mine Site is a relatively continuous hydraulic boundary surrounding the pit area, which would likely act as a natural barrier to the expansion of the cone of depression within the unconsolidated aquifer. In contrast, surface water features in the vicinity of the analog sites are not as continuous and probably have more localized effects on the response of the unconsolidated aquifer to changes in pit water level.

References

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Driscoll, F.G., 1986. Groundwater and Wells, Johnson Division. (Equations 3 and 4 on page 1021 used to estimate hydraulic conductivity from published specific capacity data).

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Siegel and Ericson, 1980. Hydrology and Water Quality of the Copper-Nickel Sudy Region, Northeastern Minnesota. USGS Water-Resources Investigations Report 80-739.

Winter, T.C., Cotter, R.D., and Young, H.L., 1973. Petrography and Stratigraphy of Glacial Drift, Mesabi-Vermilion Iron Range Area, Northeastern Minnesota, U.S. Geological Survey Bulletin 1331-C.

Table 1

Comparison of Hydrogeologic Properties - NorthMet Mine Site, Canisteo Pit Area, and Minntac Area

	NorthMet Mine Site	Canisteo Pit Area (near Bovey, MN)	Minntac Area (near Kinney, MN)
Type of Bedrock	Duluth Complex, Virginia Formation	Biwabik Iron Formation	Biwabik Iron Formation
Hydraulic Conductivity of Bedrock	0.00026-0.041 ft/day (DC)[1], 0.0024-1.0 ft/day (VF)[2]	0.007 ft/day[3], 0.2-16 ft/day[4]	0.2-16 ft/day[4]
Unconsolidated deposits	Rainy Lobe till and outwash	Des Moines Lobe till and outwash	Predominantly Rainy Lobe till and outwash
Thickness of Surficial Sediments	0 to 59 feet, not continuous [5]	50 to 100 feet, continuous at pit[6]	20 to 100 feet, continuous at mine site[7]
Hydraulic Conductivity of Surficial Deposits	0.012 to 31 ft/day[1]	0.01 to 121 ft/day[3]	425 ft/day[7], 0.012 to 31 ft/day[1]*

References:

1. Barr, 2006. Hydrogeologic Investigation - Phase 1, PolyMet NorthMet Mine Site, RS-02 Draft-02.

2. Barr, 2006. Hydrogeologic Investigation - Phase 2, PolyMet NorthMet Mine Site, RS-10 Draft-02.

3. Jones, P.M., 2002. Characterization of Ground-Water Flow Between the Canisteo Mine Pit and Surrounding Aquifers, Mesabi Iron Range, Minnesota.
USGS Water-Resources Investigations Report 02-4198.

4. Specific capacity estimates from Siegel and Ericson, 1980. Hydrology and Water Quality of the Copper-Nickel Study Region, Northeastern Minnesota.
USGS Water-Resources Investigations Report 80-739.
Equation 3 on page 1021 of Driscoll, 1986 used to estimate hydraulic conductivity. Driscoll, 1986. Groundwater and Wells, Second Edition.

5. PolyMet Mining, 2010. NorthMet Project Rock and Overburden Management Plan, Version 3, Issue Date: December 7, 2010.

6.Oakes, E.L, and Bidwell, L.E., 1968. USGS Hydrologic Investigations Atlas HA-278, Water Resources of the Mississippi Headwaters Watershed,
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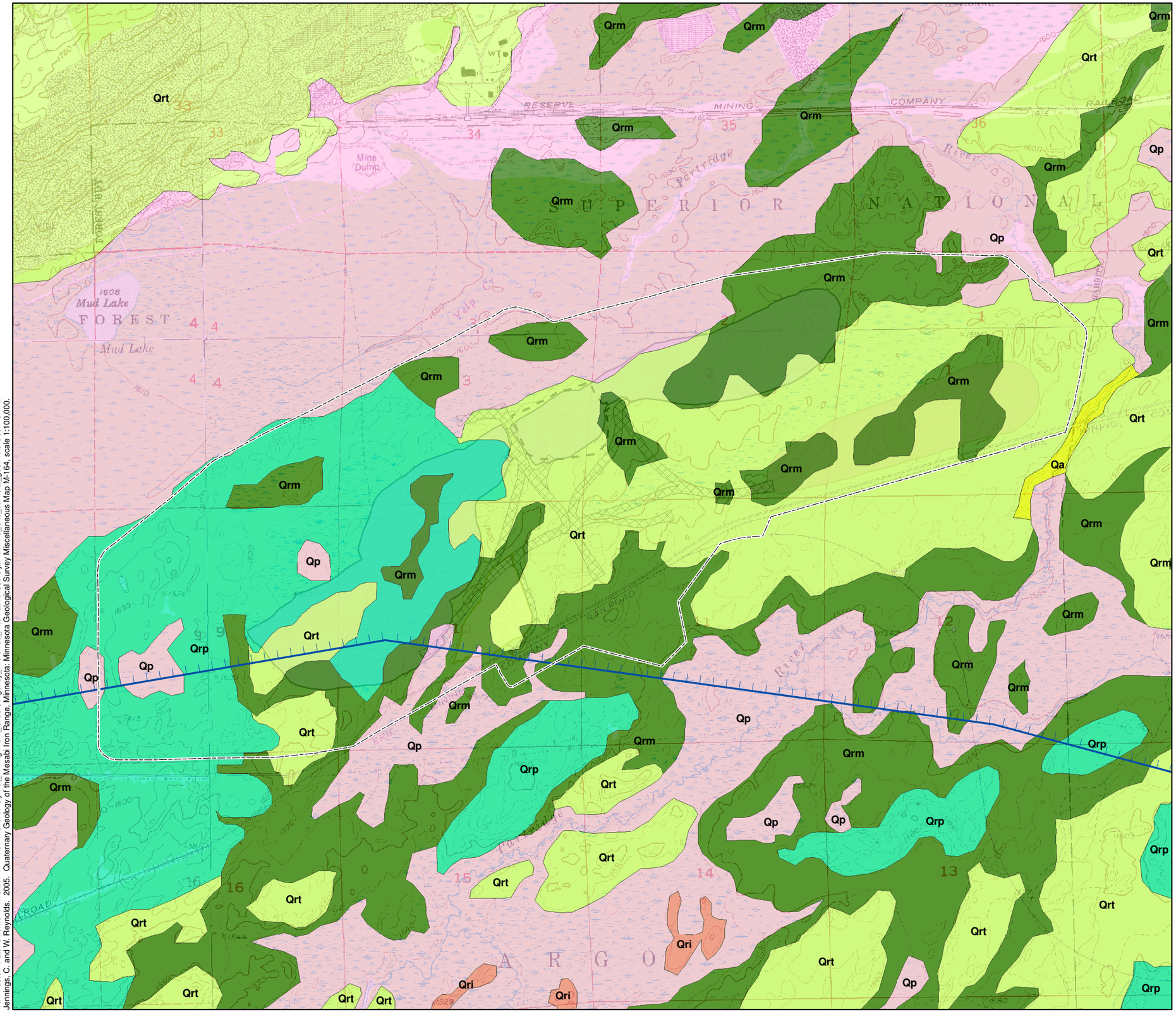
7. Cotter, R.D., Young, H.L., Petri, L.R., and Prior, C.H., 1965. Water Resources in the Vicinity of Municipalities on the Central Mesabi Iron Range, Northeastern Minnesota.
USGS Water-Supply Paper 1759-D. Specific capacity estimate for Kinney municipal well from Cotter et al., 1965.
Equation 4 on page 1021 of Driscoll, 1986 used to estimate hydraulic conductivity. Cotter notes that well was likely completed in outwash.

* Due to minimal site specific information and general similarities in characteristics of surficial deposits, hydraulic conductivity assumed to be similar to NorthMet Mine Site.



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Jennings, C. and W. Reynolds. 2005. Quaternary Geology of the Mesabi Iron Range, Minnesota: Minnesota Geological Survey Miscellaneous Map M-164, scale 1:100,000.

Legend

Quaternary Postglacial Deposits

- **Qa** — **Alluvium -** Interbedded fine-grained sand, fine-grained sandy loam, and silt loam.
- **Qp** — **Peat -** Organic material in various stages of decomposition.

Quaternary Deposits Associated with the Rainy Lobe (Rainy Provenance)

- **Qri** — **Ice-Contact Sediment -** Sand, gravelly sand, and gravel, locally interbedded with glacial till.
- **Qrt** — **Rainy Lobe Till -** Chiefly sandy loam matrix texture (48 to 87 percent sand, 9 to 40 perent silt, 0 to 13 percent clay); variable color; unsorted sediment with common pebbles, cobbles, and boulders.
- **Qrm** — **Till -** As above, but eroded by water, producing a less rugged surface expression and possibly concentrating coarse-grained clasts as a lag at the surface.
- **Qrp** — **Till, Re-Sedimented Till, and Sorted Sediment -** Forms distinct but discontinuous highlands aligned with other features that mark the transition from a glacial to a proglacial setting (for example ice-contact delta fronts).

Ice Margins

Project Boundary

Year 20 Mine Pits

Year 20 Haul Roads

Year 20 Stockpiles

- **Active**
- **Removed & Reclaimed**
- **Removed**

2,000 1,000 0 2,000
Feet

0.5 0.25 0 0.5
Miles

Figure 1

MINE SITE SURFICIAL GEOLOGY
JENNINGS AND REYNOLDS, 2005
NorthMet Project
PolyMet Mining, Inc.
Hoyt Lakes, MN

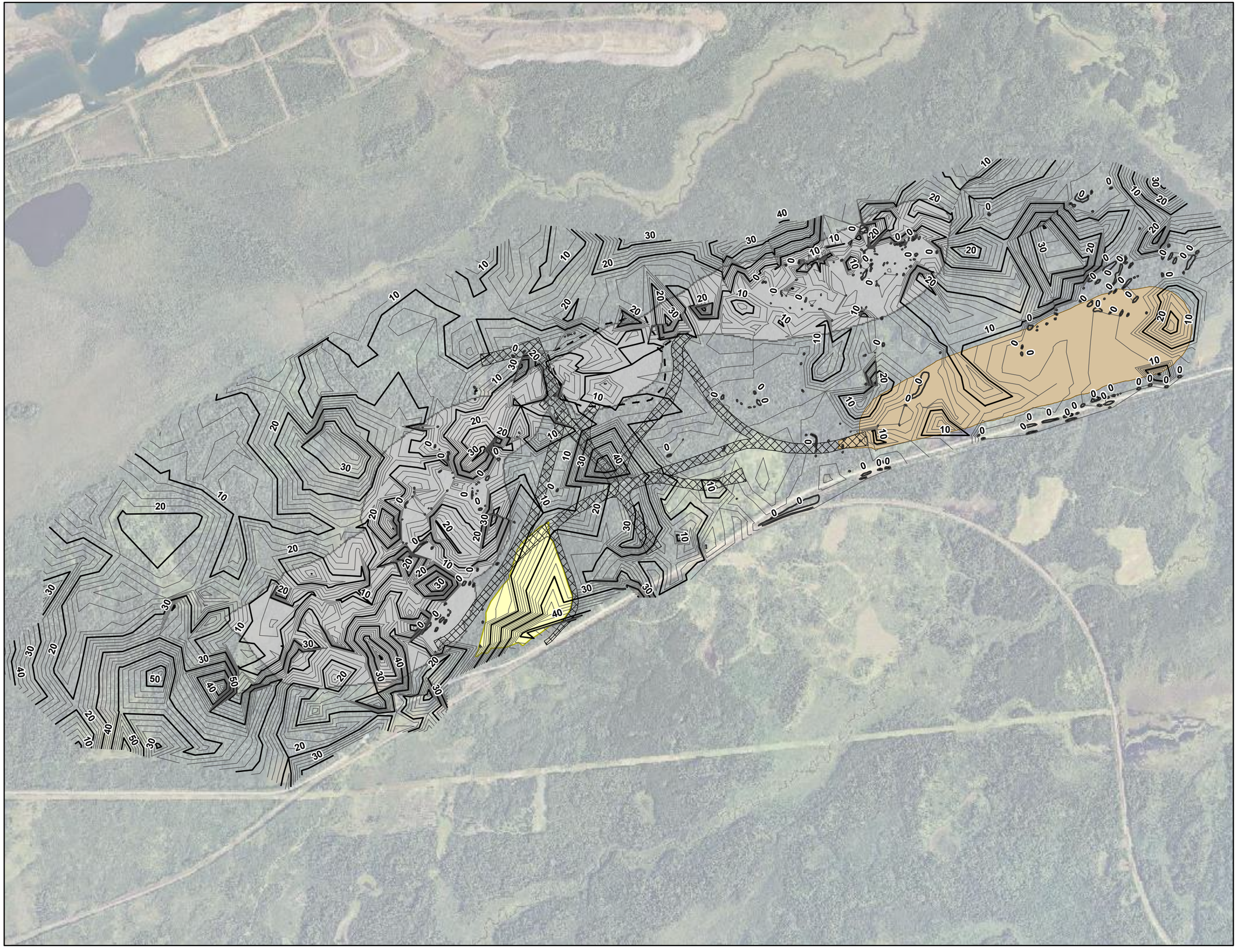

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Figure 2

DEPTH TO BEDROCK
NorthMet Project
PolyMet Mining Inc.
Hoyt Lakes, MN

Natural Ore Pit

Quaternary Postglacial Deposits

Qa — **Alluvium -** Interbedded fine-grained sand, fine-grained sandy loam, and silt loam.

Ql — **Lake Sediment -** Predominantly silt, clay,and organic material that have settled to the bottom of modern lakes.

Qp — **Peat -** Organic material in various stages of decomposition.

Deposits of Glacial-Age Lakes

Qla — **Lacustrine sediment -** Predominantly silt and clay but also includes sand.

Qls — **Lacustrine sand -** Predominantly sand deposited by moving water in current-affected portions of a lake

Qd — **Deltaic sediment -** Horizontally bedded sand and gravel (topsets), grading to sloping beds of sand with gravel (foresets).

Deposits Associated with Northwest-Sourced Ice Lobes

Qkm — **Mixed deposits, predominantly till -** Unsorted yellow-brown to gray clay to loam-textured sediment with incorporated pebbles, cobbles, and boulders juxtaposed chaotically with a variety of other glacial and ice-proximal units.

Quaternary Deposits Associated with the Rainy Lobe

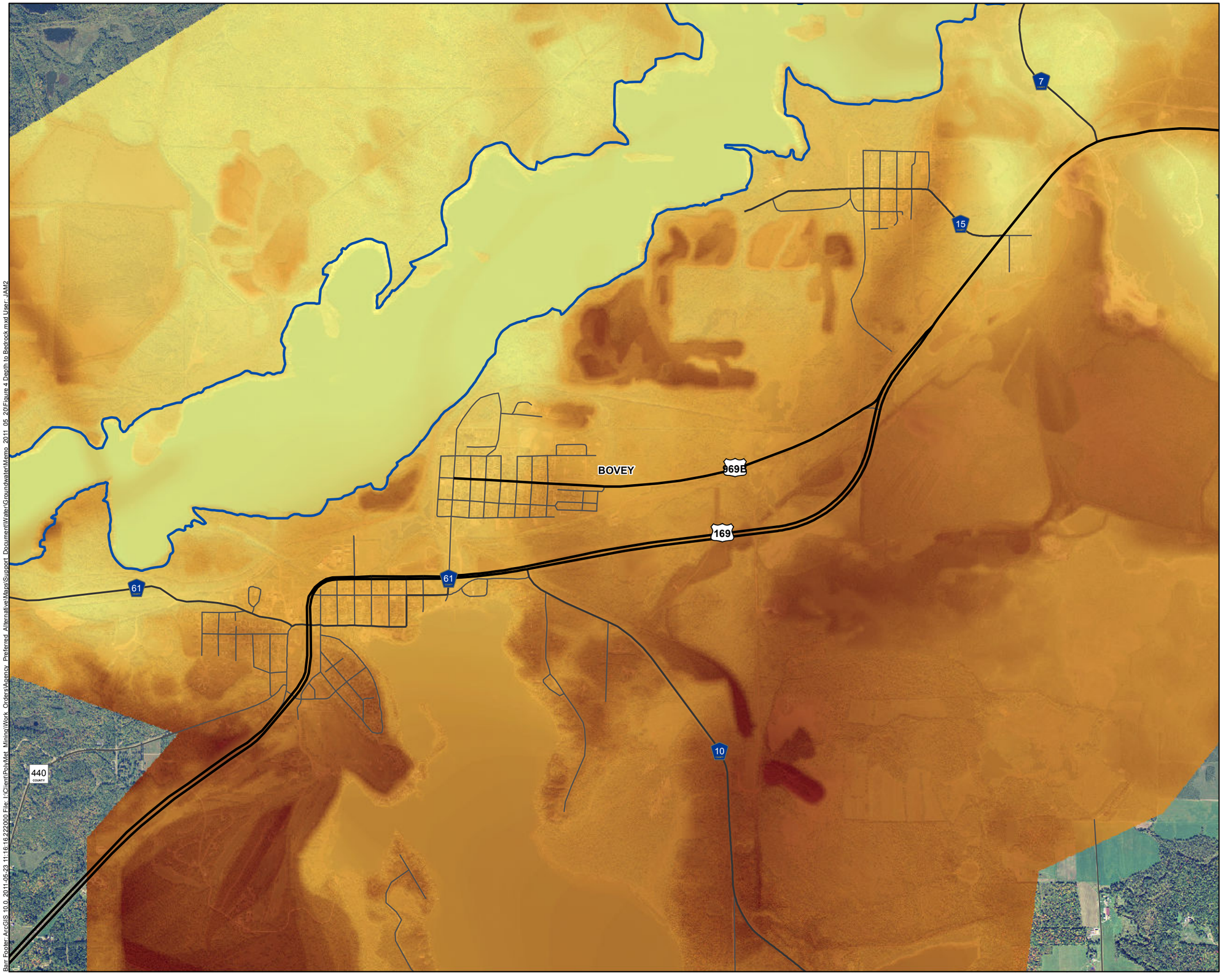
Qri — **Ice-Contact Sediment -** Sand, gravelly sand, and gravel, locally interbedded with glacial till.

2,000 1,000 0 2,000

Feet

Figure 3
SURFICIAL GEOLOGY
Canisteo Pit Area
Near Bovey, MN

Jennings, C. and W. Reynolds., 2005. Quaternary Geology of the Mesabi Iron Range, Minnesota: Minnesota Geological Survey Miscellaneous Map M-164, scale 1:100,000.
Barr Folder: ArcGIS 10.0_2011-05-20 17-54-37.451000 File: I:\Client\Polk\Met_Mining\Work_Orders\Agency_Preferred_Alternative\Maps\Support_Document\WaterGroundwaterMemo_2011_05_20\Figure 3_Surficial Geology.mxd User: arm2



Depth to Bedrock

410 feet

0 feet

Natural Ore Pit

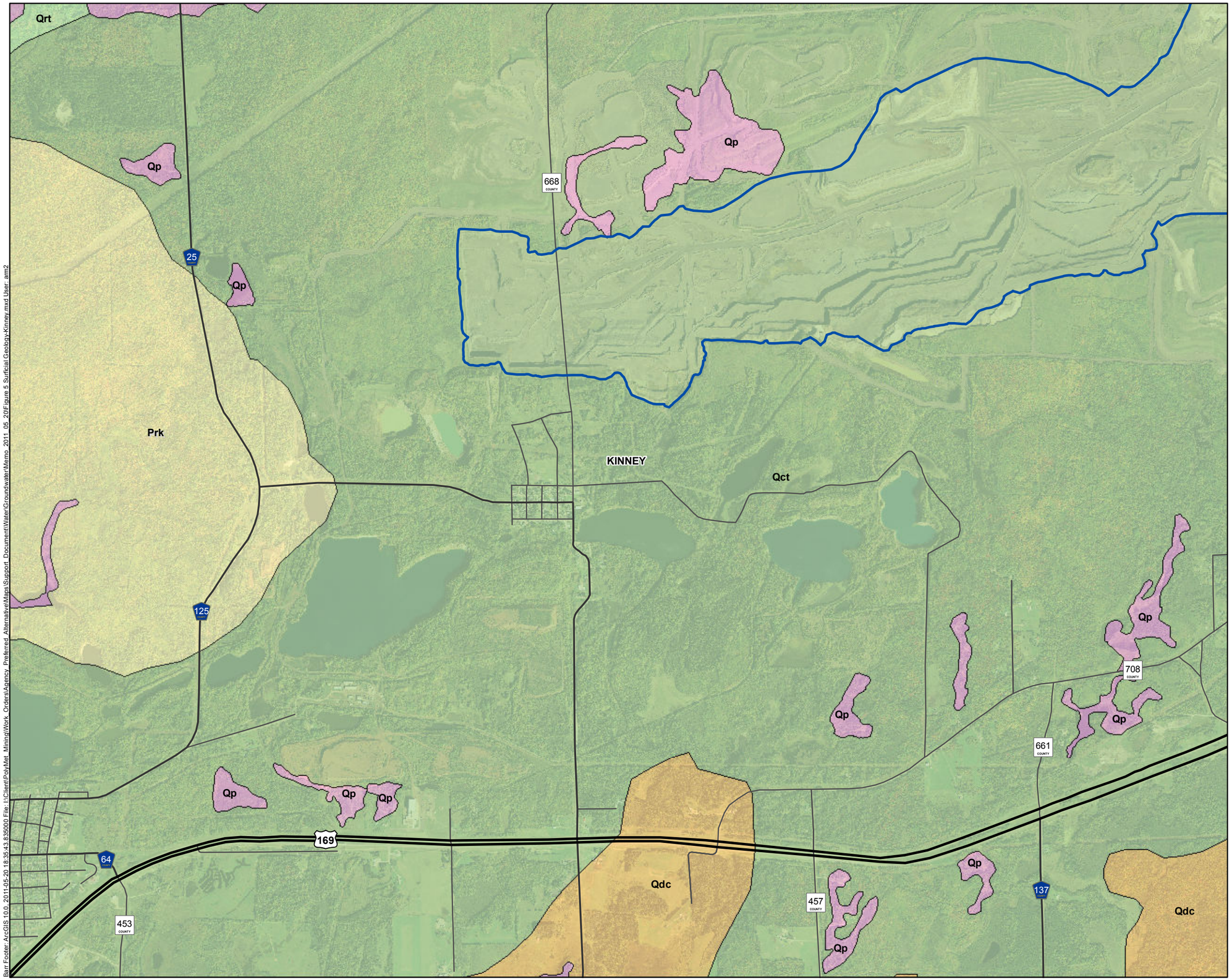
2,000 1,000 0 2,000

Feet

Figure 4
DEPTH TO BEDROCK
Canisteo Pit Area
Near Bovey, MN

Depth to bedrock data from: Herr, E.S., and Cartwright, D.F., 2005, Mesabi Iron Range Hydrogeologic Database, Minnesota Department of Natural Resources.

Base Feature ArcGIS 10.0, 2011-05-23 11:16:16.222000 File: I:\Client\Poly\Met_Mining\Work Orders\Agency Preferred Alternative\Maps\Support Document\Water\Groundwater\Memo_2011_05_20\Figure 4 Depth to Bedrock.mxd User: JAM2



Taconite Pit

Quaternary Postglacial Deposits

Qp — **Peat -** Organic material in various stages of decomposition.

Deposits of Glacial-Age Lakes

Qdc — **Deltalc sediment, collapsed -** As above, but deposited on glacial ice or with large isolated blocks of glacial ice.

Deposits Associated with Northwest-Sourced Ice Lobes

Qct — **Clayey till -** Matrix dominated red clayey till with rare clasts.

Quaternary Deposits Associated with the Rainy Lobe

Qrt — **Till -** Chiefly sandy loam matrix texture; variable color; unsorted sediment with common pebbles, cobbles and boulders.

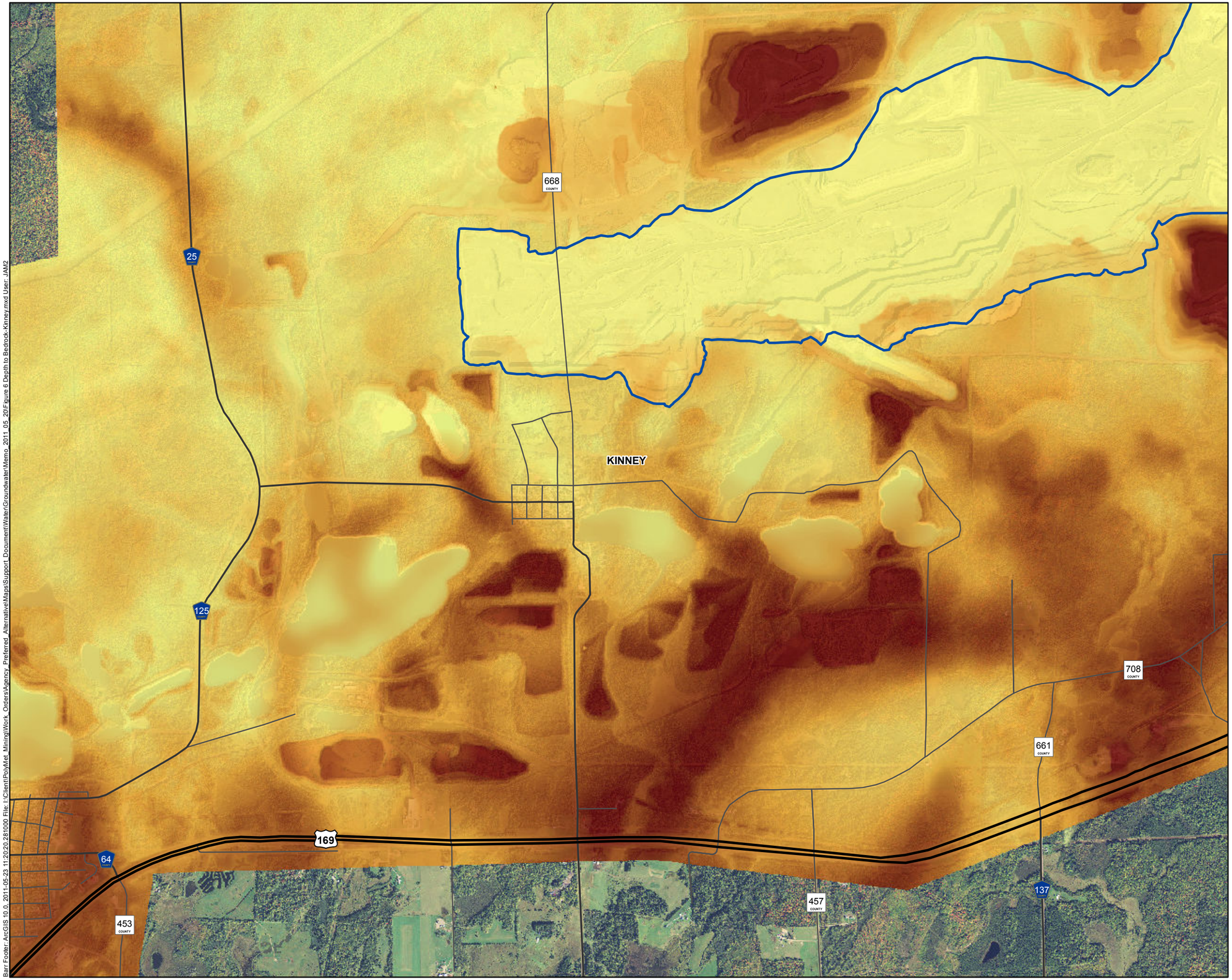
Prk — Bedrock at Surface

2,000 1,000 0 2,000

Feet

Figure 5
SURFICIAL GEOLOGY
Minntac Pit Area
Near Kinney, MN

Jennings, C. and W. Reynolds, 2005. Quaternary Geology of the Mesabi Iron Range, Minnesota: Minnesota Geological Survey Miscellaneous Map M-164, scale 1:100,000.
Barr Footer: ArcGIS 10.0, 2011-05-20 18:35:43.835000 File: I:\Client\PolyMet_Mining\Work_Orders\Agency_Preferred_Alternative\Maps\Support_Document\Water\Groundwater\Memo_2011_05_20\Figure 5 Surficial Geology-Kinney.mxd User: amn2



Depth to Bedrock

262 feet

0 feet

Taconite Pit

2,000 1,000 0 2,000

Feet

Figure 6
DEPTH TO BEDROCK
Minntac Pit Area
Near Kinney, MN

Depth to bedrock data from: Herr, E.S., and Cartwright, D.F., 2005. Mesabi Iron Range Hydrogeologic Database, Minnesota Department of Natural Resources.

Barr Footer: ArcGIS 10.0, 2011-05-23 11:20:20 281000 File: I:\Client\PolyMet_Mining\Work_Orders\Agency_Preferred_AlternativeMaps\Support_Document\Water\Groundwater\Memo_2011_05_20\Figure 6 Depth to Bedrock-Kinney.mxd User: JAM2