Appendix 2

Mine Waste Characterization Documentation and Results

PERMIT TO MINE APPLICATION

POLY MET MINING, INC.

APPENDIX 2

MINE WASTE CHARACTERIZATION

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MINE WASTE CHARACTERIZATION

As described in Section 10 of the PTM, over the last ten years, PolyMet has conducted a mine waste characterization program to support the Project in consultation with MDNR. This Appendix 2 presents additional information relating to the mine waste characterization program, and the results of that program, to further demonstrate compliance with the nonferrous mining regulations and support PolyMet's PTM Application (Application) for the Project. This Appendix provides additional detail regarding the process of developing the mine waste characterization program, the contents of the mine waste characterization program, and summary of key outcomes to-date. References are provided to additional documentation of the mine waste characterization program and results. These documents have already been provided to DNR as part of the collaborative development and implementation of the mine waste characterization program among PolyMet, its consultants, and DNR.

2.1. Development of the Mine Waste Characterization Program

Minnesota law requires that an applicant for a PTM meet with the DNR "to outline chemical and mineralogical analyses and laboratory tests to be conducted for mine waste characterization," which the DNR will then use in "evaluation of the applicant's mining and reclamation plan" (Minnesota Rules, part 6132.1000, subpart 1). In addition, the mine waste characterization must "be conducted by persons with demonstrated proficiency in such analysis and approved by the commissioner" (Minnesota Rules, part 6132.1000, subpart 2).

In accordance with these regulatory requirements, in 2004, PolyMet initiated a series of characterization conferences and other exchanges with the Lands and Minerals Division of DNR to develop a mine waste characterization program for the Project. These interactions included PolyMet's primary mine waste characterization consultant, SRK Consulting (SRK), with demonstrated proficiency in conducting mine waste characterization,[1] as documented in Appendix 1.10 of the Application.

PolyMet's technical expert, SRK, worked directly with DNR from 2004 to 2010 to develop the geochemical characterization plans that served as the primary documents outlining the parameters of the waste characterization program for the Project for the following mine waste:

- Mine Site waste rock and ore geochemical characterization work
- Flotation Tailings and Hydrometallurgical Residue geochemical characterization work
- Mine Site overburden geochemical characterization work
- other targeted studies and analyses to support the waste characterization program (collectively, characterization work).

[1] PolyMet first notified DNR of its intent to utilize SRK to work with DNR to develop the mine waste characterization program at a meeting in late 2004.

The individuals who participated in the development of the characterization work are qualified specialists, proficient in their fields. The primary individuals that participated in the conferences and other exchanges and contributed to the characterization work, including representatives from DNR, are identified in the characterization work reports. Additionally, other entities that supported the implementation of the waste characterization program, such as laboratories used to perform the analyses, are identified in the characterization work reports and were subject to the review and approval of DNR. *See* Sections 1.5 and 1.6 in Reference (1); Section 1.5 and 1.6 in Reference (2); Section 5.1.5 and 5.2 in Reference (3); Reference (4), and Reference (5). Following development of the characterization work, PolyMet and its consultant, SRK, continued to work directly with DNR throughout implementation of the characterization work.

Development of the waste characterization program was an iterative process with DNR in which DNR reviewed the plans for characterization work and evaluated results of preliminary sampling and testing, requested that PolyMet provide supplemental information in certain instances, provided PolyMet with comments and requested revisions to the characterization work, and provided PolyMet with further direction on sampling and testwork. DNR continued to provide PolyMet input throughout implementation of the waste characterization program. An overview of the timeline and steps involved in this iterative process for characterization of each of the mine wastes is provided below, with references to supporting documentation, as applicable.

2.1.1. Overview of Consultation with DNR on the Characterization Work

<u>Mine Site Waste Rock and Ore Characterization</u>

- **Preliminary Meetings (2004).** A series of meetings with DNR were held in the second half of 2004 during which PolyMet[2] and DNR had preliminary discussions related to mine waste management and mine waste characterization. Based on the information exchanged during the preliminary meetings, SRK developed a draft work plan for geochemical characterization, which was submitted to DNR and other state and federal agency officials. PolyMet also met with these officials to present and discuss the draft work plan. At this meeting, PolyMet notified DNR that it intended to use SRK to develop and finalize the characterization work.

- **Plan Development (2005 – 2006).** PolyMet and DNR worked together to develop the waste rock characterization work plan. Through a series of meetings, teleconferences, and correspondence, DNR provided comments to PolyMet's proposed waste rock characterization work, and PolyMet responded to DNR comments and provided additional information when requested. DNR and PolyMet developed a sample selection matrix and testwork design (Reference (6)). PolyMet submitted the final waste rock characterization work plan in May of 2006 (Reference (1)).

- **Implementation, Adaptation, and Reporting (2005 – 2015).** Implementation of initial testing began as early as mid-2005, as the final details of the waste rock characterization work were being finalized. At this time, PolyMet and DNR also

[2] References to PolyMet in these consultation timelines refer to PolyMet employees or their consultants or representatives.

developed outlines to serve as templates for the progress reports to be submitted by PolyMet regarding the work completed for waste rock and other geochemical characterization work. PolyMet submitted the first of multiple progress reports regarding the characterization work to DNR in mid-2006, and PolyMet continued to submit additional progress reports and/or updates to progress reports through 2014. During this time, PolyMet and DNR continued to evaluate and modify the kinetic testing portion of the waste characterization program as testing continued through the development of the FEIS (*See* References (7), (8), (9), (10), (11), (12)). While recommendations for a reduction in the kinetic test program were provided in Reference (12), no action has been taken on these recommendations as of the date of this Application. The kinetic test program continues, as described in Reference (12).

Flotation Tailings and Hydrometallurgical Residue Geochemical Characterization

- **Plan Development (2005 – 2006).** Building on the work completed in the agency consultation on the waste rock characterization work, PolyMet and DNR began to work on the Flotation Tailings and Hydromet characterization work in the second half of 2005. As with the waste rock characterization work, PolyMet and DNR held a series of meetings, and exchanged comments and responses on drafts of the Flotation Tailings and Hydromet characterization work plan. PolyMet also consulted DNR on the design of preliminary testing used to inform plan development, and on the sample analysis parameters for the plan. The final version of the Flotation Tailings and Hydromet characterization work plan was submitted concurrently with the final waste rock characterization work plan (Reference (2)).

- **Implementation and Reporting (2005 – 2015).** PolyMet began pilot plant testing to support the Flotation Tailings and Hydromet characterization work in mid-2005, and submitted results of that testing beginning in early 2006 (Reference (13)). As the Flotation Tailings and Hydromet characterization work was being finalized, PolyMet and DNR also developed outlines to serve as templates for the progress reports to be submitted by PolyMet regarding the Flotation Tailings and Hydromet characterization work and other characterization work. PolyMet submitted the first of multiple progress reports regarding the work completed under the characterization work to DNR in mid-2006, and PolyMet continued to submit additional progress reports and/or updates to progress reports through 2015. The kinetic test program continues, as described in Reference (12), and updates will be provided to DNR in PolyMet's PTM annual reports, if a PTM is issued.

Mine Site Overburden Geochemical Characterization

- **Plan Development & Supplementation (2007 – 2008, 2010).** In the second half of 2007, DNR requested that PolyMet also prepare a work plan for characterizing overburden material. PolyMet consulted with DNR on development of the overburden characterization work plan and supporting analytical testing through meetings and exchanges of comments and responses. PolyMet and DNR agreed initially to develop a work plan sufficient to support environmental review. PolyMet submitted the initial overburden characterization sampling and analytical plans to DNR in early 2008 (References (3) and (14)). Following on this initial effort, PolyMet and DNR subsequently coordinated on supplementing the overburden characterization work with a sump soil sampling program to collect additional data on the geochemical characteristics of unsaturated overburden for the purposes of supporting Project permitting. As a result of this collaboration, PolyMet provided an updated Overburden Sampling Plan (Reference (4)), and an updated Overburden Sampling Analysis Plan to DNR in early 2010 (Reference (5)).

- **Implementation, Adaptation, and Reporting (2008 – 2015).** PolyMet began implementation of the initial testing and analysis under the overburden characterization work in 2008, and submitted initial drilling program results in October 2008 (Reference (15)) and initial pebble chemical analysis results in mid-2009 (Reference (16)). Following the 2010 supplementation of the overburden characterization work, PolyMet submitted additional characterization results of the sump soil sampling in late 2010 (Reference (17)). Additional sampling of the unsaturated overburden will be conducted to confirm the prior characterization work, either prior to or concurrent with future geotechnical studies at the Mine Site, as described in Section 4.2.4 of the Rock and Overburden Management Plan (Reference (18)), and the results will be provided to DNR in PolyMet's PTM annual reports, if a PTM is issued.

2.2. Contents of the Mine Waste Characterization Program

Consistent with the regulatory requirements, PolyMet's mine waste characterization program is "based on chemical, physical, and mineralogical analyses and laboratory tests of material generated by exploration, preproduction sampling, and process testing" (Minnesota Rules, part 6132.1000, subpart 2). The mine waste characterization program includes: (1) chemical analysis of mine waste; (2) mineralogical and petrological analysis of mine waste; and (3) laboratory tests describing acid generation and dissolved solids released from mine waste.

The design and analyses identified in the characterization work to fulfill the regulatory requirements identified above are summarized below. Throughout implementation, PolyMet and DNR continued to evaluate the mine waste characterization program data needs, and adjusted or supplemented the analyses as needed to ensure the data collected were sufficient to inform the FEIS, Project design, and management plans.

- <u>Mine Site Waste Rock and Ore Characterization Work</u>. 82 samples of waste rock were identified for testing using a sampling matrix developed in collaboration with DNR. In addition, three ore composite samples were selected as part of the same characterization program. These samples were then analyzed using chemical, physical, mineralogical, and laboratory tests, including:
  - optical mineralogical and petrological characterization: reporting includes mineral identification, mineral abundance, grain sizes, and petrologic determination

- sub-optical mineral characterization: trace element content of major minerals via electron microprobe analysis

- acid-base accounting: total sulfur content, carbon content, and paste pH

- bulk chemical composition of whole rock samples: ICP analyses of 27 elements following four-acid digestion, ICP analyses of 34 elements following aqua regia digestion; whole rock oxides

- bulk chemical composition of size-fractionated samples: total sulfur and ICP analyses of 27 elements following four acid digestion

- specific gravity (G_s) and particle size distribution

- laboratory weathering tests (kinetic testing): whole rock samples were subjected to humidity cell testing (ASTM Procedure D 5744); size-fractionated portions of splits from five of the whole rock samples were also tested using a laboratory test method developed by the DNR (DNR Reactor experiments)

See Section 4 of Reference (1), Waste Rock Characterization Work Plan for additional information.

In addition to the detailed characterization of these 85 samples, the waste rock and ore characterization includes an evaluation of bulk chemical analyses from approximately 18,800 drill core samples. These chemical analyses are used to identify release rates for select chemical constituents, the procedure for which was presented by PolyMet for DNR review during meetings in early 2011. The total sulfur analyses from the drill core samples are used to estimate sulfur content of waste rock that will be produced from the Project, which is the primary driver for rock management. These usages of the drill core chemical data are described in Sections 4.3.1, 4.3.2, and 8.1.2.3 in Reference (19).

- <u>Flotation Tailings and Hydrometallurgical Residue Characterization Work</u>: Ore composites were selected for pilot-plant processing to produce flotation tailings for characterization. Thirty-three flotation tailings samples were analyzed using the following methods:

  - density determinations and size fraction analysis;

  - mineralogical characterization via optical analyses of tailings thin sections;

  - acid-base accounting: total sulfur and sulfur speciation, paste pH, neutralization potential and carbon content;

  - bulk chemical composition of whole rock samples: ICP analyses of 50 elements following aqua regia digestion; whole rock oxides; and

- kinetic testing: whole rock samples were subjected to humidity cell testing (ASTM Procedure D 5744); in addition, splits from samples were also tested using DNR Reactor experiments).

Additionally, Hydrometallurgical Residue samples were prepared for analysis. The hydrometallurgical process will produce five distinct types of residues. The residues were tested separately and as a combined sample. Two samples of the leach residue (with and without $CuSO_4$) and the combined residues (with and without gypsum) were tested, making for 8 samples total. These samples were analyzed by the following methods:

- mineralogical characterization via quantitative X-ray diffraction to identify major and minor crystalline phases and estimate relative abundance of each
- acid-base accounting: total sulfur and sulfur speciation, paste pH, neutralization potential and carbon content
- bulk chemical composition of whole rock samples: ICP analyses of 50 elements following aqua regia digestion and whole rock oxides
- leachate characterization: chemistry of leachate measured after samples are subjected to TCLP, SPLP, and a sequential shake flask leach procedure
- kinetic testing: samples were subjected to humidity cell testing (ASTM Procedure D 5744); in addition, splits from samples were also tested using DNR Reactor experiments)

See Sections 3.2 through 3.3 of (Reference (2)), Flotation Tailings and Hydromet Characterization Work Plan.

- Mine Site Overburden Characterization Work: The characterization work for Mine Site overburden initially identified 16 drilling locations for collection of samples to be analyzed as follows:
    - Physical analysis including: Atterberg limits, grain size, consolidation, permeability, and strength
    - acid-base accounting: total sulfur content, sulfur speciation, carbon content, neutralization potential, and paste pH
    - bulk chemical composition of size-fractionated samples: ICP analyses of 51 elements following aqua regia digestion and ICP analyses of 33 elements following 4-acid digestion
    - Meteoric Water Mobility Procedure: a standard laboratory test to measure metal leaching

- petrologic characterization via a pebble counting procedure to identify lithologies present

After additional access to drilling sites was permitted in 2010, PolyMet collected additional samples of unsaturated overburden for evaluation using the following analyses:

- Rinse test for pH, oxidation/reduction potential, and specific conductivity
- Particle size distribution
- Meteoric Water Mobility Procedure: a standard laboratory test to measure metal leaching
- bulk chemical composition of samples: ICP analyses of 51 elements following aqua regia digestion and ICP analyses of 44 elements following digestion in 1N nitric acid
- Moisture content
- acid-base accounting: total sulfur content, sulfur speciation, carbon content, neutralization potential, and paste pH

See References (3), (4), (5) and (14).

In addition, PolyMet's mine waste characterization program provides information regarding the reagents associated with tailings and leach residue, including their chemical composition, mass of chemical used, and, where applicable, the degradation and transport characteristics as well as the effects on mineral dissolution of those reagents, as required by Minnesota Rules, part 6132.100, subpart 2B. The list of reagents associated with the hydrometallurgical and beneficiation processes are provided in Table 8-4 and Table 8-5 of the Application, which includes the chemical composition and mass to be used for each. Only one of these reagents – copper sulfate – is expected to contribute to metal and sulfate concentrations. Process testwork showed that sulfur concentrations in the tailings can be expected to vary in response to changes in process conditions, and that the use of copper sulfate can be expected to lower sulfur content in tailings. Because PolyMet determined to proceed with the use of copper sulfate in the flotation process, DNR and PolyMet agreed that characterization testwork would primarily be performed on the residues generated by leaching of the concentrate that was produced in the pilot plant with the use of copper sulfate, but both leach residues generated with and without the use of copper sulfate were tested for evaluation of the effects of copper sulfate. The results of this testing are provided in Section 5.1 of Reference (19), and Sections 5.1.2. and 5.2.1 of Reference (20). Summary information on reagent usage is provided in Attachment 2-1.

2.3. Mine Waste Characterization Program Implementation and Results

As noted in Section 2.1 above, PolyMet began implementing the analyses and studies that comprise the mine waste characterization program as early as 2005. As noted in the timeline above, the process of developing the characterization work with DNR also involved developing outlines for reporting the results of the characterization work. These outlines were finalized in

2006, and were followed in preparing progress reports on the results of the work completed under the characterization work. PolyMet submitted a series of these progress reports and data submittals on the characterization work results beginning in 2006, as work was completed, to facilitate an iterative process between PolyMet and DNR in which ongoing data needs regarding waste characterization were evaluated and adjusted (References (21), (22), and (23)). This iterative process continued throughout the mine plan development and environmental review processes, and culminated in the submittal of a consolidated data report, the Waste Characterization Data Package, first submitted to DNR on February 14, 2011. PolyMet continued to update the waste characterization data, and provided DNR with twelve revisions of the Waste Characterization Data Package, the most recent of which was submitted to DNR on February 22, 2015 (Reference (19)). PolyMet used the data provided in these reports and submittals to develop additional studies, plans, and models for the Project, including various management plans.

The results of the mine waste characterization program have been submitted by PolyMet to the DNR, MPCA, and USEPA as part of the EIS process. PolyMet is resubmitting these results as part of the Mining and Reclamation Plan in its Application (Section 10 and this Appendix). As a courtesy, a copy of this Appendix will be submitted to the MPCA. A summary of key outcomes of the characterization work is provided below.

2.3.1. Summary of Mine Site Waste Rock and Ore Characterization Results

The NorthMet Deposit is hosted by troctolitic and gabbroic rocks of the Partridge River Intrusion (PRI) of the Duluth Complex, a large igneous intrusive body. In the area of the Mine Site, the PRI is subdivided into seven igneous stratigraphic units. The lowest unit, Unit 1, directly overlies the Virginia Formation, a formation of slaty rock which was metamorphosed near the Deposit during emplacement of the Duluth Complex. Geologic cross-sections and longitudinal sections through the mine pits are provided in the Application on Figure 7-6 and Figure 7-7. Bedrock geology of the Mine Site, including the location of the NorthMet Deposit ore body and the cross-sections through it, is depicted in Figure 7-5 of the Application.

For the purpose of waste characterization, all igneous stratigraphic units of the PRI represented in the vicinity of the Mine Site, along with the Virginia Formation, are considered potential waste rock units. A comparison of anticipated future waste rock types and quantities to the samples used for waste rock characterization are provided in Table 2-1.

Tables 2-2 to 2-6 summarize the mineralogy and bulk chemistry of waste rock and ore. Table 2-7 provides a summary of the particle size distribution for waste rock and ore humidity cell test (HCT) samples.

With regards to general outcomes of mine waste rock and ore geochemical characterization, the HCT results supports a waste rock management strategy whereby waste rock is segregated and managed according to total sulfur content. Key outcomes of the kinetic test program, as they relate to waste rock segregation (Section 3.2 of Reference (11)) include:

Category 1 waste rock (sulfur content less than or equal to 0.12%):

- All Category 1 humidity cells have yielded pH above 6 throughout the approximately 6.5 years of data evaluated in Reference (11). Initial pH for drainage of most of the HCTs were above 8 but declined rapidly and have typically fluctuated between 6.5 and 7.5.
- Sulfate leaching rates have been low throughout the program with most continuing tests showing rates below 1 mg/kg/week.
- Dissolved metals concentration in the leachate is generally low, but may show relationship between concentration and fluctuation in drainage pH.

Category 2/3 waste rock (sulfur content greater than 0.12% and less than or equal to 0.60%):

- Five samples showed pH depression below 6, while all other samples have shown stable pH above 6, with similar trends to the Category 1 samples.
- Sulfate release for Category 2/3 samples varied between 1 and 10 mg/kg/week with the highest rates being observed for samples containing higher sulfur contents.
- Dissolved metals concentration is generally higher than for Category 1 waste rock samples. Several samples showed upwards trends in nickel and cobalt that were related to pH below 7.

Category 4 waste rock (sulfur content of greater than 0.60% and all Virginia Formation):

- All tests have shown pH depression to some degree with pH below 4.
- Some increases in sulfate release have been observed as pH decreased. Peak sulfate release rates have typically been up to five times the initial lower rate. These peak sulfate release rates have not been sharp but erratic. Decline in sulfate release has been observed following the peak.

Ore Composites:

Leachate pH trends for the three ore composite samples are nearly identical and show pH has been stable near 5. Likewise, sulfate release has been similar for all three tests and has not shown consistent upward or downward trends. As pH decreased, nickel release accelerated, reaching peak rates after about three years then declining. Copper release also increased as the tests progressed but the upward trend was delayed compared to nickel. Copper release reached peak values after more than 4 years of testing and has subsequently declined.

2.3.2. Summary of Tailings and Hydrometallurgical Residue Characterization Work

Beneficiation of the ore to recover a salable product will also produce tailings and hydrometallurgical residue as waste materials. The tailings will be stored in the existing LTVSMC tailings basin, which is composed of and contains LTVSMC tailings. Therefore, the waste materials associated with processing of ore are the Flotation Tailings, the LTVSMC tailings, and the hydrometallurgical residue. Tables 2-8 through 2-13 summarize the mineralogy, bulk chemistry, and particle size distribution of tailings.

Flotation Tailings:

Mineralogy of flotation tailings is similar to the Category 1 waste rock. Key outcomes from the kinetic test program (Section 4.2.1 of Reference (11)) include:

- Tests started in 2005 and 2006 all have stable or increasing pH (up to 11-12 years). Tests started in 2008 have reached stable pH with no indication of trends below pH 7.
- Sulfate release has stabilized for all tests.
- Tests started in 2009 have shown downwards trends in pH with lowest pHs typically above 7.

LTVSMC Tailings:

Leachate pH have continued to vary in a narrow band between 7.4 and 8 with variable but non-trending alkalinity and sulfate (Section 4.2.2 of Reference (11)).

Hydrometallurgical Residue:

Conclusions of the characterization work on the hydrometallurgical residue, from Section 6.5 of Reference (19) include:

- Four of the residues (leach, gypsum, raffinate neutralization, and iron/aluminum) are expected to be acidic. The magnesium residue will be basic.
- The dominant mineral in the leach residue is jarosite, which generates acidic water when dissolved. The other residues (including magnesium) are mainly gypsum. The gypsum and raffinate neutralization residues are nearly all calcium sulfate. The iron/aluminum residue also contains goethite, and the magnesium residue contains brucite. The iron/aluminum residue also contains iron, probably in amorphous form that contains co-precipitated metals.
- None of the residues were classified as hazardous wastes using the EPA 1311 protocol.
- Neutral to basic leachates produced by combined residues are believed to represent chemical saturation conditions.
- The combined residue produced non-acidic leachate during the test but is expected to become acidic in the future unless additional basic material is added.

2.3.3. Summary of Mine Site Overburden Characterization Work

Results from the initial drilling program and the test pit investigation are consistent in the conclusion that there is a vertical, rather than a strong lateral, variation in metal and sulfur concentrations in the mineral overburden. This conclusion supports the categorization of overburden at the Mine Site into the following three types:

- Saturated mineral overburden – this includes all mineral overburden (non-peat) that has remained below the water table, has not been oxidized, and can release metals when exposed to air and oxidized.
- Unsaturated mineral overburden – this includes all mineral overburden (non-peat) located above the water table including all topsoil. At the Mine Site, this material has been oxidized and has low potential for metal release (also referred to as unsaturated overburden).
- Peat – this includes organic matter, excluding coal, formed by the partial decomposition of plant material under saturated conditions (as defined in Minnesota Rules, part 6131.0010, subpart 11)

Saturated mineral overburden tends to contain higher sulfur and metals than the unsaturated mineral overburden, with greater potential for metal leaching (Sections 2.3, 2.4, and 3.3 of Reference (17)). Summary tables of overburden chemistry, leach results, and particle size distribution are provided in Tables 2-14 through 2-17.

2.4. Application of Mine Waste Characterization Results to Water Quality Modeling

Results from the waste characterization program were used to develop the geochemical parameters used as inputs to the GoldSim water quality models for the Project ("water models"). Section 2.4.1 lists these geochemical parameters, describes their derivation from the mine waste characterization program results, provides summary tables showing values of key parameters, and describes integration of these parameters into the water modeling framework.

2.4.1. Geochemical parameters used for water quality modeling

A summary of the water model input variables relating to geochemical behavior of mine waste is provided in Table 2-18. As indicated in Table 2-18, the input variables are primarily used to define three fundamental geochemical parameters that were used by the water models to predict constituent (e.g., sulfate, calcium, magnesium, nickel) concentrations in water contacting mine waste (for example, in waste rock stockpiles, the FTB, and pit walls) for the Project. These three key parameters are solute release rates, scale factors, and concentration caps; each described below.

Solute Release Rates

Solute release rates define solute mass released from a rock mass per unit time. These are based on standardized laboratory weathering tests (ASTM D5744-07) and solids characterization of rock from drill core collected from the Mine Site and processed tailings.

Scale Factors

Scale factors are used in the water models to scale release rates measured in the laboratory to operational scale features. Scale factors are based on a comparison between an operational-scale analogue site (Dunka Mine) and laboratory tests on the same material; or on directly incorporating sub-factors that account for differences between laboratory and field conditions. The specific method for defining scale factors in the water models depended on data availability for the different mine waste types and operational-scale features.

Concentration Caps

Concentration caps refer to empirical and/or theoretical maximum attainable solute concentrations under anticipated field conditions. Because laboratory weathering tests only provide a solute release rate under relatively high water to rock ratios, predicted solute concentrations scaled up from laboratory tests can exceed empirical and theoretical maximums. Concentration caps are an estimate of maximum attainable solute concentrations for a specific environment. Concentration caps were based on theoretical mineral solubility limits, observed maximum concentrations from Duluth Complex waste rock and analogue sites, and from scaling maximum observed values from field and laboratory data.

2.4.2. Derivation of model parameters from waste characterization program results

Additional information on derivation of key geochemical parameters is described below. The descriptions herein are not exhaustive, but provide summary information. References for more detailed descriptions are provided.

Solute Release Rates

Parameters describing solute release rates from waste rock, ore, and tailings were derived from release rates measured from HCTs and ratios based on the chemical compositions of the mineral hosts for select constituents. This method is described in more detail in Sections 2.1 through 2.5 of Appendix A to Reference (19).

Summaries of the release rates used for water quality modeling are depicted in Tables 2-19 through 2-26. For constituents with release rates characterized by ratios, these ratios are either defined by bulk chemical composition of samples in the drill core database, as defined by ICP analysis after aqua regia digestion; or from point analyses of individual minerals by electron microprobe analysis. Specific methods used for constituents from each type of mine waste are indicated in Tables 2-19 through 2-26. HCTs used in the development of release rates are shown in Tables 2-27 and 2-28. Table 2-29 provides the drill core aqua regia results.

Release rates that were developed directly from HCT results were derived from time series data for different geochemical behaviors coined ‘conditions’. These rates were corroborated by DNR laboratory research data. Release rates for sulfate from Category 1 waste rock, Category 2/3 waste rock, and ore were found to strongly correlate with total sulfur content of the rock. Sulfate release rate from these rock types was defined by a linear regression of the sulfate release from individual HCTs with respect to the total sulfur content of the rock. More details on the development of laboratory release rates from mine waste characterization results are in Section 2.4.3, below, and Section 8.1 of Reference (19).

Scale Factor

Scale factors, applied in the model to account for differences between laboratory-derived and operational-scale release rates for waste rock, are derived by one of two methods, depending on waste rock type. These two methods are described separately below.

- Category 1 Waste Rock Stockpile

  The scale factor that applies to the Category 1 Waste Rock Stockpile was derived from a comparison of sulfate release rates from waste rock stockpiles at an analogue mine site (Dunka Mine) and similar rock in laboratory tests. For defining this parameter, sulfate release rates from laboratory tests conducted by the DNR on crushed rock from Dunka Mine were compared to sulfate release rates estimated from sulfate concentration in drainage from stockpiles at the Dunka Mine. Sulfate release rates for Dunka Mine stockpiles were determined from the concentration and flow data for each seep from the stockpiles on-site. DNR calculated a range of scale-up factor values as the ratio between annual field sulfate release and the average laboratory sulfate release, using all possible combinations of field and laboratory release rates. Further details are provided in Section 8.2.8 of Reference (19).

- Category 2/3 Waste Rock Stockpile, Category 4 Waste Rock Stockpile, Ore Surge Pile, and pit wall rock

  The scale factors for these features were calculated as composites from multiple individual sub-factors that lead to differences between constituent release rates at the laboratory and field scale. These factors are described separately below.

  - Water contact factor

    The water contact factor accounts for the development of preferential flow paths within operational scale features. Theoretically, the contact factor can range from 0 to 1; however, the probability of water contacting 0% or 100% of the waste rock is zero. Therefore, a triangular distribution was used for the contact factor, ranging from 0.1 to 0.9 with a mean of 0.5. Further details are provided in Section 8.2.2 of Reference (19).

  - Particle size factor

    The particle size factor accounts for differences in particle size distribution between laboratory and operational-scale rock. The particle size factor was derived from a comparison between the particle size distribution of Project HCT samples and that of blasted rock that formed the AMAX field leach test piles. Further details of this method are provided in Section 8.2.3 of Reference (19).

  - Temperature factor

    The temperature factor adjusts release rate on the basis of decreased reactivity under the cooler temperatures of the Project site relative to laboratory conditions.

The temperature factor was derived from a calculation based on site temperatures, laboratory temperatures, the activation energy for the waste rock and the Arrhenius equation. Details of the method for derivation of the temperature factor are provided in Section 8.2.4 of Reference (19).

- Acidity factor

The acidity factor accounts for differences in release rates observed under non-acidic and acidic conditions. HCT results indicated that pH and metal concentrations in the leachate tended to evolve over the duration of testing. Based on this observation, five test conditions were defined, as:

<u>Condition 0</u>: Brief (a few weeks) initial flushing of weathering products accumulated in storage. No rates were calculated for this period because a time period cannot be assigned to reflect core and sample storage prior to testing.

<u>Condition 1</u>: Sulfate release relatively stable and leachate pH above about 7.

<u>Condition 2</u>: Sulfate release relatively stable, leachate pH below about 7, nickel release unstable and typically increasing.

<u>Condition 3</u>: Sulfate release increasing and variable, leachate pH decreasing further.

<u>Condition 4</u>: Sulfate release decreasing following a peak usually under acidic conditions.

The observed increase in release rates with decreasing pH, and subsequent decrease in sulfate release, are accounted for in the water models through application of the model parameters “Acid Onset”, “Acid Factor”, and “Decay” to release rates for Category 2/3 rock, Duluth Complex Category 4 rock, and ore. The acid factor and the estimated time to acidity was derived from a comparison of non-acidic and acidic release rates in a combined dataset of 17 DNR reactors and 8 HCTs. Details on derivation methods are provided in Section 8.2.5 of Reference (19).

<u>Concentration caps</u>

Concentration caps are used in the water quality modeling to limit concentrations of dissolved metals in effluent according to theoretical and empirical limitations. The derivation of the concentration cap parameters differs according to mine waste type and condition. These are summarized below.

- Category 1 Waste Rock

The concentration caps for Category 1 waste rock are shown in Table 2-30. They are derived from data from the AMAX field leach test piles wherever possible. The concentration cap at a given pH value is determined by a uniform distribution between the 95th percentile value and the maximum observed concentration at that pH. This method was used to simulate concentration caps for the following constituents: alkalinity, cobalt, copper, iron, potassium, manganese, sodium, nickel, and zinc. The concentration cap for aluminum was calculated as a function of pH according to solubility of gibbsite. The concentration cap for cadmium was derived from the cadmium to zinc release ratio and the zinc concentration cap. The method for selenium was similar, with the selenium concentration cap equal to the sulfate concentration times the selenium to sulfate release ratio. Concentration caps for the constituents arsenic, lead, and vanadium were derived from data from the Whistle Mine under nonacidic conditions. These constituents were not detected in the Whistle Mine data set; the detection limit is used as the concentration cap. The concentration caps for silver, beryllium, and thallium were derived from data from samples collected from Dunka Mine stockpiles. For these constituents, a single sampling event was used to derive the concentration cap, with the concentration cap being equal to the maximum observed value (or detection limit, where there were no detected values) times a factor of 10, an estimate of the maximum concentration based on differences between Zn and Ni in the May 2006 sample and maximum observed concentration of those constituents in Dunka Mine seepage. For the constituent antimony, the concentration cap was defined as a uniform distribution between the highest concentration observed in uncontaminated tailings HCT and waste rock reactor experiments (lower bound) under the assumption that the highest antimony concentration was not a diluted concentration and an upper limit derived under the assumption that antimony concentrations scale similarly to sulfate concentrations between laboratory and field conditions. Further details are provided in Section 8.3.1 of Reference (19).

- Duluth Complex Category 2/3/4 Waste Rock and Ore (nonacidic)

  The concentration caps for Duluth Complex Category 2, 3, and 4 waste rock and ore under non-acidic conditions are shown in Table 2-31. The method used to derive these concentration caps was similar to that of Category 1 Waste Rock, with the exception of a modification to how the AMAX field leach test data was used. The assumed pH range for this condition for the pH-dependent constituents was 6 to 7.5 (uniform distribution), and the data from all AMAX piles was used (0.064% to 1.41% sulfur). Further details are provided in Section 8.3.2 of Reference (19).

- Duluth Complex Category 2/3/4 Waste Rock and Ore (acidic)

  The concentration caps for Duluth Complex Category 2, 3, and 4 waste rock and ore under acidic conditions are shown in Table 2-32. Probability distributions were developed for acidic conditions (all data with pH < 4.5) from constituent concentration in seepage from Whistle Mine. Further details are provided in Section 8.3.3 of Reference (19).

- Virginia Formation Category 4 Waste Rock

The concentration caps for Virginia Formation Category 4 waste rock are shown in Table 2-33. The Vangorda Mine data were used to develop concentration caps for the Virginia Formation waste rock for all constituents except Cd, Pb and Zn, which are mineralized in the Vangorda Mine deposit and are not analogous to the NorthMet Virginia Formation waste rock. Concentration caps for these constituents (Cd, Pb, Zn) were developed using the Whistle Mine data. The Vangorda Mine data were used in the same manner as the Whistle Mine data, with the assumption that each observation was an equally likely representation of concentration-capped conditions throughout the Virginia Formation waste rock. Details are provided in Section 8.3.4 of Reference (19).

2.4.3. Data processing techniques for parameter development

Waste characterization data were processed with varying methods depending on the data source and ultimate use of the information in the water models. The primary data processing methods are described below; additional detail is provided in Reference (19) and its attachments, as indicated below.

Waste rock humidity cell test (HCT) data

Development of distributions from HCT data for waste rock in general is described in Sections 8.1.2.1 through 8.1.2.2 of Reference (19). The data from each HCT were evaluated, and time periods for release "conditions" were assigned as described in Section 2.5 of Attachment A in Reference (19).

The release rates for a number of parameters were calculated based on their relationship to sulfate release rates. Therefore, the development of the sulfate release rate parameter is described here. Average sulfate release rates were calculated for each HCT (units of mg sulfate/kg rock/week), according to each of the conditions observed for all HCTs. Sulfate release rates for Conditions 1 and 2 were plotted as a function of total sulfur content of the HCT samples. The relationship between sulfate release rate and total sulfur content was evaluated for populations of HCTs that were binned according to individual waste rock categories and combinations of waste rock category. Through this analysis, it was determined that for Category 1 waste rock, Category 2/3 waste rock, and ore, sulfate release rates can be combined into a single dataset, and a linear regression was conducted to describe average sulfate release rate for these waste rock types as a function of their initial total sulfur content. Sulfate release rates for all other mine waste types was directly developed as distributions observed from HCTs. The distributions are noted in Tables 2-19 through 2-26.

For parameters that express release rates as a distribution, percentiles for distribution fitting were calculated as specified in Tables 2-19 through 2-26 (e.g., ratio of average Cd to average Zn release during Condition 2 for Category 1 waste rock). Typical percentiles used for distribution fitting were the 5^{th}, 50^{th}, and 95^{th} percentiles as well as the minimum and maximum values. From these percentiles, probability distributions were fit by minimizing the error at all percentiles, or at the upper end (95^{th} percentile) if a satisfactory fit across the entire range was not possible.

Drill core aqua regia data

Development of distributions from aqua regia data is described in Section 8.1.2.3 of Reference (19). The raw drill core data was adjusted by weighting each sample according to the quantity of each geologic unit in each waste rock category and the Block Model. For example, 6.3% of the Category 1 drill core samples are from the combined Units 4 and 5, but material from these units makes up 21.3% of the Category 1 waste rock according to the Block Model. Therefore, the weight of each sample was increased (from $6.3\%/n_{\text{Units 4-5}}$ to $21.3\%/n_{\text{Units 4-5}}$). The weighted mean and weighted standard deviation of each constituent or ratio of constituents (e.g., Cu/S) was calculated for each waste rock category. These parameters define a normal distribution for the average ratio for each constituent and waste rock category.

Tailings HCT data

Development of distributions from HCT data for tailings in general is described in Sections 10.1.1.1 and 10.1.2.1 of Reference (19). Data processing methods were similar to those for waste rock, except that no “conditions” were defined, and the average HCT release rate (mg/kg/week) was calculated for each constituent over the total durations shown in Table 2-28. The sulfate release from HCT data was handled separately as described in Section 4.3 of Attachment C in Reference (19), using the estimated sulfate release at the initial sulfur content for each HCT rather than the average HCT release rate. Probability distributions were fit to percentiles calculated from all HCTs in a given tailings category, with typical percentiles used for distribution fitting being the 10^{th}, 50^{th}, and 90^{th} percentiles.

Tailings aqua regia data

Development of distributions from tailings aqua regia in general is described in Section 10.1.1.2 of Reference (19). Data processing methods were similar to those for tailings HCT data, but used constituent concentration data rather than release rates.

2.4.4. Model implementation

The probability distributions and other values indicated here were used as inputs to the water models developed for both the Mine Site and the Plant Site. Information on model implementation is provided below, with citations to more detailed descriptions in other documentation.

Waste rock stockpiles: Modeling methods are outlined in Section 5.2.2.1.5 of Reference (25). The probabilistic modeling includes simulation of laboratory constituent release rates, lab/field scaling factors, and concentration caps for stockpile drainage. In general, probabilistic model inputs for constituent generation were randomly sampled once per realization and then held constant for the duration of each realization.

Overburden Storage and Laydown Area: Modeling methods are outlined in Section 5.2.2.5 of Reference (25). For overburden, the drainage concentration is simulated directly using the probability distributions (ranges) shown in Section 7 of Reference (19).

Mine pit walls: Modeling methods are outlined in Section 5.2.2.6.5 of Reference (25). The probabilistic modeling for the mine pit walls was similar to that for the stockpiles, with the added considerations of pit wall reactive thickness and changes in pit wall exposure to the atmosphere over time as the pits are flooded.

Tailings Basin: Modeling methods are outlined in Section 5.2.1.2.4 (LTVSMC tailings) and Section 5.2.2.2.7 (Flotation Tailings) of Reference (26). The probabilistic modeling included simulation of laboratory constituent release rates, lab/field scaling factors, oxygen transport through the unsaturated tailings, and concentration caps.

Hydrometallurgical Residue Facility: Detailed modeling of constituent loading is not included in the Plant Site water model due to the negligible leakage from the HRF (Section 5.2.2.5.4 of Reference (26)). Concentrations within the HRF are estimated from the concentrations shown in Section 6 of Reference (19).

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Table 2-1 Stockpile Rock from Block Model Compared to Waste Characterization Tests[1]

		Block Model Proposed Total Waste Rock					*Waste Characterization Tests Drill Cores Within Preliminary Pit Shell*				
Category	***Unit***	***Tons****	***% of Rock***	***Min. %S***	***Ave. %S***	***Max. %S***	***Samples***	***% of Samples***	***Min. %S***	***Ave. %S***	***Max. %S***
Category 1	1	1,153,645	0.37%	0.06	0.1	0.12	10	11.24%	0.02	0.07	0.09
Category 1	2[+]	110,439,546	35.84%	0.01	0.07	0.12	15	16.85%	0.02	0.06	0.12
Category 1	3[+]						8	8.99%	0.02	0.04	0.06
Category 1	4[+]	46,077,080	14.95%	0.01	0.06	0.12	5	5.62%	0.03	0.05	0.08
Category 1	5[+]						2	2.25%	0.02	0.04	0.06
Category 1	6	38,800,965	12.59%	0.01	0.05	0.12	2	2.25%	0.04	0.05	0.05
Category 1	7	20,223,481	6.56%	0.02	0.06	0.12					
Total Category 1		216,694,717	70.33%		0.06		42	47.19%		0.05	
Category 2/3	1	9,355,612	3.04%	0.13	0.32	0.6	13	14.61%	0.16	0.31	0.55
Category 2/3	2[+]	44,659,052	14.49%	0.13	0.19	0.6	3	3.37%	0.15	0.17	0.18
Category 2/3	3[+]						5	5.62%	0.14	0.30	0.59
Category 2/3	4[+]	23,807,049	7.73%	0.13	0.2	0.6	2	2.25%	0.21	0.36	0.51
Category 2/3	5[+]						2	2.25%	0.23	0.28	0.32
Category 2/3	6	2,558,344	0.83%	0.13	0.17	0.51	1	1.12%	0.18	0.18	0.18
Category 2/3	7	2,402,286	0.78%	0.13	0.17	0.46					
Total Category 2/3		82,782,343	26.87%		0.21		26	29.21%		0.05	
Category 4	1	1,111,358	0.36%	0.61	0.85	2.31	15	16.85%	0.68	1.50	4.46
Category 4	3[+]	1,872,851	0.61%	0.61	0.99	3.04					
Category 4	4[+]	94,604	0.03%	0.62	0.81	1.14	2	2.25%	0.77	1.07	1.37
Category 4	5[+]										
Category 4	6	4	≈0.00%	0.65	0.65	0.65					
Category 4	VF	5,557,813	1.80%	0.34	2.43	4.94	4	4.49%	2.00	3.82	5.68
Total Category 4		8,636,630	2.80%		1.90		21	23.60%		1.90	
Total All Categories		308,113,690			0.15		89				

[1]Table reproduced from Large Table 3 in Reference (19).

<u>Notes</u>

* Total of rock to stockpiles and East Pit, [+] Units 2 and 3 are combined and Units 4 and 5 are combined in the Block Model

Table 2-2. Summary Statistics of Bulk Chemical Composition of Waste Rock and Ore[1]

		Category 1 (n=38)			Category 2/3 (n=25)			Category 4 (Duluth Complex) (n=16)			Virginia Formation (n=3)			Ore (n=3)		
Constituent	**Unit**	**Ave.**	**Min.**	**Max.**	**Ave.**	**Min.**	**Max.**	**Ave.**	**Min.**	**Max.**	**Ave.**	**Min.**	**Max.**	**Ave.**	**Min.**	**Max.**
Cu	**%**	0.025	0.005	0.095	0.084	0.010	0.205	0.088	0.020	0.152	0.017	0.015	0.021	0.360	0.323	0.422
Ni	**%**	0.032	0.000	0.095	0.035	0.000	0.072	0.034	0.013	0.071	0.017	0.013	0.020	0.106	0.088	0.139
Co	**ppm**	57	21	117	51	11	94	60	21	119	29	24	36	83	76	94
Ag	**ppm**	0.2	<0.2	0.3	0.4	<0.2	1.0	0.4	<0.2	0.7	0.7	0.3	1.0	1.3	1.1	1.5
Zn	**ppm**	78	33	136	84	33	200	120	47	324	575	252	918	74	71	76
Cd	**ppm**	<0.5	<0.5	<0.5	0.5	<0.5	0.7	1.0	<0.5	4.0	3.6	1.1	6.5	<0.5	<0.5	<0.5
Mo	**ppm**	<1	<1	<1	2	<1	9	8	<1	27	22	12	28	<1	<1	<1
Pb	**ppm**	2	<2	7	4	<2	16	5	<2	12	10	5	17	6	5	6
As	**ppm**	2	<2	3	5	<2	27	23	6	67	43	41	45	6	4	7
Cr	**ppm**	98	29	289	79	22	235	98	32	229	101	76	149	80	69	95
V	**ppm**	41	7	84	58	10	232	101	25	205	121	99	157	44	40	50
Ti	**%**	0.13	0.03	0.25	0.17	0.04	0.46	0.19	0.08	0.32	0.07	0.01	0.19	0.18	0.16	0.20
Al	**%**	3.80	1.66	6.14	3.71	1.62	6.21	3.23	1.62	6.16	2.64	2.14	3.12	4.46	4.16	4.66
Ca	**%**	2.27	0.96	3.77	2.36	0.94	8.15	1.49	0.25	3.03	0.31	0.06	0.79	2.46	2.28	2.58
Fe	**%**	7.21	3.22	12.55	6.15	1.24	11.05	6.47	3.02	10.75	7.30	5.80	9.00	7.29	7.12	7.43
K	**%**	0.16	0.07	0.32	0.28	0.08	1.22	0.31	0.12	0.97	0.46	0.32	0.66	0.24	0.22	0.27
Na	**%**	0.53	0.23	0.94	0.46	0.07	0.84	0.32	0.07	0.66	0.06	0.04	0.09	0.68	0.63	0.71
Mg	**%**	4.80	1.44	10.30	3.31	0.37	7.03	2.34	0.50	6.06	1.39	0.94	1.94	3.82	3.70	3.93
Mn	**ppm**	864	351	1545	702	331	1325	451	151	1130	227	125	377	717	705	739
P	**ppm**	612	80	2140	735	150	2020	926	70	2970	273	120	470	657	600	710
B	**ppm**	11	<10	20	12	<10	50	34	<10	400	13	<10	20	<10	<10	<10
Ba	**ppm**	47	20	80	77	20	370	59	20	110	53	30	100	63	60	70
Be	**ppm**	<0.5	<0.5	<0.5	0.5	<0.5	0.9	0.7	<0.5	1.1	1.3	1.2	1.4	<0.5	<0.5	<0.5
Bi	**ppm**	2	<2	3	2	<2	4	2	<2	4	<2	<2	<2	<2	<2	<2
Ga	**ppm**	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Hg	**ppm**	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
La	**ppm**	<10	<10	<10	11	<10	20	12	<10	20	<10	<10	<10	<10	<10	<10
Sb	**ppm**	2	<2	3	2	<2	3	<2	<2	<2	3	<2	4	<2	<2	<2
Sc	**ppm**	3	1	7	4	2	15	7	3	20	13	10	16	3	3	3
Sr	**ppm**	85	33	167	80	29	143	60	14	121	15	9	26	109	102	114
W	**ppm**	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Tl	**ppm**	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
U	**ppm**	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Total S	**%**	0.05	0.02	0.12	0.29	0.14	0.59	1.44	0.68	4.46	3.82	2.00	5.68	0.87	0.86	0.90
Total C	**%**	0.05	<0.05	0.10	0.07	<0.05	0.26	0.06	<0.05	0.09	0.06	<0.05	0.09	<0.05	<0.05	<0.05

[1] Data from Appendix D.4 of Reference (24).

Notes

- All constituents other than sulfur and carbon were measured following aqua regia digestion.
- Sulfur and carbon measured by LECO analyzer.
- For purpose of calculating average values, non-detects substituted at the detection limit.

Table 2-3. Summary Statistics of Whole Rock Oxide Composition of Waste Rock and Ore[1]

		Category 1 (n=38)			Category 2/3 (n=25)			Category 4 (Duluth Complex) (n=16)			Virginia Formation (n=3)			Ore (n=3)		
Constituent	**Unit**	**Ave.**	**Min.**	**Max.**	**Ave.**	**Min.**	**Max.**	**Ave.**	**Min.**	**Max.**	**Ave.**	**Min.**	**Max.**	**Ave.**	**Min.**	**Max.**
SiO_2	%	45.54	37	48.9	46.82	43	59.1	46.28	38.1	59.9	56.00	54.8	57.1	45.33	44.8	45.6
Al_20_3	%	17.90	7.47	24.4	17.53	11.25	23.1	16.17	11.8	20.6	16.42	16.35	16.5	17.58	17.4	17.7
TiO_2	%	1.16	0.26	2.25	1.41	0.39	3.75	2.16	0.57	5.62	0.78	0.74	0.86	1.24	1.17	1.31
Fe_2O_3	%	12.91	5.88	20.1	12.80	6.81	19.55	16.55	8.19	22.6	11.22	10.1	13.25	14.37	14	14.95
FeO	%	10.47	4.85	15.85	10.67	5.79	15.95	14.06	7.59	17.55	9.29	7.85	11.4	11.22	11.05	11.35
CaO	%	8.87	3.81	11.4	8.61	4.23	20.1	5.52	1.18	8.48	1.33	0.51	2.81	8.56	8.49	8.59
MgO	%	9.74	3.56	20.6	7.79	3.77	14.55	7.55	3.23	12.65	3.32	2.64	4.62	8.50	8.22	8.88
MnO	%	0.15	0.05	0.23	0.16	0.1	0.35	0.16	0.05	0.25	0.06	0.03	0.11	0.14	0.14	0.15
Na_2O	%	2.41	0.75	3.23	2.36	1.2	3.01	1.96	0.9	2.61	1.86	1.66	2.19	2.45	2.4	2.5
K_2O	%	0.43	0.18	1.1	0.82	0.32	3.44	1.01	0.31	3.71	3.66	2.39	4.7	0.61	0.58	0.65
P_2O_5	%	0.10	0.01	0.43	0.16	0.01	0.44	0.20	0.06	0.68	0.11	0.09	0.13	0.16	0.1	0.21
Cr_2O_3	%	0.04	0.01	0.09	0.03	0.01	0.06	0.06	0.02	0.33	0.03	0.03	0.03	0.03	0.03	0.03
BaO	%	0.01	0.01	0.03	0.03	0.01	0.11	0.03	0.01	0.07	0.07	0.06	0.07	0.02	0.02	0.02
SrO	%	0.03	0.01	0.04	0.03	0.02	0.04	0.03	0.01	0.03	0.02	0.02	0.02	0.03	0.03	0.03
LOI	%	0.75	-0.78	8.37	0.92	-0.63	3.9	1.99	-0.25	5.21	5.72	4.41	7.1	0.94	0.8	1.09
Total	%	100.00	98.4	101	99.98	98.8	101	99.69	97.6	101	100.50	100.5	100.5	99.97	99.6	100.5

[1] Data from Appendix D.4 of Reference (24).

Table 2-4. Summary of Waste Rock Mineralogy[1]

	Category 1 (n=38)			Category 2/3 (n=13)			Category 4 (Duluth Complex) (n=9)			Virginia Formation (n=9)		
	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.
Plagioclase	59	-	88	50	-	82	47	-	88	45	-	88
Olivine	26	-	55	20	-	40	23	-	55	26	-	55
K-spar	1	-	25	6	-	55	14	-	55	23	-	55
Quartz	-	-	-	-	-	-	-	-	-	-	-	-
Cordierite	-	-	-	-	-	5	1	-	5	2	-	5
OPX	-	-	2	2	-	15	3	-	15	6	-	15
CPX	4	-	25	10	-	48	15	-	48	21	-	48
Amphibole	-	-	-	-	-	5	1	-	5	2	-	5
Biotite	1	-	2	1	-	5	1	-	5	2	-	5
White Mica	1	-	25	3	-	30	10	-	30	13	-	30
Chlorite	4	-	40	2	-	10	9	-	40	16	-	40
Clay minerals	-	-	3	-	-	-	1	-	3	1	-	3
Serpentine	2	-	30	-	-	2	6	-	30	12	-	30
Uralite	-	-	1	-	-	-	-	-	1	0	-	1
Epidote	-	-	12	-	-	-	2	-	12	5	-	12
Apatite	-	-	2	-	-	1	1	-	2	1	-	2
Zircon	-	-	-	-	-	-	-	-	-	-	-	-
Rutile	-	-	-	-	-	-	-	-	-	-	-	-
Graphite	-	-	-	-	-	2	-	-	2	1	-	2
Carbonates	-	-	2	2	-	25	5	-	25	10	-	25
Vesuvianite/ Idocrase	-	-	-	-	-	5	1	-	5	2	-	5
Oxides	1	-	8	1	-	5	3	-	8	4	-	8
Sulfides	-	-	4	1	-	8	2	-	8	3	-	8

[1] Mineralogy summarized from data in Appendix D.1 of Reference (24).

Notes

- All values shown as percent modal abundance.

Table 2-5. Summary of Sulfide Mineral Sssemblage[1]

	Category 1 (n=38)			Category 2/3 (n=13)			Category 4 (Duluth Complex) (n=9)			Virginia Formation (n=9)		
	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.
Pyrite	-	-	-	-	-	-	-	-	-	-	-	-
Pyrrhotite	28	-	70	54	-	90	40	-	90	43	-	90
Chalcopyrite	51	20	100	24	-	50	41	-	100	47	-	100
Bornite	2	-	30	-	-	-	5	-	30	12	-	30
Digenite	0	-	5	-	-	-	1	-	5	2	-	5
Chalcocite	-	-	-	-	-	-	-	-	-	-	-	-
Covellite	1	-	30	-	-	-	5	-	30	12	-	30
Cubanite	8	-	35	4	-	35	14	-	35	16	-	35
Pentlandite	8	-	40	6	-	25	16	-	40	19	-	40
Violarite	-	-	-	-	-	-	-	-	-	-	-	-
PGMs	-	-	-	-	-	-	-	-	-	-	-	-
Silver	-	-	-	-	-	-	-	-	-	-	-	-
Mackinawite/ Valleriite	1	-	20	4	-	40	11	-	40	17	-	40
Sphalerite	0	-	1	8	-	95	17	-	95	37	-	95
Galena	-	-	-	0	-	5	1	-	5	2	-	5
Millerite	-	-	-	-	-	-	-	-	-	-	-	-
Enargite	-	-	-	-	-	-	-	-	-	-	-	-
Talnakhite	0	-	2	-	-	-	0	-	2	1	-	2

[1] Mineralogy summarized from data in Appendix D.1 of Reference (24).

<u>Notes</u>

- All values shown as percent model abundance within sulfide assemblage.

Table 2-6. Bulk Mineralogy of Ore Composites

Mineral	Composite 1	Composite 2	Composite 3	Average
Pentlandite	0.23	0.22	0.26	0.24
Chalcopyrite	0.61	0.66	0.68	0.65
Cubanite	0.04	0.06	0.04	0.05
Fe-Sulfides	0.54	0.53	0.68	0.58
Other Sulfides	0.01	0.01	0.01	0.01
Fe/Ti/Cr-Oxides	3.99	4.55	4.06	4.20
Olivine	1.63	1.50	1.73	1.62
Talc/Serpentine	1.05	1.08	1.06	1.06
Pyroxene	20.70	22.90	20.80	21.47
Tremolite	7.15	8.19	7.09	7.48
Chlorite	1.88	2.07	1.96	1.97
Biotite/Phlogopite	1.33	1.24	1.31	1.29
Micas	4.61	4.25	4.71	4.52
Feldspar	55.60	52.30	54.40	54.10
Quartz	0.17	0.04	0.76	0.32
Carbonates	0.26	0.26	0.23	0.25
Accessories	0.12	0.16	0.21	0.16

Notes

- All values shown as percent modal abundance.

Table 2-7. Summary of Particle Size Distribution of Waste Rock and Ore[1]

	Weight Retained [%]						
	+ 1/4	**-1/4 + 10**	**-10 + 35**	**-35 + 100**	**-100 + 270**	**-270**	**TOTAL**
Average (n=82)	0.1%	44.7%	25.1%	11.6%	9.4%	9.0%	100.0%
Minimum	0.0%	18.9%	16.8%	3.8%	2.3%	1.7%	100.0%
Maximum	1.0%	73.2%	33.8%	19.6%	16.2%	18.4%	100.0%

[1] Data summarized from Appendix D.5 of Reference (24).

Table 2-8. Summary of Bulk Chemistry of Flotation Tailings[1]

		Tailings (with CuSO4) (n=8)			Tailings (with CuSO4) (n=5)		
Constituent	Unit	Ave.	Min.	Max.	Ave.	Min.	Max.
Cu	%	0.03	0.01	0.04	0.04	0.02	0.05
Ni	%	0.03	0.02	0.04	0.03	0.03	0.04
Co	ppm	48	35	58	51	46	57
Ag	ppm	0.2	0.2	0.3	0.3	0.2	0.3
Zn	ppm	64	45	79	67	57	71
Cd	ppm	0.1	0.1	0.1	0.1	0.1	0.1
Mo	ppm	2	1	3	1	1	2
Pb	ppm	5	3	7	3	2	3
As	ppm	2	1	4	3	1	7
Cr	ppm	122	76	167	104	77	130
V	ppm	41	29	53	42	34	49
Ti	%	0.2	0.1	0.2	0.2	0.1	0.2
Al	%	4.2	3.7	5.2	3.7	3.5	4.1
Ca	%	2.3	2.1	2.8	2.1	1.9	2.3
Fe	%	6.0	4.1	7.2	6.4	5.3	6.9
K	%	0.2	0.2	0.3	0.2	0.2	0.2
Na	%	0.6	0.5	0.7	0.5	0.5	0.6
Mg	%	3.5	2.4	4.2	3.6	3.2	3.8
Mn	ppm	674	468	808	714	612	753
P	ppm	553	260	880	566	290	810
B	ppm	<10	<10	<10	10	<10	10
Ba	ppm	60	50	70	52	50	60
Be	ppm	0.2	0.2	0.3	0.2	0.2	0.2
Bi	ppm	0.1	0.1	0.2	0.1	0.1	0.2
Ga	ppm	9.0	7.8	10.1	8.8	7.2	10.0
Hg	ppm	0.2	0.0	1.0	0.6	0.0	2.0
La	ppm	6.8	4.1	10.0	7.2	3.8	10.0
Sb	ppm	0.4	0.1	2.0	0.1	0.1	0.2
U	ppm	0.3	0.2	0.5	0.3	0.2	0.5
Total S	%	0	0	0	0	0	0
Total C	%	0	<0.05	0	<0.05	<0.05	<0.05

[1]Data from Appendix B.3. of Reference (21)

Notes

- All constituents other than sulfur and carbon were measured following aqua regia digestion.
- Sulfur and carbon measured by LECO analyzer.
- For purpose of calculating average values, non-detects substituted at the detection limit.

Table 2-9. Whole Rock Oxide Content of Flotation Tailings[1]

Constituent	Unit	P1 (with CuSO4)	P1 (no CuSO4)	P2 (no CuSO4)	P3 (with CuSO4)
SiO2	%	45.8	45.4	46.1	46.3
Al2O3	%	17.7	17.5	18.0	17.9
TiO2	%	1.36	1.35	1.32	1.19
Fe2O3	%	13.7	14.0	13.9	13.1
FeO	%	10.85	11.1	11.25	10.55
CaO	%	8.99	8.86	8.66	8.57
MgO	%	8.79	8.73	8.68	8.41
MnO	%	0.09	0.08	0.14	0.13
Na2O	%	2.55	2.52	2.43	2.42
K2O	%	0.62	0.60	0.58	0.59
P2O5	%	0.13	0.10	0.11	0.12
Cr2O3	%	0.03	0.04	0.04	0.03
BaO	%	0.02	0.02	0.02	0.02
SrO	%	0.03	0.03	0.03	0.03
LOI	%	0.21	0.66	0.67	0.79
Total	%	100.0	99.8	100.5	99.6

[1]Data from Appendix B.3 of Reference (21)

Table 2-10. Bulk Chemistry of LTVSMC Tailings[1]

Constituent	Unit	Ave.	Min.	Max.
Ag	**ppm**	0.042	0	0.08
Al	**%**	0.214	0	0.24
As	**ppm**	30.26	21	46.9
Au	**ppm**	0.2	<0.2	0.2
B	**ppm**	10	<10	10
Ba	**ppm**	10	10	10
Be	**ppm**	0.75	1	0.85
Bi	**ppm**	0.05	0	0.15
Ca	**%**	1.53	1	1.8
Cd	**ppm**	0.046	0	0.08
Ce	**ppm**	6.752	7	7.32
Co	**ppm**	8.24	7	9.8
Cr	**ppm**	85.8	70	106
Cs	**ppm**	2.052	2	2.35
Cu	**%**	12.04	8	20.1
Fe	**%**	9.746	8	11.45
Ga	**ppm**	0.974	1	1.02
Ge	**ppm**	0.412	0	0.55
Hf	**ppm**	0.048	0	0.06
Hg	**ppm**	0.018	0	0.02
In	**ppm**	0.0072	0	0.008
K	**%**	0.072	0	0.08
La	**ppm**	3.16	3	3.4
Li	**ppm**	2.12	2	2.3
Mg	**%**	0.824	1	1.1
Mn	**ppm**	4266	3340	6110

Constituent	Unit	Ave.	Min.	Max.
Mo	**ppm**	1.096	1	1.34
Na	**%**	0.012	0	0.02
Nb	**ppm**	0.15	0	0.18
Ni	**%**	4.92	4	7
P	**ppm**	266	250	290
Pb	**ppm**	5.22	2	14.7
Rb	**ppm**	3.66	3	4.1
Re	**ppm**	0.001	<0.001	0.001
S	**%**	0.046	0	0.07
Sb	**ppm**	0.1	0	0.16
Sc	**ppm**	1.1	1	1.3
Se	**ppm**	0.26	0	0.4
Sn	**ppm**	0.2	<0.2	0.2
Sr	**ppm**	34.96	30	37.9
Ta	**ppm**	0.01	<0.01	0.01
Te	**ppm**	0.038	0	0.05
Th	**ppm**	0.22	0	0.3
Ti	**%**	0.0088	0	0.01
Tl	**ppm**	0.026	<0.02	0.04
U	**ppm**	0.134	0	0.2
V	**ppm**	9.4	8	11
W	**ppm**	0.606	1	0.79
Y	**ppm**	4.16	4	5.03
Zn	**ppm**	11.6	5	18
Zr	**ppm**	2.16	1.8	2.2
Total S	**%**	0.03328	0	0.0576

[1]Data from splits of 5 LTVSMC humidity cell test samples.

Notes

- All constituents other than sulfur were measured following aqua regia digestion.
- Sulfur measured by LECO analyzer.
- For purpose of calculating average values, non-detects substituted at the detection limit.

Table 2-11. Summary of Flotation Tailings Mineralogy[1]

Sample Identification	P1S	P1SA	P1SOLID	P2S	P3S
Description	**Tailings prepared with CuSO4**	**Tailings prepared with CuSO4**	**Tailings prepared without CuSO4**	**Tailings prepared with CuSO4**	**Tailings prepared with CuSO4**
Plagioclase	80	75	60	50	60
Olivine	12	15	15	10	10
CPX	4	5	5	4	5
OPX	1	2	1	-	1
Biotite	1	1	1	1	1
Chlorite	0.5	0.25	1	1.5	1
Serpentine	-	-	-	-	0.25
Sericite/Musc.	0.25	0.5	1	2	1
Ilmenite	1	1	0.75	1	0.5
Clay/Unidentified	-	-	15	30	20
Pyrrhotite	0.25	0.25	0.25	0.5	0.25

[1]Data from Appendix B.1 of Reference (21)

Notes

- All values are in percent model mineral abundance.

Table 2-12. Summary of LTVSMC Tailings Mineralogy[1]

Core and Tailings Type	Units	Coarse Sand			Fine Sand			Slimes		
		Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.
Quartz	%	67.8	58.0	79.0	69.4	60.0	78.0	66.5	62.0	72.0
Pyrite	%	0.1	0.0	0.2	0.2	0.0	0.4	0.0	0.0	0.1
Calcite	%	0.3	0.1	0.7	0.4	0.1	1.0	0.7	0.3	1.0
Ankerite	%	4	2	6	5	3	7	6	4	8
Siderite	%	5	2	8	3	2	7	5	4	6
Hematite	%	2	2	3	2	1	3	3	2	3
Magnetite	%	3	2	4	2	1	3	1	1	2
Biotite	%	4	1	10	4	2	11	6	4	7
Kaolinite	%	1	1	2	2	1	4	2	1	2
Ferriprophylite	%	3	2	6	3	2	3	3	2	3
Abite low	%	2	1	4	2	0	4	2	1	5
As	ppm	25	16	36	21	14	43	19	15	25
Cd	ppm	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Co	ppm	10	7	14	10	7	12	13	9	16
Cr	ppm	67	42	100	49	27	77	36	31	40
Cu	ppm	13	7	25	13	7	20	14	7	20
Fe	%	14.7	12.9	15.9	13.5	12.1	14.6	13.3	12.0	14.2
Mn	ppm	4880	3420	7110	5514	3630	8510	8668	4830	12400
Ni	ppm	4	1	8	2	<1	4	3	1	4
P	ppm	246	240	250	374	270	550	533	460	590
Pb	ppm	6	4	7	5	<2	8	4	2	4
S	%	0.02	0.02	0.04	0.02	0.02	0.04	0.03	0.02	0.04
Zn	ppm	16	9	34	11	7	14	12	8	14

[1] Data from Table 5-1 of Reference (21).

Table 2-13. Summary of Flotation Tailings Particle Size Distribution[1]

	Percent passing					
Sieve Size	#4	#10	#20	#40	#100	#200
Sample PP-10060	100	100	100	99.6	88.2	65.4
Sample PP-10061	100	100	100	99.6	84.5	52
Sample PP-10062	100	100	99.9	99.5	85.6	58.8

[1] Data is from Attachment E of Reference (27).

Table 2-14. ABA Characteristics of Overburden Samples[1]

		Unsaturated (n=12)			Saturated (n=17)			Peat (n=5)		
		Ave.	**Max.**	**Min.**	**Ave.**	**Max.**	**Min.**	**Ave.**	**Max.**	**Min.**
CO_2	**-2 mm+74 µm**	0.20	<0.2	0.2	0.20	<0.2	0.20	0.2	<0.2	<0.2
	-74 µm	0.22	<0.2	0.4	0.22	<0.2	0.40	0.2	<0.2	<0.2
Total Sulfur	**-2 mm+74 µm**	0.01	<0.01	0.03	0.06	<0.01	0.50	0.106	0.01	0.31
	-74 µm	0.04	0.01	0.13	0.12	0.01	0.63	0.206	0.01	0.61
Sulfate	**-2 mm+74 µm**	0.01	<0.01	0.03	0.02	<0.01	0.07	0.012	<0.01	0.02
	-74 µm	0.02	<0.01	0.05	0.02	<0.01	0.05	0.0125	0.01	0.02

[1]Data from Appendix A of Reference (17).

Notes

- All values are provided in percent.

Table 2-15. Summary of MWMP Leachate Results by Overburden Type[1]

		Unsaturated Overburden			Saturated Overburden			Peat		
Constituents	**Units**	**P50**	**P95**	**Max**	**P50**	**P95**	**Max**	**P50**	**P95**	**Max**
pH		7.1	6.9	6.9	7.3	4	3.4	7.5	6.9	6.8
Alk	**mg/L**	5	12	13	13	36	38	46	79	83
F	**mg/L**	0.18	0.45	0.48	0.33	0.56	0.6	0.59	1	1.1
Cl	**mg/L**	1.9	3.4	3.6	2	3.8	4	5.9	8.8	9.2
SO4	**mg/L**	3.4	15	17	69	210	230	81	92	93
Al	**mg/L**	0.091	0.3	0.32	0.14	0.63	0.74	0.086	0.13	0.13
Sb	**mg/L**	<0.0001	0.00098	0.0011	0.0004	0.0012	0.0012	0.0006	0.00069	0.0007
As	**mg/L**	0.0005	0.0029	0.0032	0.0023	0.0028	0.0028	0.0037	0.0043	0.0044
Ba	**mg/L**	0.0035	0.013	0.014	0.011	0.026	0.028	0.023	0.034	0.035
Be	**mg/L**	<0.0002	<0.0002	<0.0002	<0.0002	0.00055	0.0008	<0.0002	<0.0002	<0.0002
B	**mg/L**	0.013	0.028	0.03	0.027	0.087	0.098	0.21	0.23	0.23
Cd	**mg/L**	0.00005	0.00015	0.00016	0.000015	0.005	0.0066	<0.00004	<0.00004	<0.00004
Ca	**mg/L**	3.9	5.7	5.9	13	26	27	19	23	23
Cr	**mg/L**	<0.0002	0.00097	0.0011	0.00005	0.0012	0.0013	0.0004	0.00094	0.001
Co	**mg/L**	0.0006	0.0015	0.0016	0.0015	0.23	0.31	0.0003	0.00066	0.0007
Cu	**mg/L**	0.0054	0.008	0.0083	0.013	0.44	0.58	0.007	0.011	0.011
Fe	**mg/L**	0.05	0.059	0.06	0.11	5.5	7.3	0.07	0.12	0.12
Pb	**mg/L**	<0.00005	<0.00005	<0.00005	<0.00005	0.0011	0.0014	0.00009	0.00022	0.00023
Mg	**mg/L**	2	2.1	2.1	11	18	18	9.3	11	11
Mn	**mg/L**	0.051	0.1	0.11	0.18	1.1	1.3	0.13	0.19	0.19
Mo	**mg/L**	0.0039	0.013	0.014	0.029	0.034	0.034	0.019	0.028	0.029
Ni	**mg/L**	0.0014	0.0031	0.0033	0.026	2.2	3	0.0041	0.0063	0.0066
Se	**mg/L**	<0.0002	0.00052	0.0006	0.002	0.0034	0.0037	0.00075	0.00089	0.0009
Ag	**mg/L**	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	0.00068	0.0013	0.0014
Na	**mg/L**	3.7	4.2	4.3	6.5	13	13	26	45	47
Te	**mg/L**	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Tl	**mg/L**	<0.00002	0.000025	0.00003	<0.00002	0.000025	0.00004	0.000045	0.0001	0.00011
V	**mg/L**	0.0005	0.00059	0.0006	0.0011	0.0022	0.0024	0.0034	0.0042	0.0043
Zn	**mg/L**	0.002	0.0056	0.006	0.003	0.86	1.2	0.0015	0.0038	0.004

[1]Reproduced from Table 4 of Reference (17).

Table 2-16. Comparison of Sulfur, Nickel, and Copper Content of Unsaturated Overburden Samples from Drilling and Test Pit Program[1]

	Total Sulfur (%)						Copper (ppm)						Nickel (ppm)					
	n	min	P5	P50	P95	max	n	min	P5	P50	P95	max	n	min	P5	P50	P95	max
Drilling Samples	11	0.01	0.01	0.01	0.03	0.03	11	20	20	31	104	126	11	17	18	50	71	72
Test Pit Samples	13	0.01	0.01	0.02	0.03	0.03	13	17	18	25	52	89	13	20	20	26	46	80

[1]Modified from Table 10 of Reference (17).

Table 2-17. Particle Size Distribution of Overburden Samples[1]

	Percent passing								
Sieve Size	**1"**	**3/4"**	**3/8"**	**#4**	**#10**	**#20**	**#40**	**#100**	**#200**
				100	100	99.9	99.7	94.5	67.4
		100	95.8	88	79.2	70.5	61.8	45.5	34.9
		100	93.2	86.3	78.5	68.6	58.8	40.4	30.8
		100	93.1	87.1	78.8	69.5	60.1	42.1	31.8
	100	81.5	78.7	72	65.1	56.3	47.6	31.2	21.1
		100	95.8	91.7	83.8	73.3	62.7	42.9	31.2

[1] Data is from Attachment E of Reference (28).

Table 2-18. Geochemical Inputs to the Project Water Model[1]

Variable Name	*Units*	*Deterministic/ Uncertain*	*Description*	*Source of Input Data*	*Modeling Package Section*
Geochemical Parameters for Pollutant Release					
OB_Concs_Unsat	[mg/L]	Uncertain	Seepage concentrations from unsaturated OB storage areas	Analysis of overburden leach test data	Waste Section 7.1 *Leachate Water Quality, Unsaturated Overburden*
OB_Concs_Peat	[mg/L]	Uncertain	Seepage concentrations from peat storage areas	Analysis of overburden leach test data	Waste Section 7.1 *Leachate Water Quality, Peat*
Cat1_Release	[varies]	Uncertain	Release rates and ratios for Category 1 waste rock	Analysis of HCT, Aqua Regia, and Microprobe data	Waste Section 8.1 *Laboratory Release Rates*
Cat23_Release	[varies]	Uncertain	Release rates and ratios for Category 2/3 waste rock	Analysis of HCT, Aqua Regia, and Microprobe data	Waste Section 8.1 *Laboratory Release Rates*
Cat4DC_Release	[varies]	Uncertain	Release rates and ratios for Duluth Complex Category 4 waste rock	Analysis of HCT, Aqua Regia, and Microprobe data	Waste Section 8.1 *Laboratory Release Rates*
Ore_Release	[varies]	Uncertain	Release rates and ratios for ore in the OSP	Analysis of HCT, Aqua Regia, and Microprobe data	Waste Section 8.1 *Laboratory Release Rates*
Cat4VF_Release	[varies]	Uncertain	Release rates and ratios for Virginia Formation Category 4 waste rock	Analysis of HCT, Aqua Regia, and Microprobe data	Waste Section 8.1 *Laboratory Release Rates*
NM_Fines_Release	[varies]	Uncertain	Distribution parameters for constituent release rates and ratios from the fine fraction of the NorthMet tailings	Analysis of HCT, Aqua Regia, and Microprobe data	Waste Section 10.1.1 - *NorthMet Tailings*
NM_Coarse_Release	[varies]	Uncertain	Distribution parameters for constituent release rates and ratios from the coarse fraction of the NorthMet tailings	Analysis of HCT, Aqua Regia, and Microprobe data	Waste Section 10.1.1 - *NorthMet Tailings*
Ratio_or_Conc_NM	[--]	Deterministic	Defines whether a release rate is from a release ratio (1) or from a concentration (0)	Release Method	Waste Section 10.1.1 - *NorthMet Tailings*
NM_Tailings_Weathering	[mg/m^2/mon]	Deterministic	Weathering rate by the NorthMet tailings beaches	RS46	Waste Section 10.6.2 - *Tailings Weathering*
Dist_Params_LTVSMC_Release	[varies]	Uncertain	Distribution parameters for the release rates from the existing LTVSMC tailings	Analysis of HCT, Aqua Regia, and Microprobe data	Waste Section 10.1.2 - *LTVSMC Tailings*
LTVSMC_Flush	[mg/kg]	Uncertain	One-time loading from the disturbed LTVSMC tailings as the dams are constructed	Analysis of HCT, Aqua Regia, and Microprobe data	Waste Section 10.1.2 - *LTVSMC Tailings*
Geochemical Parameters for Acidic Conditions and Decay					
Acid_Onset_Time_23	[yr]	Uncertain	Time for Category 2/3 rock to go acidic in the laboratory	Analysis of DNR long-term reactor data	Waste Section 8.2 *Lab to Field Scale Up*
Acid_Onset_Time_4DC	[yr]	Uncertain	Time for Duluth Complex Category 4 rock to go acidic in the laboratory	Analysis of DNR long-term reactor data	Waste Section 8.2 *Lab to Field Scale Up*
Acid_Factor_DC	[--]	Uncertain	Increase in sulfate release when Duluth Complex rock goes acidic **(correlation to a1 = -0.831)**	Analysis of DNR long-term reactor data and NorthMet humidity cells	Waste Section 8.2 *Lab to Field Scale Up*
Decay_a1	[--]	Uncertain	Parameter to define shape of decay of sulfate release in wall rock **(correlated to acid factor and a0)**	Analysis of DNR long-term reactor data and NorthMet humidity cells	Waste Section 9.4 *Acidificatoin and Long-Term Decay*
Decay_a0	[--]	Uncertain	Parameter to define shape of decay of sulfate release in wall rock **(correlation to a1 = -0.989)**	Analysis of DNR long-term reactor data and NorthMet humidity cells	Waste Section 9.4 *Acidificatoin and Long-Term Decay*

Table 2-18. Geochemical Inputs to the Project Water Model[1] (Cont.)

Variable Name	*Units*	*Deterministic/ Uncertain*	*Description*	*Source of Input Data*	*Modeling Package Section*
Geochemical Parameters for Scaling					
Scale_Factor_MDNR	[--]	Uncertain	Scaling factor for Category 1 stockpile	MDNR analysis of Dunka Mine data.	Waste Section 8.2.8 *Lab to Field Scale Up, Category 1 Waste Rock Stockpile*
Contact_Factor	[--]	Uncertain	Fraction of waste rock contacted by water	Professional judgement	Waste Section 8.2 *Lab to Field Scale Up*
Size_Factor	[--]	Uncertain	Scaling factor to adjust to field scale waste rock	Analysis of NorthMet and AMAX data	Waste Section 8.2 *Lab to Field Scale Up*
Field_Temp	[C]	Uncertain	Stockpile or wall internal temperature, same as air temperature	HiDen Climate data for1981-2010	Waste Section 8.2 *Lab to Field Scale Up*
Field_Temp_Mean	[C]	Uncertain	Average annual temperature, used for acid onset timing	HiDen Climate data for1981-2010	Waste Section 8.2 *Lab to Field Scale Up*
Lab_Temp	[C]	Deterministic	Laboratory temperature (known)	RS 53/42	Waste Section 8.2 *Lab to Field Scale Up*
Activation_Energy	[kJ/mol]	Uncertain	Activation energy of pyrrhotite for the Arrhenius equation	Literature-reported range	Waste Section 8.2 *Lab to Field Scale Up*
Wall_Temp_Solar	[C]	Deterministic	Average temp. increase for portion of pit wall that has solar heating	Energy balance for pit wall face	Waste Section 9.3 *Lab to Field Scale Up*
Size_factor_walls	[--]	Uncertain	Scaling factor to adjust to field scale wall rock	Professional judgement	Waste Section 9.3 *Lab to Field Scale Up*
O2_Mol_Weight	[g/mol]	Deterministic	Molecular weight of oxygen	Known value	Waste Section 10.1.1 - *NorthMet Tailings*
SO4_Mol_Weight	[g/mol]	Deterministic	Molecular weight of sulfate	Known value	Waste Section 10.1.1 - *NorthMet Tailings*
S_Mol_Weight	[g/mol]	Deterministic	Molecular weight of sulfide	Known value	Waste Section 10.1.1 - *NorthMet Tailings*
Sulfate_gen_ratio	[mol SO4 / mol O2]	Deterministic	Ratio of the number of moles of sulfate produced for every mole of oxygen consumed	Pyrrhotite reaction stoichiometry	Waste Section 10.3 - *Saturation and Oxygen Diffusion*
Coarse_Calib_Fact	[--]	Deterministic	Calibration factor to modify the SO4 release rate from the coarse LTVSMC tailings	Calibration of the existing conditions / No Action Model	Waste Section 10.2.1 - *Scaling / Calibration of LTVSMC Lab Data to Field Data*
Fine_Calib_Fact	[--]	Deterministic	Calibration factor to modify the SO4 release rate from the fine LTVSMC tailings	Calibration of the existing conditions / No Action Model	Waste Section 10.2.1 - *Scaling / Calibration of LTVSMC Lab Data to Field Data*
LTVSMC_Calib_Fact	[--]	Deterministic	Calibration factor applied to each constituent so that the theoretical loading matches the observed seepage data	Calibration of the existing conditions / No Action Model	Waste Section 10.2.1 - *Scaling / Calibration of LTVSMC Lab Data to Field Data*
Ratio_or_Conc_LTV	[--]	Deterministic	Defines whether a release rate is from a release ratio (1) or from a concentration (0)	Release Method	Waste Section 10.2.1 - *Scaling / Calibration of LTVSMC Lab Data to Field Data*

Table 2-18. Geochemical Inputs to the Project Water Model[1] (Cont.)

Variable Name	*Units*	*Deterministic/ Uncertain*	*Description*	*Source of Input Data*	*Modeling Package Section*
Geochemical Parameters for Concentration Caps					
Atmospheric_pH	[--]	Uncertain	Estimate of the pH in the areas of the FTB dominated by advection of surface water	See Mine Site Work Plan Tables	Waste Section 10.4 - *Concentration Caps*
Enriched_pH	[--]	Uncertain	Estimate of the pH in the CO2 enriched areas of the FTB	CDF056	Waste Section 10.4 - *Concentration Caps*
Cat1_ConcCaps	[mg/L]	Uncertain	Concentration caps for Category 1 waste rock	Analysis of laboratory and analog site data	Waste Section 8.3 *Concentration caps*
Cat1_pH	[s.u.]	Uncertain	Assumed distribution of porewater pH in the Category 1 stockpile	Geochemical modeling of Category 1 waste rock	Waste Section 8.3 *Concentration caps*
Cat234_pH	[s.u.]	Uncertain	Assumed distribution of porewater pH in the nonacidic Category 2/3 and Category 4 rock	Assumed pH prior to onset of acidic conditions	Waste Section 8.3 *Concentration caps*
Cat234_nonacid_Conc Caps	[mg/L]	Uncertain	Concentration caps for nonacidic Duluth Complex Category 2/3/4 waste rock and ore	Analysis of laboratory and analog site data	Waste Section 8.3 *Concentration caps*
Cat234_acid_ConcCaps	[mg/L]	Uncertain	Concentration caps for acidic Duluth Complex Category 2/3/4 waste rock and ore	Analysis of laboratory and analog site data	Waste Section 8.3 *Concentration caps*
Cat4VF_ConcCaps	[mg/L]	Uncertain	Concentration caps for acidic Virginia Formation Category 4 waste rock	Analysis of laboratory and analog site data	Waste Section 8.3 *Concentration caps*
NM_Solubility	[mg/L]	Uncertain	Concentration cap distributions for each constituent in the NorthMet Tailings	Category 1 Waste Rock	Waste Section 10.4 - *Solubility Limits*
Geochemical Parameters for Depletion Calculations					
Rock_Content_All	[mg/kg]	Deterministic	Content of constituents of concern in waste rock	Analysis of Aqua Regia data	Waste Section 8.4.1 *Depletion*
NM_Content	[mg/kg]	Deterministic	Whole tailings content for depletion modeling	Aqua Regia data	Waste Section 10.6.6 - *Depletion*
LTVSMC_Content	[mg/kg]	Deterministic	Whole tailings content for depletion modeling	Aqua Regia data	Waste Section 10.6.6 - *Depletion*

[1] Table adapted from Table 1-1 in Attachment C of Reference (25) and Table 1-1 in Attachment B of Reference (26).

Table 2-19. Distribution Parameters for Category 1 Waste Rock Release[1]

Distribution from Regression Analysis of Humidity Cell Data

Constituent	*Method*	*Source*	*Units*	*Distribution*	*Mean/Mode*	*St. Dev.*	*Minimum*	*Maximum*
SO_4	Rate Regression	HCT (1+2)	mg SO_4/kg/week/%S	Normal	13.92	0.581	--	--

Distribution Fit to Humidity Cell Data

Constituent	*Method*	*Source*	*Units*	*Distribution*	*Mean/Mode*	*St. Dev.*	*Minimum*	*Maximum*
Ag	Rate	HCT (1+2)*	mg Ag/kg/week	Lognormal	6.46E-06	2.11E-02	--	--
Alkalinity	Rate	HCT (1+2)	mg Alk/kg/week	Beta	4.92E+00	2.21E+00	2.63E+00	1.15E+01
As	Rate	HCT (1+2)*	mg As/kg/week	Lognormal	1.85E-04	1.84E-04	--	--
B	Rate	HCT (1+2)*	mg B/kg/week	Lognormal	4.33E-03	1.27E-02	--	--
Be	Rate	HCT (1+2)*	mg Be/kg/week	Lognormal	6.37E-06	4.61E-05	--	--
Ca	Rate	HCT (1+2)	mg Ca/kg/week	Beta	1.15E+00	3.48E-01	5.78E-01	2.34E+00
Cd	Zn rate ratio	HCT (2)	mg Cd / mg Zn	Beta	2.03E-02	5.10E-03	1.44E-02	4.44E-02
Cl	First flush	HCT (all)	mg Cl / kg rock	Beta	9.78E+00	1.17E+01	1.38E+00	7.30E+01
Co	Ni rate ratio	HCT (2)	mg Co / mg Ni	Beta	1.55E-01	5.11E-02	7.28E-02	3.11E-01
Cr	Rate	HCT (1+2)*	mg Cr/kg/week	Lognormal	5.90E-05	2.80E-05	--	--
F	Rate	HCT (1+2)	mg F/kg/week	Beta	2.33E-02	1.08E-03	1.99E-02	2.52E-02
K	Rate	HCT (1+2)	mg K/kg/week	Beta	2.14E-01	9.17E-02	1.02E-01	4.98E-01
Mg	Rate	HCT (1+2)	mg Mg/kg/week	Beta	3.14E-01	2.04E-01	1.31E-01	1.10E+00
Mn	SO_4 rate ratio	HCT (2)	mg Mn / mg SO_4	Beta	1.96E-03	9.73E-04	1.15E-03	5.95E-03
Na	Rate	HCT (1+2)	mg Na/kg/week	Beta	4.13E-01	4.02E-01	1.28E-01	2.50E+00
Pb	Rate	HCT (1+2)*	mg Pb/kg/week	Lognormal	6.56E-06	6.44E-06	--	--
Sb	Rate	Reactor*	mg Sb/kg/week	Lognormal	4.36E-04	4.81E-04	--	--
Se	SO_4 rate ratio	HCT (2)*	mg Se / mg SO_4	Lognormal	1.90E-05	2.32E-04	--	--
Tl	Rate	HCT (1+2)*	mg Tl/kg/week	Lognormal	9.23E-07	1.77E-05	--	--
V	Rate	HCT (1+2)*	mg V/kg/week	Lognormal	1.52E-04	1.68E-04	--	--

Distribution from Aqua Regia Data

Constituent	*Method*	*Source*	*Units*	*Distribution*	*Mean/Mode*	*St. Dev.*	*Minimum*	*Maximum*
Ba	K ratio	Aqua Regia	mg Ba / mg K	Normal	2.90E-02	1.98E-04	--	--
Cu	S ratio	Aqua Regia	mg Cu / mg S	Normal	5.87E-01	2.51E-02	--	--
Zn	Mg ratio	Aqua Regia	mg Zn / mg Mg	Normal	1.81E-03	1.35E-05	--	--

Distribution from Other Data

Constituent	*Method*	*Source*	*Units*	*Distribution*	*Mean/Mode*	*St. Dev.*	*Minimum*	*Maximum*
Al	Ca ratio	Anorthite Formula	mg Al / mg Ca	Constant	1.35E+00	--	--	--
	Na ratio	Albite Formula	mg Al / mg Na	Constant	1.17E+00	--	--	--
Fe	S ratio	Pyrrhotite microprobe	mg Fe / mg S	Beta	1.62E+00	8.72E-02	1.49E+00	1.92E+00
	Mg ratio	Olivine microprobe	mg Fe / mg Mg	Beta	1.87E+00	6.75E-01	1.19E+00	4.51E+00
Ni	S ratio	Cat 4 Aqua Regia	mg Ni / mg S	Normal	3.06E-02	1.86E-03	--	--
	Mg ratio	Olivine microprobe	mg Ni / mg Mg	Beta	4.59E-03	1.95E-03	1.10E-04	7.43E-03

[1]Table reproduced from Large Table 6 in Reference (19). Notes below refer to citations in Reference (19).

Notes

- Humidity cell data used through February 2011 unless noted otherwise.
- HCT (1+2) indicates average rates from humidity cells over Condition 1 and Condition 2, as defined in Large Table 1.
- HCT (2) indicates average rates from humidity cells over Condition 2, as defined in Large Table 1.
- ***** indicates average rates from humidity cells over conditions noted with refined modeling of non-detects (see Section 8.1.2.1). Data used though December 2013.
- For Sb only the smaller MDNR-style reactors were used to estimate a release rate, including refined modeling of non-detects. Data used through February 2007.
- Except for SO_4, all distributions from humidity cell data represent the full range of the observed values, with no weighting. Distributions are shown in Large Figures 1-4.
- Distributions from aqua regia data represent the uncertainty in the average ratios, weighted by geologic unit.
- Distributions from microprobe data represent the full range of the observed ratios for each mineral, with no weighting. Distributions are shown in Large Figures 21-22.
- For nickel, S ratio from Duluth Complex Category 4 aqua regia data represents the effect of all sulfide minerals combined. See example calculation in Section 8.1.2.3.
- For chloride, release is a one-time event per unit rock mass, developed from all Project humidity cells. See Section 8.4.4.

Table 2-20. Distribution Parameters for Category 2/3 Waste Rock Release[1]

Distribution from Regression Analysis of Humidity Cell Data

Constituent	*Method*	*Source*	*Units*	*Distribution*	*Mean/Mode*	*St. Dev.*	*Minimum*	*Maximum*
SO_4	Rate Regression	HCT (1+2)	mg SO_4/kg/week/%S	Normal	13.92	0.581	--	--

Distribution Fit to Humidity Cell Data

Constituent	*Method*	*Source*	*Units*	*Distribution*	*Mean/Mode*	*St. Dev.*	*Minimum*	*Maximum*
Alkalinity	Nonacidic rate	HCT (1+2)	mg Alk/kg/week	Beta	4.50E+00	2.59E+00	1.45E+00	1.10E+01
	Acidic rate	None	mg Alk/kg/week	Constant	0	--	--	--
B	Nonacidic rate	HCT (1+2)*	mg B/kg/week	Lognormal	5.84E-03	1.10E-03	--	--
	Acidic rate	HCT (3)	mg B/kg/week	Triangular	4.58E-04	--	4.58E-04	1.61E-02
Ca	SO_4 rate ratio	HCT (1+2)	mg Ca / mg SO_4	Beta	6.81E-01	4.29E-01	2.61E-01	2.59E+00
Cd	Zn rate ratio	HCT (2)	mg Cd / mg Zn	Beta	1.65E-02	1.20E-02	1.01E-03	5.84E-02
Cl	First flush	HCT (all)	mg Cl / kg rock	Beta	9.78E+00	1.17E+01	1.38E+00	7.30E+01
Co	Ni rate ratio	HCT (2)	mg Co / mg Ni	Beta	8.29E-02	3.91E-02	2.24E-02	2.06E-01
Cr	Nonacidic rate	HCT (1+2)*	mg Cr/kg/week	Lognormal	5.49E-05	2.19E-05	--	--
	Acidic rate	HCT (3)	mg Cr/kg/week	Triangular	9.17E-05	--	9.17E-05	1.06E-04
F	Nonacidic rate	HCT (1+2)	mg F/kg/week	Beta	2.36E-02	1.45E-03	2.04E-02	2.74E-02
	Acidic rate	HCT (3)	mg F/kg/week	Triangular	2.29E-02		2.27E-03	2.29E-02
K	SO_4 rate ratio	HCT (1+2)	mg K / mg SO_4	Beta	1.29E-01	8.62E-02	5.39E-02	4.00E-01
Mg	SO_4 rate ratio	HCT (1+2)	mg Mg / mg SO_4	Beta	1.39E-01	1.06E-01	3.37E-02	4.96E-01
Mn	SO_4 rate ratio	HCT (2)	mg Mn / mg SO_4	Beta	2.81E-03	2.56E-03	4.36E-04	1.10E-02
Na	SO_4 rate ratio	HCT (1+2)	mg Na / mg SO_4	Beta	1.33E-01	9.29E-02	3.54E-02	4.51E-01
Se	SO_4 rate ratio	HCT (2)	mg Se / mg SO_4	Beta	3.54E-05	1.67E-05	1.30E-05	9.16E-05
Tl	Nonacidic rate	HCT (1+2)*	mg Tl/kg/week	Lognormal	2.73E-06	8.15E-06	--	--
	Acidic rate	HCT (3)	mg Tl/kg/week	Triangular	9.17E-06	--	9.17E-06	2.29E-05
Zn	Ni rate ratio	HCT (2)	mg Zn / mg Ni	Beta	3.35E-01	3.71E-01	3.31E-02	1.60E+00

Distribution from Aqua Regia Data

Constituent	*Method*	*Source*	*Units*	*Distribution*	*Mean/Mode*	*St. Dev.*	*Minimum*	*Maximum*
Ag	S ratio	Aqua Regia	mg Ag / mg S	Normal	1.32E-04	4.54E-06	--	--
As	S ratio	Aqua Regia	mg As / mg S	Normal	1.67E-03	1.28E-04	--	--
Ba	K ratio	Aqua Regia	mg Ba / mg K	Normal	2.93E-02	5.69E-04	--	--
Be	K ratio	Aqua Regia	mg Be / mg K	Normal	1.87E-04	3.77E-06	--	--
Cu	S ratio	Aqua Regia	mg Cu / mg S	Normal	3.59E-01	8.84E-03	--	--
Pb	S ratio	Aqua Regia	mg Pb / mg S	Normal	1.24E-03	5.95E-05	--	--
Sb	S ratio	Aqua Regia	mg Sb / mg S	Normal	6.53E-04	2.81E-05	--	--
V	K ratio	Aqua Regia	mg V / mg K	Normal	2.32E-02	7.29E-04	--	--

Distribution from Other Data

Constituent	*Method*	*Source*	*Units*	*Distribution*	*Mean/Mode*	*St. Dev.*	*Minimum*	*Maximum*
Al	Ca ratio	Anorthite Formula	mg Al / mg Ca	Constant	1.35E+00	--	--	--
	Na ratio	Albite Formula	mg Al / mg Na	Constant	1.17E+00	--	--	--
Fe	S ratio	Pyrrhotite microprobe	mg Fe / mg S	Beta	1.62E+00	8.72E-02	1.49E+00	1.92E+00
	Mg ratio	Olivine microprobe	mg Fe / mg Mg	Beta	1.87E+00	6.75E-01	1.19E+00	4.51E+00
Ni	S ratio	Cat 4 Aqua Regia	mg Ni / mg S	Normal	3.06E-02	1.86E-03	--	--
	Mg ratio	Olivine microprobe	mg Ni / mg Mg	Beta	4.59E-03	1.95E-03	1.10E-04	7.43E-03

[1]Table reproduced from Large Table 7 in Reference (19). Notes below refer to citations in Reference (19).

Notes

- Humidity cell data used through February 2011 unless noted otherwise.
- HCT (1+2) indicates average rates from humidity cells over Condition 1 and Condition 2, as defined in Large Table 1.
- HCT (2) indicates average rates from humidity cells over Condition 2, as defined in Large Table 1.
- HCT (3) indicates average rates from humidity cells over Condition 3, as defined in Large Table 1.
- ***** indicates average rates from humidity cells over conditions noted with refined modeling of non-detects (see Section 8.1.2.1). Data used though December 2013.
- Except for SO_4, all distributions from humidity cell data represent the full range of the observed values, with no weighting. Distributions are shown in Large Figures 5-8.
- Acidic release rate for SO_4 to be determined from nonacidic rate times an acidic increase factor, as discussed in Section 8.2.5.
- Distributions from aqua regia data represent the uncertainty in the average ratios, weighted by geologic unit.
- Distributions from microprobe data represent the full range of the observed ratios for each mineral, with no weighting. Distributions are shown in Large Figures 21-22.
- For nickel, S ratio from Duluth Complex Category 4 aqua regia data represents the effect of all sulfide minerals combined. See example calculation in Section 8.1.2.3.
- For chloride, release is a one-time event per unit rock mass, developed from all Project humidity cells. See Section 8.4.4.

Table 2-21. Distribution Parameters for Category 4 Waste Rock Release[1]

Distribution Fit to Humidity Cell Data

Constituent	*Method*	*Source*	*Units*	*Distribution*	*Mean/Mode*	*St. Dev.*	*Minimum*	*Maximum*
Alkalinity	Nonacidic rate	HCT (1+2)	mg Alk/kg/week	Beta	4.43E+00	2.60E+00	1.47E+00	1.10E+01
	Acidic rate	None	mg Alk/kg/week	Constant	0	--	--	--
B	Nonacidic rate	HCT (1+2)*	mg B/kg/week	Lognormal	9.99E-03	6.37E-03	--	--
	Acidic rate	HCT (3)	mg B/kg/week	Beta	2.52E-03	2.49E-03	5.06E-04	1.00E-02
Ca	SO_4 rate ratio	HCT (1+2)	mg Ca / mg SO_4	Beta	3.56E-01	1.26E-01	1.80E-01	7.91E-01
Cd	Zn rate ratio	HCT (2)	mg Cd / mg Zn	Beta	9.16E-03	5.39E-03	2.70E-03	3.15E-02
Cl	First flush	HCT (all)	mg Cl / kg rock	Beta	9.78E+00	1.17E+01	1.38E+00	7.30E+01
Co	Ni rate ratio	HCT (2)	mg Co / mg Ni	Beta	1.56E-01	7.51E-02	7.79E-02	4.64E-01
Cr	Nonacidic rate	HCT (1+2)*	mg Cr/kg/week	Lognormal	4.34E-05	7.03E-05	--	--
	Acidic rate	HCT (3)	mg Cr/kg/week	Beta	1.07E-04	1.20E-05	9.34E-05	1.47E-04
F	Nonacidic rate	HCT (1+2)	mg F/kg/week	Beta	4.68E-02	4.78E-02	2.16E-02	3.37E-01
	Acidic rate	HCT (3)	mg F/kg/week	Beta	2.57E-02	4.30E-03	2.25E-02	4.19E-02
K	SO_4 rate ratio	HCT (1+2)	mg K / mg SO_4	Beta	1.00E-01	5.61E-02	2.61E-04	2.45E-01
Mg	SO_4 rate ratio	HCT (1+2)	mg Mg / mg SO_4	Beta	6.61E-02	4.17E-02	2.92E-02	2.00E-01
Mn	SO_4 rate ratio	HCT (2)	mg Mn / mg SO_4	Beta	2.94E-03	2.15E-03	5.94E-04	9.00E-03
Na	SO_4 rate ratio	HCT (1+2)	mg Na / mg SO_4	Beta	1.06E-01	1.02E-01	1.43E-02	4.51E-01
Se	SO_4 rate ratio	HCT (2)	mg Se / mg SO_4	Beta	1.87E-05	9.12E-06	9.15E-06	4.91E-05
SO_4	Nonacidic rate	HCT (1+2)	mg SO_4/kg/week	Beta	1.27E+01	8.37E+00	3.74E+00	5.50E+01
Tl	Nonacidic rate	HCT (1+2)*	mg Tl/kg/week	Lognormal	7.36E-06	6.40E-06	--	--
	Acidic rate	HCT (3)	mg Tl/kg/week	Beta	1.54E-05	7.94E-06	9.73E-06	4.26E-05
Zn	Ni rate ratio	HCT (2)	mg Zn / mg Ni	Beta	4.42E-01	6.79E-01	3.47E-02	3.50E+00

Distribution from Aqua Regia Data

Constituent	*Method*	*Source*	*Units*	*Distribution*	*Mean/Mode*	*St. Dev.*	*Minimum*	*Maximum*
Ag	S ratio	Aqua Regia	mg Ag / mg S	Normal	3.30E-05	3.21E-06	--	--
As	S ratio	Aqua Regia	mg As / mg S	Normal	1.40E-03	1.13E-04	--	--
Ba	K ratio	Aqua Regia	mg Ba / mg K	Normal	2.46E-02	1.17E-03	--	--
Be	K ratio	Aqua Regia	mg Be / mg K	Normal	3.30E-04	3.04E-05	--	--
Cu	S ratio	Aqua Regia	mg Cu / mg S	Normal	6.81E-02	4.76E-03	--	--
Pb	S ratio	Aqua Regia	mg Pb / mg S	Normal	3.97E-04	4.33E-05	--	--
Sb	S ratio	Aqua Regia	mg Sb / mg S	Normal	1.30E-04	9.01E-06	--	--
V	K ratio	Aqua Regia	mg V / mg K	Normal	4.33E-02	3.24E-03	--	--

Distribution from Other Data

Constituent	*Method*	*Source*	*Units*	*Distribution*	*Mean/Mode*	*St. Dev.*	*Minimum*	*Maximum*
Al	Ca ratio	Anorthite Formula	mg Al / mg Ca	Beta	1.35E+00	--	--	--
	Na ratio	Albite Formula	mg Al / mg Na	Beta	1.17E+00	--	--	--
Fe	S ratio	Pyrrhotite microprobe	mg Fe / mg S	Beta	1.62E+00	8.72E-02	1.49E+00	1.92E+00
	Mg ratio	Olivine microprobe	mg Fe / mg Mg	Beta	1.87E+00	6.75E-01	1.19E+00	4.51E+00
Ni	S ratio	Cat 4 Aqua Regia	mg Ni / mg S	Normal	3.06E-02	1.86E-03	--	--
	Mg ratio	Olivine microprobe	mg Ni / mg Mg	Beta	4.59E-03	1.95E-03	1.10E-04	7.43E-03

[1]Table reproduced from Large Table 8 in Reference (19). Notes below refer to citations in Reference (19).

Notes

- Humidity cell data used through February 2011 unless noted otherwise.
- HCT (1+2) indicates average rates from humidity cells over Condition 1 and Condition 2, as defined in Large Table 1.
- HCT (2) indicates average rates from humidity cells over Condition 2, as defined in Large Table 1.
- HCT (3) indicates average rates from humidity cells over Condition 3, as defined in Large Table 1.
- ***** indicates average rates from humidity cells over conditions noted with refined modeling of non-detects (see Section 8.1.2.1). Data used though December 2013.
- All distributions from humidity cell data represent the full range of the observed values, with no weighting. Distributions are shown in Large Figures 9-12.
- Acidic release rate for SO_4 to be determined from nonacidic rate times an acidic increase factor, as discussed in Section 8.2.5.
- Distributions from aqua regia data represent the uncertainty in the average ratios, weighted by geologic unit.
- Distributions from microprobe data represent the full range of the observed ratios for each mineral, with no weighting. Distributions are shown in Large Figures 21-22.
- For nickel, S ratio from Duluth Complex Category 4 aqua regia data represents the effect of all sulfide minerals combined. See example calculation in Section 8.1.2.3.
- For chloride, release is a one-time event per unit rock mass, developed from all Project humidity cells. See Section 8.4.4.

Table 2-22. Distribution Parameters for Ore Release[1]

Distribution from Regression Analysis of Humidity Cell Data

Constituent	*Method*	*Source*	*Units*	*Distribution*	*Mean/Mode*	*St. Dev.*	*Minimum*	*Maximum*
SO_4	Rate Regression	HCT (1+2)	mg SO_4/kg/week/%S	Normal	13.92	0.581	--	--

Distribution Fit to Humidity Cell Data

Constituent	*Method*	*Source*	*Units*	*Distribution*	*Mean/Mode*	*St. Dev.*	*Minimum*	*Maximum*
Alkalinity	Nonacidic rate	HCT (1+2)	mg Alk/kg/week	Triangular	1.52E+00	--	1.37E+00	1.52E+00
	Acidic rate	None	mg Alk/kg/week	Constant	0	--	--	--
B	Nonacidic rate	HCT (1+2)	mg B/kg/week	Triangular	5.85E-03	--	5.09E-03	1.49E-02
Ca	SO_4 rate ratio	HCT (1+2)	mg Ca / mg SO_4	Triangular	2.16E-01	--	2.16E-01	2.18E-01
Cd	Zn rate ratio	HCT (2)	mg Cd / mg Zn	Triangular	5.76E-03	--	5.76E-03	6.72E-03
Cl	First flush	HCT (all)	mg Cl / kg rock	Beta	9.78E+00	1.17E+01	1.38E+00	7.30E+01
Co	Ni rate ratio	HCT (2)	mg Co / mg Ni	Triangular	4.86E-02	--	4.86E-02	6.08E-02
Cr	Nonacidic rate	HCT (1+2)	mg Cr/kg/week	Triangular	1.10E-04	--	1.10E-04	1.18E-04
F	Nonacidic rate	HCT (1+2)	mg F/kg/week	Triangular	2.39E-02	--	2.39E-02	2.96E-02
K	SO_4 rate ratio	HCT (1+2)	mg K / mg SO_4	Triangular	3.97E-02	--	3.22E-02	4.16E-02
Mg	SO_4 rate ratio	HCT (1+2)	mg Mg / mg SO_4	Triangular	7.29E-02	--	7.29E-02	8.22E-02
Mn	SO_4 rate ratio	HCT (2)	mg Mn / mg SO_4	Triangular	5.89E-03	--	5.45E-03	6.27E-03
Na	SO_4 rate ratio	HCT (1+2)	mg Na / mg SO_4	Triangular	1.21E-02	--	1.21E-02	2.96E-01
Se	SO_4 rate ratio	HCT (2)	mg Se / mg SO_4	Triangular	4.01E-05	--	4.01E-05	4.42E-05
Tl	Nonacidic rate	HCT (1+2)	mg Tl/kg/week	Triangular	2.22E-05	--	1.74E-05	2.22E-05
Zn	Ni rate ratio	HCT (2)	mg Zn / mg Ni	Triangular	2.28E-02	--	2.26E-02	3.00E-02

Distribution from Aqua Regia Data

Constituent	*Method*	*Source*	*Units*	*Distribution*	*Mean/Mode*	*St. Dev.*	*Minimum*	*Maximum*
Ag	S ratio	Aqua Regia	mg Ag / mg S	Normal	1.87E-04	2.80E-06	--	--
As	S ratio	Aqua Regia	mg As / mg S	Normal	9.20E-04	3.48E-05	--	--
Ba	K ratio	Aqua Regia	mg Ba / mg K	Normal	2.77E-02	1.06E-04	--	--
Be	K ratio	Aqua Regia	mg Be / mg K	Normal	1.22E-04	1.97E-06	--	--
Cu	S ratio	Aqua Regia	mg Cu / mg S	Normal	5.04E-01	5.62E-03	--	--
Pb	S ratio	Aqua Regia	mg Pb / mg S	Normal	1.05E-03	4.85E-05	--	--
Sb	S ratio	Aqua Regia	mg Sb / mg S	Normal	3.38E-04	1.17E-05	--	--
V	K ratio	Aqua Regia	mg V / mg K	Normal	2.19E-02	3.36E-04	--	--

Distribution from Other Data

Constituent	*Method*	*Source*	*Units*	*Distribution*	*Mean/Mode*	*St. Dev.*	*Minimum*	*Maximum*
Al	Ca ratio	Anorthite Formula	mg Al / mg Ca	Constant	1.35E+00	--	--	--
	Na ratio	Albite Formula	mg Al / mg Na	Constant	1.17E+00	--	--	--
Fe	S ratio	Pyrrhotite microprobe	mg Fe / mg S	Beta	1.62E+00	8.72E-02	1.49E+00	1.92E+00
	Mg ratio	Olivine microprobe	mg Fe / mg Mg	Beta	1.87E+00	6.75E-01	1.19E+00	4.51E+00
Ni	S ratio	Ore Aqua Regia	mg Ni / mg S	Normal	1.53E-01	3.26E-03	--	--
	Mg ratio	Olivine microprobe	mg Ni / mg Mg	Beta	4.59E-03	1.95E-03	1.10E-04	7.43E-03

[1]Table reproduced from Large Table 9 in Reference (19). Notes below refer to citations in Reference (19).

<u>Notes</u>

- Humidity cell data used through February 2011 unless noted otherwise.
- HCT (1+2) indicates average rates from humidity cells over Condition 1 and Condition 2, as defined in Large Table 1.
- HCT (2) indicates average rates from humidity cells over Condition 2, as defined in Large Table 1.
- Except for SO4, all distributions from humidity cell data represent the full range of the observed values in the humidity cells, with no weighting. Distributions are shown in Large Figures 13-16. Distributions from humidity cells shown here are only used for the blended OSP; Category 2/3 humidity cells (see Large Table 8) are used to capture the full range of variability in the ore wall rock. Distributions are shown in Large Figures 13-16.
- Acidic release rate for SO_4 to be determined from nonacidic rate times an acidic increase factor, as discussed in Section 8.2.5.
- Distributions from aqua regia data represent the uncertainty in the average ratios, weighted by geologic unit.
- Distributions from microprobe data represent the full range of the observed ratios for each mineral, with no weighting. Distributions are shown in Large Figures 21-22.
- For nickel, S ratio from ore aqua regia data represents the effect of all sulfide minerals combined. See example calculation in Section 8.1.2.3.
- For B, Cr, F, and Tl no increase in release rates due to acidic conditions is indicated by laboratory data.
- For chloride, release is a one-time event per unit rock mass, developed from all Project humidity cells. See Section 8.4.4.

Table 2-23. Distribution Parameters for Virginia Formation Release[1]

Distribution Fit to Humidity Cell Data

Constituent	*Method*	*Source*	*Units*	*Distribution*	*Mean/Mode*	*St. Dev.*	*Minimum*	*Maximum*
Alkalinity	Acidic rate	None	mg Alk/kg/week	Constant	0	--	--	--
B	Acidic rate	HCT (3)	mg B/kg/week	Triangular	6.70E-03	--	6.70E-03	1.70E-02
Ca	SO_4 rate ratio	HCT (3)	mg Ca / mg SO_4	Triangular	2.32E-02	--	2.32E-02	2.50E-01
Cl	First flush	HCT (all)	mg Cl / kg rock	Beta	9.78E+00	1.17E+01	1.38E+00	7.30E+01
Cr	Acidic rate	HCT (3)	mg Cr/kg/week	Triangular	1.11E-04	--	9.14E-05	1.28E-04
F	Acidic rate	HCT (3)	mg F/kg/week	Triangular	2.50E-02	--	2.50E-02	4.98E-02
Fe	SO_4 rate ratio	HCT (3)	mg Fe / mg SO_4	Triangular	5.80E-02	--	3.98E-02	3.16E-01
K	SO_4 rate ratio	HCT (3)	mg K / mg SO_4	Triangular	8.03E-03	--	8.03E-03	1.79E-02
Mg	SO_4 rate ratio	HCT (3)	mg Mg / mg SO_4	Triangular	5.32E-02	--	2.93E-02	7.83E-02
Mn	Acidic rate	HCT (3)	mg Mn/kg/week	Triangular	7.11E-02	--	3.49E-02	1.56E-01
Na	SO_4 rate ratio	HCT (3)	mg Na / mg SO_4	Triangular	5.64E-03	--	5.64E-03	1.79E-02
Se	SO_4 rate ratio	HCT (3)	mg Se / mg SO_4	Triangular	8.52E-06	--	4.86E-06	9.20E-06
SO_4	Acidic rate	HCT (3)	mg SO_4/kg/week	Triangular	5.76E+01	--	4.44E+01	5.76E+01
Tl	Acidic rate	HCT (3)	mg Tl/kg/week	Triangular	1.11E-05	--	9.92E-06	1.21E-05

Distribution from Aqua Regia Data

Constituent	*Method*	*Source*	*Units*	*Distribution*	*Mean/Mode*	*St. Dev.*	*Minimum*	*Maximum*
Ag	S ratio	Aqua Regia	mg Ag / mg S	Normal	3.42E-05	2.23E-06	--	--
As	S ratio	Aqua Regia	mg As / mg S	Normal	2.87E-03	1.28E-04	--	--
Ba	K ratio	Aqua Regia	mg Ba / mg K	Normal	1.51E-02	5.79E-04	--	--
Be	S ratio	Aqua Regia	mg Be / mg S	Normal	1.02E-04	1.02E-05	--	--
Cd	S ratio	Aqua Regia	mg Cd / mg S	Normal	1.88E-04	5.11E-05	--	--
Co	S ratio	Aqua Regia	mg Co / mg S	Normal	4.26E-03	6.15E-04	--	--
Cu	S ratio	Aqua Regia	mg Cu / mg S	Normal	2.51E-02	2.59E-03	--	--
Ni	S ratio	Aqua Regia	mg Ni / mg S	Normal	1.76E-02	1.39E-03	--	--
Pb	S ratio	Aqua Regia	mg Pb / mg S	Normal	9.23E-04	3.07E-04	--	--
Sb	S ratio	Aqua Regia	mg Sb / mg S	Normal	2.70E-04	2.28E-05	--	--
V	K ratio	Aqua Regia	mg V / mg K	Normal	2.18E-02	1.07E-03	--	--
Zn	S ratio	Aqua Regia	mg Zn / mg S	Normal	3.03E-02	2.88E-03	--	--

Distribution from Other Data

Constituent	*Method*	*Source*	*Units*	*Distribution*	*Mean/Mode*	*St. Dev.*	*Minimum*	*Maximum*
Al	Ca ratio	Anorthite Formula	mg Al / mg Ca	Constant	1.35E+00	--	--	--
	Na ratio	Albite Formula	mg Al / mg Na	Constant	1.17E+00	--	--	--

[1]Table reproduced from Large Table 10 in Reference (19). Notes below refer to citations in Reference (19).

<u>Notes</u>

- Humidity cell data used through February 2011 unless noted otherwise.
- HCT (3) indicates average rates from humidity cells over Condition 3, as defined in Large Table 1.
- All distributions from humidity cell data represent the full range of the observed values, with no weighting. Distributions are shown in Large Figures 17-20.
- Distributions from aqua regia data represent the uncertainty in the average ratios, weighted by geologic unit.
- For chloride, release is a one-time event per unit rock mass, developed from all Project humidity cells. See Section 8.4.4.

Table 2-24. Distribution Parameters for Flotation Fine Tailings Release[1]

Distribution Fit to Humidity Cell Data

Constituent	*Method*	*Source*	*Units*	*Distribution*	*Mean/Mode*	*St. Dev.*	*Minimum*	*Maximum*
Ca	SO_4 rate ratio	HCT	mg Ca / mg SO_4	Beta	1.18E+00	3.03E-01	8.17E-01	3.45E+00
K	SO_4 rate ratio	HCT	mg K / mg SO_4	Beta	2.63E-01	6.37E-02	1.71E-01	7.51E-01
Mg	SO_4 rate ratio	HCT	mg Mg / mg SO_4	Beta	2.18E-01	4.69E-02	1.62E-01	7.94E-01
Mn	Ni rate ratio	HCT	mg Mn / mg Ni	Beta	4.68E+00	2.25E+00	2.07E+00	9.31E+00
Na	SO_4 rate ratio	HCT	mg Na / mg SO_4	Beta	8.20E-02	1.77E-02	6.03E-02	2.64E-01
Se	SO_4 rate ratio	HCT	mg Se / mg SO_4	Beta	1.79E-05	5.29E-06	1.29E-05	6.09E-05
SO_4	Rate	HCT*	mg SO_4/kg/week	Beta	1.88E+01	2.87E+00	2.66E+00	2.32E+01

Distribution Fit to Aqua Regia Data

Constituent	*Method*	*Source*	*Units*	*Distribution*	*Mean/Mode*	*St. Dev.*	*Minimum*	*Maximum*
Ag	S ratio	Aqua Regia	mg Ag / mg S	Beta	1.54E-04	1.49E-05	1.35E-04	2.54E-04
As	S ratio	Aqua Regia	mg As / mg S	Beta	1.96E-03	2.53E-04	1.67E-03	4.89E-03
Ba	K ratio	Aqua Regia	mg Ba / mg K	Beta	2.66E-02	1.27E-03	1.83E-02	3.06E-02
Be	K ratio	Aqua Regia	mg Be / mg K	Beta	1.03E-04	1.51E-05	8.13E-05	2.32E-04
Cu	S ratio	Aqua Regia	mg Cu / mg S	Beta	9.30E-02	1.46E-02	5.29E-02	1.46E-01
Pb	S ratio	Aqua Regia	mg Pb / mg S	Beta	2.67E-03	6.16E-04	1.93E-03	9.32E-03
Sb	S ratio	Aqua Regia	mg Sb / mg S	Beta	1.08E-04	3.50E-05	6.67E-05	1.99E-04
Tl	S ratio	Aqua Regia	mg Tl / mg S	Beta	7.15E-05	7.35E-06	5.97E-05	1.41E-04
V	K ratio	Aqua Regia	mg V / mg K	Beta	2.53E-02	2.61E-03	7.01E-03	3.17E-02

Distribution Fit to Waste Rock Humidity Cell Data

Constituent	*Method*	*Source*	*Units*	*Distribution*	*Mean/Mode*	*St. Dev.*	*Minimum*	*Maximum*
Cd	Zn rate ratio	2/3 HCT (2)	mg Cd / mg Zn	Beta	1.65E-02	1.20E-02	1.01E-03	5.84E-02
Co	Ni rate ratio	2/3 HCT (2)	mg Co / mg Ni	Beta	8.29E-02	3.91E-02	2.24E-02	2.06E-01
Zn	Ni rate ratio	2/3 HCT (2)	mg Zn / mg Ni	Beta	3.35E-01	3.71E-01	3.31E-02	1.60E+00

Distribution Fit to Microprobe Data or Mineral Formula

Constituent	*Method*	*Source*	*Units*	*Distribution*	*Mean/Mode*	*St. Dev.*	*Minimum*	*Maximum*
Al	Ca ratio	Anorthite Formula	mg Al / mg Ca	Constant	1.35E+00	--	--	--
	Na ratio	Albite Formula	mg Al / mg Na	Constant	1.17E+00	--	--	--
Fe	S ratio	Pyrrhotite microprobe	mg Fe / mg S	Beta	1.62E+00	8.72E-02	1.49E+00	1.92E+00
	Mg ratio	Olivine microprobe	mg Fe / mg Mg	Beta	1.87E+00	6.75E-01	1.19E+00	4.51E+00
Ni	S ratio	Pyrrhotite microprobe	mg Ni / mg S	Beta	5.63E-03	6.65E-03	5.65E-04	4.00E-02

Distribution From Defined Concentration Cap

Constituent	*Method*	*Source*	*Units*	*Distribution*	*Mean/Mode*	*St. Dev.*	*Minimum*	*Maximum*
Cl	No release	N/A	mg/L	Constant	0	--	--	--
B	Cap	Whistle Mine	mg/L	Constant	1.00E-01	--	--	--
Cr	Cap	Whistle Mine	mg/L	Constant	1.00E-02	--	--	--

[1]Table reproduced from Large Table 16 in Reference (19). Notes below refer to citations in Reference (19).

<u>Notes</u>

- HCT indicates average rates from tailings humidity cells over the entire testing period. Data used through April 2011.
- For sulfate, the release rate is the estimated release rate at the initial sulfur content for each humidity cell.
- Aqua Regia indicates ratios from whole tailings testing.
- Cat 2/3 HCT (2) indicates average rates from Category 2/3 humidity cells over Condition 2, as defined in Large Table 1.
- All distributions from humidity cell data and aqua regia data represent the full range of the observed values, with no weighting. Distributions are shown in Large Figure 42 to Large Figure 45.
- Distributions from microprobe data represent the full range of the observed ratios for each mineral, with no weighting. Distributions are shown in Large Figure 21 and Large Figure 22.
- Constituents not shown above are modeled according to the mineral solubility methods described in Section 10.1.1.

Table 2-25. Distribution Parameters for Flotation Coarse Tailings Release[1]

Distribution Fit to Humidity Cell Data

Constituent	Method	Source	Units	Distribution	Mean/Mode	St. Dev.	Minimum	Maximum
Ca	SO_4 rate ratio	HCT	mg Ca / mg SO_4	Beta	9.58E-01	3.34E-01	3.00E-01	1.60E+00
K	SO_4 rate ratio	HCT	mg K / mg SO_4	Beta	2.60E-01	8.16E-02	0.00E+00	4.91E-01
Mg	SO_4 rate ratio	HCT	mg Mg / mg SO_4	Beta	1.82E-01	3.32E-02	9.68E-02	5.46E-01
Mn	Ni rate ratio	HCT	mg Mn / mg Ni	Beta	3.37E+00	1.32E+00	1.80E+00	1.00E+01
Na	SO_4 rate ratio	HCT	mg Na / mg SO_4	Beta	6.86E-02	2.40E-02	3.58E-02	2.57E-01
Se	SO_4 rate ratio	HCT	mg Se / mg SO_4	Beta	1.75E-05	3.51E-06	0.00E+00	2.41E-05
SO_4	Rate	HCT	mg SO_4/kg/week	Beta	1.19E+01	2.55E+00	4.37E+00	2.13E+01

Distribution Fit to Aqua Regia Data

Constituent	Method	Source	Units	Distribution	Mean/Mode	St. Dev.	Minimum	Maximum
Ag	S ratio	Aqua Regia	mg Ag / mg S	Beta	2.05E-04	3.41E-05	1.42E-04	5.45E-04
As	S ratio	Aqua Regia	mg As / mg S	Beta	1.82E-03	3.31E-04	9.17E-04	5.09E-03
Ba	K ratio	Aqua Regia	mg Ba / mg K	Beta	2.74E-02	1.81E-03	2.01E-02	4.02E-02
Be	K ratio	Aqua Regia	mg Be / mg K	Beta	9.77E-05	9.41E-06	5.71E-05	1.53E-04
Cu	S ratio	Aqua Regia	mg Cu / mg S	Beta	2.11E-01	5.25E-02	2.95E-03	7.00E-01
Pb	S ratio	Aqua Regia	mg Pb / mg S	Beta	2.88E-03	7.68E-04	1.18E-03	1.08E-02
Sb	S ratio	Aqua Regia	mg Sb / mg S	Beta	1.10E-04	3.06E-05	5.45E-05	2.50E-04
Tl	S ratio	Aqua Regia	mg Tl / mg S	Beta	9.44E-05	1.27E-05	6.67E-05	1.86E-04
V	K ratio	Aqua Regia	mg V / mg K	Beta	1.81E-02	2.66E-03	1.81E-03	3.00E-02

Distribution Fit to Waste Rock Humidity Cell Data

Constituent	Method	Source	Units	Distribution	Mean/Mode	St. Dev.	Minimum	Maximum
Cd	Zn rate ratio	2/3 HCT (2)	mg Cd / mg Zn	Beta	1.65E-02	1.20E-02	1.01E-03	5.84E-02
Co	Ni rate ratio	2/3 HCT (2)	mg Co / mg Ni	Beta	8.29E-02	3.91E-02	2.24E-02	2.06E-01
Zn	Ni rate ratio	2/3 HCT (2)	mg Zn / mg Ni	Beta	3.35E-01	3.71E-01	3.31E-02	1.60E+00

Distribution Fit to Microprobe Data or Mineral Formula

Constituent	Method	Source	Units	Distribution	Mean/Mode	St. Dev.	Minimum	Maximum
Al	Ca ratio	Anorthite Formula	mg Al / mg Ca	Constant	1.35E+00	--	--	--
	Na ratio	Albite Formula	mg Al / mg Na	Constant	1.17E+00	--	--	--
Fe	S ratio	Pyrrhotite microprobe	mg Fe / mg S	Beta	1.62E+00	8.72E-02	1.49E+00	1.92E+00
	Mg ratio	Olivine microprobe	mg Fe / mg Mg	Beta	1.87E+00	6.75E-01	1.19E+00	4.51E+00
Ni	S ratio	Pyrrhotite microprobe	mg Ni / mg S	Beta	5.63E-03	6.65E-03	5.65E-04	4.00E-02

Distribution From Defined Concentration Cap

Constituent	Method	Source	Units	Distribution	Mean/Mode	St. Dev.	Minimum	Maximum
Cl	No release	N/A	mg/L	Constant	0	--	--	--
B	Cap	Whistle Mine	mg/L	Constant	1.00E-01	--	--	--
Cr	Cap	Whistle Mine	mg/L	Constant	1.00E-02	--	--	--

[1]Table reproduced from Large Table 17 in Reference (19). Notes below refer to citations in Reference (19).

Notes

- HCT indicates average rates from tailings humidity cells over the entire testing period. Data used through April 2011.
- For sulfate, the release rate is the estimated release rate at the initial sulfur content for each humidity cell.
- Aqua Regia indicates ratios from whole tailings testing.
- Cat 2/3 HCT (2) indicates average rates from Category 2/3 humidity cells over Condition 2, as defined in Large Table 1.
- All distributions from humidity cell data and aqua regia data represent the full range of the observed values, with no weighting. Distributions are shown in Large Figure 46 to Large Figure 49.
- Distributions from microprobe data represent the full range of the observed ratios for each mineral, with no weighting. Distributions are shown in Large Figure 21 and Large Figure 22.
- Constituents not shown above are modeled according to the mineral solubility methods described in Section 10.1.1.

Table 2-26. Distribution Parameters for LTVSMC Tailings Release[1]

Distribution Fit to Humidity Cell Data

Constituent	*Method*	*Source*	*Units*	*Distribution*	*Mean/Mode*	*St. Dev.*	*Minimum*	*Maximum*
Se	SO_4 rate ratio	HCT	mg Se / mg SO_4	Beta	7.22E-05	4.63E-05	3.04E-05	3.04E-04
SO_4	Rate	HCT	mg SO_4/kg/week	Beta	1.87E+00	5.02E-01	8.13E-01	2.54E+00
Zn	SO_4 rate ratio	HCT	mg Zn / mg SO_4	Beta	5.32E-05	9.20E-06	4.28E-05	8.33E-05

Distribution Fit to Aqua Regia Data

Constituent	*Method*	*Source*	*Units*	*Distribution*	*Mean/Mode*	*St. Dev.*	*Minimum*	*Maximum*
Ag	S ratio	Aqua Regia	mg Ag / mg S	Beta	1.85E-04	1.51E-04	3.47E-05	1.99E-03
As	S ratio	Aqua Regia	mg As / mg S	Beta	1.11E-01	5.43E-02	2.85E-02	8.75E-01
Cd	S ratio	Aqua Regia	mg Cd / mg S	Beta	7.69E-05	6.83E-05	8.21E-06	4.62E-03
Co	S ratio	Aqua Regia	mg Co / mg S	Beta	4.10E-02	3.17E-02	9.94E-03	3.75E-01
Cu	S ratio	Aqua Regia	mg Cu / mg S	Beta	4.26E-02	3.66E-02	7.95E-03	7.00E-01
Ni	S ratio	Aqua Regia	mg Ni / mg S	Beta	1.71E-02	1.10E-02	3.46E-03	1.92E-01
Pb	S ratio	Aqua Regia	mg Pb / mg S	Beta	6.66E-03	3.95E-03	1.12E-03	4.17E-02
Sb	S ratio	Aqua Regia	mg Sb / mg S	Beta	3.44E-04	2.34E-04	8.93E-05	2.92E-03
Tl	S ratio	Aqua Regia	mg Tl / mg S	Beta	9.04E-05	7.48E-05	1.95E-05	8.33E-04

Distribution Fit to Microprobe Data

Constituent	*Method*	*Source*	*Units*	*Distribution*	*Mean/Mode*	*St. Dev.*	*Minimum*	*Maximum*
Fe	S ratio	Pyrite microprobe	mg Fe / mg S	Beta	8.85E-01	1.36E-02	8.50E-01	9.06E-01

Distribution Fit to Observed Seepage Data

Constituent	*Method*	*Source*	*Units*	*Distribution*	*Mean/Mode*	*St. Dev.*	*Minimum*	*Maximum*
Al	Cap	Well Data	mg/L	Uniform	--	--	5.00E-03	2.50E-02
B	Cap	Well Data	mg/L	Beta	3.39E-01	1.03E-01	2.50E-02	5.65E-01
Be	Cap	Well Data	mg/L	Uniform	--	--	1.00E-04	2.50E-04
Ca	Cap	Well Data	mg/L	Beta	7.86E+01	3.79E+01	1.39E+01	1.77E+02
Cl	Cap	Well Data	mg/L	Beta	2.04E+01	7.74E+00	9.25E-01	2.97E+01
Cr	Cap	Well Data	mg/L	Beta	3.65E-03	4.90E-03	4.46E-04	2.81E-02
K	Cap	Well Data	mg/L	Beta	5.58E+00	3.87E+00	1.54E+00	2.02E+01
Mg	Ca ratio	Well Data	mg Mg / mg Ca	Beta	1.07E+00	4.57E-01	5.80E-01	2.10E+00
Mn	Cap	Well Data	mg/L	Beta	9.34E-01	9.92E-01	4.46E-02	6.54E+00
Na	Cap	Well Data	mg/L	Beta	6.01E+01	2.15E+01	4.18E+01	1.51E+02
V	Cap	Well Data	mg/L	Uniform	--	--	5.00E-04	1.00E-03

[1]Table reproduced from Large Table 18 in Reference (19). Notes below refer to citations in Reference (19).

Notes

- HCT indicates average rates from tailings humidity cells over the entire testing period. Data used through April 2011.
- Aqua Regia indicates ratios from whole tailings testing.
- Cat 2/3 HCT (2) indicates average rates from Category 2/3 humidity cells over Condition 2, as defined in Large Table 1.
- All distributions from humidity cell data, aqua regia and microprobe data represent the full range of the observed values, with no weighting. Distributions are shown in Large Figure 50 to Large Figure 52.
- All distributions from well data represent the full range of observed values for wells GW-001, GW-006, GW-007, GW-008, and GW-012. Distributions are shown in Large Figure 53 to Large Figure 55.
- Constituents not shown above are modeled according to the mineral solubility methods described in Section 10.1.2.

Table 2-27. Summary of NorthMet Project Humidity Cells (Waste Rock and Ore)[1]

Rock Type	*Waste Category*	*Sample ID*	*Sulfur (%)*	*Condition 1 Start (weeks)*	*Condition 2 Start (weeks)*	*Condition 3 Start (weeks)*	*Condition 4 Start (weeks)*	*Total Duration (weeks)*
Anorthositic	1	99-320C(830-850)	0.09	4	179	-	-	436
Anorthositic	1	00-361C(345-350)	0.05	6	184	-	-	436
Anorthositic	1	00-366C(185-205)	0.02	0	-	-	-	198
Anorthositic	1	00-366C(230-240)	0.02	4	60	-	-	198
Anorthositic	1	99-320C(165-175)	0.03	0	72	-	-	198
Anorthositic	1	00-334C(30-50)	0.02	4	-	-	-	436
Anorthositic	1	00-368C(125-145)	0.04	0	80	-	-	436
Anorthositic	1	00-368C(20-40)	0.04	0	80	-	-	198
Troctolitic	1	00-340C(595-615)	0.04	0	-	-	-	198
Troctolitic	1	00-334C(580-600)	0.06	1	179	-	-	436
Troctolitic	1	00-334C(640-660)	0.07	12	224	-	-	436
Troctolitic	1	00-347C(795-815)	0.07	0	103	-	-	198
Troctolitic	1	99-318C(250-270)	0.04	0	72	-	-	198
Troctolitic	1	00-373C(95-115)	0.04	0	-	-	-	198
Troctolitic	1	00-373C(75-95)	0.06	0	-	-	-	198
Troctolitic	1	00-357C(110-130)	0.08	10	-	-	-	198
Troctolitic	1	99-320C(315-330)	0.07	4	72	-	-	436
Troctolitic	1	00-366C(35-55)	0.02	0	-	-	-	198
Troctolitic	1	00-334C(110-130)	0.04	0	-	-	-	198
Troctolitic	1	00-347C(155-175)	0.06	0	72	-	-	198
Troctolitic	1	00-347C(280-300)	0.06	16	65	-	-	198
Troctolitic	1	00-367C(50-65)	0.03	0	-	-	-	198
Troctolitic	1	00-367C(260-280)	0.04	0	-	-	-	198
Troctolitic	1	00-367C(290-310)	0.04	0	-	-	-	436
Troctolitic	1	00-370C(20-30)	0.08	10	-	-	-	198
Troctolitic	1	26064(44-54)	0.02	0	-	-	-	436
Troctolitic	1	26064(264+146269+156)	0.06	4	-	-	-	436
Troctolitic	1	26056(110-125)	0.04	0	-	-	-	198
Troctolitic	1	26029(815-825)	0.02	0	-	-	-	194
Troctolitic	1	26056(135-153)	0.05	0	-	-	-	430
Troctolitic	1	00-326C(250-265)	0.08	4	-	-	-	186
Ultramafic	1	00-357C(335-340)	0.08	12	187	-	-	198
Ultramafic	1	00-368C(460-465)	0.06	0	-	-	-	198
Ultramafic	1	26055(940-945)	0.06	16	-	-	-	198
Ultramafic	1	26098+00-337C	0.1	0	-	-	-	198
Ultramafic	1	00-361C(240-245)	0.06	14	184	-	-	436
Ultramafic	1	26039(310-315)	0.06	8	-	-	-	186
Ultramafic	1	00-326C(225-235)	0.12	8	-	-	-	425
Anorthositic	2/3	00-361C(310-320)	0.18	0	111	-	-	436
Anorthositic	2/3	99-320C(400-405)	0.18	14	-	-	-	425
Sedimentary Hornfels	2/3	26030(1047-1052)	0.24	53	-	-	-	436
Sedimentary Hornfels	2/3	26061(1218-1233)	0.44	4	-	-	-	436
Sedimentary Hornfels	2/3	00-340C(990-995)	0.55	0	189	-	-	436
Troctolitic	2/3	00-350C(580-600)	0.19	0	196	-	-	436
Troctolitic	2/3	00-327C(225-245)	0.44	0	182	-	-	198
Troctolitic	2/3	00-369C(335-345)	0.18	4	181	-	-	436
Troctolitic	2/3	00-326C(60-70)	0.14	0	75	164	-	436
Troctolitic	2/3	00-369C(305-325)	0.25	4	187	-	-	436
Troctolitic	2/3	00-369C(20-30)	0.21	0	187	-	-	436
Troctolitic	2/3	00-367C(170-175)	0.51	0	172	-	-	436
Troctolitic	2/3	00-340C(380-390)	0.15	4	-	-	-	198
Troctolitic	2/3	26049+26030	0.59	4	-	-	-	198
Troctolitic	2/3	26056(302-312)	0.23	12	212	-	-	436
Troctolitic	2/3	26142(360+345-365+350)	0.18	0	168	-	-	436
Troctolitic	2/3	99-318C(325-330)	0.17	0	180	-	-	425
Troctolitic	2/3	26056(282-292)	0.32	2	178	-	-	186
Troctolitic	**2/3**	**00-340C(910-925)**	**0.36**	**0**	**72**	**110**	**180**	**425**
Troctolitic	**2/3**	**00-331C(190-210)**	**0.42**	**0**	**48**	**201**	**229**	**425**
Troctolitic	2/3	00-367C(495-500)	0.28	8	114	-	-	425
Ultramafic	2/3	00-326C(680-685)	0.3	0	69	-	-	198
Ultramafic	2/3	00-357C(535-540)	0.2	0	78	194	194	436
Ultramafic	**2/3**	**00-344C(630-635)**	**0.34**	**0**	**51**	**160**	**-**	**186**
Ultramafic	2/3	00-326C(495-505)	0.16	0	-	-	-	186

Table 2-27. Summary of NorthMet Project Humidity Cells (Waste Rock and Ore) (Cont.)[1]

Rock Type	*Waste Category*	*Sample ID*	*Sulfur (%)*	*Condition 1 Start (weeks)*	*Condition 2 Start (weeks)*	*Condition 3 Start (weeks)*	*Condition 4 Start (weeks)*	*Total Duration (weeks)*
Anorthositic	4	00-343C(240-250)	0.68	0	161	-	-	198
Anorthositic* **	**4**	**26027(616-626)*** **	**1.83**	**4**	**18**	**24**	**-**	**436**
Anorthositic* **	**4**	**00-331C(255-260)*** **	**0.86**	**0**	**19**	**162**	**184**	**425**
Sedimentary Hornfels	**4**	**00-340C(965-974.5)**	**1.74**	**0**	**25**	**34**	**80**	**198**
Sedimentary Hornfels	**4**	**26043+26027**	**2.47**	**0**	**9**	**26**	**48**	**436**
Sedimentary Hornfels	4	26062+26026	4.46	0	3	3	-	438
Sedimentary Hornfels	4	26058(704-715)	1.46	8	41	-	-	427
Troctolitic* **	**4**	**00-371C(435-440)*** **	**0.88**	**0**	**51**	**90**	**196**	**436**
Troctolitic* **	**4**	**00-340C(765-780)*** **	**1.68**	**0**	**61**	**82**	**200**	**436**
Troctolitic	4	00-367C(395-400)	0.77	0	82	-	-	198
Troctolitic	4	00-340C(725-745)	0.91	6	118	-	-	198
Troctolitic	**4**	**00-367C(400-405)**	**1.37**	**4**	**39**	**78**	**-**	**198**
Ultramafic	4	99-318C(725-735)	0.72	0	96	-	-	198
Ultramafic	4	99-317C(460-470)	1.24	0	39	-	-	198
Ultramafic	**4**	**00-344C(515-520)**	**1.2**	**4**	**47**	**152**	**-**	**198**
Ultramafic	4	00-330C(275-280)	0.75	0	164	-	-	186
Virginia	4	00-361C(737-749)	2	0	39	164	194	436
Virginia	4	00-364C(210-229)	3.79	0	0	5	-	436
Virginia	4	00-337C(510-520)	5.68	0	0	5	-	198
Ore Composite	4	P10	0.86	4	88	-	-	432
Ore Composite	4	P20	0.9	6	88	-	-	434
Ore Composite	4	P30	0.86	6	88	-	-	432

[1]Table reproduced from Large Table 1 in Reference (19). Notes below refer to citations in Reference (19).

Notes

- Time periods as of December 20, 2013. "--" indicates condition not observed.
- Condition 1: relatively stable sulfate release, leachate pH above about 7
- Condition 2: relatively stable sulfate release, leachate pH below about 7 and nickel release unstable and typically increasing (i.e., neutral conditions)
- Condition 3: sulfate release increasing and variable, pH decreasing
- Condition 4: sulfate release decreasing following peak, acidic pH
- Humidity cells in **bold** are used to develop the acidity factor in Section 8.2.5
- Humidity cells marked with (***) are used to develop decay relationships in Section 9.4. Although several cells had not reached Condition 4 as of February 24, 2011, decay relationships were evident in further analysis as of July 2011.

Table 2-28. Summary of NorthMet Project Humidity Cells (Tailings)[1]

Tailings Portion	*Tailings Source*	*Size (Mesh)*	*HCT ID*	*Sulfur (%)*	*Total Duration (weeks)*
Fine	Parcel 1-2	< #200	T10	0.09	413
Fine	Parcel 3	< #200	T13	0.14	413
Fine	Pilot Plant 2	< #200	T55	0.09	276
Fine	Pilot Plant 3	< #200	T59	0.08	288
Fine	SCAV	< #200	T63	0.11	216
Fine	SCAV	< #200	T67	0.14	216
Fine	SCAV	< #200	T71	0.13	216
Coarse	Parcel 1-2	#200 - #100	T9	0.1	413
Coarse	Parcel 3	#200 - #100	T12	0.14	413
Coarse	Pilot Plant 2	#200 - #100	T54	0.06	288
Coarse	Pilot Plant 3	#200 - #100	T58	0.08	288
Coarse	SCAV	#200 - #100	T62	0.09	216
Coarse	SCAV	#200 - #100	T66	0.14	216
Coarse	SCAV	#200 - #100	T70	0.1	216
Coarse	Parcel 1-2	> #100	T8	0.11	413
Coarse	Parcel 3	> #100	T11	0.11	413
Coarse	Pilot Plant 2	> #100	T53	0.08	288
Coarse	Pilot Plant 3	> #100	T57	0.1	288
Coarse	SCAV	> #100	T61	0.1	216
Coarse	SCAV	> #100	T65	0.11	216
Coarse	SCAV	> #100	T69	0.1	216
LTVSMC	2E North Embankment	Whole LTVSMC	T73	0.03	181
LTVSMC	1E/2E Separator	Whole LTVSMC	T75	0.04	181
LTVSMC	1E South Beach	Whole LTVSMC	T76	0.01	181
LTVSMC	2W North Embankment	Whole LTVSMC	T77	0.06	181

[1]Table reproduced from Large Table 4 in Reference (19). Notes below refer to citations in Reference (19).

Notes

- Time periods as of January 17, 2014.
- All Flotation Tailings samples included the use of $CuSO_4$ in the pilot plant processing
- All humidity cells referenced here were conducted according to ASTM methods
- Material retained on mesh #100 (previously referred to as “coarse”) and material passing mesh #100 but retained on mesh #200 (previously referred to as “mid”) are collectively considered as coarse material (retained on mesh #200) according to the modeling methodology described in Section 5.1.3.1

Table 2-29. Summary of NorthMet Project Humidity Cells (Tailings)[1]

Constituent	*Category 1 Waste Rock*	*Category 2/3 Waste Rock*	*Duluth Complex Category 4 Waste Rock*	*Virginia Formation Category 4 Waste Rock*	*Ore*
Silver	1.35E-01	2.80E-01	3.63E-01	3.61E-01	1.31E+00
Aluminum	4.07E+04	3.86E+04	4.04E+04	3.23E+04	3.84E+04
Alkalinity	--	--	--	--	--
Arsenic	2.47E+00	3.52E+00	1.99E+01	3.20E+01	6.92E+00
Boron	7.94E+00	7.32E+00	9.16E+00	8.82E+00	5.02E+00
Barium	4.07E+01	4.85E+01	5.57E+01	1.04E+02	4.72E+01
Beryllium	2.43E-01	2.66E-01	6.15E-01	5.77E-01	1.81E-01
Calcium	2.22E+04	2.18E+04	1.79E+04	5.93E+03	2.11E+04
Cadmium	4.19E-01	4.59E-01	7.34E-01	1.42E+00	9.72E-01
Chlorine	--	--	--	--	--
Cobalt	4.83E+01	4.99E+01	6.05E+01	2.56E+01	7.48E+01
Chromium	1.01E+02	8.74E+01	1.23E+02	1.86E+02	8.26E+01
Copper	2.15E+02	7.47E+02	7.18E+02	2.17E+02	3.58E+03
Fluoride	--	--	--	--	--
Iron	6.17E+04	5.97E+04	5.47E+04	5.28E+04	7.14E+04
Potassium	1.40E+03	1.72E+03	2.66E+03	8.18E+03	1.75E+03
Magnesium	4.00E+04	3.30E+04	2.00E+04	1.37E+04	3.63E+04
Manganese	7.01E+02	6.28E+02	3.69E+02	2.43E+02	6.65E+02
Sodium	5.80E+03	5.12E+03	3.40E+03	9.94E+02	4.87E+03
Nickel	2.55E+02	3.29E+02	3.33E+02	1.35E+02	9.72E+02
Lead	2.45E+00	2.52E+00	5.10E+00	5.87E+00	6.22E+00
Antimony	1.34E+00	1.31E+00	1.48E+00	1.74E+00	1.78E+00
Selenium	--	--	--	--	--
Sulfur	6.40E+02	2.10E+03	9.50E+03	2.43E+04	9.00E+03
Thallium	4.78E+00	4.74E+00	4.75E+00	4.30E+00	3.40E+00
Vanadium	3.32E+01	3.77E+01	9.11E+01	1.36E+02	3.69E+01
Zinc	6.83E+01	7.18E+01	1.04E+02	2.51E+02	8.11E+01

[1] Table adapted from Table 8-8 of Reference (19).

Notes

- Aqua regia data not available for alkalinity, chlorine, fluoride and selenium. No depletion is modeled.
- Sulfur values are from the Block Model, not the aqua regia dataset.

Table 2-30. Distribution Parameters for Category 1 Waste Rock Concentration Caps[1]

Cap Value From Various Data Sources

Constituent	*Method*	*Source*	*Units*	*Distribution*	*Mean/Mode*	*Std. Deviation*	*Min.*	*Max.*
Ag	Limit	Dunka Seep	mg/L	Constant	2.00E-04	--	--	--
As	Limit	Whistle Mine	mg/L	Constant	1.00E-01	--	--	--
B	Limit	Whistle Mine	mg/L	Constant	1.00E-01	--	--	--
Be	Limit	Dunka Seep	mg/L	Constant	4.00E-04	--	--	--
Cr	Limit	Whistle Mine	mg/L	Constant	1.00E-02	--	--	--
Pb	Limit	Whistle Mine	mg/L	Constant	1.00E-01	--	--	--
Sb	Limit	NorthMet Lab Data	mg/L	Uniform	--	--	8.30E-03	1.00E-01
Tl	Limit	Dunka Seep	mg/L	Constant	2.00E-04	--	--	--
V	Limit	Whistle Mine	mg/L	Constant	1.00E-02	--	--	--

pH-based Range from AMAX Data
(95th percentile values, all units mg/L)

pH	*Alkalinity*	*Co*	*Cu*	*Fe*	*K*	*Mn*	*Na*	*Ni*	*Zn*
8.1	5.00E+01	3.00E-02	3.00E-02	2.00E-02	4.00E+01	1.40E-01	2.40E+02	3.60E-01	2.00E-02
8.0	4.50E+01	1.00E-02	2.00E-02	2.00E-02	4.30E+01	1.40E-01	1.15E+02	2.00E-01	5.20E-02
7.9	4.00E+01	7.58E-02	5.73E-02	3.80E-02	4.80E+01	2.88E-01	3.90E+02	5.26E-01	8.88E-02
7.8	4.20E+01	6.00E-02	1.31E-01	5.50E-02	3.95E+01	2.05E-01	3.70E+02	3.75E-01	6.50E-02
7.7	4.50E+01	4.36E-02	1.23E-01	6.35E-02	4.37E+01	3.19E-01	4.68E+02	4.85E-01	1.15E-01
7.6	5.07E+01	4.00E-02	1.54E-01	7.75E-02	4.72E+01	2.10E-01	3.10E+02	4.55E-01	1.19E-01
7.5	4.82E+01	5.00E-02	1.00E-01	4.00E-02	4.60E+01	2.27E-01	2.18E+02	9.05E-01	9.64E-02
7.4	4.92E+01	7.00E-02	9.68E-02	4.20E-02	4.28E+01	1.72E-01	2.19E+02	1.28E+00	7.00E-02
7.3	3.59E+01	9.30E-02	2.00E-01	5.00E-02	5.04E+01	2.00E-01	2.31E+02	1.62E+00	1.33E-01
7.2	3.55E+01	1.36E-01	1.78E-01	1.01E-01	4.28E+01	1.75E-01	1.73E+02	2.08E+00	1.70E-01
7.1	3.45E+01	2.33E-01	2.85E-01	7.50E-02	4.61E+01	3.86E-01	1.38E+02	4.31E+00	2.93E-01
7.0	2.60E+01	2.80E-01	5.20E-01	4.00E-02	3.99E+01	3.08E-01	1.32E+02	5.91E+00	4.05E-01

pH-based Range from AMAX Data
(maximum values, all units mg/L)

pH	*Alkalinity*	*Co*	*Cu*	*Fe*	*K*	*Mn*	*Na*	*Ni*	*Zn*
8.1	7.00E+01	4.00E-02	4.00E-02	6.00E-02	4.60E+01	1.60E-01	3.17E+02	4.60E-01	2.50E-02
8.0	5.50E+01	1.00E-02	2.00E-02	2.00E-02	4.30E+01	1.40E-01	1.15E+02	2.00E-01	5.20E-02
7.9	4.00E+01	9.00E-02	6.00E-02	4.00E-02	4.90E+01	2.90E-01	3.95E+02	5.65E-01	9.00E-02
7.8	5.90E+01	7.00E-02	1.70E-01	6.00E-02	4.00E+01	2.40E-01	3.72E+02	4.20E-01	7.00E-02
7.7	5.10E+01	5.20E-02	1.31E-01	7.00E-02	5.00E+01	3.40E-01	5.55E+02	5.90E-01	1.20E-01
7.6	5.90E+01	6.00E-02	1.90E-01	2.10E-01	5.20E+01	2.30E-01	3.39E+02	1.07E+00	1.34E-01
7.5	5.27E+01	5.00E-02	1.30E-01	7.00E-02	6.00E+01	2.40E-01	3.13E+02	1.70E+00	1.00E-01
7.4	5.40E+01	8.00E-02	1.80E-01	6.00E-02	5.32E+01	1.90E-01	3.22E+02	1.35E+00	1.12E-01
7.3	3.60E+01	1.20E-01	2.60E-01	6.00E-02	5.90E+01	3.00E-01	2.60E+02	2.29E+00	2.30E-01
7.2	4.50E+01	1.50E-01	3.40E-01	7.00E-01	4.43E+01	2.40E-01	2.00E+02	3.42E+00	2.30E-01
7.1	4.10E+01	3.10E-01	7.50E-01	8.00E-02	4.80E+01	9.70E-01	5.91E+02	7.02E+00	3.70E-01
7.0	4.30E+01	6.20E-01	2.30E+00	4.00E-02	4.30E+01	3.80E-01	2.60E+02	1.30E+01	5.50E-01

[1]Table reproduced from Large Table 12 in Reference (19). Notes below refer to citations in Reference (19).

Notes

- All distributions from AMAX data represent a uniform distribution between the 95th percentile and maximum observed value at the referenced pH for AMAX piles with 0.64% S. Data for pH values above 7.5 are used for Flotation Tailings as discussed in Section 10.4 (not for Category 1 waste rock).
- Whistle Mine indicates the concentrations observed from the Whistle Mine in Ontario, Canada for acidic & nonacidic waters as presented in Attachment A.
- Vangorda Mine indicates the concentrations observed from the Anvil Range Mine Complex in Yukon, Canada for acidic waters as presented in Attachment A.
- Dunka Seep indicates the highest observed concentration or detection limit from the available Dunka Mine data (a single sampling event in May 2006 at Seep X) multiplied by a factor of 10.
- NorthMet Lab Data indicates a range between the highest observed concentration in the NorthMet tailings humidity cells and an estimated field-scale value developed by MDNR.
- Concentration caps for all constituents not shown are calculated from the equations shown in Section 8.3.1.

Table 2-31. Distribution Parameters for Duluth Complex Category 2/3, 4, and Ore Concentration Caps (nonacidic)

Cap Value From Various Data Sources

Constituent	*Method*	*Source*	*Units*	*Distribution*	*Mean/Mode*	*Std. Deviation*	*Min.*	*Max.*
Ag	Limit	Dunka Seep	mg/L	Constant	2.00E-04	--	--	--
As	Limit	Whistle Mine	mg/L	Constant	1.00E-01	--	--	--
B	Limit	Whistle Mine	mg/L	Constant	1.00E-01	--	--	--
Be	Limit	Dunka Seep	mg/L	Constant	4.00E-04	--	--	--
Cr	Limit	Whistle Mine	mg/L	Constant	1.00E-02	--	--	--
Pb	Limit	Whistle Mine	mg/L	Constant	1.00E-01	--	--	--
Sb	Limit	NorthMet Lab Data	mg/L	Uniform	--	--	8.30E-03	1.00E-01
Tl	Limit	Dunka Seep	mg/L	Constant	2.00E-04	--	--	--
V	Limit	Whistle Mine	mg/L	Constant	1.00E-02	--	--	--

pH-based Range from AMAX Data
(95th percentile values, all units mg/L)

pH	*Alkalinity*	*Co*	*Cu*	*Fe*	*K*	*Mn*	*Na*	*Ni*	*Zn*
7.5	4.79E+01	2.48E-01	1.30E-01	7.45E-02	4.60E+01	1.40E+00	4.68E+02	1.50E+00	1.00E-01
7.4	4.90E+01	2.04E-01	1.47E-01	5.90E-02	4.21E+01	1.49E+00	3.94E+02	1.58E+00	9.73E-02
7.3	3.59E+01	9.30E-02	2.00E-01	5.00E-02	5.04E+01	2.00E-01	2.31E+02	1.62E+00	1.33E-01
7.2	3.53E+01	1.89E-01	2.33E-01	1.68E-01	4.25E+01	1.72E+00	3.47E+02	3.21E+00	1.82E-01
7.1	3.45E+01	2.31E-01	2.84E-01	8.00E-02	4.60E+01	6.46E-01	1.85E+02	4.31E+00	2.91E-01
7.0	2.60E+01	5.08E-01	5.59E-01	5.00E-02	3.96E+01	2.48E+00	2.41E+02	7.40E+00	4.09E-01
6.9	2.80E+01	1.02E+00	3.70E+00	1.78E-01	4.18E+01	1.90E+00	1.82E+02	1.98E+01	7.30E-01
6.8	2.16E+01	1.45E+00	5.02E+00	7.00E-02	5.06E+01	1.13E+00	1.50E+02	2.98E+01	1.24E+00
6.7	2.18E+01	1.24E+00	4.30E+00	1.02E-01	4.80E+01	3.61E+00	1.69E+02	2.06E+01	8.78E-01
6.6	1.44E+01	1.05E+00	5.44E+00	1.26E-01	5.07E+01	2.91E+00	2.05E+02	2.46E+01	8.66E-01
6.5	1.60E+01	1.52E+00	6.50E+00	6.00E-02	4.65E+01	1.39E+00	1.42E+02	3.15E+01	1.26E+00
6.4	1.53E+01	2.10E+00	7.09E+00	1.86E-01	4.88E+01	3.45E+00	1.78E+02	5.08E+01	1.51E+00
6.3	1.17E+01	2.11E+00	8.85E+00	8.40E-02	5.04E+01	3.03E+00	2.38E+02	4.75E+01	1.29E+00
6.2	6.90E+00	2.56E+00	1.02E+01	4.00E-02	5.37E+01	4.01E+00	4.39E+02	7.00E+01	1.87E+00
6.1	9.90E+00	3.13E+00	1.49E+01	5.85E-02	6.15E+01	3.26E+00	1.27E+02	8.35E+01	2.33E+00
6.0	9.40E+00	1.42E+00	8.56E+00	3.00E-02	4.97E+01	3.40E+00	1.64E+02	3.02E+01	1.60E+00

pH-based Range from AMAX Data
(maximum values, all units mg/L)

pH	*Alkalinity*	*Co*	*Cu*	*Fe*	*K*	*Mn*	*Na*	*Ni*	*Zn*
7.5	5.27E+01	2.80E-01	1.70E-01	1.50E-01	6.00E+01	1.68E+00	7.00E+02	1.70E+00	1.74E-01
7.4	5.40E+01	2.16E+00	1.80E-01	7.00E-02	5.32E+01	2.40E+00	4.91E+02	2.15E+01	3.96E-01
7.3	3.60E+01	1.20E-01	2.60E-01	6.00E-02	5.90E+01	3.00E-01	2.60E+02	2.29E+00	2.30E-01
7.2	4.50E+01	8.10E-01	3.40E-01	7.00E-01	4.43E+01	2.14E+00	8.62E+02	6.70E+00	2.30E-01
7.1	4.10E+01	3.10E-01	7.50E-01	1.20E-01	4.80E+01	1.64E+00	1.11E+03	7.02E+00	3.70E-01
7.0	4.30E+01	1.24E+00	2.30E+00	6.00E-02	4.30E+01	3.05E+00	2.69E+02	1.30E+01	5.50E-01
6.9	5.03E+01	1.71E+00	6.24E+00	3.00E-01	5.52E+01	2.28E+00	2.13E+02	4.50E+01	1.15E+00
6.8	3.30E+01	2.41E+00	7.25E+00	1.20E-01	5.80E+01	1.74E+00	3.13E+02	4.40E+01	1.65E+00
6.7	3.30E+01	1.41E+00	5.01E+00	1.30E-01	4.84E+01	5.57E+00	3.30E+02	4.10E+01	1.17E+00
6.6	3.90E+01	3.22E+00	1.10E+01	1.02E+00	8.40E+01	3.23E+00	2.40E+02	8.00E+01	2.25E+00
6.5	2.10E+01	1.87E+00	6.95E+00	6.00E-02	5.60E+01	1.89E+00	3.04E+02	4.30E+01	1.53E+00
6.4	2.20E+01	3.24E+00	7.57E+00	3.90E-01	5.10E+01	4.07E+00	2.70E+02	7.95E+01	1.69E+00
6.3	1.36E+01	2.30E+00	1.70E+01	1.00E-01	5.20E+01	3.32E+00	2.49E+02	6.70E+01	1.56E+00
6.2	6.90E+00	3.65E+00	1.20E+01	4.00E-02	5.40E+01	4.10E+00	6.09E+02	9.10E+01	2.01E+00
6.1	9.90E+00	3.34E+00	1.70E+01	6.00E-02	6.35E+01	3.36E+00	1.30E+02	9.10E+01	2.58E+00
6.0	1.11E+01	1.60E+00	1.10E+01	3.00E-02	5.20E+01	3.40E+00	2.01E+02	3.20E+01	1.61E+00

[1]Table reproduced from Large Table 13 in Reference (19). Notes below refer to citations in Reference (19).

Notes

- All distributions from AMAX data represent a uniform distribution between the 95th percentile and maximum observed value at the referenced pH for all AMAX piles (0.64% S to 1.4% S).
- Whistle Mine indicates the concentrations observed from the Whistle Mine in Ontario, Canada for acidic & nonacidic waters as presented in Attachment A.
- Vangorda Mine indicates the concentrations observed from the Anvil Range Mine Complex in Yukon, Canada for acidic waters as presented in Attachment A.
- Dunka Seep indicates the highest observed concentration or detection limit from the available Dunka Mine data (a single sampling event in May 2006 at Seep X) multiplied by a factor of 10.
- NorthMet Lab Data indicates a range between the highest observed concentration in the NorthMet tailings humidity cells and an estimated field-scale value developed by MDNR.
- Concentration caps for all constituents not shown are calculated from the equations shown in Section 8.3.1.

Table 2-32. Distribution Parameters for Duluth Complex Category 2/3, 4, and Ore Concentration Caps (acidic)[1]

Distribution Fit to AMAX, Whistle, and Vangorda Mine Data

Constituent	*Method*	*Source*	*Units*	*Distribution*	*Mean/Mode*	*St. Dev.*	*Minimum*	*Maximum*
Ag	Cap	Whistle Mine	mg/L	Beta	4.20E-02	4.62E-03	3.40E-02	5.00E-02
Al	Cap	Whistle Mine	mg/L	Beta	4.33E+02	2.68E+02	1.13E+02	1.00E+03
As	Cap	Whistle Mine	mg/L	Constant	1.00E-01	--	--	--
B	Cap	Whistle Mine	mg/L	Beta	2.19E-01	9.45E-02	9.23E-02	5.00E-01
Be	Cap	Whistle Mine	mg/L	Beta	1.62E-02	4.31E-03	5.26E-03	2.21E-02
Ca	Cap	Whistle Mine	mg/L	Beta	4.09E+02	4.15E+01	2.62E+02	5.54E+02
Cd	Cap	Whistle Mine	mg/L	Beta	1.47E-01	8.84E-02	5.35E-02	4.51E-01
Co	Cap	Whistle Mine	mg/L	Beta	3.04E+01	1.01E+01	8.68E+00	4.14E+01
Cr	Cap	Whistle Mine	mg/L	Beta	1.60E-02	5.77E-04	1.50E-02	1.70E-02
Cu	Cap	AMAX pH 3-4	mg/L	Beta	1.49E+02	1.30E+01	9.79E+01	1.79E+02
Fe	Cap	Whistle Mine	mg/L	Beta	9.57E+01	5.56E+01	1.61E+00	4.32E+02
K	Cap	Whistle Mine	mg/L	Beta	2.92E+01	9.52E+00	9.39E+00	1.53E+02
Mg	Cap	Whistle Mine	mg/L	Beta	9.92E+02	3.92E+02	4.82E+02	2.11E+03
Mn	Cap	Whistle Mine	mg/L	Beta	5.48E+01	2.32E+01	1.75E+01	1.03E+02
Na	Cap	Whistle Mine	mg/L	Beta	8.75E+01	6.32E+01	2.48E+01	7.17E+02
Ni	Cap	Whistle Mine	mg/L	Beta	6.41E+02	1.90E+02	9.97E+01	8.41E+02
Pb	Cap	Whistle Mine	mg/L	Beta	3.64E-01	1.36E-01	1.28E-01	6.00E-01
Sb	Cap	Whistle Mine	mg/L	Beta	2.00E+00	5.77E-01	1.00E+00	3.00E+00
Se	Cap	Whistle Mine	mg/L	Constant	1.00E-01	--	--	--
SO4	Cap	Whistle Mine	mg/L	Beta	9.52E+03	3.39E+03	3.29E+03	1.81E+04
Tl	Cap	Vangorda Mine	mg/L	Beta	4.47E-02	1.22E-01	2.00E-03	2.18E+00
V	Cap	Whistle Mine	mg/L	Beta	5.50E-02	2.89E-03	5.00E-02	6.00E-02
Zn	Cap	Whistle Mine	mg/L	Beta	1.54E+01	1.27E+01	6.34E+00	6.00E+01

[1]Table reproduced from Large Table 14 in Reference (19). Notes below refer to citations in Reference (19).

Notes

- All distributions from Whistle and Vangorda Mine data represent the full range of the observed values.
- All distributions from AMAX data represent the full range of the highest 5% of observed values in each 0.1 pH increment over the indicated pH range.
- Concentration caps for all constituents not shown are calculated from the equations shown in Section 8.3.1.
- Distributions shown as constant indicate zero detections in the referenced data set, the detection limit is set as the concentration cap.

Table 2-33. Distribution Parameters for Virginia Formation Category 4 Waste Rock Concentration Caps[1]

Distribution Fit to AMAX, Whistle, and Vangorda Mine Data

Constituent	*Method*	*Source*	*Units*	*Distribution*	*Mean/Mode*	*St. Dev.*	*Minimum*	*Maximum*
Ag	Cap	Vangorda Mine	mg/L	Beta	5.86E-02	7.07E-02	6.24E-03	8.65E-01
Al	Cap	Whistle Mine	mg/L	Beta	4.33E+02	2.68E+02	1.13E+02	1.00E+03
As	Cap	Vangorda Mine	mg/L	Beta	4.21E-01	6.39E-01	1.13E-02	2.50E+00
B	Cap	Vangorda Mine	mg/L	Beta	1.39E+00	9.80E-01	1.30E-02	3.27E+00
Ba	Cap	Vangorda Mine	mg/L	Beta	2.61E-01	3.60E-01	4.96E-03	1.92E+00
Be	Cap	Vangorda Mine	mg/L	Beta	4.59E-02	6.82E-02	5.24E-03	3.20E-01
Ca	Cap	Vangorda Mine	mg/L	Beta	4.09E+02	4.85E+01	3.28E+02	4.98E+02
Cd	Cap	Whistle Mine	mg/L	Beta	1.47E-01	8.84E-02	5.35E-02	4.51E-01
Co	Cap	Vangorda Mine	mg/L	Beta	1.53E+01	6.86E+00	6.98E+00	3.08E+01
Cr	Cap	Vangorda Mine	mg/L	Beta	9.19E-02	1.52E-01	9.60E-03	8.70E-01
Cu	Cap	Vangorda Mine	mg/L	Beta	1.37E-01	1.03E-01	3.06E-02	6.08E-01
Fe	Cap	Vangorda Mine	mg/L	Beta	8.60E+02	1.23E+03	6.00E+00	5.08E+03
K	Cap	Vangorda Mine	mg/L	Beta	1.26E+01	8.42E+00	6.00E-01	3.00E+01
Mg	Cap	Vangorda Mine	mg/L	Beta	2.03E+03	1.48E+03	5.75E+02	6.20E+03
Mn	Cap	Vangorda Mine	mg/L	Beta	1.55E+03	1.13E+03	3.30E+02	4.32E+03
Na	Cap	Vangorda Mine	mg/L	Beta	1.67E+01	1.01E+01	7.39E+00	1.22E+02
Ni	Cap	Vangorda Mine	mg/L	Beta	1.08E+01	5.45E+00	4.17E+00	2.33E+01
Pb	Cap	Whistle Mine	mg/L	Beta	3.64E-01	1.36E-01	1.28E-01	6.00E-01
Sb	Cap	Vangorda Mine	mg/L	Beta	3.25E+00	2.78E+00	1.00E-03	1.60E+01
Se	Cap	Vangorda Mine	mg/L	Beta	4.34E-01	6.24E-01	7.33E-02	3.20E+00
SO4	Cap	Vangorda Mine	mg/L	Beta	2.23E+04	2.21E+04	3.54E+03	1.00E+05
Tl	Cap	Vangorda Mine	mg/L	Beta	4.47E-02	1.22E-01	2.00E-03	2.18E+00
V	Cap	Vangorda Mine	mg/L	Beta	6.00E-02	1.11E-01	3.00E-03	5.15E-01
Zn	Cap	Whistle Mine	mg/L	Beta	1.54E+01	1.27E+01	6.34E+00	6.00E+01

[1]Table reproduced from Large Table 15 in Reference (19). Notes below refer to citations in Reference (19).

Notes

- All distributions from Whistle and Vangorda Mine data represent the full range of the observed values.
- Concentration caps for all constituents not shown are calculated from the equations shown in Section 8.3.1.

Attachment 2-1

Industrial Chemical Additives (Beneficiation and Hydromet)
March 13, 2015.

Minnesota Pollution Control Agency
520 Lafayette Road North
St. Paul, MN 55155-4194

Industrial Chemical Additives Attachment

NPDES/SDS Permit Program

Doc Type: Permit Application

The National Pollutant Discharge Elimination System (NPDES)/State Disposal System (SDS) Permit Program regulates wastewater discharges to land and surface waters. This is an attachment to the Industrial Applications for facilities with multiple chemical additives.

Complete the attachment by typing or printing in black ink. Attach additional sheets as necessary. For more information, please contact the Minnesota Pollution Control Agency (MPCA) at: In Metro Area: 651-296-6300 or Outside Metro Area: 800-657-3864.

Permittee name: PolyMet Mining Inc. - THIS APPLICATION FORM IS PROVIDED TO FOTH AS DRAFT (3/13/2015) **Permit number:** MN TBD

Chemical	**Purpose**	**Location of chemical addition in process** (e.g., to raw water supply, at greensand filter, before RO unit #2, etc.)	**Amount/duration/ frequency of addition**	**Average rate of use** (weight or volume per day)	**Maximum rate of use** (weight or volume per day)
SIPX (sodium isopropyl xanthate)	Collector: Selectively adsorb minerals based on hydrophobicity of the collector and mineral	Flotation Circuit, specifically the Flotation Roughers, Scavengers, Cleaner Circuit	Continuous	2.74 t/day (1,000 t/year)	4.79 t/day (1,750 t/year)
PAX (potassium amyl xanthate)	Collector: Selectively adsorb minerals based on hydrophobicity of the collector and mineral	Flotation Circuit, specifically the Flotation Roughers, Scavengers, and Cleaner Flotation Cells	Continuous	2.74 t/day (1,000 t/year)	4.79 t/day (1,750 t/year)
MIBC (methyl isobutyl carbinol 100% solution)	Frother: Used to improve stability of froth bubbles as they rise through the flotation cells	Flotation Circuit, specifically the Flotation Roughers, Scavengers, and Cleaner Flotation Cells	Continuous	2.88 t/day (1,050 t/year)	4.11 t/day (1,500 t/year)
Frother (F-160-05)	Frother: Used to improve stability of froth bubbles as they ris through the flotation cells (Potential substitute for MIBC)	Flotation Circuit, specifically the Flotation Roughers, Scavengers, and Cleaner Flotation Cells	Continuous	2.88 t/day (1,050 t/year)	4.11 t/day (1,500 t/year)
Frother (F-160-13)	Frother: Used to improve stability of froth bubbles as they ris through the flotation cells (Potential substitute for MIBC)	Flotation Circuit, specifically the Flotation Roughers, Scavengers, and Cleaner Flotation Cells	Continuous	2.88 t/day (1,050 t/year)	4.11 t/day (1,500 t/year)
Frother (DVS4U038)	Frother: Used to improve stability of froth bubbles as they ris through the flotation cells (Potential substitute for MIBC)	Flotation Circuit, specifically the Flotation Roughers, Scavengers, and Cleaner Flotation Cells	Continuous	2.88 t/day (1,050 t/year)	4.11 t/day (1,500 t/year)
Copper Sulfate	Activator: Used as an activator to increse the available adsorption sites on the mineral to allow for adsorption by the Collector	Flotation Circuit, specifically Scavenger Cells	Continuous	1.71 t/day (625 t/year)	2.05 t/day (750 t/year)
Flocculant (MagnaFloc 10)	Flocculant: Promote flocculation of suspended particles in liquors	Flotation Circuit, specifically Concentrate Thickeners	Continuous	0.082 t/day	0.14 t/day

				(30 t/year)	(50 t/year)
Flocculant (MagnaFloc 455)	Flocculant: Promote flocculation of suspended particles in liquors (Potential substitute for Magnafloc 10)	Flotation Circuit, specifically Concentrate Thickeners	Continuous	0.07 t/day (25 t/year)	0.14 t/day (50 t/year)
Flocculant (Neo NS 6655)	Flocculant: Promote flocculation of suspended particles in liquors (Potential substitute for Magnafloc 10/455)	Flotation Circuit, specifically Concentrate Thickeners	Continuous	0.07 t/day (25 t/year)	0.14 t/day (50 t/year)
Flocculant (NALCO 83949)	Flocculant: Promote flocculation of suspended particles in liquors (Potential substitute for Magnafloc 10/455)	Flotation Circuit, specifically Concentrate Thickeners	Continuous	0.07 t/day (25 t/year)	0.14 t/day (50 t/year)
Flocculant (NALCO 9877 Pulv)	Flocculant: Promote flocculation of suspended particles in liquors (Potential substitute for Magnafloc 10/455)	Flotation Circuit, specifically Concentrate Thickeners	Continuous	0.07 t/day (25 t/year)	0.14 t/day (50 t/year)
CMC (Carboxyl methyl cellulose)	Flocculant: Used to depress gangue minerals in flotation cells to improve selectivity towards Cu Ni minerals	Flotation Circuit, specifically Rougher and Pyrhotite Cleaner Flotation Cells	Continuous	3.29 t/day (1,200 t/year)	4.79 t/day (1,750 t/year)
Lime slurry	pH Modifier: Used to regulate pH in the Flotation Circuit	Flotation Circuit, specifically the Separation Cleaner Flotation Cells	Continuous	28.15 t/day as hydrated lime (10,274 t/year as hydrated lime)	41.10 t/day as hydrated lime (15,000 t/year as hydrated lime)

***Remember to attach the *Material Safety Data Sheets*, complete product labels and any other information on chemical composition, aquatic toxicity, human health, and environmental fate for each chemical additive.**

Please make a copy for your records.

Refer to the *Transmittal Form* for mailing instructions.

Minnesota Pollution Control Agency
520 Lafayette Road North
St. Paul, MN 55155-4194

Industrial Chemical Additives Attachment

NPDES/SDS Permit Program

Doc Type: Permit Application

The National Pollutant Discharge Elimination System (NPDES)/State Disposal System (SDS) Permit Program regulates wastewater discharges to land and surface waters. This is an attachment to the Industrial Applications for facilities with multiple chemical additives.

Complete the attachment by typing or printing in black ink. Attach additional sheets as necessary. For more information, please contact the Minnesota Pollution Control Agency (MPCA) at: In Metro Area: 651-296-6300 or Outside Metro Area: 800-657-3864.

Permittee name: PolyMet Mining Inc. - THIS APPLICATION FORM IS PROVIDED TO FOTH AS DRAFT (3/13/2015) **Permit number:** MN TBD

Chemical	**Purpose**	**Location of chemical addition in process** (e.g., to raw water supply, at greensand filter, before RO unit #2, etc.)	**Amount/duration/ frequency of addition**	**Average rate of use** (weight or volume per day)	**Maximum rate of use** (weight or volume per day)
Sodium hydrosulfide (30% solution)	Cementation of copper from solution as CuS	Hydromet, specifically copper cementation	Continuous	3.17 t/day (1,160 t/year)	4.10 t/day (1,750 t/year)
Caustic soda (Sodium hydroxide, 50% solution)	Increase pH of off-gases by removing traces of H2S and SO2 in vent scrubbers	Hydromet, specifically the plant scrubber	Continuous	57.53 gal/day (21,000 gal/year)	82.19 gal/day (30,000 gal/year)
Sulfuric acid (93% solution)	Used as wash water for leach residue filter	Hydromet, specifically the residue filter wash water	Continuous	0.47 t/day (170 t/year)	0.68 t/day (250 t/year)
Hydrochloric acid (32% solution)	Addition of chloride used to promote mineral leaching	Hydromet, specifically the autoclave	Continuous	13.70 t/day (5,000 t/year)	20.55 t/day (7,500 t/year)
Flocculant (MagnaFloc 342)	Promote flocculation of suspended particles in liquors	Hydromet, specifically mixed hydroxide precipitation	Continuous	0.06 t/day (21 t/year)	0.11 t/day (40 t/year)
Flocculant (NALCO 9877 Pulv)	Promote flocculation of suspended particles in liquors (Potential substitute for MagnaFloc 342)	Hydromet, specifically mixed hydroxide precipitation	Continuous	0.11 t/day (40 t/year)	0.21 t/day (75 t/year)
Flocculant (MagnaFloc 155)	Promote flocculation of suspended particles in liquors	Hydromet, specifically mixed hydroxide precipitation	Continuous	0.11 t/day (40 t/year)	0.21 t/day (75 t/year)
Flocculant (Neo NS 6670)	Promote flocculation of suspended particles in liquors (Potential substitute for MagnaFloc 342 or 155)	Hydromet, specifically mixed hydroxide precipitation	Continuous	0.11 t/day (40 t/year)	0.21 t/day (75 t/year)
Flocculant (NALCO	Promotes flocculation of suspended	Hydromet, specifically mixed hydroxide	Continuous	0.11 t/day	0.21 t/day

8173 PULV)	particles in liquors (Potential substitute for MagaFloc 342 or 155)	precipitation		(40 t/year)	(75 t/year)
Flocculant (MagnaFloc 351)	Promote flocculation of suspended particles in liquors	Hydromet, specifically in the leach residue thickener, PGM thickener, and CuS cementation thickener	Continuous	0.27 t/day (100 t/year)	0.41 t/day (150 t/year)
Flocculant (Neo NS 6500)	Promote flocculation of suspended particles in liquors (Potential substitute for MagnaFloc 351)	Hydromet, specifically in the leach residue thickener, PGM thickener, and CuS cementation thickener	Continuous	0.41 t/day (150 t/year)	0.55 t/day (200 t/year)
Flocculant (NALCO 9876 PULV)	Promote flocculation of suspended particles in liquors (Potential substitute for MagnaFloc 351)	Hydromet, specifically in the leach residue thickener, PGM thickener, and CuS cementation thickener	Continuous	0.41 t/day (150 t/year)	0.68 t/day (250 t/year)
Sulfur dioxide (liquid)	Used to reduce ferric ions to ferrous ions	Hydromet, specifically iron reduction and PGM precipitation	Continuous	4.14 t/day (1,510 t/year)	6.16 t/day (2,250 t/year)
Limestone (lump)	Used to promote precipitation of Fe and Al	Hydromet, specifically in iron removal	Continuous	276.71 t/day (101,000 t/year)	410.96 t/day (150,000 t/year)
Limestone (ground)	Used to promote precipitation of Fe and Al (Potential substitute fo lump limestone)	Hydromet, specifically in iron removal	Continuous	276.71 t/day (101,000 t/year)	410.96 t/day (150,000 t/year)
Lime (dry)	Used to promote precipitation of Ni and Co sulfates as Ni and Co hydroxides (mixed hydroxide precipitates)	Hydromet, specifically mixed hydroxide precipitation	Continuous	10.55 t/day as CaO (3,850 t/year as CaO)	16.44 t/day as CaO (6,000 t/year as CaO)
Magnesium hydroxide (60% slurry)	Used to promote precipitation of Ni and Co sulfates as Ni and Co hydroxides (mixed hydroxide precipitate)	Hydromet, specifically mixed hydroxide precipitation	Continuous	16.44 t/day (6,000 t/year)	24.66 t/day (9,000 t/year)
Magnesium hydroxide (dry)	Used to promote precipitation of Ni and Co sulfates as Ni and Co hydroxides (mixed hydroxide precipitate) (Potential substitute for magnesium hydroxide - 60% slurry)	Hydromet, specifically mixed hydroxide precipitation	Continuous	16.44 t/day (6,000 t/year)	24.66 t/day (9,000 t/year)

***Remember to attach the *Material Safety Data Sheets*, complete product labels and any other information on chemical composition, aquatic toxicity, human health, and environmental fate for each chemical additive.**

Please make a copy for your records.

Refer to the *Transmittal Form* for mailing instructions.