REPLY TO THE ATTENTION OF: WQ-16J

Ann M. Foss, Director
Metallic Mining Sector, Industrial Division
Minnesota Pollution Control Agency
520 Lafayette Road North
St. Paul, Minnesota 55155-4194

Dear Ms. Foss:

Thank you for your letter of October 26, 2012, submitting Minnesota's proposed variance from the water quality standards for hardness, bicarbonate, total dissolved solids, and specific conductance for Mesabi Nugget Delaware LLC (Mesabi), Permit No. MN0067687, to the U.S. Environmental Protection Agency for review under section 303(c) of the Clean Water Act (CWA). On December 18, 2012, EPA received legal certification of adoption of the variance from Beverly M. Conerton, completing the submittal. The proposed action would grant Mesabi a variance from Minnesota's water quality criterion for hardness to protect the use of the water for industrial water supply, and bicarbonate, total dissolved solids, and specific conductance to protect the use of the water for agricultural irrigation, and establish the interim requirements listed in Table 1 for the variance parameters during the term of the variance applicable to Mesabi's discharge into Second Creek in St. Louis County, Minnesota.

Table 1

	Interim (effective on issuance of the permit implementing the variance)		Final (effective no later than August 1, 2021)	
	Daily Max	Monthly Avg	Daily Max	Monthly Avg
Hardness	863	831	532	512
Specific conductivity	1965	1889	1066	1025
TDS	1228	1160	768	726
Bicarbonates	378	363	267	257

Consistent with section 303(c) of the CWA and federal regulations at 40 CFR 131.21, EPA is required to review and approve state water quality standards. EPA has reviewed the information submitted and hereby approves the proposed variance.
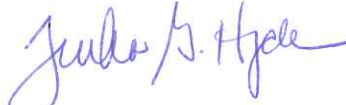
As required under section 7 of the Endangered Species Act and federal regulations at 50 CFR Part 402, EPA is required to consult with the U.S. Fish and Wildlife Service (FWS) on any action that may affect federally-listed threatened and endangered species or designated critical habitat. We have examined technical information for all endangered, threatened, candidate, and

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non-essential experimental populations in St. Louis County. EPA has determined that this approval action will have no effect on federally-listed species, nor will it adversely modify designated critical habitat in the action area. Further consultation with the FWS is therefore not required.

If you or your staff have any questions regarding this approval, please contact myself or David Pfeifer of my staff at (312) 353-9024 or pfeifer.david@epa.gov.

Sincerely,

Tinka G. Hyde
Director, Water Division

cc: Kevin Leecy, Chairman, Bois Forte Tribal Council
        Tara Geschick, Acting Commissioner, Department of Natural Resources, Bois Forte
        Chris Holm, Department of Natural Resources, Bois Forte
        Karen Diver, Chairwoman, Fond du Lac Tribal Council
        Wayne Dupuis, Environmental Program Manager, Environmental Program, Fond du Lac
        Nancy Schuldt, Water Projects Coordinator, Environmental Program, Fond du Lac
        Norman W. Deschampe, Chairman, Grand Portage Tribal Council
        Seth Moore, Biology Program, Grand Portage
        Margaret Watkins, Environmental Program, Grand Portage
        Joseph Henderson, MPCA
        Tony Sullins, USFWS

Technical Memorandum

To: Richard Clark, MPCA
From: **Jasmine** Scheuring, Mesabi Nugget
Subject: **Interim Limits for Total Dissolved Solids (TDS) and Specific Conductance**
Date: August 29, 2012
**cc:**   Ann Foss, Joe Henderson, Brian Timerson

The interim limits for TDS and Specific Conductance are the "lowest limits practical"[1] and represent "reasonable further progress"[2] towards meeting the water quality criterion. Further, the proposed NPDES permit's requirements for permittee to take short-term and long-term steps designed to improve the discharge's water quality until the standards are ultimately met without a variance will ensure that the permit's interim limits are consistent with the variance criteria.

The limits in the proposed draft permit are less than the limits in the 2005 permit, and show "reasonable further progress" towards meeting the standards. The proposed interim limits are 28% lower for TDS and nearly 13% lower for specific conductance.

|	Monthly Average		
	2005 Permit	Proposed 2012 Permit	WQ Criteria
TDS (mg/L)	1619	1160	700
Sp. Cond. (uS/cm)	2159	1889	1000

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[1] MN Rules 7000.7000, Subp. 2.H.(2)
[2] CWA Section 302(b)(2)(B)

TDS and Sp. Cond. Monthly Average Limits
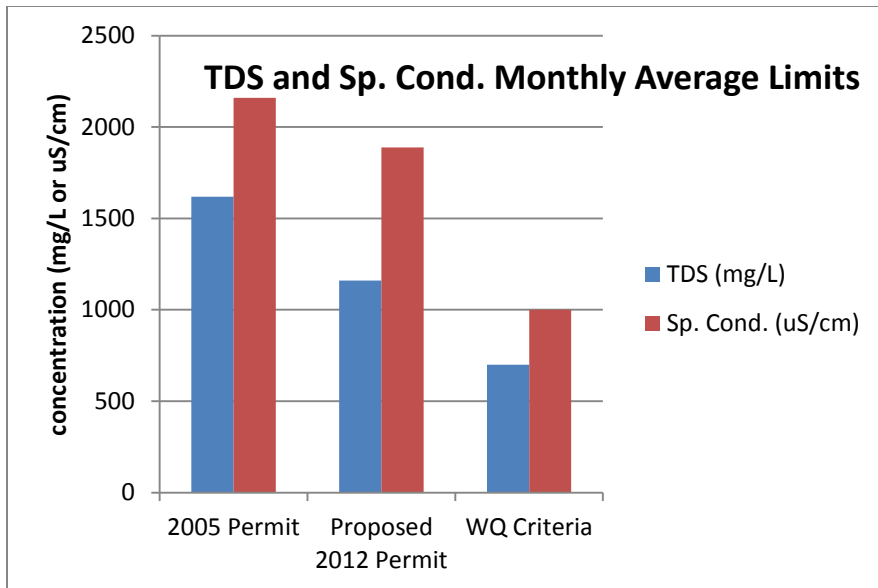
The ITMk3 iron nugget plant began operating in January 2010 and is ramping up, but concentrations in Area 1 Pit for TDS and specific conductivity have been trending upward even before January 2010. Concentrations of TDS averaged 753 mg/L for the period from October 1972 to December 2009, while concentrations of TDS averaged 886 mg/L for the period from January 2010 to July 2012. Given the trend of the observed values, we are not able to definitively say if the continued upward trend is due to the operation of the nugget facility or other factors that were already and continue be in play.

Area 1 Pit TDS 1972-2009
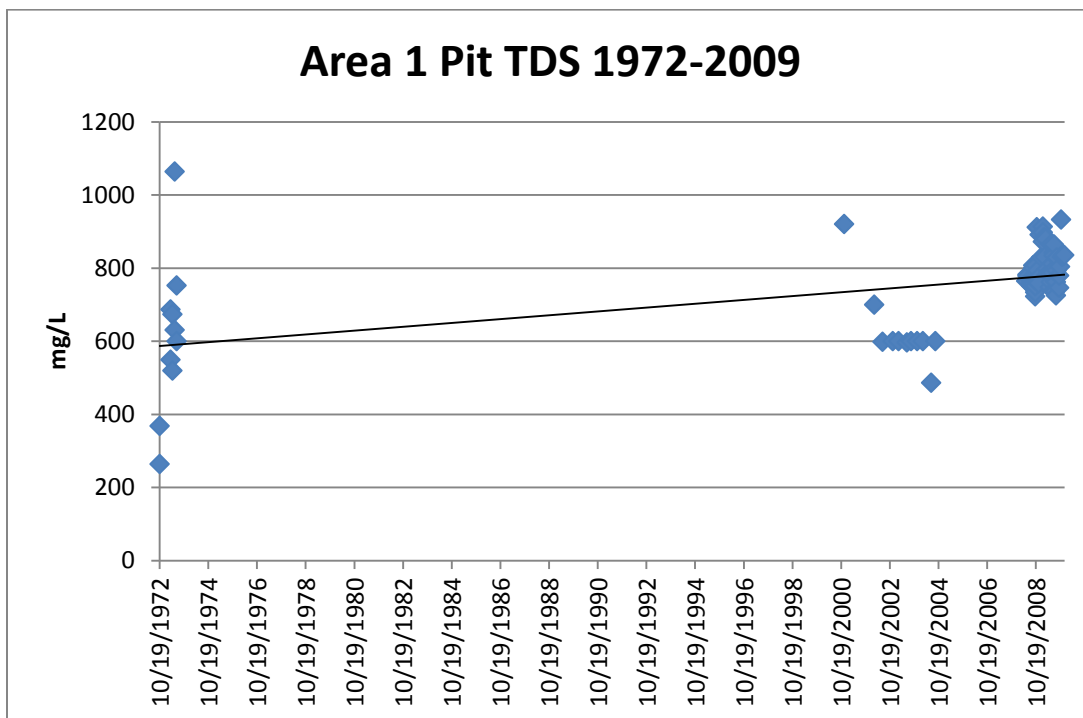
Area 1 Pit TDS 2010-2012
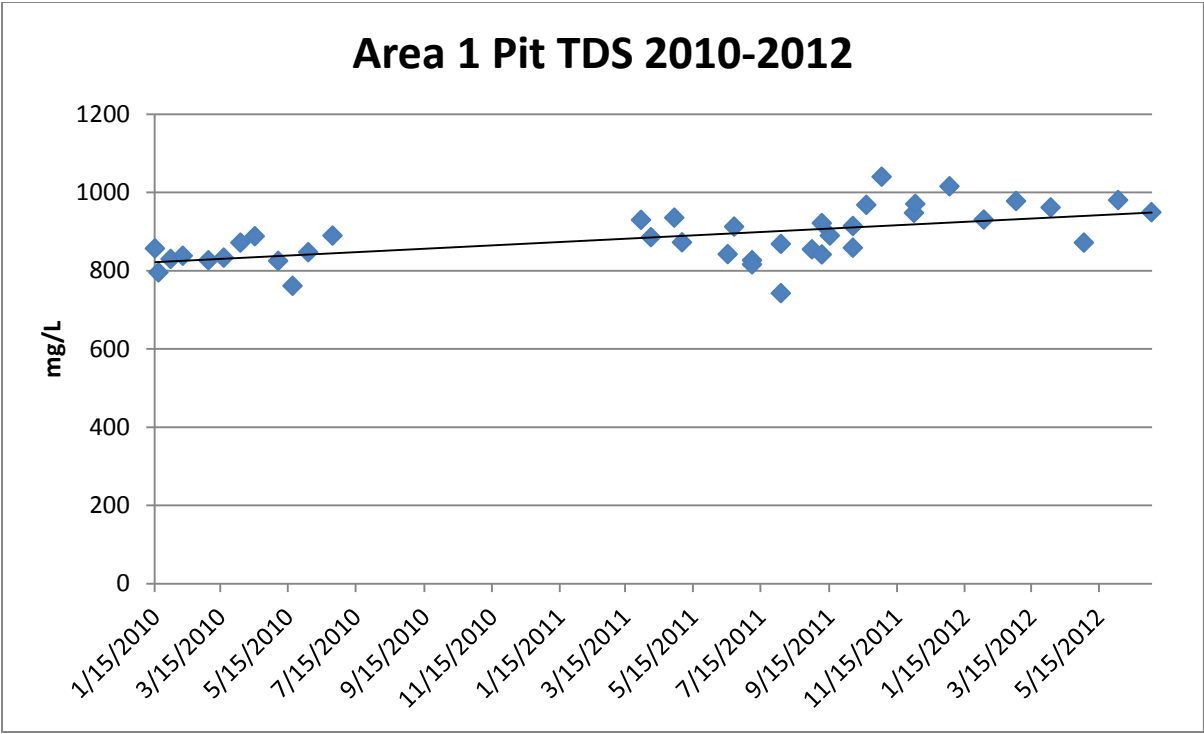
Similarly, concentrations of specific conductance averaged 1183 µS/cm for the period from December 2000 to December 2009), while concentrations of specific conductance averaged 1226 µS/cm for the period from January 2010 to July 2012. Given the trend of the observed values, we are not able to definitively say if the continued slight upward trend is due to the operation of the nugget facility or other factors that were already and continue to be in play.
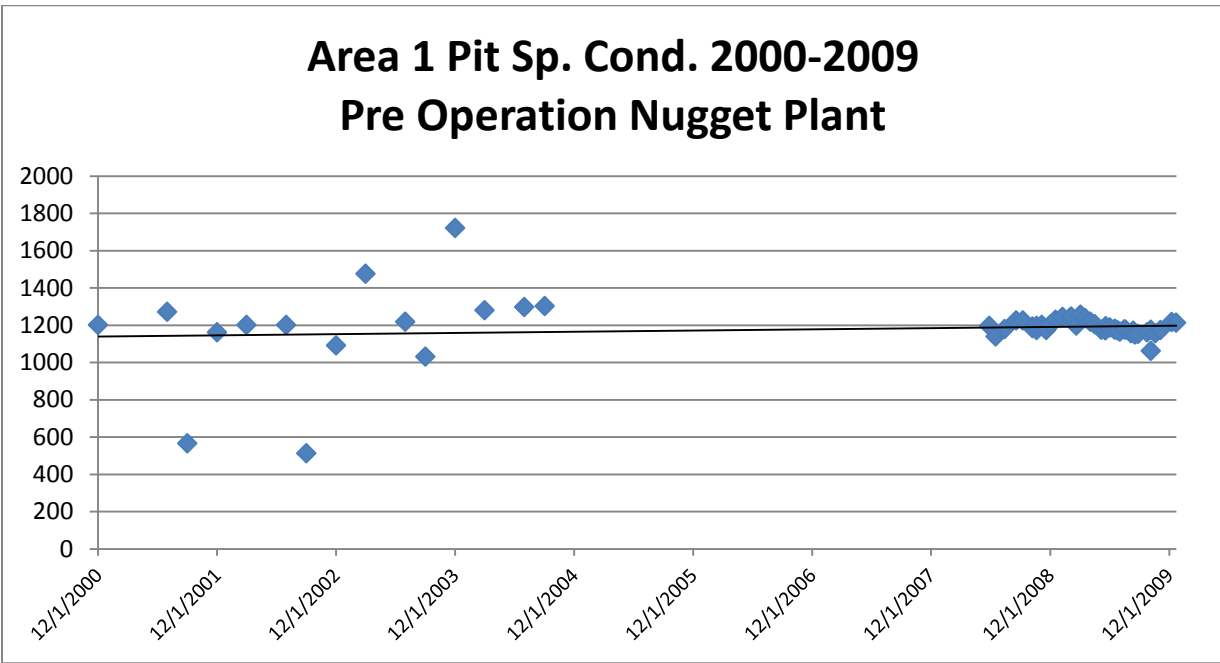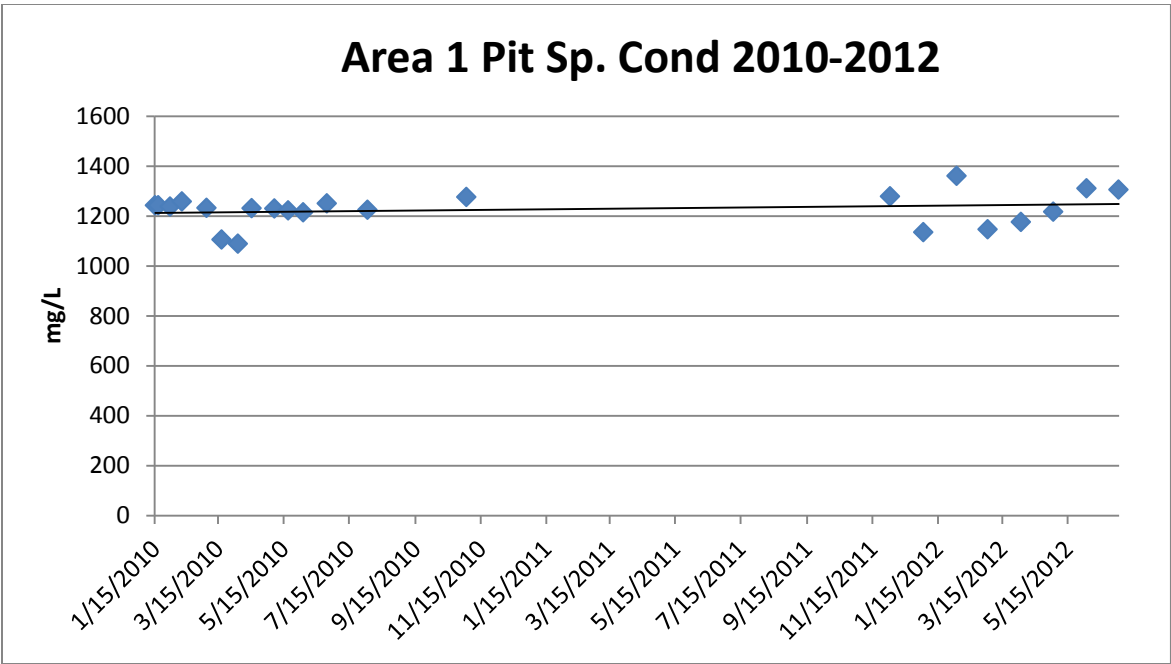
Area 1 Pit Sp. Cond. 2000-2009
**Pre Operation Nugget Plant**

Area 1 Pit Sp. Cond 2010-2012

Since operations began, production has only been able to achieve approximately 50 % of capacity on a month to month basis[3], due to the fact that this is the first of its kind commercial operations in the world. While production approached 100% of capacity for a brief time period in January 2012 (during the air quality compliance tests), it has not been possible to consistently maintain that level of production.

Preliminary modeling conducted for the Mesabi Mining EIS[4] predicted that concentrations would be 920 mg/L TDS and would ramp up to 1,200 mg/L by the end of year five, assuming 100% nugget plant capacity operation 100% of the time. Taking into account the lower starting average concentrations of 795 mg/L, and a lower capacity operation an interim limit of 1160 mg/L is reasonable and appropriate for a variance limit, given the uncertainties in the operation of the nugget facility and in water quality modeling with relatively limited data.

## Predicted TDS Concentrations

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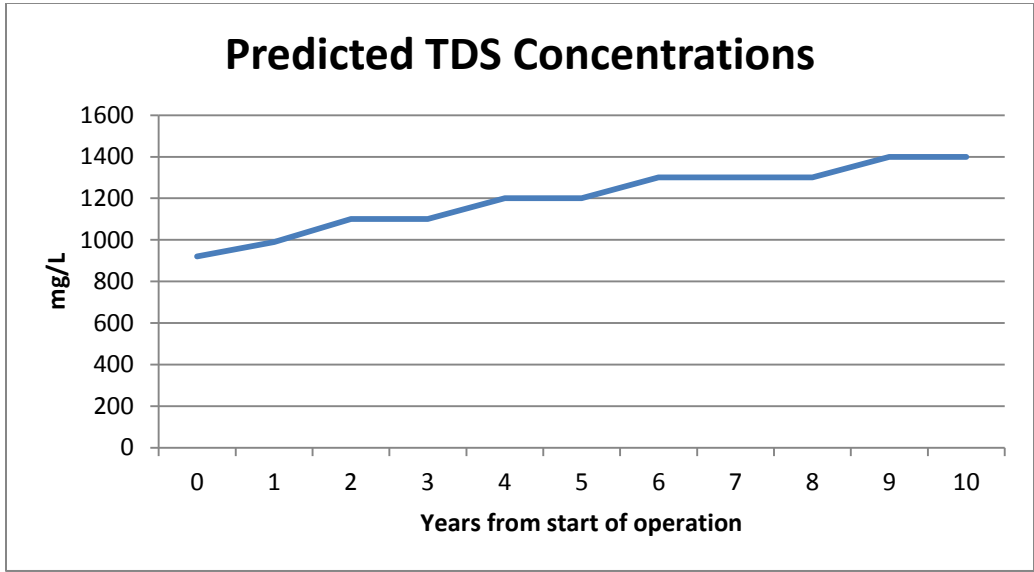
[3] Additional Information Submittal, Mesabi Nugget NPDES Permit MN0067687 March 2012
[4] Dissolved Solids & Chemical Balance Report, December 2009, Barr Engineering Company, Appendix C, No action alternative

Similarly for specific conductance, preliminary modeling[5] predicted that concentrations would be 1,500 mg/L and would ramp up to 2,000 mg/L by the end of year five. Taking into account a lower starting concentration and a lower capacity operation, the interim limit of 1,889 is reasonable and appropriate for a variance limit.

Predicted Spec. Cond. Concentrations
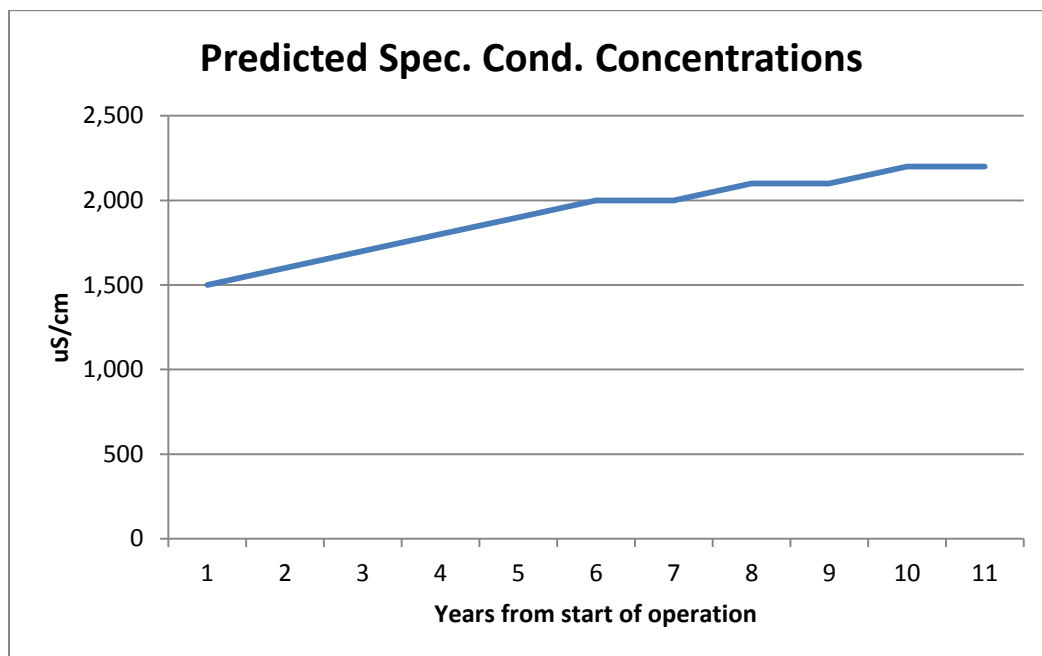
Given the uncertainty in the models and the relative scarcity of data prior to operation of the nugget plant, it is not possible to determine at this time whether the upward trends observed and predicted are the result of the operation of the nugget plant or other factors that were already and continue to be in play. Therefore the interim limits for TDS and Specific Conductance are the "lowest limits practical"[6] and represent "reasonable further progress"[7] towards meeting the water quality criteria.

Further, the proposed NPDES permit's requirements for the permittee to take short-term and long-term steps designed to improve the discharge's water quality until the standards are ultimately met without a variance will ensure that the permit's interim limits are consistent with the variance criteria. This includes the on-going WET testing and TRE work to minimize the intermittent chronic toxicity exhibited by the Area 1 Pit.

Finally, the variances for TDS and specific conductance are for protection of agricultural irrigation uses. Because of the seasonal discharge to protect wild rice uses (e.g. discharges only from September 1 through March 31), there are no agricultural uses in northern Minnesota at the time of discharge. Therefore, the interim limits will fully protect the uses for which these water quality criteria are specified.

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[5] Ibid.
[6] MN Rules 7000.7000, Subp. 2.H.(2)
[7] CWA Section 302(b)(2)(B)

Area 1 Pit Water Treatment Evaluation in Support of the Nondegradation Analysis

Mesabi Nugget Phase II Project

Prepared for
Mesabi Mining, LLC

June 2011

Area 1 Pit Water Treatment Evaluation in Support of the Nondegradation Analysis

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June 2011

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Executive Summary

Area 1 Pit has been partially dewatered to provide a reservoir for process water to be used in Mesabi Nugget's Large Scale Demonstration Plant (LSDP). A future use of this pit is to provide a disposal location for tailings resulting from mining operations. Dewatering began in June 2008, and Mesabi Nugget voluntarily ceased discharging on June 30, 2010 because the Minnesota Pollution Control Agency (MPCA) had not reissued the permit and extended the water quality variances beyond the expiration date of the permit. In February 2010, the MPCA informed Mesabi Nugget that the wild rice rule limiting sulfate levels in waters used for the production of wild rice will be in effect for discharges to Second Creek and the Partridge River. During the initial dewatering, the Area 1 Pit contained approximately 13.7 billion gallons of water, with a surface elevation of approximately 1548 ft MSL. Between June 2008 and June 2010, the pit water level was drawn down to an approximate elevation of 1541.7ft MSL to stop seepage in the southeast corner of the pit. The seepage stopped at an elevation of 1546 ft MSL. This level provides a minimum of six months of storage.

When dewatering was occurring, water pumped from the pit was discharged to Second Creek under the NPDES/SDS discharge permit (MN0067687). As part of the reissued permit (still pending), Mesabi Nugget has committed to discharge to Second Creek only during those times when wild rice in the waters used for production of wild rice (e.g. Partridge River downstream from Second Creek) is not susceptible to damage by sulfate. The MPCA has currently tentatively identified this period as April 1 through August 31 of each year.   However, the revised Proposed Water Management Plans for the Phase II project (Barr, 2011b) includes a proposal to relocate the outfall of this discharge to the St. Louis River, once the Mesabi Nugget Phase II Project has completed environmental review, and permits are modified to allow construction of an outfall on the St. Louis River.

The chemistry of the Area 1 Pit water was analyzed throughout 2008 and 2009 and the future chemistry was modeled and projected in the forthcoming revised Dissolved Solids and Chemical Balance report. The Area 1 Pit discharge is projected to have concentrations of sulfate, total dissolved solids (TDS), alkalinity, and hardness that may exceed in-stream water quality standards. Additionally, the water from the Area 1 Pit has caused intermittent chronic toxicity to *Cerodaphnia dubia*. This report presents detailed evaluations of technical feasibility and preliminary costs for implementation of treatment for the Area 1 Pit discharge water to meet the applicable water quality

standards in Second Creek, including the Class 4 wild rice standard of 10 mg/L, in lieu of relocation of the discharge to the St. Louis River.

In accordance with the nondegradation requirements in MN Rules 7050.0185 subpart 4, the evaluation of discharges that have the potential to degrade the quality of the receiving water, even though they may meet water quality standards, needs to include an evaluation of potential treatment technologies. Because of the low sulfate concentration requirement for wild rice, reverse osmosis was evaluated for its feasibility to meet the 10 mg/L standard. Reverse osmosis is one of few commercially available technologies that may be able to reliably achieve this treatment goal. While this technology may be able to meet the numerical water quality standards, removing most of the dissolved constituents from the water is necessary. The impact of this change in ionic composition on whole effluent toxicity is not known. Removal of the majority of the dissolved constituents from the water (salts and trace micronutrients) may actually exacerbate the observed toxicity. Chemical additions may be necessary to make the water more suitable for *C. dubia* survival and reproduction after the wild rice sulfate standard is met. Further investigations are necessary to determine if whole effluent toxicity is affected by the treatment process and to confirm that the treatment process is technically feasible. Table E-1 summarizes the results of the treatment evaluations for Mining Alternatives 1 and 2 and the No Action Alternative for the Area 1 Pit.

Table E-1. Results of Reverse Osmosis Treatment Evaluations

Mining Alternative	Maximum mass of sulfate removed (lb/d)	Average mass of sulfate removed (lb/d)	Capital cost	Annual O&M cost	Net present value
Alternative 1	34,290	18,180	$ 40,600,000	$ 3,300,000	$ 91,700,000
Alternative 2	29,151	16,511	$ 40,000,000	$ 2,900,000	$ 84,800,000
No Action	29,207	17,808	$ 40,800,000	$ 3,300,000	$ 91,000,000

Based on the treatment evaluations reverse osmosis is not cost effective for the treatment of Area 1 Pit water, and is not an "additional control measures [which is] reasonable", per the requirement of MN Rules 7050.0185, Subpart 8. Treatment of the discharge to reduce alkalinity, hardness, total dissolved solids, specific conductivity and to meet the wild rice standard of 10 mg/L has present worth value that is the same order of magnitude as the entire cost of the Phase II project.

1.1 Introduction

This treatment evaluation report has been developed as part of the nondegradation analysis required for the application for modification of the existing NDPES discharge permit and associated request for variances. In accordance with MN Rules 7050.0185 subpart 4, the evaluation of discharges that have the potential to degrade the quality of the receiving water, even though they may meet water quality standards, must include an evaluation of potential treatment technologies. Additionally, in accordance with variance requirements contained in MN Rules 7000.7000, an analysis of "steps to be taken by the applicant during the period of the variance, even if the applicant is seeking a permanent variance, to reduce emission levels or discharges to the lowest practical limit" must also be conducted.

This report presents a detailed evaluation of the treatment options for the Area 1 Pit water. As outlined in the rules, this evaluation includes an assessment of the ability of each technology to meet the water quality goals, a discussion of important design considerations for each, and an opinion of probable cost for each treatment option. Additionally, recommendations for further action prior to implementing any of the technologies are presented.

1.2 Background

The proposed Mesabi Nugget Phase II project (Project) will be located on the Mesabi Iron Range (Mesabi Range) north of Aurora and Hoyt Lakes, Minnesota (Figure 1-1). The Project includes re-opening of taconite mines and construction of a new crushing and concentrating facility. The Project has been undertaken by Mesabi Mining, LLC. The Project will provide iron ore concentrate for use in the previously permitted Large Scale Demonstration Plant (LSDP), which began operations in January, 2010. The Project is entirely located on portions of the site of the former LTV Steel Mining Company (LTVSMC) facility (also known as Erie Mining Company prior to 1986).

Mesabi Nugget, LLC began dewatering of the Area 1 Pit in June 2008 to provide a reservoir for process water that will be used in the LSDP. However, Mesabi Nugget voluntarily ceased dewatering June 30, 2010 because the Minnesota Pollution Control Agency (MPCA) had not reissued the permit and extended the water quality variances beyond the expiration date of the permit. In February 2010, the MPCA informed Mesabi Nugget that the wild rice rule limiting sulfate levels in waters used for the production of wild rice will be in effect for discharges to Second Creek and the Partridge River.

During the initial dewatering, the Area 1 Pit contained approximately 13.7 billion gallons of water, with a surface elevation of approximately 1548 ft MSL. Between June 2008 and June 2010, the pit water level was drawn down to an approximate elevation of 1541.7 ft MSL to stop seepage in the southeast corner of the pit. The seepage stopped at an elevation of 1546 ft MSL. The dewatering goal was to provide a minimum of six months of storage.

When dewatering occurred, the pumped water from the Area 1 Pit was discharged to Second Creek under an existing NPDES/SDS discharge permit (MN0067687).   Under the existing Area 1 Pit permit, Mesabi Nugget was authorized to discharge up to a maximum of approximately 4,000 gpm (5.8 MGD) of water from Area 1 Pit.

The revised Mine Pit Hydrology and Water Balances report, (Barr, 2011a) describes the proposed water balance for Area 1 Pit during the proposed Phase II mining operations. Several water sources will be flowing into the Area 1 Pit during the Phase II operations and it is anticipated that the water quality in the Area 1 Pit will change over time as process water from the LSDP is returned to the pit following use and treatment and as chemical interactions between the pit water and in-pit tailings occur. The resulting water quality within the Area 1 Pit during the proposed Phase II project has been modeled and the modeling methodology and detailed water quality projections can be found in the forthcoming revised Dissolved Solids and Chemical Balance report.

2.0 Water Quality and Treatment Goals

2.1 Current Pit Water Quality and Treatment Goals

Sampling and analysis of Area 1 Pit water quality has been on-going since May 2008. Some historic water quality data are also available. Water samples have been collected from three discrete depths, in accordance with the Barr memorandum "Proposed surface water monitoring locations, parameters and frequencies" dated April 14, 2008 (and subsequent revisions). Northeast Technical Services (NTS) has been responsible for sample collection and analysis. A summary of the recent analytical data is presented in Table 2-1, along with a listing of the applicable water quality standard for each parameter and the current water quality of Second Creek. While a relocation of the outfall of Area 1 Pit to the St. Louis River is being proposed, for the purpose of this report, the treatment of the Area 1 Pit to meet the water quality standards within Second Creek (the current receiving water) is evaluated as an alternative to discharging to the St. Louis River. The 7Q10 flow in Second Creek is 0 cfs and therefore the discharge from Area 1 Pit must meet the water quality standards at the "end of the pipe".

Table 2-1. Summary of Area 1 Pit and Second Creek Water Quality

		Current Average	Treatment Goal	Second Creek (MNSW1)
Alkalinity, Total	mg/L	364	250	354
Aluminum	µg/L	12.5	125	25.2
Antimony	µg/L	0.04	31	0.11
Arsenic	µg/L	1.00	53	2.7
Barium	µg/L	4.31		22.4
Beryllium	µg/L	0.10		0.1
Boron	µg/L	131	500	145
Bromide	µg/L	0.03		0.1
Cadmium	µg/L	0.08	3.37	15.2
Calcium	mg/L	42.7		69.7
Chemical Oxygen Demand, COD	mg/L	13.8		37.3
Chloride	mg/L	10.5	230	14.7
Chromium	µg/L	0.60	11	0.43
Cobalt	µg/L	0.72	5	0.38
Copper	µg/L	0.59	23.21	0.78
Fluoride	mg/L	0.10		1.3
Hardness	mg/L	779	500	518
Iron	mg/L	0.03		570
Lead	µg/L	0.20	18.58	0.23
Magnesium	mg/L	163		86.8
Manganese	µg/L	862		258
Mercury	ng/L	0.80	1.3	1.7
Methylmercury	ng/L	0.09		0.4
Molybdenum	µg/L	1.6		12.9
Nickel	µg/L	2.25	168.54	2.8
Nitrogen, total	mg/L	--		--
pH	SU	8.10		7.7
Phosphorus	mg/L	0.003		0.023
Potassium	mg/L	13.4		7.2
Selenium	µg/L	0.60		0.53
Silicon	ug/L	3.94		--
Silver	µg/L	0.04		0.04
Sodium	mg/L	15.2		31.2
Solids, Total Dissolved	mg/L	850	700	605
Solids, Total Suspended	mg/L	0.74	30	2.5
Specific Conductance	umhos	1281	1000	933
Strontium	µg/L	134		268
Sulfate	mg/L	386	10	166
Thallium	µg/L	0.18	0.56	0.17
Titanium	µg/L	5.00		5
Total Organic Carbon, TOC	mg/L	1.62		11.8
Zinc	µg/L	3.80	343.12	6
Parameter of concern				

The constituents present in the Area 1 Pit water that are currently above the Minnesota water quality standards include: alkalinity, hardness (primarily magnesium), specific conductivity, and TDS. Because of a February, 2010 change in MPCA interpretation of an agricultural irrigation water quality standard for sulfate in waters used for the production of wild rice, the MPCA has determined that the discharge from Area 1 Pit will exceed that standard in the Partridge River where wild rice was discovered in field surveys in 2009 (Barr, 2009c). In addition to these specific chemical parameters, the water in the Area 1 Pit has shown intermittent low-level, chronic toxicity to *Ceriodaphnia dubia* (*C. dubia*). Identifying the specific source of toxicity is the subject of an on-going toxicity identification evaluation (TIE) study. As indicated in Table 2-1, the TDS water quality standard referenced is 700 mg/L. Achieving this concentration of TDS in the Area 1 Pit discharge may help to mitigate the current intermittent toxicity issues. All effluent toxicity testing laboratories are required to perform "reference toxicity tests" so that the sensitivity of the test organisms from different laboratories can be compared or the results of individual tests can be compared relative to the reference toxicity test results. For the test species *C. dubia*, the reference toxicant is sodium chloride. The reference chronic IC25 for the laboratory conducting the WET testing for Mesabi Nugget (Environmental Toxicity Control, Inc.) is approximately 800 mg/L total dissolved solids (TDS) as sodium chloride. Therefore, water with a TDS concentration less than 800 mg/L should pass the WET test because solutions that consist of just sodium and chloride are generally more toxic than solutions with similar TDS levels but with a broader array of ions. Hence, using a TDS target of 700 mg/L should be conservative for achieving a non-toxic condition. However, the 10 mg/L sulfate standard is the controlling standard for treatment purposes.

2.2 Future Water Quality Projections

Under the water balance scenarios described in the Mine Pit Hydrology and Water Balances Report (Barr 2011a) as Mining Alternatives 1 and 2, during mining operations, several water sources are flowing into the pit:

- Groundwater inflow
- Precipitation and surface runoff
- Inflow from Area 9 Pit
- Process water from the LSDP
- Water from Area 2WX, 6 or 6NW pits (after year 10 when additional water is needed for concentration and processing)

Water leaves the pit via the following processes:

- Intake of process and cooling water for the LSDP and subsequent evaporation from the process
- Displacement of water by tailings disposal
- Intake for final grinding and concentrating of iron ore at the concentrator
- Discharge to Second Creek
- Evaporation from the Area 1 Pit

Various concentrations of solutes are associated with each of the inflows and outflows for the Area 1 Pit. Of all the solute loads, the process water from the LSDP is the primary source of total dissolved solids. Water quality in the Area 1 Pit will change over time as process water from the LSDP is returned to the pit following use and treatment.

The chemical interactions occurring between the pit water and tailings and the in-pit waste rock stockpile also contribute a significant load. Additionally, the quality of the water coming into the Area 1 Pit from the Area 9 Pit will vary over time as waste rock that is being disposed in the Area 9 Pit interacts with water that water is subsequently displaced to the Area 1 Pit. The resulting chemical composition of water in the Area 1 Pit will vary over time and the projected compositions for Alternatives 1 and 2 are summarized in Tables 2-2 and 2-3, respectively. The projections presented in these tables are from the Dissolved Solids and Chemical Balance report (Barr, 2009b). Updates to these projections are currently being developed. The projected water quality is not expected to change substantially. As is described in more detail in the sections that follow, the selection of treatment technology is largely driven by the sulfate water quality standard for the protection of wild rice (10 mg/L), for which there are limited treatment alternatives. Changes to the projected pit discharge water quality are not expected to alter the treatment technology evaluation. More detail can be found in the Dissolved Solids and Chemical Balance report (Barr, 2009b) and its forthcoming revision.

Table 2-2. Mining Alternative 1 Projected Area 1 Pit Water Quality

Parameter	Units	Year 1	Year 5	Year 10	Year 15	Year 20
Area 1 Clear Pit Water Pool						
Alternative 1						
Sulfate	mg/L	400.0	600.0	800.0	700.0	800.0
Calcium	mg/L	40.0	40.0	50.0	50.0	60.0
Magnesium	mg/L	100.0	100.0	100.0	100.0	200.0
Hardness	mg/L	600.0	600.0	600.0	700.0	800.0
Alkalinity	mg/L	300.0	300.0	300.0	300.0	400.0
Iron	µg/L	0.0	0.0	0.0	0.0	0.0
Manganese	µg/L	400.0	600.0	500.0	500.0	400.0
TDS	mg/L	900.0	1,300.0	1,700.0	1,500.0	1,600.0
Conductivity	µmhos/cm	1,400.0	2,000.0	2,700.0	2,400.0	2,600.0
Mercury	ng/L	1.0	2.0	3.0	3.0	3.0
Aluminum	µg/L	5.0	4.0	4.0	4.0	4.0
Cobalt	µg/L	0.0	1.0	1.0	1.0	1.0
Copper	µg/L	1.0	1.0	1.0	1.0	1.0
Arsenic	µg/L	1.0	1.0	1.0	1.0	1.0
Selenium	µg/L	1.0	1.0	0.0	1.0	1.0
pH	su	8.0	7.0	7.0	7.0	8.0
Silver	µg/L	0.0	0.0	0.0	0.0	0.0
Boron	µg/L	100.0	100.0	100.0	100.0	100.0
Barium	µg/L	2.0	9.0	8.0	8.0	7.0
Beryllium	µg/L	0.0	0.0	0.0	0.0	0.0
Bromide	mg/L	0.0	0.0	0.0	0.0	0.0
Cadmium	µg/L	0.0	0.0	0.0	0.0	0.0
Chloride	mg/L	100.0	100.0	200.0	100.0	100.0
Chromium	µg/L	0.0	0.0	0.0	1.0	1.0
Fluoride	mg/L	1.0	2.0	3.0	3.0	3.0
Potassium	mg/L	10.0	10.0	9.0	7.0	7.0
Molybdenum	µg/L	20.0	70.0	110.0	80.0	80.0
Nitrogen	mg/L	0.0	1.0	2.0	1.0	1.0
Sodium	mg/L	100.0	200.0	400.0	300.0	300.0
Nickel	µg/L	2.0	3.0	4.0	3.0	3.0
Phosphorus	mg/L	0.0	0.0	0.0	0.0	0.0
Lead	µg/L	1.0	2.0	2.0	2.0	2.0
Antimony	µg/L	0.0	1.0	2.0	1.0	1.0
Silicon	mg/L	1.0	1.0	1.0	0.0	0.0
Strontium	µg/L	100.0	100.0	130.0	150.0	180.0
Thallium	µg/L	0.0	0.0	0.0	0.0	0.0
Zinc	µg/L	3.0	4.0	4.0	3.0	3.0
Flow	MGD	3.92	5.76	5.33	1.64	1.19
Flow	gpm	2722.7	4000.0	3703.6	1136.9	824.0

Table 2-3. Mining Alternative 2 Projected Area 1 Pit Water Quality

Parameter	Units	Year 1	Year 5	Year 10	Year 15	Year 20
Area 1 Clear Pit Water Pool						
Alternative 2						
Sulfate	mg/L	400.0	600.0	800.0	900.0	900.0
Calcium	mg/L	40.0	40.0	50.0	60.0	60.0
Magnesium	mg/L	100.0	100.0	100.0	200.0	200.0
Hardness	mg/L	600.0	600.0	600.0	800.0	800.0
Alkalinity	mg/L	300.0	300.0	300.0	300.0	400.0
Iron	µg/L	0.0	0.0	0.0	0.0	0.0
Manganese	µg/L	400.0	600.0	600.0	500.0	500.0
TDS	mg/L	900.0	1,300.0	1,700.0	1,800.0	1,900.0
Conductivity	µmhos/cm	1,400.0	2,000.0	2,800.0	2,900.0	3,000.0
Mercury	ng/L	1.0	2.0	3.0	3.0	3.0
Aluminum	µg/L	5.0	4.0	4.0	4.0	4.0
Cobalt	µg/L	0.0	1.0	1.0	1.0	1.0
Copper	µg/L	1.0	1.0	1.0	1.0	1.0
Arsenic	µg/L	1.0	1.0	1.0	1.0	1.0
Selenium	µg/L	1.0	1.0	0.0	0.0	0.0
pH	su	8.0	7.0	7.0	8.0	8.0
Silver	µg/L	0.0	0.0	0.0	0.0	0.0
Boron	µg/L	100.0	100.0	100.0	100.0	200.0
Barium	µg/L	2.0	9.0	8.0	7.0	7.0
Beryllium	µg/L	0.0	0.0	0.0	0.0	0.0
Bromide	mg/L	0.0	0.0	0.0	0.0	0.0
Cadmium	µg/L	0.0	0.0	0.0	0.0	0.0
Chloride	mg/L	100.0	100.0	200.0	200.0	200.0
Chromium	µg/L	0.0	0.0	0.0	1.0	1.0
Fluoride	mg/L	1.0	2.0	4.0	3.0	3.0
Potassium	mg/L	10.0	10.0	9.0	9.0	8.0
Molybdenum	µg/L	20.0	70.0	120.0	100.0	100.0
Nitrogen	mg/L	0.0	1.0	2.0	1.0	1.0
Sodium	mg/L	100.0	200.0	400.0	300.0	300.0
Nickel	µg/L	2.0	3.0	4.0	3.0	3.0
Phosphorus	mg/L	0.0	0.0	0.0	0.0	0.0
Lead	µg/L	1.0	2.0	2.0	2.0	2.0
Antimony	µg/L	0.0	1.0	2.0	2.0	2.0
Silicon	mg/L	1.0	1.0	1.0	1.0	0.0
Strontium	µg/L	100.0	100.0	130.0	170.0	200.0
Thallium	µg/L	0.0	0.0	0.0	0.0	0.0
Zinc	µg/L	3.0	4.0	4.0	4.0	4.0
Flow	MGD	5.76	4.63	4.46	0.92	0.91
Flow	gpm	4000.0	3217.5	3094.5	639.2	631.5

Under the No Action Alternative, no mining will occur as part of the Project, and concentrate will be acquired from other sources on the open market.   However, the LSDP will operate, and the Area 1 Pit will be used for process supply water. The projected discharge composition under the No Action Alternative is presented in Table 2-4.

Table 2-4. No Action Alternative Projected Area 1 Pit Water Quality

		Area 1 Pit				
		Alternative 2				
		Year				
Parameter	Units	1	5	10	15	20
Sulfate	mg/L	400.0	500.0	600.0	700.0	700.0
Calcium	mg/L	40.0	40.0	40.0	40.0	40.0
Magnesium	mg/L	100.0	100.0	100.0	100.0	100.0
Hardness	mg/L	700.0	600.0	500.0	400.0	400.0
Alkalinity	mg/L	300.0	300.0	300.0	200.0	200.0
Iron	µg/L	0.0	0.0	0.0	0.0	0.0
Manganese	µg/L	600.0	800.0	900.0	1,100.0	1,200.0
TDS	mg/L	1,000.0	1,200.0	1,400.0	1,500.0	1,500.0
Conductivity	µmhos/cm	1,600.0	2,000.0	2,200.0	2,400.0	2,500.0
Mercury	ng/L	1.0	2.0	3.0	4.0	4.0
Aluminum	µg/L	3.0	3.0	3.0	3.0	3.0
Cobalt	µg/L	0.0	1.0	1.0	1.0	1.0
Copper	µg/L	1.0	1.0	1.0	1.0	1.0
Arsenic	µg/L	1.0	1.0	1.0	1.0	1.0
Selenium	µg/L	1.0	1.0	0.0	0.0	0.0
pH	su	7.0	7.0	7.0	7.0	7.0
Silver	µg/L	0.0	0.0	0.0	0.0	0.0
Boron	µg/L	100.0	100.0	100.0	100.0	100.0
Barium	µg/L	1.0	1.0	1.0	0.0	0.0
Beryllium	µg/L	0.0	0.0	0.0	0.0	0.0
Bromide	mg/L	0.0	0.0	0.0	0.0	0.0
Cadmium	µg/L	0.0	0.0	0.0	0.0	0.0
Chloride	mg/L	100.0	100.0	100.0	100.0	200.0
Chromium	µg/L	0.0	0.0	0.0	0.0	0.0
Fluoride	mg/L	1.0	2.0	2.0	3.0	3.0
Potassium	mg/L	10.0	7.0	5.0	3.0	2.0
Molybdenum	µg/L	20.0	40.0	60.0	60.0	70.0
Nitrogen	mg/L	0.0	0.0	0.0	0.0	0.0
Sodium	mg/L	100.0	200.0	300.0	400.0	400.0
Nickel	µg/L	3.0	3.0	4.0	4.0	5.0
Phosphorus	mg/L	0.0	0.0	0.0	0.0	0.0
Lead	µg/L	1.0	2.0	3.0	3.0	3.0
Antimony	µg/L	1.0	2.0	2.0	3.0	3.0
Silicon	mg/L	1.0	1.0	1.0	0.0	0.0
Strontium	µg/L	100.0	90.0	80.0	70.0	70.0
Thallium	µg/L	0.0	0.0	0.0	0.0	0.0
Zinc	µg/L	3.0	4.0	4.0	4.0	4.0
Flow	MGD	3.11	3.15	5.76	3.15	3.14
Flow	gpm	2159.7	2184.7	4000.0	2184.7	2183.4

Under Mining Alternatives 1 and 2 and the No Action Alternative, over time, the values of a number of parameters are projected to increase over their current values – alkalinity, hardness, chloride, sodium, sulfate, total dissolved solids, and specific conductivity. Treatment of these parameters is the focus of this treatment evaluation.

2.3 Treatment Approach

The focus of the treatment evaluations presented in this report is to remove sulfate, alkalinity, hardness, total dissolved solids (TDS), and specific conductivity. As can be seen in Table 2-1, the sulfate standard is the most stringent of the applicable water quality standards, and as such, largely determines the treatment approach. The biochemical oxygen demand (BOD) and chemical oxygen demand (COD) concentrations in the Area 1 Pit water have been monitored and are generally low and not likely to require treatment. Similarly, the concentrations of metals in the Area 1 Pit water are low and do not present a concern with respect to the applicable water quality standards and do not contribute appreciably to TDS or specific conductivity. Current plans for mercury removal would be incorporated into any plans for additional treatment. Treatment will also consider the overall toxicity of the water that would be discharged.

2.3.1 Sulfate Removal

As can be seen in Tables 2-1 through 2-4, the sulfate concentration in the discharge from Area 1 Pit is, and is projected to continue to be, above the water quality standard for wild rice (10 mg/L). Treatment to such as low discharge sulfate concentration is not commonly undertaken and therefore a review of treatment technologies was completed. A technology screening matrix was developed to provide an efficient method of comparing potential treatment alternatives. The technology screening matrix is presented in Table 2-5. The screening matrix includes a preliminary evaluation of effectiveness, ability to be implemented, and cost of each technology. In Table 2-5, effectiveness is described in relation to the ability of a technology to remove sulfate as well as the other parameters of concern such as alkalinity, hardness, total dissolved solids, and specific conductivity. The evaluation of the ability to implement potential treatment technologies focuses primarily upon whether the technology has been used on a commercial scale. Finally, costs are compared on a relative basis at this stage (high, medium, or low) based on previous experience at other facilities.

Table 2-5. Sulfate Removal Technologies Matrix

Treatment Technology	Effectiveness			Implementability		Relative net present value	Emerging or established technology?	Other comments/considerations
	Can achieve 250 mg/L sulfate?	Can achieve 10 mg/L sulfate?	Can reduce other parameters of concern (TDS, hardness, alk)?	Multiple commercial installations?	Implementible within 2 years?			
Biological Treatment (Sulfate Reduction)								
Constructed wetlands	(orange)	(red)	(red)	(green)	(green)	$$	Established	Air emissions (sulfide), reliability
Floating wetlands	(orange)	(red)	(red)	(orange)	(orange)	$$	Emerging	Air emissions (sulfide), reliability
Natural wetlands	(orange)	(red)	(red)	(green)	(green)	$	Established	Air emissions (sulfide), reliability
Biofilters	(orange)	(red)	(red)	(green)	(green)	$$	Established	Air emissions (sulfide), reliability
In-pit biological treatment	(orange)	(red)	(red)	(red)	(orange)	$$	Emerging	Air emissions (sulfide), reliability; largest full-scale trial is 70 Mgal
Anaerobic reactors	(orange)	(red)	(red)	(green)	(green)	$$$	Established	Air emissions (sulfide), reliability
Chemical Precipitation								
Barium precipitation	(green)	(green)	(orange)	(orange)	(red)	$$$$	Established	Extremely expensive
SAVMIN (Ettringite)	(green)	(orange)	(red)	(red)	(red)	$$$	Emerging	Not ready for commercial application, per developer
CESR (Ettringite)	(green)	(orange)	(red)	(red)	(red)	$$$	Emerging	
Gypsum precipitation	(red)	(red)	(green)	(green)	(orange)	$$$	Established	
Lime softening (hardness and alkalinity reduction)	(red)	(red)	(green)	(green)	(orange)	$$$	Established	No/minimal sulfate removal, but hardness and alk removal
Ion Exchange								
Sulf-IX (Bioteq)	(green)	(orange)	(orange)	(red)	(red)	$$$	Emerging	No commercial installations at this time but pilot available
Membrane Treatment								
Microfiltration	(red)	(red)	(red)	(green)	(orange)	$$	Established	Only suitable for NF or RO pretreatment
Ultrafiltration	(red)	(red)	(red)	(green)	(orange)	$$	Established	Only suitable for NF or RO pretreatment
Nanofiltration	(green)	(orange)	(green)	(green)	(green)	$$$	Established	
Reverse Osmosis	(green)	(green)	(green)	(green)	(orange)	$$$	Established	Effective to 10 mg/L sulfate
Electrodialysis reversal	(green)	(green)	(green)	(green)	(orange)	$$$	Established	

Legend:
- (green) Yes, known
- (orange) Potential, but some uncertainty or limited installations
- (red) No, very unlikely

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Potential sulfate treatment technologies can generally be grouped into four categories – biological treatment, chemical precipitation, ion exchange, and membrane separation. These broad categories have been used to consolidate similar treatment technologies for consideration in the screening matrix. A general discussion of each of these categories is provided below.

2.3.1.1   Biological Treatment

In general, biological processes rely on an organic substrate (or potentially hydrogen) to serve as an electron donor in the biologically mediated process of sulfate reduction. The biological conversion of sulfate to sulfide reduces the solubility of sulfur, especially when iron or other divalent metal species are available to drive precipitation. While all of the biological treatment processes use the same basic steps to convert sulfate to the insoluble (sulfide) form for subsequent precipitation and removal from the aqueous phase, they vary in their configurations from systems with relatively large foot-prints and minimal operation or maintenance – for example, natural or constructed wetlands – to systems with a smaller footprint requiring more input of operation and maintenance – such as anaerobic reactors. While all of these technologies likely have the potential to reduce sulfate concentrations to less than 250 mg/L, their ability to reduce sulfate concentrations to less than 10 mg/L is questionable, and likely dependent on the use of secondary treatment processes (chemical precipitation) to control the removal of precipitated sulfur species and prevent re-oxidation and subsequent re-dissolution of sulfate into the aqueous phase.

2.3.1.2   Chemical Precipitation

Chemical precipitation is a demonstrated and established process that can be used to convert dissolved species to non-soluble materials for removal from the aqueous phase. Most of these processes are commonly used steps in water treatment and are based on fundamental chemical principles such as solubility limits.

Sulfate precipitation as gypsum (calcium sulfate) is a common technique used in wet scrubbers. While it is effective for flows with sulfate concentrations above 1,500 to 2,000 mg/L, it would be ineffective at Area 1 Pit because the concentration of sulfate projected to be present in the discharge is less than 1,000 mg/L. Barium sulfate precipitation has the advantage of a much lower solubility limit than gypsum; however, the cost of barium is prohibitive for this situation.

Precipitation of sulfate as a metal sulfide can be an effective removal mechanism in combination with a sulfate reduction process and was therefore not considered independent of sulfate reduction processes described in Section 2.3.1.1.

One area where the current understanding of precipitation reactions is still being developed is in the area of ettringite (calcium-alumino-sulfate) precipitation. Ettringite forms at high pH (generally greater than 11) and is a common intermediate product in the conversion of cement to concrete. While cement has been manufactured and used for over 1,000 years, the exact reactions that occur during the hydration of cement are complex and remain an area of extensive research (Day, 1992). Two processes that have attempted to transfer knowledge of ettringite precipitation in cement to sulfate removal from wastewater are the CESR and the SAVMIN processes (Lorax, 2003). The CESR process actually uses a by-product of cement manufacturing to facilitate the ettringite reaction. While both of these processes continue to be studied, they are not likely to be applicable at Area 1 Pit because they have not been applied at this scale for water treatment and have not been demonstrated to remove sulfate to 10 mg/L.

Given the potential limitations for chemical precipitation, chemical precipitation was not considered for the treatment of the Area 1 Pit discharge for sulfate removal.

2.3.1.3   Ion Exchange

Ion exchange relies on proprietary resins with an affinity for charged species. By loading these resins with hydrogen or hydroxide ions using concentrated acidic or basic solutions, they will 'exchange' these ions for the charged species being removed from the water. Ion exchange is a common treatment technology in home water softeners – where dissolved iron and hardness (calcium and magnesium) are removed from water and replaced by sodium that has been 'charged' onto the resin using a brine solution. Ion exchange is also common in demineralization systems for boiler feed water.

For sulfate, BioteQ Environmental Technologies, Inc. has developed a proprietary ion exchange resin that is charged with hydroxide ions using lime and will remove sulfate from solution. When the charge on the resin has been used, the lime is used to recharge the resin and to precipitate a small flow with concentrated sulfate (greater than gypsum solubility). While promising, this process has not been demonstrated to remove sulfate to 10 mg/L, especially on a large commercial scale. Therefore, ion exchange was not considered for the treatment of the Area 1 Pit discharge.

2.3.1.4   Membrane Treatment

Membrane treatment removes dissolved constituents from a portion of the flow by concentrating the dissolved species in the remaining portion of the flow. The clean water (permeate) generally has reduced concentrations of dissolved constituents while the remaining flow (brine or concentrate) has much higher concentrations. While permeate can generally be discharged, the concentrate still

requires treatment to remove the dissolved constituents or careful consideration of management options. Membrane treatment is an established process and is used at commercial scale for the treatment of drinking water and industrial process water. Of the potential membrane separation processes, reverse osmosis is the best-demonstrated and the most widely used. For these reasons, reverse osmosis has been carried forward for additional evaluation.

2.3.2   Dissolved Solids, Alkalinity, and Hardness Removal

The projected TDS in the Area 1 Pit is comprised of a mixture of both monovalent and divalent constituents, including sulfate, bicarbonate, alkalinity, sodium, chloride, magnesium and calcium (hardness). The contribution of the monovalent sodium and chloride ions to TDS ranges from approximately 100 mg/L to nearly 600 mg/L over the twenty years of operation. Because a significant portion of the dissolved solids loading is attributed to monovalent ions, the core treatment technology considered in this evaluation was membrane separation using reverse osmosis. This technology is the only viable alternative for monovalent ions and it can also remove divalent ions from water. Membrane treatment was shown in the Area 6 Water Treatment Evaluation in Support of the Non-Degradation Analysis report (Barr, 2009d) to be the least expensive of all the treatment options evaluated. Additionally, membrane treatment was found to be the only technology that is widely commercially available, having a number of large-scale installations, which can reliably produce treated water that could meet the water quality standards. As discussed in the previous section, membrane treatment is applicable for removing sulfate to low concentrations, in addition to the other TDS constituents, hardness, and alkalinity. Use of membrane treatment simplifies the overall treatment process required, by using one technology to removal all of the dissolved constituents of concern in the Area 1 Pit discharge. For this reason, only reverse osmosis was evaluated for treatment of the Area 1 Pit discharge to meet the applicable water quality standards.

2.3.3   Mercury Removal

For this report, it is assumed that mercury concentrations discharged from the Area 1 Pit in the future will remain within the permit limits established in the current permit – 1.8 ng/L monthly average and 3.2 ng/L daily maximum. A review of current sampling results, in Table 1, indicates that the water currently in the Area 1 Pit meets these standards. Once operation of the LSDP begins, an increase in the mercury concentration is predicted. To address the additional mercury load, two Mesabi Nugget Corporation (MNC) Mercury Filters have been installed. The first filter is located after the LSDP water softening system and prior to discharge to the Area 1 Pit. The filter is designed to reduce mercury concentration by an order of magnitude or more in the treated LSDP discharge. This filter has been commissioned. The second filter is located prior to discharge to Second Creek. This second

filter is designed to "polish" the effluent from the Area 1 Pit to Second Creek so that it meets the interim and final mercury discharge limitations of 1.8 ng/L calendar monthly average and 3.2 ng/L calendar monthly maximum. Although installed this second filter has not been commissioned. The first filer has been successful in meeting the compliance limits established in the permit.

2.3.4   Toxicity Reduction

As noted previously, the Area 1 Pit water exhibits intermittent chronic toxicity to *C. dubia* (as determined by WET testing). The toxicity appears to vary by season, but to-date no specific toxicant has been identified. Preliminary toxicity studies indicate that the overall TDS (and associated conductivity), sulfate concentration, and pH rise during the WET test are the potential causative agents for the observed intermittent toxicity. A summary of recent investigations into the intermittent pit toxicity can be found in the three reports developed that present the on-going WET testing results (Barr, 2009a; Barr, 2009e; Barr, 2009f).

For the purpose of this report, it has been assumed that reducing TDS (including alkalinity, hardness and sulfate) and specific conductivity will mitigate toxicity. However, given the substantial change in the ionic composition of the effluent that may be required to meet the wild rice water quality standard, it is difficult to predict what affect this may have on WET. Additional amendments to the treated discharge water may be necessary to make the water more suitable for *C. dubia* survival and reproduction after the wild rice sulfate standard is met.

2.4 Basis of the Preliminary Cost Estimates

The treatment alternatives presented in this report include capital, operation and maintenance, and present worth costs. To develop the estimated capital costs for the treatment alternatives for the Area 1 Pit water, preliminary engineering was completed to identify potential locations for major treatment components. This report provides potential values for building area and clearing requirements, pipeline sizes and lengths, pumping requirements, and other values for basic components of the conceptual treatment systems such as access roads and utility (power) installation. Preliminary consideration has been given to plant location, so as to capitalize upon existing infrastructure such as roads and power.

The opinions of probable cost provided in this report are made on the basis of Barr's experience and represents our best judgment as experienced and qualified professionals familiar with the project and should be considered Class 5 estimates (according to the Association for the Advancement of Cost Engineering (AACE)), with a typical range of accuracy of ±25 to 100 percent. The cost opinions are

based on project-related information available to Barr at this time and are based on the conceptual-level development of the project. The opinions of cost may change as more information becomes available, further design is completed, or as the project needs change. In addition, since we have no control over the cost of labor, materials, equipment, or services furnished by others, or over contractors' methods of determining prices, or over competitive bidding or market conditions, Barr cannot and does not guarantee that proposals, bids, or actual construction costs will not vary from the opinion of probable costs prepared by Barr. While the costs of some specific items for a specified set of conditions can be determined with precision, for example some of the individual process units, the factors controlling the design conditions, namely the actual water quality and the potential treatment endpoints are still highly variable. The high potential for changes in these controlling values precludes a lower contingency in cost estimates at this stage of a project. Similarly, significant changes in the proposed mining operations for this project are likely to have a significant impact on the potential cost for the wastewater treatment component of the project. Until the potential variability of these controlling factors is reduced, greater precision in the overall cost of water treatment for Area 1 Pit water is not feasible.

The capital and operation and maintenance costs were developed using a number of sources, including information from recent local pricing and the following general resources:

- Engineering News Record (2011), Construction Cost Index History (accessed on the internet).

- Office of Management and Budget (1992), Guidelines and Discount Rates for Benefit Cost Analysis for Federal Programs, Appendix C, updated December 2009.

- U. S. EPA (2000), A Guide to Developing and Documenting Cost Estimates During the Feasibility Study, U.S. EPA 540-R00-002.

- U.S.G.S. (2011), Mineral Commodity Summary for lime (accessed on the internet - http://minerals.usgs.gov/minerals/pubs/commodity/lime/mcs-2011-lime.pdf)

The following assumptions were used in developing the opinion of probable cost:

- The capital costs assume a 20-year equipment life for mechanical equipment.

- A real discount rate of 2.7% and a time frame of 20 years were used in calculating the net present value of the operation and maintenance costs. Present value analyses are

typically conducted for the duration of the project (U.S. EPA, 2000). In this case, the duration of the project has been assumed to be the life of the equipment, which is approximately 20 years. The conceptual treatment facilities presented in this report were developed with the assumption that they could be incorporated into a long-term treatment strategy, if necessary.

- A 40% contingency has been included in the capital and O&M costs to account for items not detailed in the estimate but known to be part of the project such as process pumps, piping and supports, painting and protective coatings, process ancillary equipment, spare parts, operation and maintenance consumables, contractor mobilization and demobilization, and demolition.

- A 20% contingency has been included for professional services and reflects the lesser degree to which changes in capital items impact the cost of required engineering services.

- As discussed earlier, the range of accuracy for the costs presented is ±25 to 100%. This reflects the uncertainties associated with the scope of the project at this time, including: site and subsurface conditions, costs of materials and services, and utility requirements. This degree of accuracy falls within the level of accuracy suggested for screening and conceptual development of alternatives by the U.S. EPA (U.S. EPA, 2000).

- The cost of electricity used was $0.10/kW-h.

The following paragraphs provide brief descriptions of the major assumptions made to calculate and the capital costs for the treatment evaluation.

2.4.1 Plant Location
For this evaluation, we have assumed that a water treatment facility would likely be located directly east of the LSDP, on the north side of the Area 1 Pit, as shown in Figure 1-1. The plant building would be at an approximate grade level elevation of 1,600 ft MSL.

2.4.2 Pumping Requirements
To transport water from either the LSDP or the Area 1 Pit to the water treatment facility, a pump station will be needed. Figure 1-1 shows a preliminary partial site map with the approximate locations of the potential pump stations, forcemain routing, and the potential location of the water

treatment facility to treat Area 1 Pit water. These forcemains have been assumed to be HDPE pipe, and located above ground.

2.4.3 Treatment Building and Site Assumptions

A treatment building will be necessary to house treatment equipment. The buildings that have been estimated are precast concrete wall panel-type building. A steel building was not used due to the large sizes required and because additional coating requirements would be needed to provide a 2-hour fire rating, thereby increasing the cost of the steel building to an amount similar to that of a precast building.

It is assumed that some blasting will be required in order to construct the water treatment plant building. To account for this cost, the cost per square foot of the structures has been increased by increasing the estimated cost of the foundation construction. Actual soil boring data are needed to further define these costs.

A driveway rated for heavy traffic has been included in the preliminary cost estimate to serve the water treatment plant for deliveries of treatment chemicals. Additionally semi-trailers will need to be able to get into and out of the plant daily to transport dewatered sludge from the filter press operation for off-site disposal.

3.0 Treatment Evaluations

3.1 Reverse Osmosis with Zero Liquid Discharge (RO/ZLD)

3.1.1 Overview

The most common membrane processes in the water treatment marketplace today are microfiltration, ultrafiltration, nanofiltration and reverse osmosis. Microfiltration and ultrafiltration are particulate removal technologies. Nanofiltration and reverse osmosis are capable of removing dissolved constituents from water. The constituents of concern in the Area 1 Pit discharge are dissolved; therefore nanofiltration and reverse osmosis are the suitable membrane options for the primary treatment process. These membrane technologies separate dissolved constituents from water by applying energy to the fluid in the form of pressure to drive water molecules across the membrane and away from the dissolved constituents. Clean water (permeate) passes through the membrane, and a concentrated brine solution (concentrate) is retained by the membrane. Without the addition of this driving pressure, the concentration of dissolved solids on both sides of a membrane would naturally equilibrate to approximately the same concentration.

Reverse osmosis is highly effective in removing dissolved constituents from water, including both monovalent and divalent ions. Nanofiltration will preferentially remove divalent ions (such as magnesium, calcium, and sulfate), though it does also retain monovalent ions (depending on the balance of charged species present), but with much less efficiency than reverse osmosis. One of the advantages of nanofiltration over reverse osmosis is the lower required operating pressure of the system, which generally results in lower power requirements and lower operating costs for the membrane system. Both technologies are widely available from a number of membrane equipment suppliers and have been employed for potable and industrial water treatment for several years, though membrane treatment is still considered an emerging technology for mining water treatment (Mortazavi, 2008).

The projected water qualities for the Area 1 Pit mining alternatives are shown in Tables 2-2, 2-3, and 2-4. On average, TDS, alkalinity, hardness and sulfate are elevated. For nanofiltration and reverse osmosis, the treated water concentration requirements are critical to the design approach and resulting capital and operating costs. Preliminary modeling of the discharge water using publicly available nanofiltration / reverse osmosis simulation software (IMS Design by Hydranautics) was used to model treatment of the discharge by nanofiltration and reverse osmosis. To achieve a

permeate sulfate concentration of 10 mg/L, reverse osmosis was evaluated because of the higher retention provided by the reverse osmosis membranes.

Reverse osmosis is commonly employed for desalination of seawater for potable water production, and when these facilities are located on the coasts or in arid regions of the country, disposal of the concentrate can involve surface water discharge (to the ocean, typically), subsurface injection, or evaporation ponds. However, when the facilities are located inland, disposal of concentrate is more difficult. The primary options available for concentrate disposal are:

- Land application
- Discharge to the sanitary sewer system
- Evaporation ponds
- Subsurface injection
- Zero liquid discharge (with solids disposal)

Land application of concentrate in northern Minnesota is not a practical, year-round disposal option. Additionally, use of water for irrigation that has a conductivity of greater than 3,000 μS/cm (or roughly TDS of greater than 6,000 mg/L) and containing greater than 350 mg/L of chloride is not recommended because of the potential to cause physiological drought and soil damage (Bauder, et al., 2007). The RO concentrate is projected to have over 1,000 mg/L of chloride and has an estimated TDS of over 9,000 mg/L and is unsuitable for irrigation. Therefore land application of the concentrate is not a viable disposal option.

Another common concentrate disposal method is discharge of the concentrate to a sanitary sewer for treatment at a municipal wastewater treatment plant (WWTP). Conventional biological treatment systems do not provide substantial treatment for TDS, so the concentrate flow must be small relative to the overall WWTP flow (Metcalf & Eddy, 2007). Typical effluent from a conventional activated sludge system has a TDS concentration of 500 to 700 mg/L (Metcalf & Eddy, 2007). For each of the mining alternatives, the concentrate from the RO system is estimated to be approximately 300 gpm (average flow) with a TDS of greater than 9,000 mg/L. In order to produce blended wastewater effluent at the municipal plant with a TDS of less than 700 mg/L, a municipal plant with a flow of at least 18 MGD would be necessary. There are no WWTPs in the area that have this capacity.

Evaporation ponds are lined basins in which the concentrate water is placed for evaporation of the water into the atmosphere. The ponds are used in warm, dry climates conducive to this method. Most municipal RO facilities employing this method are treating less than 0.4 MGD of water and

generating only a fraction of that as concentrate (AWWA, 2007). With the climate in Minnesota and the volume of concentrate that must be managed, this option is not technically feasible.

Subsurface injection involves the injection of concentrate into deep, brackish or saline aquifers. These aquifers are typically hundreds to thousands of feet below the surface and must be overlaid with impermeable layers of rock and have TDS levels of 10,000 mg/L or more (AWWA, 2007). There are brackish aquifers in western and southwestern Minnesota (Winter, 1974) but no such aquifers have been identified in the project area in northern Minnesota, making this disposal option infeasible.

Because other technically feasible disposal options are not available, zero liquid discharge (ZLD) has been selected as the concentrate management approach. In ZLD, water is removed from the concentrate solution using thermal evaporation (with brine concentrators) and crystallization. The resulting product is a solid that can be disposed of in a solid waste landfill. Both processes are very energy-intensive. Waste steam can be used as an energy source for evaporation when it is available; otherwise a mechanical vapor compression (MVP) system is used. For this evaluation, use of electrically-driven MVP system has been assumed. For evaporation, roughly 85 kWh per 1,000 gallons of reverse osmosis concentrate is required and for crystallization, roughly 250 kWh per 1,000 gallons of evaporator concentrate is required (Mickley, 2006). The product from the brine concentrator is a very concentrated liquid, along with a low TDS distillate (water) stream. The crystallizers complete the dehydration process and produce a solid salt product. The costs for implementation and operation of ZLD equipment are included with the costs presented later in this section.

3.1.2 Treatment Requirements

The basic equipment and infrastructure requirements necessary for implementing RO treatment with ZLD concentrate management are shown in the conceptual process flow diagram, Figure 3-1. Of critical importance to the success of any reverse osmosis application is proper pretreatment of the water to prevent clogging and fouling of the membrane. Pretreatment will need to include both particulate removal and scale prevention. Particulate removal can be accomplished with sand filtration, microfiltration, or ultrafiltration. For this application, ultrafiltration was selected. Backwash waste from the ultrafiltration membranes will have similar dissolved chemistry as the feed water, but with greater total suspended solids, iron and manganese oxide solids, and can be returned to the Area 1 Pit for settling. The ultrafiltration system would also be used for iron and manganese removal.

The salts that are expected to require the use of chemical pretreatment ahead of the reverse osmosis system are calcium carbonate, barium sulfate, calcium sulfate, calcium fluoride, and calcium phosphate. As these salts concentrate on the feed side of the membrane, they have the potential to precipitate out of solution, and form a scale on the membrane that can dramatically reduce the throughput of the system and damage the membrane. Calcium carbonate scaling of the membrane can be remedied by lowering the pH of the feed water to the membrane to a pH of 6.5. This reduces the carbonate present in the water to prevent calcite precipitation. Unlike carbonate scaling, acidification of the feed water is not sufficient to prevent precipitation of sulfates, phosphates, or fluorides. The approach to scaling control would be to lower the system recovery and/or add proprietary antiscalants. Achievable recovery directly affects the amount of membrane area required to produce a given volume of treated water. In Years 2 and beyond, calcium fluoride is projected to limit the system recovery.

As shown in Figure 3-1, the major treatment components for treating the Area 1 Pit discharge under all of the three mining alternatives are:

- Influent pumping
- Pretreatment for UF:
    - Oxidation + filtration for iron and manganese removal
    - Fine screens
- Ultrafiltration system
- Pretreatment for RO:
    - Particulate removal by cartridge filters
    - pH adjustment to mitigate carbonate scaling
    - Antiscalant and bisulfite addition for scaling management
- Evaporator system:
    - RO concentrate tank and pumps
- Crystallizer system
- Effluent stabilization
    - Lime storage and feed equipment
- Effluent pumping
    - Permeate tank and pumps

Preliminary modeling of reverse osmosis system for each mining alternative was conducted using IMS Design. The modeling indicated that the water quality standards, including the wild rice sulfate

standard of 10 mg/L, could be met. The model also indicated that the recovery of the reverse osmosis membrane system is likely to vary, as the scaling potential changes because the water quality the pits will vary with time. This was particularly true for Mining Alternative 2, for which the model indicated that up to 90% recovery may be achievable in the early years of dewatering. The following values, which are a summary of the IMS Design results, were used as the basis of the preliminary costs estimates presented in Section 3.2

Mining Alternative 1

- Maximum flow to the treatment plant: 4,000 gpm
- 20-yr average flow to the treatment plant: 2,272 gpm
- Assumed UF membrane recovery: 90%
- RO system maximum feed flow rate: 3,600 gpm
- RO system average feed flow rate: 2,045 gpm
- RO system recovery: 85%
- Maximum concentrate flow to the evaporator: 540 gpm
- Average concentrate flow to the evaporator: 307 gpm

Mining Alternative 2

- Maximum flow to the treatment plant: 4,000 gpm
- 20-yr average flow to the treatment plant: 1,882 gpm
- Assumed UF membrane recovery: 90%
- RO system maximum feed flow rate: 3,600 gpm
- RO system average feed flow rate: 1,693 gpm
- RO system recovery: 85% (higher recovery predicted for Year 1 when the annual flow is the greatest)
- Maximum concentrate flow to the evaporator: 434 gpm
- Average concentrate flow to the evaporator: 254 gpm

No Action Alternative

- Maximum flow to the treatment plant: 4,000 gpm
- 20-yr average flow to the treatment plant: 2,184 gpm
- Assumed UF membrane recovery: 90%

- RO system maximum feed flow rate: 3,600 gpm

- RO system average feed flow rate: 1,966 gpm

- RO system recovery: 85%

- Maximum concentrate flow to the evaporator: 540 gpm

- Average concentrate flow to the evaporator: 295 gpm

Pilot testing of the UF/RO process prior to implementation is recommended. The pilot testing goals would be to: (1) evaluate the efficacy of antiscalants on membrane throughput, (2) determine the appropriate design flux and recovery for the system (and hence optimize the capital cost), and (3) conduct bench scale studies on the concentrate to support design of the chemical precipitation concentrate treatment system. It is important to note that antiscalant chemicals will be required and the efficacy of those chemicals in achieving the RO recoveries used for this evaluation must be determined through pilot-scale testing. The RO system recovery has a substantial effect on the size of the evaporator and crystallizer and on their respective capital and operating costs.

3.1.3 Post-Treatment Effluent Stabilization

In order to achieve discharge water that contains no more than 10 mg/L of sulfate, no (or very minimal) blending of feed water and RO permeate is possible. For this analysis, we have not used blending. The RO permeate that is produced has very little TDS (<20 mg/L), very little buffering capacity, and is acidic (pH ≈ 5). This water is likely to be corrosive and toxic and will require stabilization prior to discharge. Stabilization can be accomplished by adding a number of chemicals, including sodium hydroxide, sodium bicarbonate, sodium carbonate, and lime. For this evaluation, we have used lime addition to raise the pH to 7 and restore some buffering capacity to the water. A more detailed investigation into the optimal stabilization method is recommended at the pilot scale.

3.2 Preliminary Cost Estimates

The preliminary cost estimates for the three mining alternatives can be found in Tables 3-1 through 3-3. A summary of the costs is presented here:

Mining Alternative 1

- Capital cost: $40.6M

- Annual O&M cost: $3.3M

- Net present value: $91.7M

Mining Alternative 2

- Capital cost: $40.0M
- Annual O&M cost: $2.9M
- Net present value: $84.8M

No Action Alternative

- Capital cost: $40.8M
- Annual O&M cost: $3.3M
- Net present value: $91.0M

Within the range of typical accuracy for Class 5 cost estimates, the net present values for each option is essentially the same.

Table 3-1. Mining Alternative 1 Preliminary Cost Estimate

Item	Unit	Unit Cost	Qty	Cost
Preliminary Costs				
UF/RO pilot unit	MO	$ 50,000	3	$ 150,000
Capital Costs				
Influent pump station (4000 gpm)	LS	$ 400,000	1	$ 400,000
20" HDPE forcemain from Pit 1 to WTF	LF	$ 75	1000	$ 75,000
Treatment building - precast wall panel + site blasting and fill preparation	SF	$ 150	45000	$ 6,750,000
UF and RO systems	LS	$ 4,500,000	1	$ 4,500,000
ZLD feed tank	LS	$ 80,000	1	$ 80,000
Evaporator system	LS	$ 5,600,000	1	$ 5,600,000
Crystallizer system	LS	$ 2,300,000	1	$ 2,300,000
Liquid chemical storage and feed equipment	EA	$ 30,000	6	$ 180,000
Lime storage and feed system	LS	$ 250,000	1	$ 250,000
Effluent pumping (3000 gpm)	LS	$ 300,000	1	$ 300,000
Process equipment installation @ 30%	LS	$ 1,638,000	1	$ 1,638,000
Mechanical systems @ 15%	LS	$ 819,000	1	$ 819,000
Electrical and control systems @ 25%	LS	$ 1,365,000	1	$ 1,365,000
Civil/site work	LS	$ 200,000	1	$ 200,000
Capital Cost Subtotal				$ 24,457,000
Capital Cost Contingency	40%			$ 9,782,800
Capital Cost Total				***$ 34,239,800***
Professional Services				
Design and procurement	10%	$ 3,423,980	1	$ 3,423,980
Construction services	5%	$ 1,711,990	1	$ 1,711,990
Legal	LS	$ 50,000	1	$ 50,000
Professional Services Subtotal				$ 5,185,970
Professional Services Contingency	20%			$ 1,037,194
Professional Services Total				***$ 6,223,164***
Annual Operation and Maintenance				
Ultrafiltration O&M	LS	$ 600,000	1	$ 600,000
Reverse Osmosis O&M	LS	$ 860,000	1	$ 860,000
Evaporator O&M	LS	$ 1,500,000	1	$ 1,500,000
Crystallizer O&M	LS	$ 200,000	1	$ 200,000
Chemical cost (lime, effluent stabilization)	LS	$ 75,000	1	$ 75,000
Energy costs (pumping)	KWH	$ 0.10	400000	$ 40,000
Sludge hauling and disposal	WT	$ 30	15000	$ 450,000
Labor	FTE	$ 60,000	2	$ 120,000
Operation and Maintenance Cost Subtotal				$ 2,385,000
Operation and Maintenance Cost Contigency	40%			$ 954,000
Operation and Maintenance Cost Total				***$ 3,339,000***

Table 3-2. Mining Alternative 2 Preliminary Cost Estimate

Item	Unit	Unit Cost	Qty	Cost
Preliminary Costs				
UF/RO pilot unit	MO	$ 50,000	3	$ 150,000
Capital Costs				
Influent pump station (4000 gpm)	LS	$ 400,000	1	$ 400,000
20" HDPE forcemain from Pit 1 to WTF	LF	$ 75	1000	$ 75,000
Treatment building - precast wall panel + site blasting and fill preparation	SF	$ 150	45000	$ 6,750,000
UF and RO systems	LS	$ 4,500,000	1	$ 4,500,000
ZLD feed tank	LS	$ 80,000	1	$ 80,000
Evaporator system	LS	$ 5,200,000	1	$ 5,200,000
Crystallizer system	LS	$ 2,300,000	1	$ 2,300,000
Liquid chemical storage and feed equipment	EA	$ 30,000	6	$ 180,000
Lime storage and feed system	LS	$ 250,000	1	$ 250,000
Effluent pumping (3000 gpm)	LS	$ 300,000	1	$ 300,000
Process equipment installation @ 30%	LS	$ 1,638,000	1	$ 1,638,000
Mechanical systems @ 15%	LS	$ 819,000	1	$ 819,000
Electrical and control systems @ 25%	LS	$ 1,365,000	1	$ 1,365,000
Civil/site work	LS	$ 200,000	1	$ 200,000
Capital Cost Subtotal				$ 24,057,000
Capital Cost Contingency	40%			$ 9,622,800
Capital Cost Total				***$ 33,679,800***
Professional Services				
Design and procurement	10%	$ 3,367,980	1	$ 3,367,980
Construction services	5%	$ 1,683,990	1	$ 1,683,990
Legal	LS	$ 50,000	1	$ 50,000
Professional Services Subtotal				$ 5,101,970
Professional Services Contingency	20%			$ 1,020,394
Professional Services Total				***$ 6,122,364***
Annual Operation and Maintenance				
Ultrafiltration O&M	LS	$ 500,000	1	$ 500,000
Reverse Osmosis O&M	LS	$ 700,000	1	$ 700,000
Evaporator O&M	LS	$ 1,300,000	1	$ 1,300,000
Crystallizer O&M	LS	$ 180,000	1	$ 180,000
Chemical costs (lime, effluent stabilization)	LS	$ 65,000	1	$ 65,000
Energy costs (pumping)	KWH	$ 0.10	400000	$ 40,000
Sludge hauling and disposal	WT	$ 30	13000	$ 390,000
Labor	FTE	$ 60,000	2	$ 120,000
Operation and Maintenance Cost Subtotal				$ 2,095,000
Operation and Maintenance Cost Contigency	40%			$ 838,000
Operation and Maintenance Cost Total				***$ 2,933,000***

Table 3-3. No Action Alternative Preliminary Cost Estimate

Item	Unit	Unit Cost	Qty	Cost
Preliminary Costs				
UF/RO pilot unit	MO	$ 50,000	3	$ 150,000
Capital Costs				
Influent pump station (4000 gpm)	LS	$ 400,000	1	$ 400,000
20" HDPE forcemain from Pit 1 to WTF	LF	$ 75	1000	$ 75,000
Treatment building - precast wall panel + site blasting and fill preparation	SF	$ 150	45000	$ 6,750,000
UF and RO systems	LS	$ 4,500,000	1	$ 4,500,000
ZLD feed tank	LS	$ 80,000	1	$ 80,000
Evaporator system	LS	$ 5,600,000	1	$ 5,600,000
Crystallizer system	LS	$ 2,400,000	1	$ 2,400,000
Liquid chemical storage and feed equipment	EA	$ 30,000	6	$ 180,000
Lime storage and feed system	LS	$ 250,000	1	$ 250,000
Effluent pumping (3000 gpm)	LS	$ 300,000	1	$ 300,000
Process equipment installation @ 30%	LS	$ 1,638,000	1	$ 1,638,000
Mechanical systems @ 15%	LS	$ 819,000	1	$ 819,000
Electrical and control systems @ 25%	LS	$ 1,365,000	1	$ 1,365,000
Civil/site work	LS	$ 200,000	1	$ 200,000
Capital Cost Subtotal				$ 24,557,000
Capital Cost Contingency	40%			$ 9,822,800
Capital Cost Total				*$ 34,379,800*
Professional Services				
Design and procurement	10%	$ 3,437,980	1	$ 3,437,980
Construction services	5%	$ 1,718,990	1	$ 1,718,990
Legal	LS	$ 50,000	1	$ 50,000
Professional Services Subtotal				$ 5,206,970
Professional Services Contingency	20%			$ 1,041,394
Professional Services Total				*$ 6,248,364*
Annual Operation and Maintenance				
Ultrafiltration O&M	LS	$ 580,000	1	$ 580,000
Reverse Osmosis O&M	LS	$ 800,000	1	$ 800,000
Evaporator O&M	LS	$ 1,500,000	1	$ 1,500,000
Crystallizer O&M	LS	$ 190,000	1	$ 190,000
Chemical costs (lime, effluent stabilization)	LS	$ 75,000	1	$ 75,000
Energy costs (pumping)	KWH	$ 0.10	400000	$ 40,000
Sludge hauling and disposal	WT	$ 30	14000	$ 420,000
Labor	FTE	$ 60,000	2	$ 120,000
Operation and Maintenance Cost Subtotal				$ 2,345,000
Operation and Maintenance Cost Contigency	40%			$ 938,000
Operation and Maintenance Cost Total				*$ 3,283,000*

4.0 Conclusions

The projected discharge water quality from the Area 1 Pit under three mining alternatives was reviewed and compared to the water quality standards for Second Creek. The discharge water quality is projected to be above the water quality standards for alkalinity, hardness, total dissolved solids, and specific conductivity under all three mining alternatives. Because of a February, 2010 change in MPCA interpretation of an agricultural irrigation water quality standard for sulfate in waters used for the production of wild rice, the MPCA has determined that the discharge from Area 1 Pit will exceed that standard in the Partridge River where wild rice was discovered in field surveys in 2009 (Barr, 2009c).   Treatment process selection was driven by the MPCA's February 2011 interpretation of the agricultural irrigation water quality standard of 10 mg/L sulfate for waters used for the production of wild rice. Membrane treatment using reverse osmosis was evaluated to meet this water quality standard. Reverse osmosis will also reduce the hardness, alkalinity, and total dissolved solids (and resulting specific conductivity) of the Area 1 Pit discharge. Preliminary modeling of the reverse osmosis process showed that the water quality standards can likely be met, including the 10 mg/L sulfate standard. While the numerical water quality standards may be able to be met, removing most of the dissolved constituents from the water is necessary. The impact of this change in ionic composition on whole effluent toxicity is not known. Removal of the majority of the dissolved constituents from the water (salts and trace micronutrients) may actually exacerbate the observed toxicity. Chemical additions may be necessary to make the water more suitable for *C. dubia* survival and reproduction after the wild rice sulfate standard is met. Further investigations are necessary to determine if whole effluent toxicity is affected by the treatment process and to confirm that the treatment process is technically feasible.

Based on the treatment evaluations reverse osmosis is not cost effective for the treatment of Area 1 Pit water, and is not an "additional control measures [which is] reasonable", per the requirement of MN Rules 7050.0185, Subpart 8. Treatment of the discharge to reduce alkalinity, hardness, total dissolved solids, specific conductivity and to meet the wild rice standard of 10 mg/L has present worth value that is the same order of magnitude as the entire cost of the Phase II project.

Preliminary cost estimates were developed for each of the mining alternatives. Capital and operation and maintenance costs were developed based on costs for recent similar projects, typical industry values, and IMS Design modeling. The present worth costs were developed assuming 2.7 percent discount rate and 20 years of plant operation.

The net present values for each mining alternative are quite similar, ranging from $85M to $92M. The net present value of the options evaluated is on the same order of magnitude as the cost of the Mesabi Nugget Phase II project. As such, none of the treatment alternatives are "additional control measures [which] are reasonable", per the nondegradation requirements in MN Rule 7050.0185, Subpart 8.
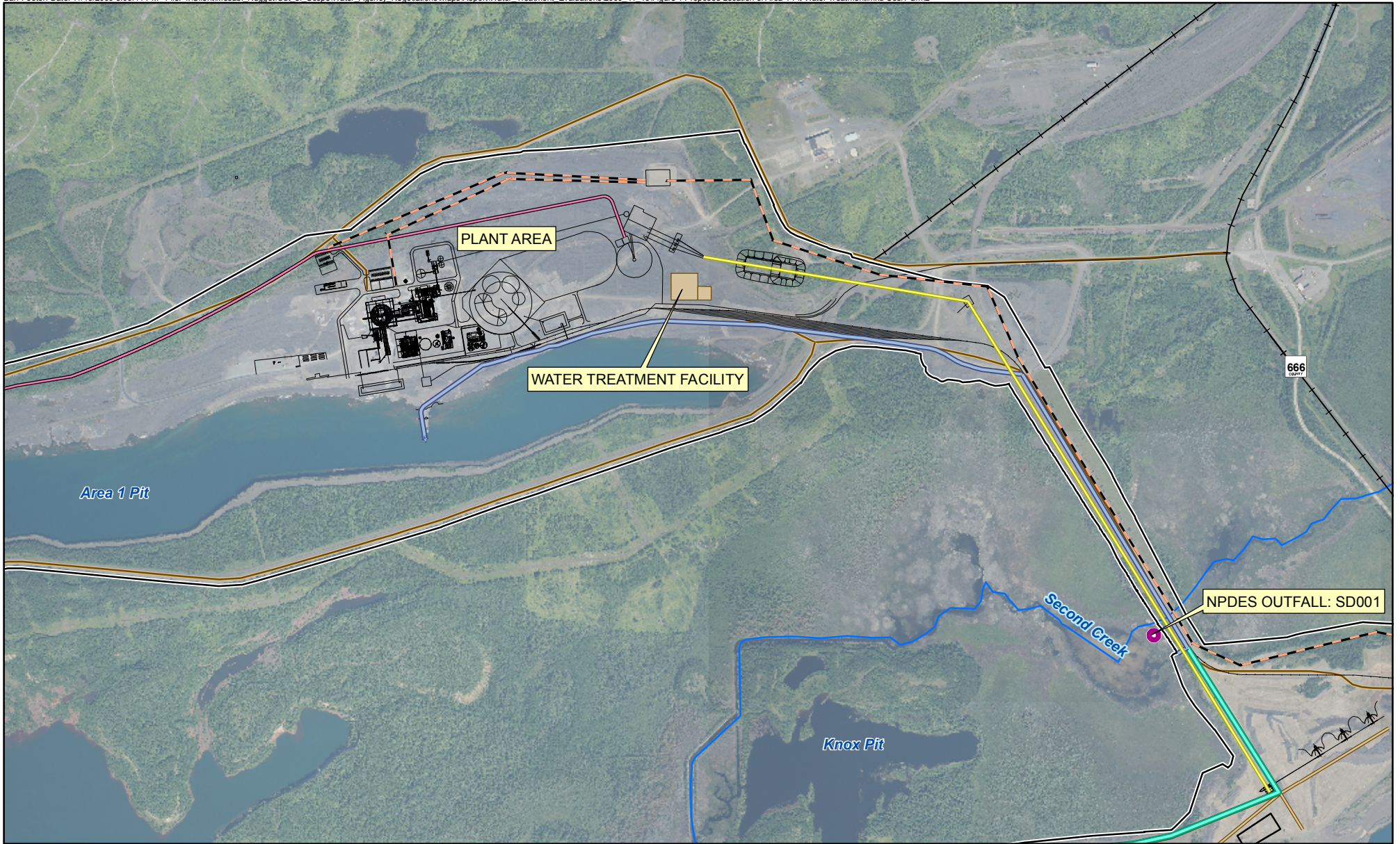
The costs presented in this report should be considered planning level costs only. While this degree of accuracy is sufficient for comparison of cost-effectiveness in this report, actual costs will vary, depending on the changing need of the project and the final detailed design. Prior to implementing any of the treatment strategies, pilot scale testing is recommended to refine design parameters and define equipment sizes and chemicals and chemical dosages required.

5.0 References

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Figures

PLANT AREA

WATER TREATMENT FACILITY

Area 1 Pit

Second Creek

NPDES OUTFALL: SD001

Knox Pit

Legend

- NPDES Outfall
- Project Boundary
- Water Treatment Facility
- Plant Features
- Proposed Pipeline Route
- Water Line
- Conveyor
- Tailings Pipe Line
- Existing Transmission Line
- Proposed Transmission Line
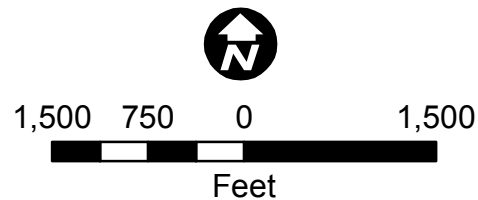- At-Grade Haul Road
- Service Road
- Existing Railroads

1,500   750   0   1,500

Feet

Figure 1-1
PROPOSED LOCATION OF AREA 1
PIT WATER TREATMENT
Mesabi Nugget Phase II
Hoyt Lakes, Minnesota

Figure 3-1 Conceptual Process Flow Diagram