Appendix A

Hydrogeologic Report for the Eagle Project Groundwater Discharge Permit Application

(Appendix B of Application sent to MDEQ)

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Supplemental Hydrogeologic Study for Groundwater Discharge

Prepared for

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1.0 Introduction

Kennecott Minerals Company is evaluating environmental conditions and engineering plans for its Eagle Project (Project) location in the Yellow Dog Plains (Plains), approximately 9.5 miles (mi) southwest of Big Bay in northern Marquette County, Michigan (Figure 1). The proposed mining plan includes underground mining of a massive and semi-massive sulfide ore body (primarily copper and nickel mineralization). This report presents the results of the supplemental hydrogeologic study (HS) conducted from July through September 2005 to assess soil and hydrologic conditions of an area proposed for the discharge of treated mine inflow water to groundwater (proposed discharge area) using rapid surficial infiltration. The work was performed on behalf of Kennecott Minerals Company and supplements the Environmental Baseline Study (EBS) hydrologic assessment (North Jackson Company (NJC) 2005a), performed from November 2002 through May 2005.

The scope of the HS was presented in the HS Study Work Plan (NJC 2005b) which was submitted to the Michigan Department of Environmental Quality in May 2005. The HS was designed to meet the requirements of Rule 2221 of the Part 22 rules of Part 31 of the Natural Resources and Environmental Protection Act, 1994 PA 451 and included the following specific objectives:

- Define earth material characteristics at the proposed discharge area;
- Define groundwater conditions at the proposed discharge area;
- Predict groundwater mounding at the proposed discharge area during artificial recharge; and
- Develop data for the design of a groundwater monitoring program to be incorporated into the groundwater discharge permit.

In addition soil borings and monitoring wells were constructed as part of this study in order to provide additional hydrogeologic and geotechnical data in support of the mine surface facility engineering plans and groundwater monitoring system.

Following this introductory section the report is organized into the following sections:

Section 2 – Background information including a summary of the regional geology, hydrology, and groundwater quality based on information developed for the EBS (NJC 2005a).

Section 3 – Description of HS methods.

Section 4 – Results of the HS.

Section 5 – Conclusions relative to the hydrogeologic conditions of the proposed discharge area and its suitability for discharge of treated water.

Section 6 – Recommendations as to further hydrogeologic investigation and monitoring for the proposed discharge area.

2.0 Background Information

The Project is located near the headwaters of the Salmon Trout River within the Plains (Figure 2). The Plains are a relatively flat-lying, sandy geomorphologic feature covering about 27 square miles (mi^2), as shown on the regional topographic map (Figure 2). The Plains trend from the northwest to southeast and are bounded to the south by shallow igneous and metamorphic bedrock that rises above the Plains and to the north by a steep, terraced escarpment (north terrace) of glacial moraine that slopes north to a northwest to southeast-trending valley below the Plains. The Yellow Dog Peridotite (Peridotite) containing the ore body of interest is contained within an igneous intrusion (dike) into the metasedimentary basin rock formations underlying the Plains. The Peridotite outcrops in the Plains at two locations in close proximity to the headwaters of the main branch of the Salmon Trout River (Main Branch).

2.1 Geology

The geology of the Plains can be described generally as surficial deposits of unconsolidated glacial outwash and till, and post-glacial sedimentation underlain by igneous and metamorphosed sedimentary (metasedimentary) rocks of Precambrian age. Within Marquette County this type of geologic setting is not unique, as large areas of outwash plains overlying Precambrian bedrock are well documented (Twenter 1981). The closest well-studied example of a similar hydrogeologic setting is the Sands Plain, a 225 mi^2 feature located between the towns of Marquette and Gwinn in central Marquette County (Figure 1) (Grannemann 1984). In the Sands Plain area the principal water-bearing strata are found in the glacial deposits. Precambrian bedrock formations in Marquette County are typically found to yield low quantities of water compared to glacial outwash aquifers (Grannemann 1984, Twenter 1981).

2.1.1 Bedrock Geology

The bedrock beneath the Plains is mostly metasedimentary rocks of the Michigamme Formation, part of the Marquette Range Supergroup of Proterozoic age (Precambrian) rocks roughly 2 billion years old (Figure 3). In the Project area the Michigamme Formation is contained in an east-west trending structural trough known as the Baraga Basin (Klasner et al. 1979). The trough is flanked on the north, south and east by gneiss and greenstone Archean basement rocks, older than 2.5 billion years.

The Michigamme Formation consists mostly of fine-grained clastic rocks, largely black slate and argillite (fine-grained sedimentary rock hardened by incipient metamorphism) (Klasner et al. 1979). The term siltstone (fine-grained, nonfissile rocks) has also been used to describe these units. These units are commonly thought to have been deposited in marine waters and later deformed and metamorphosed regionally to the greenschist facies which is indicative of very widespread "low grade" metamorphism. The metamorphism has been dated at about 1.9 billion years before present, during the Penokean orogenic (mountain building) event (Dorr and Eschman 1970). In central Upper Michigan the mountain building was the apparent result of compressional forces acting from present day north-to-south, resulting in synclines (troughs) whose long axes trend east-west (Dorr and Eschman 1970).

Emplaced into the Michigamme Formation are east-to-west-trending diabase dikes which are iron-rich igneous rocks from magma intrusions into the older sedimentary rocks. These intrusives are Keweenawan age (about 1.1 billion years old) and are found in many areas around the Lake Superior Basin (Dorr and Eschman 1970) and are associated with the Mid Continent Rift system in the Lake Superior Region.

Two of these dike intrusions outcrop in the Plains near the Salmon Trout River Main Branch (T50N, R29W, Section 11 and 12) (Figure 2). The Peridotite outcrop in Section 12 is crystalline, coarse-grained and massive, very hard, and greenish black, with a thin weathered rind a few tenths of inches thick on the surface (Klasner et al. 1979). It is composed mainly of ferromagnesian minerals and derived from molten magma crystallized deep in the subsurface. These outcrops are part of dike swarm that has been identified regionally with geophysical exploration techniques, primarily using magnetic and gravity field surveys (Klasner et al. 1979). A detailed gravity anomaly map prepared by Kennecott Exploration Company indicates the outcrops are associated with very prominent gravity "highs" compared to the surrounding terrain (Figure 4).

The mineralized ore body is located within the Peridotite, generally beneath the outcrop located in Section 11 (the center of which occurs at approximately UTM coordinates 5177500N and 431500E, Figure 4). Higher grade mineralization and deformation is found at depth. The mineralization either postdates or is syn-deformational. Geotechnical logging of mineral exploration cores indicates that open and cemented joints are present within the Peridotite and although there is no dominant joint set, most strike parallel to the east-west trend of the intrusion (Kennecott Exploration Company 2005).

The competent nature and solid structure that is typically found in igneous and metasedimentary rocks of this age results in limited capacity for water storage and transmission (Driscoll 1986). Alterations caused by secondary jointing, fracturing, or chemical weathering may allow the hydraulic properties of these rocks to improve. Hydraulic characteristics of both the igneous and metasedimentary rock formations near the Project are being investigated for mine geotechnical and tunneling properties as well as for estimates of groundwater inflow to tunnels and stopes (Golder 2005a, 2005b).

2.1.2 Quaternary Geology

The Quaternary deposits of the Plains are described as a large outwash-fan delta (Drexler 1981) that become finer and better sorted from the north toward the south (Segerstrom 1964) and are mapped regionally as glacial outwash sand and gravel and post-glacial alluvium (Twenter 1981). Along the north terrace the surficial deposits are mapped as coarse-textured glacial till of extremely heterogeneous particle size. This unit is referred to in geologic literature as the Negaunee Moraine (Segerstrom 1964). The regional Quaternary geology map is shown in Figure 5, and the cross sectional representation of this model is shown in Figure 6.

The glacial depositional model proposed by Segerstrom indicates a late glacial history dominated by a stagnated ice margin along the valley that now separates the Plains from the Huron Mountains to the north. This glacier was part of a late-continental glacier readvance referred to as the "Marquette" phase that nearly refilled the Lake Superior basin about 10,000 years before present (Farrand and Drexler 1985). Locally, the ice was thickest through the valley along the southern edge of the Huron Mountains. Melt water then deposited kames and outwash plains as it flowed southward from this ice margin. The flow of melt water was obstructed by the high bedrock hills to the south, causing ponding within a glacial lake basin that stood at an elevation well above the elevation of other glacial lakes and outlets present in this area during this time period (Drexler 1981). Ponding of the melt water continued until the water surface increased enough to flow southward through the Mulligan Plains to the valley containing the Dead River (Segerstrom 1964).

Subsequent erosion of the gap resulted in drainage of the glacial lake. Following deglaciation, drainage of the Plains soon became dominated by rapid headward cutting of tributary streams of the Salmon Trout River into the steep slope of the north terrace and the re-excavation of the Yellow Dog River along the southern Plains and then north toward Lake Superior.

The observed thickness of Quaternary deposit within the EBS study area ranges from 0 ft (at the Peridotite outcrops) to greater than 200 ft. The deposit thickens in all directions away from the Peridotite outcrops, with the greatest thickness observed east and west of the Project area. The Quaternary deposits that define the Plains then thin toward the north and south, terminating at the boundary of the Archean bedrock formations that also mark the north and south boundaries of the Baraga Basin metasedimentary rocks.

Quaternary deposit data generated during the EBS are generally in good agreement with the glacial depositional model summarized above. A cross section view of Quaternary formation stratigraphy within the Project area is shown in Figure 7. A general hydrostratigraphic correlation nomenclature system was developed for the EBS and is summarized below.

Surface Soil Layer

A surface soil layer (black color with organic material and tree litter) was identified at most drilling locations within the EBS study area. This layer is generally less than 1 ft thick (and mapped regionally as 0-2 inches (in.) thick on the Plains). This surface layer is classified as a sandy organic soil (Unified Soil Classification System (USCS) OL/OH).

Outwash and Beach Deposits (A Zone)

The outwash and beach deposits are comprised of well-sorted, stratified fine- to medium-grained sand, with some gravel and minor quantities of silt and clay (less than 10%, NJC 2005a) (USCS SP to SP/SP-SM). The sand fraction of this material appears to be predominantly rounded quartz with trace to minor amounts of angular and sometimes platy mafic or fine-grained sedimentary rock grains. The unsaturated portion of this deposit is typically red to reddish brown and the saturated portion is brown. These surficial deposits are mapped regionally as having very rapid water infiltration rate characteristics (greater than 10 in./hour) (Twenter 1981). An unconfined water table defined in the EBS as the A zone hydrostratigraphic unit occurs in the saturated portion of this deposit. Generally a fining downward sequence is found in the A zone, with the fine sand fraction increasing with depth.

Transitional Deposit (B Zone)

A gradational contact exists between the A zone outwash sand and a deeper transitional zone that contains a mix of fine sand, silt and clay (SM), and typically continues to fine downward to predominantly silt (ML) and clay (CL). While the A zone outwash and this transitional deposit may both be derived from melt water processes and could be lumped as outwash, the grain size characteristic change from predominantly sand (USCS coarse-grained material) to predominantly silt and clay (USCS fine-grained material). This transition is considered significant to primary conditions affecting groundwater flow as it indicates a decrease in permeability of the Quaternary formation from the coarse-grained material to the fine-grained material.

Lacustrine Deposit (C Zone)

A laterally extensive, massive clay deposit (USCS CL) was identified in samples from most borings, and is found to be thickest south of the Peridotite outcrops, and thinnest north of the outcrops towards the north terrace. The clay deposit is easily recognized in soil sample cores as lean clay with high plasticity. A sharp contact is typically observed at both the top and bottom of this deposit. On average the deposit contains 98% silt and clay (NJC 2005a). This deposit is defined as the C zone hydrostratigraphic unit.

The top of the clay deposit was encountered in borings between 1,315 and 1,399 feet above mean sea level (ft MSL) and ranged in thickness from 7-63 ft, thickest and most consistent in its elevation in the south/southeast part of the Plains (from locations QAL005A/D to QAL010A) and thinnest and less continuous in nature towards the north and northeast of the proposed discharge area, where this unit eventually pinches out near the edge of the north terrace. The pinch-out of the transitional and lacustrine deposits of the B zone near the north terrace is consistent with the glacial depositional model presented by Segerstrom, as the transitional unit would be expected to pinch out toward the north where regional maps show the outwash deposit terminating at the edge of the moraine (Figure 5). This areal distribution pattern indicates that the deposit was formed in ponded water between the bedrock highlands south of the Plains and glacial ice to the north, consistent with the depositional model proposed by Segerstrom (1964).

Outwash/Ablation Till (D Zone)

A deposit of coarser-grained material was encountered beneath the C zone lacustrine deposit at most EBS drilling locations. Samples from this deposit are classified as SP to SM materials (predominantly fine- to medium-grained sand) and are similar to samples of A zone material. This material appears to be outwash deposited prior to the glacial lake period on the Plains. This deposit is defined as the D zone hydrostratigraphic unit.

Greater heterogeneity in grain size characteristics was observed within the D zone compared to the A zone. At 2 locations (QAL004A/D and QAL005A/D) south and southwest of the proposed discharge area the deposit contains a layer with significant amounts of gneiss and granitoid cobble and gravel-sized outwash material (indicative of high flow velocity glacial drainage channel deposits). At other locations (QAL001A/D, QAL002A/D and the base of QAL004A/D) the deposit contains a relatively high percentage of fine sand and silt, and generally this deposit becomes increasingly finer-grained toward its base. The finer-grained portion is possibly derived from direct ice melt or sublimation (ablation till), since the base of this zone is most often identified in contact with a basal till deposit, described below. This outwash deposit is also discontinuous, interrupted by shallow bedrock and pinched out between the fine-grained units above and below. This deposit was not encountered beneath the C zone southeast of the proposed discharge area (QAL006A/B and QAL010A). This deposit appears to be confined or partially confined, except at location QAL009A/D east of proposed discharge area where the overlying C zone clay is absent. North or northeast of the termination of the B and C deposits the A and D zone aquifers appear to be a single unconfined system.

Basal Till (E Zone)

Poorly-sorted basal till consisting of boulder- to sandy-sized clasts in a fine-grained matrix is the lowermost Quaternary deposit material identified in samples from all but one boring (QAL004A/D) within 3,000 ft of the proposed discharge area. This unit is substantially thicker east (QAL009A/D), west (QAL007A/D) and southeast (QAL010A) of the proposed discharge area. Bedrock is encountered at greater depths at these locations, indicating that earlier glacial moraine deposition occurred in the bedrock valleys. Boulders are commonly present along the north terrace, corresponding to the mapping of the Negaunee Moraine (Figure 5).

Lower Outwash Units (F Zone)

At 2 locations distant from the proposed discharge area (QAL007A/D and QAL010A), lower outwash deposits were found interlayered with E zone till. Representative samples of the lower outwash material are classified as SP to SM (predominantly fine- to medium-grained sand). In QAL010A these units were dry. The interlayered nature of the till and lower outwash units indicates fluctuations in glacial advances and retreats during earlier glacial depositional sequences. This lower outwash deposit is defined as the F zone hydrostratigraphic unit.

2.2 Hydrology

2.2.1 Precipitation

From April to September most precipitation in the region occurs as rain, while from November to mid-March it is usually in the form of snow. Precipitation stored in the form of snow throughout winter months is released to streams and groundwater in late winter and early spring.

Data from October 2004-September 2005 (National Weather Service 2005) indicate regional precipitation was 2.22 in. below the 1979-1998 average (35.39 in.). Notable changes to the average distribution of precipitation were dryer than average conditions in November 2004 (2.11 in. of rain compared to 3.32 in.) and August 2005 (1.95 in. of rain compared to 3.45 in.) and wetter than average conditions in December 2004 (5.05 in. compared to 2.38 in.). These data indicate that regional monthly precipitation patterns during the HS were close to recent climatologic averages.

2.2.2 Surface Water

The proposed discharge area is located near a hydrologic divide of surface watersheds mapped by the State of Michigan (State): those drained by the Salmon Trout River and those drained by the Yellow Dog River (MI DNR 2000) (Figure 2). Both streams flow to Lake Superior (average elevation 602 ft MSL).

The Salmon Trout River watershed encompasses an area of approximately 50 mi^2 and flows northward from its headwaters emptying into Lake Superior at Salmon Trout Bay northwest of the town of Big Bay. The upper portion of the State-defined Salmon Trout River watershed (MI DNR 2000) has been further divided into 3 topographically delineated subwatersheds referred to as the West Branch (3.3 mi^2), Main Branch (8.8 mi^2) and East Branch (13.0 mi^2) (Figure 2). The headwaters of the Salmon Trout River Main Branch originate from a large wetland complex on the Plains located south of the Project at elevations between 1,430 and 1,460 ft above MSL. The Main Branch flows from the wetland complex northerly down the north terrace, joining the East Branch and West Branch tributaries downstream of the north terrace. Most of the tributaries of the East Branch and West Branch emerge from groundwater seepage along the north terrace.

The Yellow Dog River watershed area is approximately 98 mi^2. The Yellow Dog River headwaters are in bedrock highlands at the outlet of Bulldog Lake in the Ottawa National Forest, Baraga County. The headwater lake elevation is approximately 1,730 ft above MSL, about 300 ft higher than the Plains. After flowing northward from these highlands, the Yellow Dog River flows west to east across the southern edge of the Plains (normal to the direction of flow of the Salmon Trout River Main Branch). The river then continues northward to Lake Independence in the town of Big Bay. The portion of the Yellow Dog River watershed within the EBS study area is roughly 30 mi^2.

Regional surface water typically follows a seasonal pattern of peak flows during spring following snowmelt runoff, and low flows in late summer and winter (Grannemann 1984). The hydrographs of area streams recorded for the EBS generally follow this pattern (Figure 8). Other precipitation events contributing to increased surface runoff are seen in the hydrographs, including fall precipitation and some short duration winter thaw and snowfall events.

The Salmon Trout River tributaries within the north terrace have steep gradients and well-confined channels and consistently show increasing flow with distance downstream indicating that groundwater provides significant input to these tributaries.

During the portion of the EBS that included continuous flow monitoring (September 2004 through May 2005), the mean daily flow range of the Salmon

Trout River Main Branch (STRM004) was 4.2 to 41 cubic feet per second (cfs) with an average flow of 7.3 cfs. The mean daily flow range of the Salmon Trout River East Branch (STRE002) was 12 to 119 cfs with an average flow of 22 cfs. Both tributaries have maximum flow to minimum flow ratios of 10.

By comparison the Salmon Trout River near the mouth (STRM005) exhibits somewhat higher peak response and longer duration to the significant runoff events. The mean daily flow range was 22 to 397 cfs with an average flow of 48 cfs. The maximum to minimum flow ratio of this location is 18, which indicates greater sensitivity downstream to surface runoff from the shallow bedrock terrain located north of the Plains. The Salmon Trout River East Branch and Main Branch subwatersheds account for about 46% and 15% of the total average flow (as measured at the downstream station STRM005), respectively.

The Yellow Dog River in the vicinity of the Project also shows a more pronounced response to surface runoff events in both peak flows and event duration. The mean daily flow range was 7.2 to 242 cfs with an average flow of 34 cfs. The maximum to minimum flow ratio is 37 which indicates considerable "flashiness" due to high surface flow inputs from headwaters portions of the watershed that are mostly shallow bedrock terrain.

2.2.3 Groundwater

Groundwater flow on the Plains principally occurs in the transmissive portions of the glacial deposits. These hydrostratigraphic units are the saturated, coarse-grained outwash deposits (A and D hydrostratigraphic zones).

Groundwater in both the A and D zones can be generally described as flowing from the south/southwest to the north/northeast near the Project area and at the proposed discharge location (Figures 9 and 10). The Plains wetland complex south of the Project is primarily a groundwater recharge location supported by precipitation. Conversely, the north terrace is drained by seeps and streams and is a discharge area for groundwater of both the A and D zones. A detailed map of seep zones downgradient of the proposed discharge area is presented in Figure 11. This flow pattern is consistent with the conceptual model of hydrology developed by Segerstrom (1964) based on regional drainage patterns and the glacial depositional model.

Regional groundwater elevations in the Quaternary aquifers and wetland areas were measured during discrete events seasonally during the EBS and continuous data were collected at selected locations. The fluctuation patterns generally show typical seasonality, resulting in rising groundwater elevations in the spring and after snowmelt recharge and declining groundwater elevations from late summer through the winter months. The groundwater elevation contour maps developed from potentiometric data measured during the EBS indicate similar flow patterns during each seasonal measurement event and fairly similar flow patterns to those represented by the flow lines on the potentiometric contour maps show in Figures 9 and 10.

Figure 12 presents continuous groundwater elevation data recorded from August 2004 through May 2005 for monitoring locations QAL004A/D, QAL008A/D, QAL018 and WLD001, which are generally situated along the hydrogeologic cross section shown in Figure 7. This cross section generally coincides with a groundwater flow path through the Project area and the proposed discharge area. The data show that groundwater elevations have been fairly stable with fluctuations generally less than 2 ft. The influence of seasonal infiltration is however apparent, with declining groundwater elevations from summer 2004 through winter 2005, followed by an increase in groundwater elevations following snowmelt, particularly at locations close to the Plains wetland recharge area (e.g., QAL004A/D).

The continuous groundwater elevation data show significant vertical gradients between the A and D zones where the B and C zone fine-grained units are present, indicating a high degree of hydraulic separation and the presence of the confining units. The direction of the vertical gradient between zones varies, with an upward gradient consistently present at location QAL004A/D and a downward gradient at QAL008A/D. This pattern suggests that the D zone at QAL004A/D is connected hydraulically to a recharge area upgradient (southwest) of the well and that the D zone at QAL008A/D is connected hydraulically to a discharge area downgradient (northeast of the well). Similar downward gradients are present at the other monitoring locations near the northern edge of Plains (well nests QAL001A/D and QAL002A/D), while upward gradients are present at well nest QAL007A/D, which is located closer to recharge areas and more distal to discharge areas along the north terrace. By comparison, data for well nest QAL009A/D indicate essentially no vertical gradient in the absence of the fine-grained confining units east of the proposed discharge area.

2.2.4 Hydraulic Characteristics of Quaternary Formations

Hydraulic characteristics of the quaternary formations were determined during the EBS using multiple well pumping tests, single well specific capacity tests, laboratory permeability tests, and estimates based on laboratory sieve analyses of grain size distribution. The EBS pumping test area was located near QAL004, about 3,000 ft southwest of the proposed discharge area. At this location the average D zone transmissivity is about 6,100 gallons per day per foot (gpd/ft) and is generally consistent throughout most of the pumping test area. The transmissivity is likely lower, however, to the north/northeast and south/southeast toward the bedrock outcrops as a result of D zone discontinuity. The average horizontal hydraulic conductivity of the D zone at this location is 40 feet per day (ft/d). The average storage coefficient for the D zone is 1.7E-4.

The A zone transmissivity increases from northeast to southwest in the EBS pumping test area, ranging from about 7,700-12,400 gpd/ft. Because the saturated thickness of the hydrostratigraphic unit is similar along the test array, the areal increase in transmissivity likely results from higher hydraulic conductivity of the sediments. Horizontal hydraulic conductivities in the A zone pumping test area range from 37 to 69 ft/d with the highest values in the southwest portion of the area. The average value determined from the test is 50 ft/d. The average specific yield of the A zone is 0.048. The average anisotropy ratio of A zone sediments is 0.036. The average vertical hydraulic conductivity of the A zone is 1.9 ft/d or approximately 26 times less than the average horizontal hydraulic conductivity value.

The EBS pumping test data indicate that water flow in the primary productive hydrostratigraphic units (A and D zones) is strongly horizontal. The A zone hydrostratigraphic unit is unconfined. As indicated by the groundwater gradients at monitoring well nests described above, the B and C zones act together as a hydraulic barrier, restricting groundwater movement, or leakage, between the A and D zones in the pumping test area. The D zone hydrostratigraphic unit is confined in the presence of the B and C zones.

The EBS specific capacity tests in the outwash units generally result in lower hydraulic conductivity estimates by one-half to one-third when compared to data for the same wells obtained in the longer term, multiple-well EBS pumping tests described above. This testing scale relationship is typical of these test methodologies (Bradbury and Muldoon 1990). These specific capacity test results are very similar to those presented in hydrogeologic studies of similar glacial hydrostratigraphic units in Marquette County, which employed the same methodologies for parameter testing over a broad area of the Sands Plain groundwater basin (Grannemann 1984).

Hydraulic conductivity estimates have also been obtained from laboratory permeability tests on fine-grained material (C zone) and sieve analyses for all of the glacial hydrostratigraphic units. These units show hydraulic conductivity values of three to six orders of magnitude (10E-01 to 10E-05 ft/day) lower than the coarse grained outwash deposits.

2.2.5 Groundwater Basins

The analysis of surface water and groundwater interaction on the Plains was aided through the use of a numerical groundwater flow model developed by Fletcher Driscoll & Associates using Visual MODFLOW. A complete description of the flow modeling methodology is presented in the EBS (NJC 2005a). The primary objective of the modeling was to develop a groundwater/surface water assessment of baseline conditions to assess the water balance of the Plains and to delineate groundwater basins associated with the primary streams of the Project area (Salmon Trout River tributaries and the Yellow Dog River). The model is calibrated to both piezometric head and streamflow data.

Based on an evaluation of average subwatershed flow normalized to surface water drainage area, it appears that groundwater basins are likely significantly larger than the mapped surface watersheds particularly for the Salmon Trout River tributaries originating from the north terrace. This is particularly noticeable in the calculated average flow per square mile of surface watershed area for the Salmon Trout River East Branch, which is approximately double that of the other subwatersheds measured with continuous stage recorders.

In order to estimate the area of groundwater basins associated with water budget zones, the groundwater basin divides were determined from EBS groundwater model simulations by backward particle tracking from model river cells. Groundwater divides (and associated groundwater basins) for the subwatersheds of the Salmon Trout River West Branch, Main Branch, East Branch and Yellow Dog River are shown in Figure 13 (approximate A zone) and in Figure 14 (approximate D zone). A comparison of these modeled groundwater basins to the State-defined surface watershed delineations (Figure 2) suggests that the Salmon Trout River basin captures groundwater from a significantly larger area of the Plains than is represented by the State-defined surface watershed. This is particularly true in the area of the Salmon Trout River East Branch basin, where the groundwater basin divide is offset approximately 1 mi south from the estimated surface watershed divide.

Significantly the proposed discharge area is located in the groundwater basin of the Salmon Trout River East Branch for both the A and D hydrostratigraphic zones.

2.3 Groundwater Quality

Wetland deposit and Quaternary deposit groundwater quality data obtained for the EBS is generally categorized as very fresh (total dissolved solids (TDS <100 mg/L) to fresh (TDS 100-1000 mg/L) and soft (hardness <60 mg/L) to moderately hard (60-120 mg/L). The A zone Quaternary deposit groundwater is largely very fresh (TDS <100 mg/L) and soft (hardness <60 mg/L) while the D zone Quaternary deposit groundwater trends toward fresh and moderately hard. Where the water table is shallow (e.g. wetland complex south of the Project area), A zone samples tend to be weakly acidic, with low calcium concentrations and low specific conductance. Mineralization increases and pH increases to weakly alkaline with depth. Dissolved oxygen concentrations generally decrease with depth, with A zone samples having dissolved oxygen levels as high as 7 mg/L while D zone samples typically have concentrations less than 0.001 mg/L. This pattern suggests that shallow water is recharged by precipitation infiltration and becomes more mineralized and depleted in oxygen with depth and residence time in the aquifer.

Water quality of most Quaternary aquifer and wetland deposit groundwater samples is dominated by calcium and bicarbonate ions. Exceptions are the samples collected from well QAL006A, with no dominant (greater than 50% milliequivalents per liter (meq/L)) anion chemistry, wells QAL005A, QAL006A and

WLD006, with no to weakly calcium dominant cation chemistry. All of these samples are representative of groundwater strongly dominated by precipitation recharge from the wetland complex south of the proposed discharge area.

Minor constituents detected include iron, fluoride and nitrate (mostly at concentrations <1 mg/L). Dissolved iron and manganese are redox-sensitive parameters and thus they tend to increase in concentration in response to oxygen depletion with depth, and in wetland soils. Other dissolved trace metals consistently detected in groundwater samples in relatively close proximity to the proposed discharge area consist of arsenic (identified at QAL004D, QAL005D, QAL008D and QAL009D), and possibly zinc (identified at QAL009A). Mercury was detected in most groundwater samples at concentrations less than 1 ng/L.

3.0 Methods

Additional background data was obtained from publicly available sources and Kennecott Exploration Company mineral exploration data. Hydrogeologic Study methods are described in detail in the Eagle Project Supplemental Hydrogeologic Study Work Plan for Groundwater Discharge (NJC 2005b), Quality Assurance Project Plan for Stage 2 Hydrological Assessments (NJC 2004a) and Eagle Project Hydrological Assessments Standard Operating Procedures Manual (NJC 2004b).

A summary of the primary components of the HS methods is included below.

3.1 Infiltrometer Tests

Quaternary outwash deposit infiltrometer tests were performed at 8 locations in shallow test pits spaced approximately 250 ft apart within the 10 acre proposed discharge area (Figure 15). The test areas were excavated with a rubber-tired backhoe to a depth of about 2 ft to remove stumps, tree litter and logging slash and surface layer materials and to expose the upper surface of the Quaternary outwash deposits. Test locations were leveled using a hand shovel prior to installation of the double-ring infiltrometer. The tests were performed in accordance with the Standard Test Method for Infiltration Rate of Soils in Field Using Double-Ring Infiltrometer (ASTM D 3385-03).

The infiltrometer rings (12-in. and 24-in. diameter) were set to a depth of 6 in. (outer ring) using a sledgehammer and wood blocking. A head of 3 in. of water was maintained during testing. Test data were recorded on field data forms. Each test was run beyond the point at which steady-state (i.e., saturated) flow occurred, as evidenced by reasonably stable infiltration rates as the tests progressed.

Due to the relatively high infiltration rates, open-topped 55-gallon drums fitted with outflow gate valves and tubing were used to introduce water to the infiltrometers in place of standard volume Mariotte tubes specified in the ASTM Standard. Water for the tests was obtained from the Powell Township potable groundwater system in Big Bay, Michigan. The pH of the water ranged from 7.8 to 8.3 SU, similar to Quaternary aquifer groundwater on the Plains.

Following completion of each infiltrometer test, a trench was excavated to bisect the tested soil column to a depth of 8 ft using a backhoe. The flow path of water and the soil profile were recorded on test pit logs in 1-foot increments using the USCS and Munsell Soil Color Charts for soil descriptions. A minimum of one soil sample was collected from each test pit for subsequent laboratory analysis of grain size distribution. Each test pit was restored to original topography after testing was complete.

3.2 Soil Cores and Classification

Eight Quaternary deposit soil borings designated with a QAL prefix (QAL031, QAL036 – QAL042) were constructed within the 10-acre HS area using sonic drilling methods (Figure 15). The borings were placed adjacent to the infiltrometer test locations described above. The soil borings were extended from the ground surface to the bedrock surface. Soil boring locations were surveyed for horizontal position (NAD 83 projection, UTM zone 16, ± 3 ft) and ground surface elevation (NGVD ± 1 ft).

Core intervals (4-in. diameter) within the borings were continuous with the first interval beginning at the ground surface to 7 ft below grade followed by 10 ft intervals for each additional core run. Representative soil samples were collected for laboratory analyses of grain size distribution and laboratory classification. Soil logging was performed as described in the EBS SOP Manual (NJC 2004b). A summary of soil boring construction is presented in Table 1 and

Grain size distribution testing locations and results are presented in Table 2. Boring logs are presented in Appendix A.

Additional sonic borings were placed at locations QAL024 – QAL026, and QAL043 and QAL044 for the purpose of constructing additional piezometric monitoring points to better define local water table system flow in the vicinity of the proposed mine surface facilities and the underground workings. Also, hollow stem auger geotechnical borings were completed at locations QAL027 – QAL030, and QAL032 – QAL035 to aid surface facility engineering plans.

3.3 Monitoring Well Installation

Two Quaternary deposit monitoring wells (QAL031D and QAL041D) were installed within the proposed discharge area (Figure 15). These wells supplement the network of existing background water quality monitoring wells (QAL004A/D, QAL005A/D, QAL006A/B, QAL008A/D and QAL009A/D) located upgradient and downgradient of the proposed discharge area. The HS work plan (NJC 2005b) specified a well nest location at QAL031. Groundwater, however, was only encountered in the D zone sediments yielding a single-well placement. An additional single-well placement was installed to the southeast (QAL041D) where groundwater saturation was also only encountered in the D zone sediments.

In addition to the proposed discharge area wells, eight other monitoring wells consisting of 1 well nest (QAL029A/D) and 7 single-well placements (QAL024/A-QAL028A, QAL043B and QAL044B) were installed to assist in mapping the potentiometric surfaces and shallow aquifer flow around the propose surface facility and above the ore body (Figure 15).

The new monitoring wells have the same QAL identifier as was used for the corresponding soil boring. Well location (NAD 83 projection, UTM zone 16, ± 3 ft) and riser elevation (NGVD ± 0.01 ft) were surveyed by a registered land surveyor. The survey point was marked with indelible ink on the riser as the reference point for subsequent water level measurements.

All wells except QAL031D are constructed from 2-in. diameter, schedule 40 polyvinyl chloride (PVC) pipe in 6-in. diameter boreholes using either sonic or hollow stem auger drilling methods. Well screens are 10-foot long, with 0.02-in. slot size. The well screen for the lower hydrostratigraphic unit at well nest QAL029A/D is 5-foot long with a 0.02-in. slot size. Well QAL031D is constructed from 2.5-in. diameter schedule 80 PVC pipe, with a 5-foot long well screen of 0.02-in. continuous slot size. An artificial sand filter pack was placed in the borehole annulus around and extending 2 ft above the well screen at all locations. An annular seal above the sand filter pack was constructed with 3/8-in. diameter bentonite pellets (4 ft thick). Bentonite grout extended from the annular seal to the ground surface, with a surface concrete well pad. Above-grade risers (nominal 3-foot stick up above grade) and 4-in. steel casings with locking caps completed each well installation.

A construction summary and boring logs for these monitoring wells are included in Appendix A.

3.4 Aquifer Hydraulic Testing

Hydrologic data collection consisted of groundwater elevations and a single well specific capacity pumping test.

3.4.1 Groundwater Elevations

Discrete groundwater elevations were collected at monitoring wells and piezometers for the entire Project area groundwater monitoring system during summer 2005 base flow conditions in August 2005. Continuous groundwater elevation recorders (pressure transducers) were used to measure elevations on an hourly basis at select monitoring wells (QAL008A/D) near the proposed discharge area.

3.4.2 Aquifer Hydraulic Testing

Single well pumping test methodology with specific capacity testing was conducted following the procedures outlined in the SOP Manual (NJC 2004b). The thin saturated zone and grain size characteristics (16 ft of predominantly fine-grained sand) precluded a second multi-well test at higher pumping rates. The procedure involved pumping monitoring well QAL031D at a constant rate (2.9 gallons per minute) for 4 hours at an apparent equilibrium water level (about 2.5 ft of drawdown) in the pumping well. Pumping rates were measured with a calibrated container. Continuous water level measurements were recorded with pressure transducers for the pumping test. As stated above, background water levels were measured at nest QAL008A/D prior to the pumping test as part of the EBS.

Pumping test data were analyzed by Fletcher Driscoll & Associates for aquifer transmissivity using the Cooper-Jacob semi-log method. Recovery data were also recorded by pressure transducers and analyzed for aquifer transmissivity. The data analyses and time drawdown data are presented in Appendix C.

3.4.3 Predictive Simulation of Groundwater Discharge Effects

Predictive simulation of the effects of the discharge on the groundwater system (mounding simulation) has been performed by other engineering consultants as part of the treated mine water discharge system design. This analysis indicates that the predicted groundwater table mound will be well below the ground surface of the discharge area, and the areal limits of the mound do not extend to potential groundwater discharge areas on the northern terraced escarpment of the Yellow Dog Plains (Foth and Van Dyke, 2005).

3.5 Groundwater Quality Monitoring

Groundwater quality samples representative of summer base flow hydrologic conditions were collected from proposed discharge area at wells QAL031D and QAL008A/D. In addition, regional background water quality sampling initiated during the EBS was also continued using monitoring well nests QAL004A/D, QAL005A/D, QAL006A/B and QAL009A/D (Figure 9). Eight monitoring events have been completed at well nests QAL004A/D, QAL005A/D and QAL006A/B (Table 5), and 5 monitoring events have been completed at well nests QAL008A/D and QAL009A/D (installed October 2004). Samples were analyzed for pH, dissolved oxygen, specific conductance, ferrous iron and temperature in the field and submitted to laboratories for analysis of parameters listed in Appendix D. Hardness was calculated using calcium and magnesium concentrations (Freeze and Cherry 1979).

4.0 Results

4.1 Well Survey and Designated Wellhead Protection Areas

The MDEQ Well Logic system, MDEQ scanned well logs, and Marquette County Health Department records were checked for presence of wells located within 0.5 mi of the proposed discharge area. Because no private land owners with camps or residences are present within this search radius, and because no camps have been observed, no additional contacts were made for this assessment.

The Powell Township Wellhead Protection Program was reviewed. This wellhead protection zone is for an unconsolidated glacial deposit aquifer which is described as an unconfined, localized sand and gravel aquifer (UP Engineers & Architects, Inc. 2003) located about 1 mi south of the Village of Big Bay. Big Bay is located about 9.5 mi northeast of the proposed discharge area. Because the Quaternary aquifers present beneath the proposed discharge site do not extend to this area, the Powell Township WellHead Protection area is not in any direct hydraulic connection to aquifers present on the Plains. The location of this well head protection area and the 0.5 mi radius around the proposed discharge area is presented in Figure 16.

4.2 Geology

4.2.1 Surface Soil

The surface soil layer identified in the regional EBS (black color with organic material and tree litter) is present within the proposed discharge area. This layer is generally less than 1 ft thick. Using the USCS system this surface layer is classified as a sandy organic soil (OL/OH).

4.2.2 Quaternary Deposit

Quaternary deposit data obtained during the HS are generally in good agreement with EBS findings, regional data, and the glacial depositional model summarized in Section 2.

The base of the Quaternary deposits is defined by the bedrock surface and the bedrock surface is considered to be a no flow boundary to the Quaternary aquifer. The structure of this surface is presented in Figure 17. This surface slopes steeply towards the east/northeast from the proposed discharge area.

The corresponding observed thickness of Quaternary deposit within the proposed discharge area ranges from about 97 ft to 140 ft, generally increasing towards the northeast (Figure 18). This pattern follows the regional trend with the Quaternary deposits thickening in a somewhat radial pattern away from the Peridotite outcrops.

Within the proposed discharge area, all of the hydrostratigraphic units identified as the A – E hydrostratigraphic zones were encountered. Grain size analyses performed on representative samples indicates good correlation to the regional data for these units. In general the outwash deposits are predominantly fine-grained sand, with somewhat more coarse sands present in the unsaturated outwash above the water table (Table 2).

The observed thickness of the vadose zone ranges from about 75 to 105 ft in the proposed discharge area (Figure 19), increasing towards the southeast. The corresponding observed thickness of the saturated zone ranges from about 12 to 60 ft, generally increasing from southeast to northwest. The decrease in saturated thickness towards the southeast appears to be related to the pinch-out of the B and C zone confining units within the proposed discharge area (Figure 20). These confining units are not significantly present in approximately the southeastern two-thirds of the proposed discharge area. Some thin,

NE not SE

northeastern

discontinuous units of fine-grained deposits are present between about 50 to 60 ft below ground surface (approximate elevation 1,410 to 1,400 ft above MSL). While these units appear to have similar geotechnical characteristics to the B or C zone deposits analyzed as part of the EBS (Table 3), the elevation, thickness and discontinuities suggest that they are likely a localized deposit rather than correlated with the more continuous B and C confining units identified in the EBS.

The relationship of these units is presented in the hydrogeologic cross sections through the proposed discharge area shown in Figures 21 through 25.

4.3 Hydrology

4.3.1 Groundwater Flow and Water Level Fluctuations

The groundwater elevations recorded during August 2005 reflect low precipitation of the summer baseflow monitoring period (Table 4). The potentiometric surface maps for both the A zone and D zone aquifers are presented in a regional view and HS view of the proposed mine surface facilities and discharge area (Figures 26 – 29). These maps indicate flow patterns that are quite similar to those reported in the EBS (Figures 9 and 10). The detailed HS view potentiometric surface maps indicate a somewhat steeper water table gradient in the area of the proposed discharge area. All potentiometric data strongly indicate flow towards the east/northeast from the proposed discharge area towards the north terrace, and discharging/draining to the Salmon Trout River East Branch tributary system. A Salmon Trout River East Branch and Main Branch flow divide is located west of the proposed discharge area with the ore body located beneath the Main Branch system.

Continuous water level data indicates relatively stable water levels in the vicinity of the proposed discharge area as indicated by the continuous record for well nest QAL008 (Figure 30). In comparison, more seasonal fluctuations are observed in the regionally upgradient portions of the aquifer represented by the hydrograph for well nest QAL004 (Figure 30). This difference appears to be related to the change in spatial relationship from recharge to discharge areas with more fluctuation observed in closer proximity to the primary reacharge area of the Quaternary aquifers.

4.3.2 Infiltration Rate of Unsaturated Outwash Deposit

Infiltration rates (inner ring trials) measured at the proposed discharge area ranged from 24 to 38 in./hr (61 to 97 cm/hr) with a mean of 31 in./hr (79 cm/hr, Figure 31). Infiltration rates were relatively stable from the beginning to end of each test (Appendix B), and the inner and outer ring infiltration rates were very similar (relative percent difference <10%) at all locations except QAL042 (relative percent difference of 41%).

Soil samples obtained from test pits document primarily fine- to medium-grained outwash sand (SP) with 5 to 20% rounded coarse sand and gravel (Table 2). In 4 of the 8 test locations, blocky structures of weakly cemented sand grains were observed between 1 and 4 ft below grade. These structures did not appear to have a consistent spatial pattern and did not appear to be a determining factor in the measured infiltration rates at the test sites.

Water flow in the test area was strongly vertical with negligible evidence of horizontal flow. The wetting front typically extended vertically below the test area (greater than 8 ft).

4.3.3 Hydraulic Conductivity of the Quaternary Aquifer

Site specific testing of the Quaternary aquifer hydraulic conductivity was performed at monitoring well QAL031D utilizing a single well test methodology based on the specific capacity of the well. A specific capacity of 1.1 gpm/ft was calculated from the discharge-drawdown data. This specific capacity is very similar to that achieved for the unconfined, A zone multiple well pumping test performed for the EBS (NJC 2005a). The specific capacity data indicates that additional multiple well pumping tests with high yields will not be achievable in this area.

The data analyses for both the pumping and recovery period indicate aquifer transmissivity between about 1,200 and 1,900 gpd/ft, corresponding to hydraulic conductivity of about 10 to 16 ft/d assuming an aquifer saturated thickness of 16 ft. Based on correlation of the multi-well test data to other specific capacity tests as assessed in the EBS (discussed in Section 2 of this report), and an estimate of well efficiency at this location (Appendix C), the true aquifer hydraulic conductivity is more likely on the order of 25 ft/d at this location.

The EBS range of values determined for hydraulic conductivity of the coarse-grained deposits and at this HS test location is presented in Figure 32. This data plot indicates that these materials typically have hydraulic conductivity values between 20 – 60 ft/day, with a few outliers corresponding to somewhat atypical grain-size characteristics of the deposits at location with very coarse-grained drainage channel deposits (QAL005D) and silty ablation till or more poorly sorted outwash (QAL001D, QAL002D, and QAL004D). These values are quite consistent with hydraulic characteristic data determined for glacial outwash deposits on the Sands Plain aquifer materials in central Marquette County (Grannemann 1984).

The range of hydraulic conductivity of the fine-grained B and C zone deposits (clay tills and lacustrine deposits) is much greater, up to six orders of magnitude lower than the hydraulic conductivity of the D zone coarse-grained outwash unit (NJC 2005a). As a result, it appears that the lateral and vertical distribution of the B and C zone deposits have the greatest potential to effect discharge mounding and flow patterns. The distribution of the hydrostratigraphic units is incorporated into the model for the simulation of the groundwater discharge, discussed below.

4.3.4 Predictive Simulation of Groundwater Mound

For this mounding simulation, the discharge flow was set at 400 gallons per minute (gpm), which was established as the design basis flow for engineering plans for the system (Foth & Van Dyke 2005). The groundwater mound predicted by this analytical simulation is approximately 22 ft above the static water table surface. The site investigation data indicate that the unsaturated zone thickness is 75 to 105 ft in this area; therefore, the top of the predicted groundwater mound is well below the groundwater surface and the infiltration system apparatus. ground?

4.4 Groundwater Quality

4.4.1 Quality Assurance

Data quality control, field and laboratory quality control procedures and analytical results were reviewed according to the Quality Assurance Project Plan (NJC 2004a). Appendices G and H present the laboratory data and quality control reports for the summer base flow 2005 groundwater quality sampling event. Quality control and laboratory reports for the remainder of the monitoring events are presented in the EBS report (NJC 2005a).

These quality control checks indicate that the data can be considered valid and representative of baseline conditions. All exceptions to quality control guidelines are indicated in the water quality data tables.

4.4.2 Groundwater Quality

Groundwater quality data are presented in Table 5. Field sampling reports for the summer base flow 2005 groundwater quality sampling event are attached in Appendix E and in the EBS report (NJC 2005a) for the remainder of the monitoring events.

Quaternary deposit groundwater quality at and down gradient of the proposed discharge area can be generally categorized as:

- Very fresh (total dissolved solids (TDS) <100 mg/L)
- Soft (hardness <60 mg/L) to moderately hard (60-120 mg/L).
- Weakly alkaline
- Dominated by calcium and bicarbonate ions
- Largely free (less than the laboratory reporting limits) of dissolved metals. Exceptions are the relatively frequent detection of arsenic (QAL008D) and zinc (QAL009A) at trace concentrations and the nearly ubiquitous detection of mercury at very low concentrations (less than 1.5 ng/L).
- Dissolved oxygen concentrations which decrease with depth.
- Chloride and sulfate reported for some monitoring points with most concentrations less than 10 mg/L
- Nitrate concentrations ranging from <0.05 to 0.22 mg/L

These data are consistent with the water quality data reported for the EBS and summarized in Section 2.3 of this report. The piper diagram plot presented in Figure 33 indicates that QAL008D and QAL031D have quite similar major ion chemistries and that data from both monitoring points can be considered representative of baseline (background) conditions at the proposed discharge area.

5.0 Conclusions

The following conclusions are supported by the results of this HS:

- The proposed discharge does not affect any water supply wells within 0.5 mi of the proposed discharge area or designated wellhead protection areas.

- Very rapid infiltration rates are achievable across the proposed discharge area.

- The aquifer hydraulic characteristics are capable of assimilating the estimated discharge.

- A groundwater mound will develop beneath the infiltration and will remain greater than 50 ft below ground surface at the proposed discharge area, as simulated with conservative assumptions of discharge rate.

- Baseline water quality and gradient conditions indicate that the groundwater system will be monitorable due to naturally low concentrations of dissolved constituents and consistent flow direction and stable water levels near the proposed discharge area.

6.0 Recommendations

Monitoring of the discharge should be developed along with an engineered treatment system design. Monitoring should include Quaternary aquifer water quality and water level monitoring, as well as surface water quality and flow in the Salmon Trout East Branch system. Monitoring locations should be established as part of the discharge system operation plan.

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