Area 1 Pit Water Treatment Evaluation in Support of the Non-Degradation Analysis

Mesabi Nugget Phase II Project

Prepared for
Steel Dynamics, Inc.
Mesabi Mining, LLC

November 2009

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Executive Summary

Area 1 Pit is in the process of being dewatered to provide a reservoir for process water to be used in its Large Scale Demonstration Plant (LSDP) and to provide a disposal location for tailings resulting from mining operations. At the initiation of dewatering, the Area 1 Pit contained approximately 13.7 billion gallons of water, with a surface elevation of approximately 1548 ft MSL. In order to stop seepage in the southeast corner of the pit the water level in the pit was lowered to 1546 ft MSL. Additionally lowering of the water elevation to between 1541.7 and 1545.2 ft MSL (seasonally dependent) was necessary to provide a minimum of six months of storage. The water being pumped from the pit is being discharged to Second Creek under an existing NPDES/SDS discharge permit (MN0067687); however, the new *Water Management Plan* for the Phase II project (Barr, estimated issue date November 2009) includes a proposal to relocate this discharge to the Partridge River. The chemistry of the Area 1 Pit water has been analyzed throughout 2008 and 2009 and the future chemistry has been modeled and projected in the *Dissolved Solids and Chemical Balance Report* (Barr, estimated issue date November 2009). The Area 1 Pit discharge is projected to have concentrations of total dissolved solids (TDS), alkalinity, and hardness that may exceed in-stream water quality standards. Sulfate concentrations may also need to be considered as they are a significant portion of the TDS. 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 and operation for four treatment strategies for the Area 1 Pit discharge water.

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, needs to include an evaluation of potential treatment technologies. The treatment technologies evaluated were:

- Eliminating the return of treated process water from the LSDP to the Area 1 Pit by using reverse osmosis (RO). The treated RO permeate would be returned directly to the LSDP as make-up water, while the RO concentrate would be treated using evaporation and crystallization to achieve a zero liquid discharge (ZLD).
- Eliminating the return of treated process water from the LSDP to the Area 1 Pit using RO with concentrate ZLD and treatment of the Area 1 Pit discharge using lime softening.

- Eliminating the return of treated process water from the LSDP to the Area 1 Pit using RO with concentrate ZLD and membrane softening of the Area 1 Pit discharge.
- Treatment of the Area 1 Pit discharge using RO with evaporation and crystallization of the RO concentrate.

Of key importance to developing these alternatives was the determination that a significant contributor to the Area 1 Pit water quality is the return of treated process water from the LSDP. This flow of only 445 gpm, contains 22,000 kg/d of TDS. This flow represents only 11 percent of the projected maximum dewatering rate from Area 1 pit of 4,000 gpm, however it contributes up to 45 percent of the total mass of dissolved solids under Mine Alternative 1 and up to 50 percent of the total mass of dissolved solids under Mine Alternative 2. Eliminating this concentrated load before it is discharged into the Area 1 Pit removes a substantial portion of the TDS load to the pit and, as shown in the cost estimates, provides the most economical method of removing TDS on a mass basis. Tables E1 and E2 summarize the results of the evaluations for Mine Alternative 1 and 2, respectively.

Table E1. Results of Treatment Alternatives Evaluations for Mine Alternative 1

Treatment at the LSDP	Treatment at the Area 1 Pit Discharge	Maximum Mass of TDS removed[1] (kg/d)	Average Mass of TDS removed[2] (kg/d)	Net Present Value
RO/ZLD	none	22,000	22,000	$ 42,700,000
RO/ZLD	Lime softening	27,900	26,700	$ 87,200,000
RO/ZLD	RO/ZLD	26,400	25,500	$ 110,400,000
none	RO/ZLD	24,000	19,200	$ 112,600,000

Notes:
1. Mass removal treating maximum permitted flow of 4,000 gpm
2. Mass removal treating 20-year average flow of 3,200 gpm

Table E2. Results of Treatment Alternatives Evaluations for Mine Alternative 2

Treatment at the LSDP	Treatment at the Area 1 Pit Discharge	Maximum Mass of TDS removed[1] (kg/d)	Average Mass of TDS removed[2] (kg/d)	Net Present Value
RO/ZLD	none	22,000	22,000	$ 42,700,000
RO/ZLD	Lime softening	28,100	25,400	$ 83,400,000
RO/ZLD	RO/ZLD	30,100	26,500	$ 109,700,000
none	RO/ZLD	30,500	17,200	$ 109,500,000

Notes:
1. Mass removal treating maximum permitted flow of 4,000 gpm
2. Mass removal treating 20-year average flow of 2,250 gpm

Even with the elimination of the load from the LSDP, some alkalinity and hardness remains in the pit that may require additional softening to avoid any degradation of the receiving stream – either Second Creek or the Partridge River. However, the costs for this incremental additional treatment are significant.

None of the treatment alternatives are cost effective for the treatment of Area 1 Pit water, and none are "additional control measures [which] are reasonable", per the requirement of MN Rules 7050.0185, Subpart 8. All of the alternatives have present worth values that are the same order of magnitude as the entire cost of the Phase II project.

1.0 Introduction

1.1 Introduction

This treatment evaluation report has been developed as part of the non-degradation 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 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). The Project will include re-opening of a taconite mine and construction of a new crushing and concentrating facility. The Project will be undertaken by Mesabi Mining, LLC and Steel Dynamics, Inc. These entities are collectively managed by Steel Dynamics, Inc. and are referred to as "Mesabi Nugget." The Project will provide iron concentrate for use in the previously permitted Large Scale Demonstration Plant (LSDP) expected to be operational in the fourth quarter of 2009 at the Project site. The Project will be 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 is currently in the process of dewatering the Area 1 Pit to provide a reservoir for process water that will be used in the LSDP and to provide a disposal location for tailings resulting from the proposed Phase II mining operations. At the initiation of dewatering, the Area 1 Pit contained approximately 13.7 billion gallons of water, with a surface elevation of approximately 1548 ft MSL. In order to stop seepage in the southeast corner of the pit the water level in the pit was lowered to 1546 ft MSL. Additionally lowering of the water elevation to between 1541.7 and 1545.2 ft MSL (seasonally dependent) was necessary to provide a minimum of six months of storage. The pumped water from the Area 1 Pit is being discharged to Second Creek under an existing NPDES/SDS discharge permit (MN0067687). After the initial lowering of the Area 1 Pit water level, Mesabi Nugget may discharge up to a maximum of approximately 4,000 gpm (5.8 MGD) of water from Area 1 Pit.

The draft *Mine Pit Hydrology and Water Balances Report*, issued March 2009, and the October 2009 update memorandum, 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 draft *Dissolved Solids and Chemical Balance* report, issued November 2009. The water quality projections from this report are summarized in Tables 1 and 2.

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 1, along with a listing of the applicable water quality standard for each parameter and the current water quality of Second Creek and the Partridge River.

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. The sulfate concentration in the pit is also elevated and represents a significant portion of the TDS. In addition to these specific chemical parameters, the water in the Area 1 Pit has shown intermittent low-level, chronic toxicity to *Ceriodaphnia dubia* (daphnia). Identifying the specific source of toxicity is the subject of an on-going toxicity identification evaluation (TIE) study. In Table 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 *Ceriodaphnia dubia*, the reference toxicant is sodium chloride. For ERA laboratories (the whole effluent toxicity testing laboratory that has been used for the Mesabi Nugget tests), the chronic IC25 is approximately 800 mg/L total dissolved solids (TDS) as sodium chloride. This means that 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 water.

2.2 Future Water Quality Projections

Under the water balance scenarios described in the draft *Mine Pit Hydrology and Water Balances Report* (as Mine 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 leaves the pit via the following processes:

- Intake of process and cooling water for the LSDP
- 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. 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 flow from the LSDP to the pit is approximately 445 gpm, containing approximately 9,000 mg/L TDS, which results in a load of 22,000 kg/d of TDS to the pit. The load is estimated to increase the concentration of TDS and in the specific conductivity of the pit water. The contributions to the salinity of the pit water from the LSDP are illustrated in Figures 2 and 3 for one point in time (Year 10 of operations) for both Mine Alternatives 1 and 2, respectively.

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 of 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 1 and 2, respectively. More detail can be found in the *Dissolved Solids and Chemical Balance* report.

Over time, the values of a number of parameters are projected to increase over their current values. Of particular importance are chloride, sodium, sulfate, total dissolved solids, and specific conductivity. Hardness and alkalinity are also projected to increase over time, but to a lesser degree. 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 alkalinity, hardness, TDS, and specific conductivity. The BOD and 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 Dissolved Solids Removal Technologies

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. 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, as presented in Tables 1 and 2. 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. 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 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.

Technologies capable of removing sulfate, alkalinity, and hardness with no treatment of the monovalent constituents and that were considered in the treatment evaluation of the Area 6 Pit water – for example, lime softening, lime softening with ettringite precipitation, lime softening with barium sulfate precipitation, and ion exchange – would not likely be sufficient to reduce the concentration of TDS to near the water quality standards or the current in-stream water quality for Second Creek or the Partridge River and have not been included in this report.

Because, as noted above, up to approximately 50 percent of the dissolved solids load to the Area 1 Pit can be attributed to the treated effluent from the LSDP (which represents only 11 percent of the total potential discharge flow), this waste stream represents a significant opportunity to reduce the dissolved solids load to the Area 1 Pit. This may reduce or eliminate the need to treat the Pit discharge to Second Creek or the Partridge River. In accordance with the Phase I NPDES discharge permit, water taken from the pit for use at the facility is treated at the LSDP by lime-soda ash softening and chemical precipitation for metals removal before being returned to the pit. The operation of the LSDP (particularly the scrubber) and those water treatment processes at the LSDP, along with the addition of other chemicals to the water at the facility, result in an increase in sodium, sulfate, and chloride in the water returned to the pit.

Eliminating the load of dissolved solids to the Area 1 Pit from the LSDP would result in a substantial reduction in TDS, as shown in Figures 2 and 3. Eliminating this load to the pit can be accomplished by further treating the wastewater with reverse osmosis (RO). Reverse osmosis can produce treated water (permeate) that can be reused within the LSDP, while the RO waste stream (concentrate) can be solidified using evaporation and crystallization to produce a solid salt product thereby eliminating the return of water from the LSDP to the pit (zero liquid discharge, ZLD). This approach forms the basis of the treatment alternatives presented in this report and is described in more detail in Section 3.0.

The projected Area 1 Pit water quality with the implementation of RO/ZLD is also shown in Tables 3 and 4 for Alternatives 1 and 2, respectively. Eliminating the load of dissolved solids from the LSDP to the pit would substantially improve the projected Area 1 Pit water quality, however, it may not result in pit water quality that would be comparable to the current water quality of second Creek or the Partridge River and may not be able to result in a discharge water that would meet potentially applicable in-stream water quality standards at the end of the pipe (i.e., a mixing zone would still be required to achieve standards in the receiving stream).

The range of potential treatment options evaluated in Section 3.0 is as follows:

1. Implementation of RO with reuse of the permeate in the LSDP and evaporation and crystallization of the RO concentrate to eliminate the flow of treated process water to the Area 1 Pit (RO/ZLD).
2. RO/ZLD of the LSDP effluent with lime softening of the Area 1 Pit discharge.
3. RO/ZLD of the LSDP effluent with RO of part of the Area 1 Pit discharge. Concentrate from the RO treatment of the pit discharge would be treated by evaporation and crystallization.
4. Treatment of a portion of the Area 1 Pit discharge by RO, coupled with evaporation and crystallization treatment of the RO concentrate. Under this treatment option, RO/ZLD

would not be implemented at the LSDP and treated process water would continue to be discharged to the Area 1 Pit.

2.3.2 Mercury Removal Technologies

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 in predicted. To address the additional mercury load, up to two Mesabi Nugget Corporation (MNC) Mercury Filters will be installed. The first filter will be located after the LSDP water softening system and prior to discharge to the Area 1 Pit. This filter would be necessary only under treatment alternative four described in Section 2.3.1 above because under alternatives 1-3, there is no discharge from the LSDP to the pit. The filter is designed to reduce mercury concentration by an order of magnitude or more in the treated LSDP discharge. The second filter will be located prior to discharge to Second Creek and would be installed under all four of the treatment alternatives described in Section 2.3.1. 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.

2.3.3 Toxicity Reduction Technologies

As noted previously, the Area 1 Pit water exhibits intermittent chronic toxicity to *C. dubia* (as determined by Whole Effluent Toxicity 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. For the purpose of this report, it has been assumed that reducing TDS (including alkalinity, hardness and sulfate) and specific conductivity will mitigate toxicity, but additional toxicity identification evaluation (TIE) and toxicity reduction evaluation (TRE) studies may be required. A summary of recent investigations into the intermittent pit toxicity can be found in the June 2009 report entitled *Toxicity Identification Evaluation Study for the Mesabi Nugget Pits*.

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. These general items would likely be common to all potential treatment options. Preliminary consideration has been given to plant location, so as to capitalize upon existing infrastructure that would be common to both project phases such as roads and power. However, opportunities for cost sharing for pipe lines, pump stations, and treatment equipment for this Phase of the project have not been considered. Construction for Phase 1 of the project is nearly complete and is scheduled to start-up in late 2009. The treatment system constructed for Phase 1 consists of lime-soda ash softening and metals removal via precipitation. Neither of these technologies is sufficient to treat Area 1 Pit water, as is described in more detail elsewhere in this report, limiting the potential for cost sharing with treatment of Area 1 pit water.

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 4 estimates (according to the Association for the Advancement of Cost Engineering (AACE)), with a typical range of accuracy of ±15 to 50 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. Until these variables can be better defined, it is not even possible to determine what pilot testing may be needed to better refine the process unit design and likely operating characteristics. 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

A 40 percent 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. A 20 percent 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 ±15 to 50 percent. This reflects the uncertainties associated with the scope of the project at this time, including: site conditions, costs of materials and services, utility requirements and availability, and modifications to an existing facility. This degree of accuracy falls within the level of accuracy suggested for alternatives analysis by the U.S. EPA (U.S. EPA, 2000).

The following paragraphs provide brief descriptions of the major assumptions made to calculate and the capital costs for the treatment alternatives. The assumptions described below are common to most of the treatment alternatives described in Section 3.0.

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. 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 shows a preliminary partial site map with the approximate locations of the potential pump stations, force-main routing, and the potential location of the water treatment facility to treat Area 1 Pit water. These force-mains 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 Alternatives

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

3.1.1 Overview

Two membrane treatment processes are capable of removing dissolved constituents from water: nanofiltration (NF) and reverse osmosis (RO). 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 while 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.

RO is highly effective in removing dissolved constituents from water, including both monovalent and divalent ions. NF 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 RO. An advantage of NF over RO is the lower required operating pressure of the system, which generally results in lower power requirements and lower operating costs.

In the case of the Area 1 Pit LSDP, monovalent ions (sodium, chloride and bicarbonate) represent a significant contribution to TDS and specific conductivity. Therefore, RO treatment was selected over NF for evaluation in this report, because RO will produce permeate with lower TDS and specific conductivity than NF with greater removal of the monovalent ions from solution. The quality of the permeate achievable with RO would enable it to be reused within the LSDP. RO is also more effective at concentrating ions from solution because of its removal of both mono- and divalent ions so that the salt load to the concentrate management system is maximized.

Pretreatment of the LSDP process water (prior to RO) will need to include both particulate removal and scale prevention. Particulate removal can be accomplished with ultrafiltration (UF), a common fine particulate removal technology, which employs hollow fiber membranes with small pore sizes to filter out suspended solids. The size of the UF system required is dependent largely upon flow, water temperature, influent total suspended solids, and overall UF system recovery. A recovery of 95 percent has been assumed.

In order to eliminate the TDS load from the LSDP to the Area 1 Pit, the ions that are removed by RO, must be managed in a way that does not involve the returning this load to pit or sending it to the NDPES discharge. 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 LSDP water *before* it is concentrated with RO contains over 700 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). The concentrate from the LSDP RO system is estimated to be 88 gpm with a TDS of greater than 35,000 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 21 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 for the LSDP RO system. 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 (GE, 2009). 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 in later in this section.

3.1.2 Treatment Requirements

The basic equipment and infrastructure requirements necessary for implementing RO treatment with ZLD concentrate management at the LSDP were developed in consultation with GE Water. A conceptual process flow diagram is shown in Figure 4. The current LSDP water treatment process consists of lime-soda ash softening for calcium and magnesium removal and chemical precipitation with clarification for removal of select metals. The facility is currently expected to begin operation during the fourth quarter of 2009. The facility design did not anticipate the requirement for additional treatment equipment.

Implementation of RO/ZLD on the effluent from the LSDP facility will involve procuring and installing of the following unit processes:

- Ultrafiltration (UF) system to provide fine particulate removal prior to reverse osmosis. The system would be sized to treat 445 gpm of water from the LDSP wastewater treatment process. An average recovery of 95 percent across the UF system has been assumed. The UF system would be compromised of the following major components:
    - Feed pumps
    - Feed water strainers
    - Permeate/backwash pumps
    - Backwash strainers
    - Air scour system
    - Chemical storage and feed systems
    - Clean-in-place system
    - Membrane tanks
    - Membranes
- Single-pass RO system for the removal of dissolved solids from the water. 80 percent recovery across the RO system has been assumed, producing an estimated 338 gpm of permeate for reuse within the plant. The RO system would be compromised of the following major components:
    - Feed pumps
    - Cartridge filters
    - Chemical storage and feed systems (for cleaning, pretreatment, and permeate stabilization)
    - Clean-in-place system
    - Permeate break tanks and storage
    - Permeate transfer pump
    - RO skids, housings, and membranes
- Brine evaporator sized to receive 88 gpm of RO concentrate. The evaporator would be compromised of the following major components:
    - Feed tank and pump
    - Deaerator vessel
    - Distillate tank and pump
    - Evaporator vessel

  - Evaporate tank and mixer
  - Chemical storage and feed system
  - Heat exchanger
  - Vapor compressor
  - Seeding system
  - Boiler

- Crystallizer sized to receive 20 gpm of concentrated brine from the evaporator. The crystallizer would be compromised of the following major pieces of equipment:

  - Crystallizer vapor body
  - Heater
  - Feed and recirculation pumps
  - Thermocompressor
  - Condensor
  - Condensate tank and pump
  - Centrifuge with centrate storage and pumping system
  - Chemical storage and feed systems (antifoaming and cleaning chemicals)

It is estimated that a building of approximately 8,000 sf will be needed to house the treatment equipment, with clearing and preparation of additional 2,000 sf for the evaporator and crystallizer, which are typically located outside. Additional information on equipment requirements can be found in Appendix A.

The permeate produced by the RO system will be of high quality and would likely be reused within the LSDP. While some make-up water from the Area 1 Pit will still be required, reuse of the RO permeate will reduce amount of water needed from the pit.

The water quality in Area 1 Pit that results from eliminating the load from the LSDP is shown in Tables 3 and 4 for both Mine Alternatives.

3.1.3 Preliminary Cost Estimates

Overall, this treatment option would reduce the load of TDS to the pit (and subsequently to the pit discharge) by an estimated 22,000 kg/d. The estimated capital cost for this treatment option is $25.7M, with an annual operation and maintenance cost of $1.4M. Most of the annual operation and maintenance costs are associated with the ZLD equipment operation, and of that, roughly two thirds are the energy costs associated with the evaporation of water in the brine concentrator and crystallizer. Over 20 years (the design life of the facility), assuming a real discount rate of 5.0 percent, the net present value of the treatment facility is $42.7M.

3.2 RO/ZLD with Lime Softening of the Area 1 Pit Discharge

3.2.1 Overview

As discussed in Section 2.3 and illustrated in Figures 2 and 3, after eliminating the treated LSDP return water to the Area 1 Pit, some hardness, alkalinity and TDS remain that may require additional treatment to comply with in-stream water quality standards.

Lime softening of the Area 1 Pit water (after implementation of RO with ZLD for the LSDP flow) was modeled using PHREEQC, a computer model developed by the USGS (Parkhurst et al., 1999), and the water quality shown in Tables 3 and 4. PHREEQC simulates water-based chemical reactions and transport phenomena. PHREEQC is based on equilibrium chemistry of aqueous solutions with minerals and has simulation capabilities for scenarios such as:

- Mixing of aqueous solutions
- Irreversible reactions
- Dissolution and precipitation reactions
- Solid-solution equilibria
- Surface complexation

In lime softening, lime (calcium hydroxide) is added and bicarbonate and calcium are precipitated as calcium carbonate and magnesium is precipitated as magnesium hydroxide. Removal of the magnesium hardness from the water requires the addition of more lime than is required for bicarbonate removal alone. The addition of more lime results in an increase in calcium concentrations that must be subsequently removed using soda ash (sodium carbonate) or recarbonation, which causes the precipitation of the excess calcium as calcite. For this application, only recarbonation was modeled. While soda ash addition can remove the calcium as calcite, it adds sodium ions to the water which results in an increase in TDS and conductivity.

Preliminary modeling indicates that lime softening and recarbonation can produce water that meets the alkalinity, hardness, and TDS water quality standards for Mine Alternative 1 for Years 1 through 20. However, for Mine Alternative 2, by Year 20, lime softening is unable to meet the TDS water quality standard due to the increasing contribution of sulfate to TDS. Recarbonation is able to achieve a small amount of calcium removal, but is limited in its effectiveness because the process of restoring bicarbonate alkalinity to the water is more efficient than the precipitation of calcite at the pH levels in question.

3.2.2 Treatment Requirements

In addition to the RO and ZLD equipment described in Section 3.1.2, lime softening and recarbonation equipment are needed for treatment of the Area 1 Pit discharge flow. A conceptual process flow diagram of this treatment option is shown in Figure 5. The major process equipment required would be:

- Lime softening
  - Lime storage silo(s)
  - Lime slaker(s)
  - Solids contact clarifier(s)
  - Sludge holding tank
  - Filter press(es)
- Recarbonation
  - Carbon dioxide storage tank
  - Carbon dioxide solution feed system
  - Clarifier

3.2.3 Preliminary Cost Estimates

The addition of lime softening is estimated to provide up to an additional 5,900 kg/d of TDS removal for Mine Alternative 1 and up to an additional 6,100 kg/d of TDS removal for Mine Alternative 2 (assuming treatment at the full capacity of 4,000 gpm) over the 22,000 kg/d removed by using RO and ZLD of the LSDP process water. The estimated capital cost for this treatment option is $50.2M, with an annual operation and maintenance cost of $3.0M for Mine Alternative 1. Over 20 years (the design life of the facility), assuming a real discount rate of 5.0%, the net present value of the treatment facility is $87.2M. For Mine Alternative 2, the estimate capital cost is $50.2M, the annual O&M cost is estimated to be $2.7M, resulting in a net present value of $83.4M.

3.3 RO/ZLD with Membrane Softening of the Area 1 Pit Discharge

3.3.1 Overview

Another option for removing the hardness and alkalinity remaining after implementation of RO with ZLD at the LSDP is to treat the Area 1 Pit discharge with RO. This option was modeled for Mine Alternatives 1 and 2 using publicly available NF/RO simulation software (IMS Design by

Hydranautics). The preliminary modeling indicates that RO can produce permeate that meets the treatment goals and can do so with partial treatment of the discharge flow. The ability to treat only part of the discharge and blend is advantageous because it minimizes the amount of concentrate that must be managed. For Mine Alternative 1 (Year 20, the year with the highest projected TDS), the following treatment scenario was indicated to provide effective treatment:

- Final blended product water flow: 4,000 gpm
- RO recovery: 90 percent
- Blend ratio: 50 percent
- RO permeate production: 2,000 gpm
- Untreated flow for blending: 2,000 gpm

For Mine Alternative 2 (Year 20, the year with the highest projected TDS), the following treatment scenario was indicated to provide effective treatment:

- Final blended product water flow: 4,000 gpm
- RO recovery: 90 percent
- Blend ratio: 37.5 percent
- RO permeate production: 2,500 gpm
- Untreated flow for blending: 1,500 gpm

An advantage of membrane softening over lime softening is that it will provide effective treatment for both Mine Alternatives 1 and 2 over 20 years, whereas lime softening was not effective for Mine Alternative 2 by Year 20 due primarily to increasing sulfate concentration which is not reduced by lime softening at the concentrations in question.

Evaporation and crystallization (ZLD) is, again, the primary technically feasible option for concentrate management under this treatment alternative. Because both of these unit processes would already be installed as part of treatment the LSDP process water as described in Section 3.1, the units would be upsized to manage the concentrate from this additional RO process used for treating the pit discharge.

3.3.2 Treatment Requirements

Of critical importance to the success of any RO application is proper pretreatment of the water to prevent clogging and fouling of the membrane. Pretreatment for the Area 1 Pit water will need to include both particulate removal and scale prevention. Particulate removal will be accomplished with ultrafiltration (UF), a common fine particulate removal technology, which employs hollow fiber membranes with small pore sizes to filter out suspended solids and cartridge filters. The size of the UF system required is dependent largely upon flow, water temperature, influent total suspended solids, and overall UF system recovery. A recovery of 95 percent has been assumed. Pretreatment for the UF and RO systems will also need to include oxidation and/or oxidation and filtration for manganese removal. Manganese can cause severe fouling of both types of membranes.

The salts that would be expected to limit the recovery of the RO system for Area 1 Pit discharge include barium sulfate, calcium carbonate, and calcium sulfate. 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 at least pH 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. The approach to sulfate scaling control would be to lower the system recovery and add proprietary anti-scalants. Achievable recovery directly affects the amount of membrane area required to produce a given volume of treated water. This evaluation has used a recovery of 90 percent, which the preliminary modeling indicates is feasible, but anti-scalants are necessary to achieve this recovery.

Figure 6 presents a conceptual process flow diagram of the proposed treatment scenario. An outside storage tank provides decoupling of the forcemain and membrane feed pumps. The storage tank has been sized for 4 hours of influent storage capacity. This tank provides storage of influent water prior to membrane treatment and allows for orderly shut down of the membrane system and other routine maintenance of the water treatment facility. The UF backwash water was routed into the Area 1 Pit via a separate gravity outfall.

The LSDP evaporator and crystallizer would be upsized to receive concentrate from the pit discharge RO system.

A summary of major equipment capacities used for development of the preliminary capital cost estimate for treatment under Mine Alternative 1 is provided below. This equipment is in addition to that described in Section 3.1.2.

- Influent pumping: 4,340 gpm of pumping capacity total
    - Blending flow: 2,000 gpm

  - UF feed: 2,340 gpm
- Influent feed tank:
  - Volume: 561,600 gallons
- Ultrafiltration system:
  - Feed flow: 2,340 gpm
  - System recovery: 95 percent
  - Pretreatment: fine screens, potassium permanganate addition for Fe and Mn oxidation
- Reverse osmosis system:
  - Permeate flow: 2,000 gpm
  - System recovery: 90 percent
  - Pretreatment: cartridge filters, acid addition, anti-scalant addition, bisulfite addition
- Evaporator system:
  - Feed flow: 220 gpm
- Crystallizer system:
  - Feed flow (estimated): 50 gpm
- Effluent pumping:
  - RO concentrate tank and pumps
  - Permeate tank and pumps

For Mine Alternative 2, the following capacities were used to develop the preliminary capital cost estimate:

- Influent pumping: 4,424 gpm of pumping capacity total
  - Blending flow: 1,500 gpm
  - UF feed: 2,924 gpm
- Influent feed tank:
  - Volume: 701,760 gallons
- Ultrafiltration system:
  - Feed flow: 2,924 gpm
  - System recovery: 95 percent
  - Pretreatment: fine screens, potassium permanganate addition for Fe and Mn oxidation
- Reverse osmosis system:
  - Permeate flow: 2,500 gpm

  - System recovery: 90 percent
  - Pretreatment: cartridge filters, acid addition, anti-scalant addition, bisulfite addition
- Evaporator system:
  - Feed flow: 280 gpm
- Crystallizer system:
  - Feed flow (estimated): 60 gpm
- Effluent pumping:
  - RO concentrate tank and pumps
  - Permeate tank and pumps

Pilot testing of the UF/RO process prior to implementation is recommended. The pilot testing goals would be to: (1) evaluate the efficacy of anti-scalants 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.

3.3.3 Preliminary Cost Estimates

RO treatment of the pit discharge flow is estimated to provide up to an additional 4,400 kg/d of TDS removal for Mine Alternative 1 and up to an additional 8,100 kg/d of TDS removal for Mine Alternative 2 (assuming treatment at the full capacity of 4,000 gpm) over the 22,000 kg/d removed by using RO and ZLD of the LSDP process water. Actual TDS removal will depend on the membrane selected for the process and pre- and post treatment chemicals required for membrane operation.

The estimated capital cost for this treatment option is $53.5M, with an annual operation and maintenance cost of $4.6M for Mine Alternative 1. Over 20 years (the design life of the facility), assuming a real discount rate of 5.0%, the net present value of the treatment facility is $110M. For Mine Alternative 2, the estimated capital cost is $58.0M, the annual O&M cost is estimated to be $4.1M, resulting in a net present value of $110M.

3.4 Membrane Treatment of Area 1 Pit Discharge

3.4.1 Overview

If treated process water from the LSDP is to continue to be returned to the Area 1 Pit, the pit discharge water would require treatment to remove both monovalent and divalent ions in order to meet the water quality standards for hardness, alkalinity, and total dissolved solids at the end of the pipe. Sulfate removal may also be necessary. In order to accomplish this, RO was evaluated for both Mine Alternatives 1 and 2 because, as discussed earlier, RO is one of the few technologies available for removing the monovalent ions sodium and chloride. For each Mine Alternative, water quality from the year projected to have the highest concentration of TDS was used for evaluation. For Mine Alternative 1, Year 10 was used and for Mine Alternative 2, Year 20 was used. These projected water qualities can be found in Tables 1 and 2. IMS Design by Hydranautics was used for the preliminary modeling of the RO system.

The preliminary modeling indicates that RO can produce permeate that meets the treatment goals at the end of the pipe and can do so with partial treatment of the discharge flow. The ability to treat only part of the discharge and blend is advantageous because it minimizes the amount of concentrate that must be managed. For Mine Alternative 1, the following treatment scenario was indicated to provide effective treatment:

- Final blended product water flow: 4,000 gpm
- RO recovery: 85 percent
- Blend ratio: 25 percent
- RO permeate production: 3,000 gpm
- Untreated flow for blending: 1,000 gpm

For Mine Alternative 2, the following treatment scenario was indicated to provide effective treatment:

- Final blended product water flow: 4,000 gpm
- RO recovery: 85 percent
- Blend ratio: 12.5 percent
- RO permeate production: 3,500 gpm
- Untreated flow for blending: 500 gpm

Evaporation and crystallization (ZLD) is again the primary technically feasible option for concentrate management under this treatment alternative. Compared with the treatment proposed in Section 3.3 (RO with ZLD of the LDSP process water *and* RO with ZLD of the part of the pit discharge), the total concentrate volume that must be managed under this alternative is greater – 530 gpm versus 220 gpm for Mine Alternative 1 and 620 gpm versus 280 gpm for Mine Alternative 2.

3.4.2 Treatment Requirements

Figure 7 presents a conceptual process flow diagram of the proposed treatment scenario. Flow estimates are also shown on the drawing. The treatment considerations for a RO system for the pit discharge are very similar to that necessary for the treatment of the pit discharge treatment described in Section 3.3:

- Pretreatment for UF and RO: oxidation and/or oxidation + filtration for manganese removal
- Pretreatment for RO:
  - Particulate removal by UF and cartridge filters
  - pH adjustment to mitigate carbonate scaling
  - Anti-scalants for barium sulfate and calcium sulfate scaling prevention

The achievable RO system recovery and blend ratios for both Mine Alternatives 1 and 2 are predicted to be less than what is achievable under the other treatment scenarios presented in this report. As a result, the equipment capacities needed are larger. Similarly to other alternatives, an outside storage tank would provide decoupling of the forcemain and membrane feed pumps. The storage tank has been sized for 4 hours of influent storage capacity. This tank provides storage of influent water prior to membrane treatment and allows for orderly shutdown of the membrane system and other routine maintenance of the water treatment facility. The UF backwash water would be routed into the Area 1 pit via a separate gravity outfall.

A summary of major equipment capacities used for development of the preliminary capital cost estimate for treatment under Mine Alternative 1 is provided below.

- Influent pumping: 4,715 gpm of pumping capacity total
  - Blending flow: 1,000 gpm
  - UF feed: 3,715 gpm
- Influent feed tank:
  - Volume: 891,600 gallons
- Ultrafiltration system:
  - Feed flow: 3,715 gpm
  - System recovery: 95 percent
  - Pretreatment: fine screens, potassium permanganate addition for Fe and Mn oxidation
- Reverse osmosis system:
  - Permeate flow: 3,000 gpm

  - System recovery: 85 percent
  - Pretreatment: cartridge filters, acid addition, anti-scalant addition, bisulfite addition
- Evaporator system:
  - Feed flow: 530 gpm
- Crystallizer system:
  - Feed flow (estimated): 115 gpm
- Effluent pumping:
  - RO concentrate tank and pumps
  - Permeate tank and pumps

For Mine Alternative 2, the following capacities were used to develop the preliminary capital cost estimate:

- Influent pumping: 4,834 gpm of pumping capacity total
  - Blending flow: 500 gpm
  - UF feed: 4,334 gpm
- Influent feed tank:
  - Volume: 1,040,000 gallons
- Ultrafiltration system:
  - Feed flow: 4,334 gpm
  - System recovery: 95 percent
  - Pretreatment: fine screens, potassium permanganate addition for Fe and Mn oxidation
- Reverse osmosis system:
  - Permeate flow: 3,500 gpm
  - System recovery: 85 percent
  - Pretreatment: cartridge filters, acid addition, anti-scalant addition, bisulfite addition
- Evaporator system:
  - Feed flow: 620 gpm
- Crystallizer system:
  - Feed flow (estimated): 120 gpm
- Effluent pumping:
  - RO concentrate tank and pumps
  - Permeate tank and pumps

Pilot testing of the UF/RO process prior to implementation is recommended. The pilot testing goals would be to: (1) evaluate the efficacy of anti-scalants 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.

3.4.3 Preliminary Cost Estimate

Treatment of only the Area 1 Pit discharge by RO is estimated to remove up to 24,000 kg/d of TDS for Mine Alternative 1 and up to 30,500 kg/d of TDS for Mine Alternative 2. Actual TDS removal will depend on the membrane selected for the process and pre- and post treatment chemicals required for membrane operation.

The estimated capital cost for this treatment option is $52.2M, with an annual operation and maintenance cost of $4.8M for Mine Alternative 1. Over 20 years (the design life of the facility), assuming a real discount rate of 5.0%, the net present value of the treatment facility is $113M. For Mine Alternative 2, the estimated capital cost is $55.3M, the annual O&M cost is estimated to be $4.4M, resulting in a net present value of $110M.

4.0 Conclusions

An evaluation of the primary loads to the Area 1 Pit was used to develop a range of treatment strategies to reduce the hardness, alkalinity, and total dissolved solids (and resulting specific conductivity) of the Area 1 Pit discharge to meet in stream water quality treatment goals or the existing in-stream water quality of Second Creek or the Partridge River. It was found that the treated process water from the LSDP, which is returned to the pit, contributes up to 50% of TDS, including sulfate, sodium, and chloride. Because of the significance of the LSDP return, the treatment strategies developed for the Area 1 Pit discharge are all based on the ability to remove both monovalent and divalent ions that are contributing to TDS, alkalinity, and hardness. Because of the monovalent ions present, RO was the core of all the potential treatment strategies. Reverse osmosis was selected because it is a widely commercially available, reliable treatment technology that is one of a limited number of technologies than can effectively remove monovalent ions.

The treatment methods evaluated are as follows:

1. Implementation of RO with reuse of the permeate in the LSDP and evaporation and crystallization of the RO concentrate to eliminate the flow of treated process water to the Area 1 Pit (RO/ZLD).
2. RO/ZLD of the LSDP effluent with lime softening of the Area 1 Pit discharge.
3. RO/ZLD of the LSDP effluent with RO of the Area 1 Pit discharge. Concentrate from the RO treatment of the pit discharge would be treated by evaporation and crystallization.
4. Treatment of the Area 1 Pit discharge by RO, coupled with evaporation and crystallization treatment of the RO concentrate. Under this treatment option, RO/ZLD would not be implemented at the LSDP and treated process water would continue to be discharged to the Area 1 Pit.

All four of these options can reduce the load of alkalinity, hardness, and TDS discharged from Area 1 Pit during either Mine Alternative 1 or Mine Alternative 2. Only options 3 and 4 above are able to consistently meet the applicable in stream water quality standards for Second Creek or the Partridge River at the end of the pipe over the entire 20 years of operation. Increasing sulfate in Mine Alternative 2 over time reduces the effectiveness of lime softening (option 2 above) in the later years of operation. As is shown in Tables 1 and 2, the concentrations of many of the parameters of concern in both Second Creek and the Partridge River are currently below the in stream water quality standard. Treatment of the pit discharge for these parameters to the same concentrations in these receiving waters (instead of the in stream water quality standard) would require additional membrane treatment, and the capital and operation and maintenance costs would be beyond those presented in this report.

Preliminary cost estimates were developed for each of the treatment strategies. Capital and operation and maintenance costs were developed based on costs for recent similar projects, typical industry values, specific vendor quotations, and PHREEQC modeling. The present worth costs were developed assuming 5 percent discount rate and 20 years of plant operation.

The treatment strategies have net present values ranging from $43M to over $100M for both Mine Alternatives. As can be seen in Tables E1 and E2, reducing the loads to the pit *at their source* results in a lower cost per mass of TDS removed than treatment of the pit discharge alone. Treatment of the Area 1 Pit discharge without first treating the LSDP discharge would involve treating a more dilute water stream of larger volume, which has the following important implications:

- More membrane treatment equipment is required to remove about the same mass of dissolved solids
- Less efficiency across the reverse osmosis process
- Larger volume of concentrate to manage which results in higher capital and operating costs for the evaporator and crystallizer(s)

These factors *significantly* impact the capital and operation and maintenance costs for the project. The net present value of the options evaluated exceeded the cost of the project itself. As such, none of the treatment alternatives are “additional control measures [which] are reasonable”, per 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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Tables

Table 1. Mine Alternative 1 Projected Area 1 Pit Water Quality

			Time							
		Current Average	Year 1	Year 5	Year 10	Year 15	Year 20	Treatment Goal	Second Creek (MNSW1)	Partridge River (MNSW12)
Alkalinity, Total	mg/L	364	285	292	326	334	353	250	354	110
Aluminum	µg/L	12.5	5.1	3.6	4.0	4.1	4.3	125	25.2	113
Antimony	µg/L	0.04	0.5	1.3	2.0	1.5	1.5	31	0.11	0.11
Arsenic	µg/L	1.00	1.0	1.1	1.3	1.4	1.5	53	2.7	0.99
Barium	µg/L	4.31	2.1	9.3	7.9	7.6	7.4		22.4	15.6
Beryllium	µg/L	0.10	0.1	0.1	0.1	0.1	0.1		0.1	0.094
Boron	µg/L	131	112	120	139	128	141	500	145	99
Bromide	µg/L	0.03	0.0	0.0	0.0	0.0	0.0		0.1	0.09
Cadmium	µg/L	0.08	0.1	0.2	0.3	0.3	0.3	3	15.2	0.092
Calcium	mg/L	42.7	37.7	40.4	49.5	53.9	55.7		69.7	28.5
Chemical Oxygen Demand, COD	mg/L	13.8	--	--	--	--	--		37.3	55.8
Chloride	mg/L	10.5	62.3	121	175	133	128	230	14.7	4.9
Chromium	µg/L	0.60	0.5	0.5	0.5	0.5	0.5	11	0.43	0.55
Cobalt	µg/L	0.72	0.4	0.6	0.7	0.6	0.6	5	0.38	0.45
Copper	µg/L	0.59	0.7	0.8	0.9	0.8	0.8	23	0.78	3.4
Fluoride	mg/L	0.10	0.6	2.1	3.3	2.5	2.5		1.3	0.19
Hardness	mg/L	779	612	588	624	677	763	500	518	289
Iron	mg/L	0.03	0.0	0.0	0.0	0.0	0.0		570	1032
Lead	µg/L	0.20	0.7	1.6	2.3	1.8	1.8	19	0.23	0.3
Magnesium	mg/L	163	126	119	122	132	152		86.8	53
Manganese	µg/L	862	383	565	541	484	442		258	255
Mercury	ng/L	0.80	--	--	--	--	--	1.3	1.7	4.5
Methylmercury	ng/L	0.09	--	--	--	--	--		0.4	0.72
Molybdenum	µg/L	1.6	17.1	69.4	111	84.2	82.7		12.9	1.7
Nickel	µg/L	2.25	2.2	3.1	3.7	3.0	2.9	169	2.8	3.6
Nitrogen, total	mg/L	--	0.3	1.0	1.5	1.2	1.2		--	--
pH	SU	8.10	7.6	7.4	7.5	7.5	7.5		7.7	7.61
Phosphorus	mg/L	0.003	0.0	0.0	0.1	0.1	0.1		0.023	0.015
Potassium	mg/L	13.4	10.0	9.9	9.4	7.3	6.7		7.2	4.6
Selenium	µg/L	0.60	0.5	0.5	0.5	0.6	0.6	5	0.53	0.55
Silicon	ug/L	3.94	1.3	1.0	0.7	0.4	0.3		--	--
Silver	µg/L	0.04	0.0	0.1	0.2	0.2	0.1		0.04	0.048
Sodium	mg/L	15.2	77.9	227	364	279	272		31.2	9.7
Solids, Total Dissolved	mg/L	850	875	1,276	1,707	1,526	1,606	700	605	370
Solids, Total Suspended	mg/L	0.74	--	--	--	--	--	30	2.5	1.21
Specific Conductance	umhos	1281	1,400	2,041	2,731	2,442	2,569	1000	933	599
Strontium	µg/L	134	99.0	96.6	127	149	180		268	173
Sulfate	mg/L	386	384	577	781	712	772	varies	166	162
Thallium	µg/L	0.18	0.2	0.2	0.3	0.3	0.3	0.56	0.17	0.2
Titanium	µg/L	5.00	--	--	--	--	--		5	5
Total Organic Carbon, TOC	mg/L	1.62	--	--	--	--	--		11.8	19.7
Zinc	µg/L	3.80	3.1	3.6	3.9	3.1	3.0	343	6	3.5

Parameter of concern

Table 2. Mine Alternative 2 Projected Area 1 Pit Water Quality

			Time							
		Current Average	Year 1	Year 5	Year 10	Year 15	Year 20	Treatment Goal	Second Creek (MNSW1)	Partridge River (MNSW12)
Alkalinity, Total	mg/L	364	285	288	305	346	355	250	354	110
Aluminum	µg/L	12.5	5.1	3.6	3.8	4.3	4.4	125	25.2	113
Antimony	µg/L	0.04	0.5	1.4	2.2	1.8	1.7	31	0.11	0.11
Arsenic	µg/L	1.00	1.0	1.1	1.3	1.4	1.5	53	2.7	0.99
Barium	µg/L	4.31	2.1	9.2	7.6	6.8	6.8		22.4	15.6
Beryllium	µg/L	0.10	0.1	0.1	0.1	0.1	0.1		0.1	0.094
Boron	µg/L	131	112	120	144	148	160	500	145	99
Bromide	µg/L	0.03	0.0	0.0	0.0	0.0	0.0		0.1	0.09
Cadmium	µg/L	0.08	0.1	0.2	0.4	0.3	0.3	3.37	15.2	0.092
Calcium	mg/L	42.7	37.7	40.2	50.4	60.3	61.1		69.7	28.5
Chemical Oxygen Demand, COD	mg/L	13.8	--	--	--	--	--		37.3	55.8
Chloride	mg/L	10.5	62.3	122	189	160	153	230	14.7	4.9
Chromium	µg/L	0.60	0.5	0.5	0.4	0.5	0.5	11	0.43	0.55
Cobalt	µg/L	0.72	0.4	0.6	0.8	0.9	0.8	5	0.38	0.45
Copper	µg/L	0.59	0.7	0.8	1.0	0.9	0.9	23.21	0.78	3.4
Fluoride	mg/L	0.10	0.6	2.1	3.6	3.0	2.9		1.3	0.19
Hardness	mg/L	779	612	578	570	766	828	500	518	289
Iron	mg/L	0.03	0.0	0.0	0.0	0.0	0.0		570	1032
Lead	µg/L	0.20	0.7	1.6	2.4	2.0	2.0	18.58	0.23	0.3
Magnesium	mg/L	163	126	116	108	150	165		86.8	53
Manganese	µg/L	862	383	575	612	483	468		258	255
Mercury	ng/L	0.80	--	--	--	--	--	1.3	1.7	4.5
Methylmercury	ng/L	0.09	--	--	--	--	--		0.4	0.72
Molybdenum	µg/L	1.6	17.1	70.5	121	99.9	96.4		12.9	1.7
Nickel	µg/L	2.25	2.2	3.1	3.9	3.4	3.2	168.54	2.8	3.6
Nitrogen, total	mg/L	--	0.3	1.0	1.6	1.4	1.4		--	--
pH	SU	8.10	7.6	7.4	7.4	7.5	7.5		7.7	7.61
Phosphorus	mg/L	0.003	0.0	0.0	0.1	0.1	0.1		0.023	0.015
Potassium	mg/L	13.4	10.0	9.7	9.2	8.8	8.1		7.2	4.6
Selenium	µg/L	0.60	0.5	0.5	0.5	0.5	0.5		0.53	0.55
Silicon	ug/L	3.94	1.3	1.0	0.7	0.5	0.4		--	--
Silver	µg/L	0.04	0.0	0.1	0.2	0.2	0.2		0.04	0.048
Sodium	mg/L	15.2	77.9	230	396	337	326		31.2	9.7
Solids, Total Dissolved	mg/L	850	875	1,275	1,739	1,805	1,860	700	605	370
Solids, Total Suspended	mg/L	0.74	--	--	--	--	--	30	2.5	1.21
Specific Conductance	umhos	1281	1,400	2,041	2,783	2,889	2,976	1000	933	599
Strontium	µg/L	134	99.0	97	129	168	201		268	173
Sulfate	mg/L	386	384	577	794	873	924	varies	166	162
Thallium	µg/L	0.18	0.2	0.2	0.3	0.3	0.3	0.56	0.17	0.2
Titanium	µg/L	5.00	--	--	--	--	--		5	5
Total Organic Carbon, TOC	mg/L	1.62	--	--	--	--	--		11.8	19.7
Zinc	µg/L	3.80	3.1	3.6	3.9	3.1	3.0	343.12	6	3.5

Parameter of concern

Table 3. Mine Alternative 1 Projected Area 1 Pit Water Quality Without LSDP Return Flow to Pit

			Time							
		Current Average	Year 1	Year 5	Year 10	Year 15	Year 20	Treatment Goal	Second Creek (MNSW1)	Partridge River (MNSW12)
Alkalinity, Total	mg/L	364	280	290	330	300	320	250	354	110
Aluminum	µg/L	12.5	5	4	4	4	4	125	25.2	113
Antimony	µg/L	0.04	<1	<1	<1	<1	<1	31	0.11	0.11
Arsenic	µg/L	1.00	<1	1	1	1	1	53	2.7	0.99
Barium	µg/L	4.31	2	16	17	13	12		22.4	15.6
Beryllium	µg/L	0.10	<1	<1	<1	<1	<1		0.1	0.094
Boron	µg/L	131	110	110	120	110	130	500	145	99
Bromide	µg/L	0.03	<1	<1	<1	<1	<1		0.1	0.09
Cadmium	µg/L	0.08	<1	<1	<1	<1	<1	3.37	15.2	0.092
Calcium	mg/L	42.7	38	40	48	43	45		69.7	28.5
Chemical Oxygen Demand, COD	mg/L	13.8	--	--	--	--	--		37.3	55.8
Chloride	mg/L	10.5	38	43	46	34	32	230	14.7	4.9
Chromium	µg/L	0.60	<1	<1	<1	<1	<1	11	0.43	0.55
Cobalt	µg/L	0.72	<1	<1	<1	<1	<1	5	0.38	0.45
Copper	µg/L	0.59	<1	<1	<1	<1	<1	23.21	0.78	3.4
Fluoride	mg/L	0.10	<1	<1	2	1	1		1.3	0.19
Hardness	mg/L	779	627	632	652	639	685	500	518	289
Iron	mg/L	0.03	<1	<1	<1	<1	<1		570	1032
Lead	µg/L	0.20	<1	<1	<1	<1	<1	18.58	0.23	0.3
Magnesium	mg/L	163	130	130	130	130	140		86.8	53
Manganese	µg/L	862	330	430	360	420	380		258	255
Mercury	ng/L	0.80	--	--	--	--	--	1.3	1.7	4.5
Methylmercury	ng/L	0.09	--	--	--	--	--		0.4	0.72
Molybdenum	µg/L	1.6	--	--	--	--	--		12.9	1.7
Nickel	µg/L	2.25	2	1	1	<1	<1	168.54	2.8	3.6
Nitrogen, total	mg/L	--	<1	1	2	1	1		--	--
pH	SU	8.10	7.6	7.4	7.5	7.5	7.5		7.7	7.61
Phosphorus	mg/L	0.003	<1	<1	<1	<1	<1		0.023	0.015
Potassium	mg/L	13.4	10	10	10	8	7		7.2	4.6
Selenium	µg/L	0.60	<1	<1	<1	<1	<1		0.53	0.55
Silicon	ug/L	3.94	1	1	<1	<1	<1		--	--
Silver	µg/L	0.04	<1	<1	<1	<1	<1		0.04	0.048
Sodium	mg/L	15.2	13	18	22	18	18		31.2	9.7
Solids, Total Dissolved	mg/L	850	690	700	760	720	800	700	605	370
Solids, Total Suspended	mg/L	0.74	--	--	--	--	--	30	2.5	1.21
Specific Conductance	umhos	1281	1100	1100	1200	1100	1300	1000	933	599
Strontium	µg/L	134	100	100	140	160	190		268	173
Sulfate	mg/L	386	290	280	300	300	350	varies	166	162
Thallium	µg/L	0.18	0.2	0.2	0.3	0.3	0.3	0.56	0.17	0.2
Titanium	µg/L	5.00	--	--	--	--	--		5	5
Total Organic Carbon, TOC	mg/L	1.62	--	--	--	--	--		11.8	19.7
Zinc	µg/L	3.80	3	2	2	2	2	343.12	6	3.5

Parameter of concern

Table 4. Mine Alternative 2 Projected Area 1 Pit Water Quality Without LSDP Return Flow to Pit

			Time							
		Current Average	Year 1	Year 5	Year 10	Year 15	Year 20	Treatment Goal	Second Creek (MNSW1)	Partridge River (MNSW12)
Alkalinity, Total	mg/L	364	280	290	310	330	330	250	354	110
Aluminum	µg/L	12.5	5	4	4	4	4	125	25.2	113
Antimony	µg/L	0.04	<1	<1	<1	<1	<1	31	0.11	0.11
Arsenic	µg/L	1.00	<1	1	1	1	1	53	2.7	0.99
Barium	µg/L	4.31	2	16	17	13	11		22.4	15.6
Beryllium	µg/L	0.10	<1	<1	<1	<1	<1		0.1	0.094
Boron	µg/L	131	110	110	120	130	150	500	145	99
Bromide	µg/L	0.03	<1	<1	<1	<1	<1		0.1	0.09
Cadmium	µg/L	0.08	<1	<1	<1	<1	<1	3.37	15.2	0.092
Calcium	mg/L	42.7	38	40	50	51	51		69.7	28.5
Chemical Oxygen Demand, COD	mg/L	13.8	--	--	--	--	--		37.3	55.8
Chloride	mg/L	10.5	38	43	48	41	38	230	14.7	4.9
Chromium	µg/L	0.60	<1	<1	<1	<1	<1	11	0.43	0.55
Cobalt	µg/L	0.72	<1	<1	<1	<1	<1	5	0.38	0.45
Copper	µg/L	0.59	<1	<1	<1	<1	<1	23.21	0.78	3.4
Fluoride	mg/L	0.10	<1	<1	2	1	1		1.3	0.19
Hardness	mg/L	779	627	591	616	782	823	500	518	289
Iron	mg/L	0.03	<1	<1	<1	<1	<1		570	1032
Lead	µg/L	0.20	<1	<1	<1	<1	<1	18.58	0.23	0.3
Magnesium	mg/L	163	130	120	120	160	170		86.8	53
Manganese	µg/L	862	330	430	380	370	370		258	255
Mercury	ng/L	0.80	--	--	--	--	--	1.3	1.7	4.5
Methylmercury	ng/L	0.09	--	--	--	--	--		0.4	0.72
Molybdenum	µg/L	1.6	--	--	--	--	--		12.9	1.7
Nickel	µg/L	2.25	2	1	1	1	1	168.54	2.8	3.6
Nitrogen, total	mg/L	--	<1	1	2	2	2		--	--
pH	SU	8.10	7.6	7.4	7.5	7.5	7.5		7.7	7.61
Phosphorus	mg/L	0.003	<1	<1	<1	<1	<1		0.023	0.015
Potassium	mg/L	13.4	10	10	10	10	10		7.2	4.6
Selenium	µg/L	0.60	<1	<1	<1	<1	<1		0.53	0.55
Silicon	ug/L	3.94	1	<1	<1	<1	<1		--	--
Silver	µg/L	0.04	<1	<1	<1	<1	<1		0.04	0.048
Sodium	mg/L	15.2	13	18	23	24	24		31.2	9.7
Solids, Total Dissolved	mg/L	850	690	690	710	920	970	700	605	370
Solids, Total Suspended	mg/L	0.74	--	--	--	--	--	30	2.5	1.21
Specific Conductance	umhos	1281	1100	1100	1100	1500	1500	1000	933	599
Strontium	µg/L	134	100	100	140	180	220		268	173
Sulfate	mg/L	386	290	280	270	430	470	varies	166	162
Thallium	µg/L	0.18	0.2	0.2	0.3	0.3	0.3	0.56	0.17	0.2
Titanium	µg/L	5.00	--	--	--	--	--		5	5
Total Organic Carbon, TOC	mg/L	1.62	--	--	--	--	--		11.8	19.7
Zinc	µg/L	3.80	3	2	2	3	2	343.12	6	3.5

Parameter of concern

Table 5. Preliminary Cost Estimate – RO Treatment of the LSDP Process Water With ZLD

Item	Unit	Unit Cost	Qty	Cost
Preliminary Costs				
UF/RO pilot unit	MO	$ 50,000	3	$ 150,000
Capital Costs				
ZLD feed tank	LS	$ 50,000	1	$ 50,000
UF, RO, evaporator and crystallizer systems	LS	$ 7,900,000	1	$ 7,900,000
Treatment building - precast wall panel + site blasting and fill preparation	SF	$ 150	10000	$ 1,500,000
Liquid chemical storage and feed equipment	EA	$ 30,000	6	$ 180,000
Process equipment installation @ 30%	LS	$ 2,439,000	1	$ 2,439,000
Mechanical systems @ 15%	LS	$ 1,219,500	1	$ 1,219,500
Electrical and control systems @ 25%	LS	$ 2,032,500	1	$ 2,032,500
Civil/site work	LS	$ 200,000	1	$ 200,000
Capital Cost Subtotal				$ 15,521,000
Capital Cost Contingency	40%			$ 6,208,400
Capital Cost Total				***$ 21,729,400***
Professional Services				
Design and procurement	10%	$ 2,172,940	1	$ 2,172,940
Construction services	5%	$ 1,086,470	1	$ 1,086,470
Legal	LS	$ 50,000	1	$ 50,000
Professional Services Subtotal				$ 3,309,410
Professional Services Contingency	20%			$ 661,882
Professional Services Total				***$ 3,971,292***
Annual Operation and Maintenance				
ZLD system O&M	LS	$ 550,000	1	$ 550,000
Energy costs (heating)	KWH	$ 0.07	3005000	$ 210,350
Sludge hauling and disposal	WT	$ 30	2900	$ 87,000
Labor	FTE	$ 60,000	2	$ 120,000
Operation and Maintenance Cost Subtotal				$ 967,350
Operation and Maintenance Cost Contigency	40%			$ 386,940
Operation and Maintenance Cost Total				***$ 1,354,290***

Table 6. Mine Alternative 1 Preliminary Cost Estimate – RO with ZLD and Lime Softening

Item	Unit	Unit Cost	Qty	Cost
Preliminary Costs				
UF/RO pilot unit	MO	$ 50,000	3	$ 150,000
Capital Costs				
ZLD feed tank	LS	$ 50,000	1	$ 50,000
UF, RO, evaporator and crystallizer systems	LS	$ 7,900,000	1	$ 7,900,000
Influent pump station (4000 gpm)	LS	$ 625,000	1	$ 625,000
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	35000	$ 5,250,000
Lime storage and feed equipment	LS	$ 750,000	1	$ 750,000
Liquid chemical storage and feed equipment	EA	$ 30,000	7	$ 210,000
Softening reactors, mixers, clarifier/thickeners (4000 gpm)	LS	$ 3,100,000	1	$ 3,100,000
Filter presses	EA	$ 750,000	2	$ 1,500,000
Effluent pump station (4000 gpm)	LS	$ 450,000	1	$ 450,000
Process equipment installation @ 30%	LS	$ 4,375,500	1	$ 4,375,500
Mechanical systems @ 15%	LS	$ 2,187,750	1	$ 2,187,750
Electrical and control systems @ 25%	LS	$ 3,646,250	1	$ 3,646,250
Civil/site work	LS	$ 200,000	1	$ 200,000
Capital Cost Subtotal				$ 30,319,500
Capital Cost Contingency	40%			$ 12,127,800
Capital Cost Total				***$ 42,447,300***
Professional Services				
Design and procurement	10%	$ 4,244,730	1	$ 4,244,730
Construction services	5%	$ 2,122,365	1	$ 2,122,365
Legal	LS	$ 50,000	1	$ 50,000
Professional Services Subtotal				$ 6,417,095
Professional Services Contingency	20%			$ 1,283,419
Professional Services Total				***$ 7,700,514***
Annual Operation and Maintenance				
ZLD system O&M	LS	$ 550,000	1	$ 550,000
Energy costs (pumping)	KWH	$ 0.07	2500000	$ 175,000
Energy costs (heating)	KWH	$ 0.07	5750000	$ 402,500
Softening O&M	LS	$ 375,000	1	$ 375,000
Sludge hauling and disposal	WT	$ 30	14400	$ 432,000
Labor	FTE	$ 60,000	3	$ 180,000
Operation and Maintenance Cost Subtotal				$ 2,114,500
Operation and Maintenance Cost Contigency	40%			$ 845,800
Operation and Maintenance Cost Total				***$ 2,960,300***

Table 7. Mine Alternative 2 Preliminary Cost Estimate – RO with ZLD and Lime Softening

Item	Unit	Unit Cost	Qty	Cost
Preliminary Costs				
UF/RO pilot unit	MO	$ 50,000	3	$ 150,000
Capital Costs				
ZLD feed tank	LS	$ 50,000	1	$ 50,000
UF, RO, evaporator and crystallizer systems	LS	$ 7,900,000	1	$ 7,900,000
Treatment building - precast wall panel + site blasting and fill preparation	SF	$ 150	35000	$ 5,250,000
Influent pump station (4000 gpm)	LS	$ 625,000	1	$ 625,000
20" HDPE Forcemain from Pit 1 to WTF	LF	$ 75	1000	$ 75,000
Liquid chemical storage and feed equipment	EA	$ 30,000	7	$ 210,000
Lime storage and feed equipment	LS	$ 750,000	1	$ 750,000
Softening reactors, mixers, clarifier/thickeners (4000 gpm)	LS	$ 3,100,000	1	$ 3,100,000
Filter presses	EA	$ 750,000	2	$ 1,500,000
Effluent pump station (4000 gpm)	LS	$ 450,000	1	$ 450,000
Process equipment installation @ 30%	LS	$ 4,375,500	1	$ 4,375,500
Mechanical systems @ 15%	LS	$ 2,187,750	1	$ 2,187,750
Electrical and control systems @ 25%	LS	$ 3,646,250	1	$ 3,646,250
Civil/site work	LS	$ 200,000	1	$ 200,000
Capital Cost Subtotal				$ 30,319,500
Capital Cost Contingency	40%			$ 12,127,800
Capital Cost Total				***$ 42,447,300***
Professional Services				
Design and procurement	10%	$ 4,244,730	1	$ 4,244,730
Construction services	5%	$ 2,122,365	1	$ 2,122,365
Legal	LS	$ 50,000	1	$ 50,000
Professional Services Subtotal				$ 6,417,095
Professional Services Contingency	20%			$ 1,283,419
Professional Services Total				***$ 7,700,514***
Annual Operation and Maintenance				
ZLD system O&M	LS	$ 550,000	1	$ 550,000
Energy costs (pumping)	KWH	$ 0.07	2500000	$ 175,000
Energy costs (heating)	KWH	$ 0.07	5750000	$ 402,500
Softening O&M	LS	$ 250,000	1	$ 250,000
Sludge hauling and disposal	WT	$ 30	11250	$ 337,500
Labor	FTE	$ 60,000	3	$ 180,000
Operation and Maintenance Cost Subtotal				$ 1,895,000
Operation and Maintenance Cost Contigency	40%			$ 758,000
Operation and Maintenance Cost Total				***$ 2,653,000***

Table 8. Mine Alternative 1 Preliminary Cost Estimate – RO with ZLD and Membrane Softening

Item	Unit	Unit Cost	Qty	Cost
Preliminary Costs				
UF/RO pilot unit	MO	$ 50,000	3	$ 150,000
Capital Costs				
ZLD feed tank	LS	$ 80,000	1	$ 80,000
UF, RO, evaporator and crystallizer systems	LS	$ 12,310,000	1	$ 12,310,000
Treatment building - precast wall panel + site blasting and fill preparation	SF	$ 150	17500	$ 2,625,000
Liquid chemical storage and feed equipment	EA	$ 30,000	6	$ 180,000
Influent pump station (4340 gpm)	LS	$ 650,000	1	$ 650,000
20" HDPE Forcemain (pit water) from Pit 1 to WTF	LF	$ 75	1000	$ 75,000
UF and RO systems (pit water treatment)	LS	$ 3,750,000	1	$ 3,750,000
Effluent pumping (4000 gpm)	LS	$ 400,000	1	$ 400,000
Process equipment installation @ 30%	LS	$ 5,211,000	1	$ 5,211,000
Mechanical systems @ 15%	LS	$ 2,545,500	1	$ 2,545,500
Electrical and control systems @ 25%	LS	$ 4,222,500	1	$ 4,222,500
Civil/site work	LS	$ 200,000	1	$ 200,000
Capital Cost Subtotal				$ 32,249,000
Capital Cost Contingency	40%			$ 12,899,600
Capital Cost Total				***$ 45,148,600***
Professional Services				
Design and procurement	10%	$ 4,514,860	1	$ 4,514,860
Construction services	5%	$ 2,257,430	1	$ 2,257,430
Legal	LS	$ 50,000	1	$ 50,000
Professional Services Subtotal				$ 6,822,290
Professional Services Contingency	20%			$ 1,364,458
Professional Services Total				***$ 8,186,748***
Annual Operation and Maintenance				
Ultrafiltration O&M	LS	$ 270,000	1	$ 270,000
Reverse Osmosis O&M	LS	$ 590,000	1	$ 590,000
ZLD system O&M	LS	$ 1,590,000	1	$ 1,590,000
Energy costs (pumping)	KWH	$ 0.07	2500000	$ 175,000
Energy costs (heating)	KWH	$ 0.07	3500000	$ 245,000
Sludge hauling and disposal	WT	$ 30	9000	$ 270,000
Labor	FTE	$ 60,000	2	$ 120,000
Operation and Maintenance Cost Subtotal				$ 3,260,000
Operation and Maintenance Cost Contigency	40%			$ 1,304,000
Operation and Maintenance Cost Total				***$ 4,564,000***

Table 9. Mine Alternative 2 Preliminary Cost Estimate – RO with ZLD and Membrane Softening

Item	Unit	Unit Cost	Qty	Cost
Preliminary Costs				
UF/RO pilot unit	MO	$ 50,000	3	$ 150,000
Capital Costs				
ZLD feed tank	LS	$ 80,000	1	$ 80,000
UF, RO, evaporator and crystallizer systems	LS	$ 13,500,000	1	$ 13,500,000
Treatment building - precast wall panel + site blasting and fill preparation	SF	$ 150	20000	$ 3,000,000
Liquid chemical storage and feed equipment	EA	$ 30,000	6	$ 180,000
Influent pump station (4424 gpm)	LS	$ 650,000	1	$ 650,000
20" HDPE Forcemain (pit water) from Pit 1 to WTF	LF	$ 75	1000	$ 75,000
UF, RO systems	LS	$ 3,850,000	1	$ 3,850,000
Effluent pumping (4000 gpm)	LS	$ 400,000	1	$ 400,000
Process equipment installation @ 30%	LS	$ 5,598,000	1	$ 5,598,000
Mechanical systems @ 15%	LS	$ 2,799,000	1	$ 2,799,000
Electrical and control systems @ 25%	LS	$ 4,665,000	1	$ 4,665,000
Civil/site work	LS	$ 200,000	1	$ 200,000
Capital Cost Subtotal				$ 34,997,000
Capital Cost Contingency	40%			$ 13,998,800
Capital Cost Total				***$ 48,995,800***
Professional Services				
Design and procurement	10%	$ 4,899,580	1	$ 4,899,580
Construction services	5%	$ 2,449,790	1	$ 2,449,790
Legal	LS	$ 50,000	1	$ 50,000
Professional Services Subtotal				$ 7,399,370
Professional Services Contingency	20%			$ 1,479,874
Professional Services Total				***$ 8,879,244***
Annual Operation and Maintenance				
Ultrafiltration O&M	LS	$ 240,000	1	$ 240,000
Reverse Osmosis O&M	LS	$ 520,000	1	$ 520,000
ZLD system O&M	LS	$ 1,450,000	1	$ 1,450,000
Energy costs (pumping)	KWH	$ 0.07	2500000	$ 175,000
Energy costs (heating)	KWH	$ 0.07	3500000	$ 245,000
Sludge hauling and disposal	WT	$ 30	7000	$ 210,000
Labor	FTE	$ 60,000	2	$ 120,000
Operation and Maintenance Cost Subtotal				$ 2,960,000
Operation and Maintenance Cost Contigency	40%			$ 1,184,000
Operation and Maintenance Cost Total				***$ 4,144,000***

Table 10. Mine Alternative 1 Preliminary Cost Estimate – RO of the Area 1 Pit Discharge

Item	Unit	Unit Cost	Qty	Cost
Preliminary Costs				
UF/RO pilot unit	MO	$ 50,000	3	$ 150,000
Capital Costs				
Influent pump station (4715 gpm)	LS	$ 675,000	1	$ 675,000
20" HDPE Forcemain (pit water) from Pit 1 to WTF	LF	$ 75	1000	$ 75,000
ZLD feed tank	LS	$ 80,000	1	$ 80,000
UF and RO systems	LS	$ 4,000,000	1	$ 4,000,000
Evaporator and crystallizer	LS	$ 9,500,000	1	$ 9,500,000
Treatment building - precast wall panel + site blasting and fill preparation	SF	$ 150	40000	$ 6,000,000
Liquid chemical storage and feed equipment	EA	$ 30,000	6	$ 180,000
Effluent pumping (4000 gpm)	LS	$ 400,000	1	$ 400,000
Process equipment installation @ 30%	LS	$ 4,450,500	1	$ 4,450,500
Mechanical systems @ 15%	LS	$ 2,225,250	1	$ 2,225,250
Electrical and control systems @ 25%	LS	$ 3,708,750	1	$ 3,708,750
Civil/site work	LS	$ 200,000	1	$ 200,000
Capital Cost Subtotal				$ 31,494,500
Capital Cost Contingency	40%			$ 12,597,800
Capital Cost Total				***$ 44,092,300***
Professional Services				
Design and procurement	10%	$ 4,409,230	1	$ 4,409,230
Construction services	5%	$ 2,204,615	1	$ 2,204,615
Legal	LS	$ 50,000	1	$ 50,000
Professional Services Subtotal				$ 6,663,845
Professional Services Contingency	20%			$ 1,332,769
Professional Services Total				***$ 7,996,614***
Annual Operation and Maintenance				
Ultrafiltration O&M	LS	$ 430,000	1	$ 430,000
Reverse Osmosis O&M	LS	$ 880,000	1	$ 880,000
Evaporator and crystallizer O&M	LS	$ 2,400,000	1	$ 2,400,000
Energy costs (pumping)	KWH	$ 0.07	2500000	$ 175,000
Energy costs (heating)	KWH	$ 0.07	5800000	$ 406,000
Sludge hauling and disposal	WT	$ 30	12000	$ 360,000
Labor	FTE	$ 60,000	2	$ 120,000
Operation and Maintenance Cost Subtotal				$ 3,461,000
Operation and Maintenance Cost Contigency	40%			$ 1,384,400
Operation and Maintenance Cost Total				***$ 4,845,400***

Table 11. Mine Alternative 2 Preliminary Cost Estimate – RO of the Area 1 Pit Discharge

Item	Unit	Unit Cost	Qty	Cost
Preliminary Costs				
UF/RO pilot unit	MO	$ 50,000	3	$ 150,000
Capital Costs				
Influent pump station (4834 gpm)	LS	$ 675,000	1	$ 675,000
20" HDPE Forcemain (pit water) from Pit 1 to WTF	LF	$ 75	1000	$ 75,000
ZLD feed tank	LS	$ 80,000	1	$ 80,000
UF and RO systems	LS	$ 4,500,000	1	$ 4,500,000
Evaporator and crystallizer	LS	$ 9,900,000	1	$ 9,900,000
Treatment building - precast wall panel + site blasting and fill preparation	SF	$ 150	42000	$ 6,300,000
Liquid chemical storage and feed equipment	EA	$ 30,000	6	$ 180,000
Effluent pumping (4000 gpm)	LS	$ 400,000	1	$ 400,000
Process equipment installation @ 30%	LS	$ 4,720,500	1	$ 4,720,500
Mechanical systems @ 15%	LS	$ 2,360,250	1	$ 2,360,250
Electrical and control systems @ 25%	LS	$ 3,933,750	1	$ 3,933,750
Civil/site work	LS	$ 200,000	1	$ 200,000
Capital Cost Subtotal				$ 33,324,500
Capital Cost Contingency	40%			$ 13,329,800
Capital Cost Total				***$ 46,654,300***
Professional Services				
Design and procurement	10%	$ 4,665,430	1	$ 4,665,430
Construction services	5%	$ 2,332,715	1	$ 2,332,715
Legal	LS	$ 50,000	1	$ 50,000
Professional Services Subtotal				$ 7,048,145
Professional Services Contingency	20%			$ 1,409,629
Professional Services Total				***$ 8,457,774***
Annual Operation and Maintenance				
Ultrafiltration O&M	LS	$ 350,000	1	$ 350,000
Reverse Osmosis O&M	LS	$ 830,000	1	$ 830,000
Evaporator and crystallizer O&M	LS	$ 1,900,000	1	$ 1,900,000
Energy costs (pumping)	KWH	$ 0.07	2500000	$ 175,000
Energy costs (heating)	KWH	$ 0.07	5800000	$ 406,000
Sludge hauling and disposal	WT	$ 30	17000	$ 510,000
Labor	FTE	$ 60,000	2	$ 120,000
Operation and Maintenance Cost Subtotal				$ 3,111,000
Operation and Maintenance Cost Contigency	40%			$ 1,244,400
Operation and Maintenance Cost Total				***$ 4,355,400***

Figures

Barr Footer: Date: 11/16/2009 3:09:41 PM File: I:\Client\Mesabi_Nugget\Out_of_Scope\Water_Agency_Negotiations\Maps\Report\Water_Treatment_Evaluations\2009_11_16\Figure 1 Proposed Location of Area 1 Pit Water Treatment.mxd User: arm2

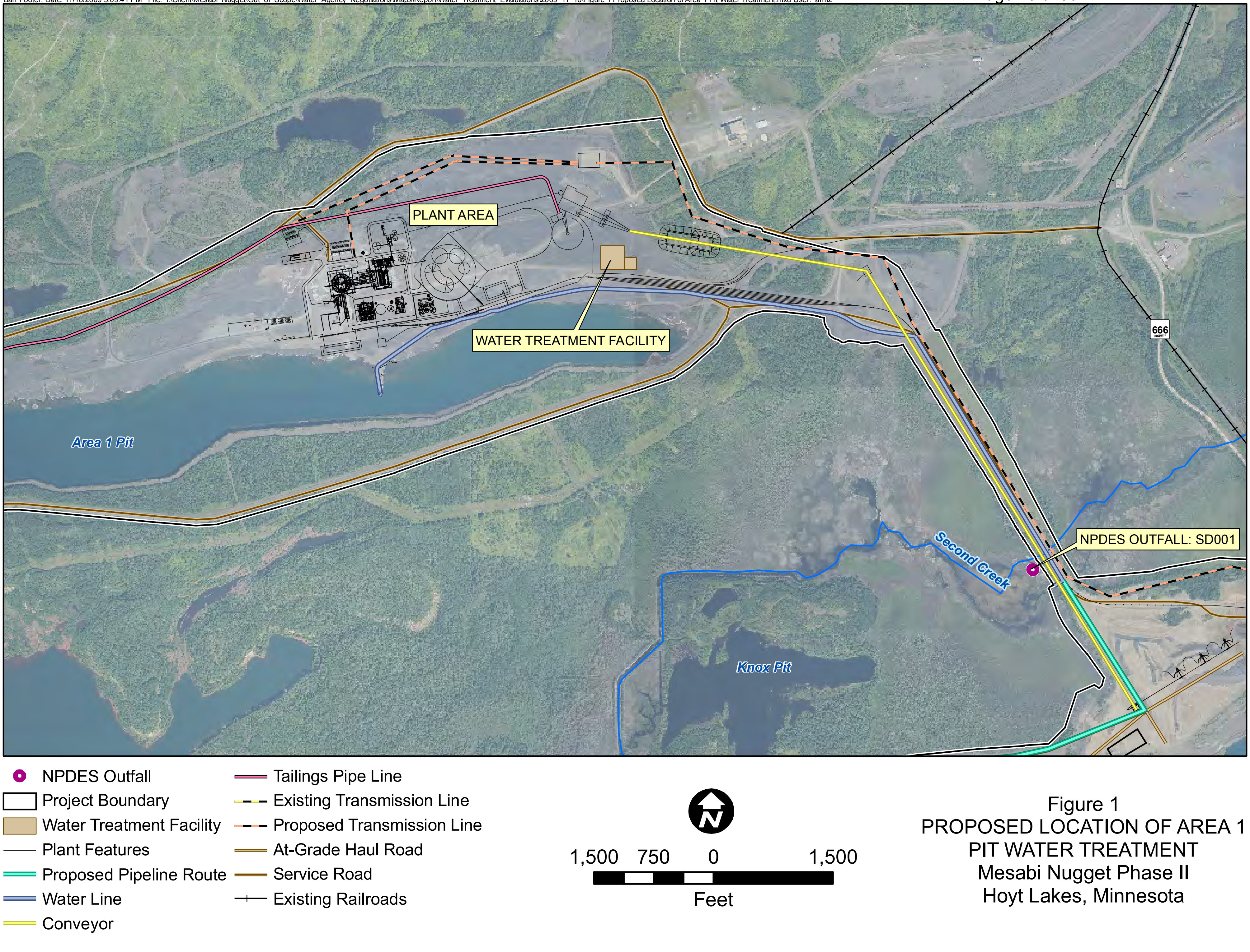


Figure 1
PROPOSED LOCATION OF AREA 1 PIT WATER TREATMENT
Mesabi Nugget Phase II
Hoyt Lakes, Minnesota

Figure 2. Area 1 Pit Year 10 Water Quality – Mine Alternative 1

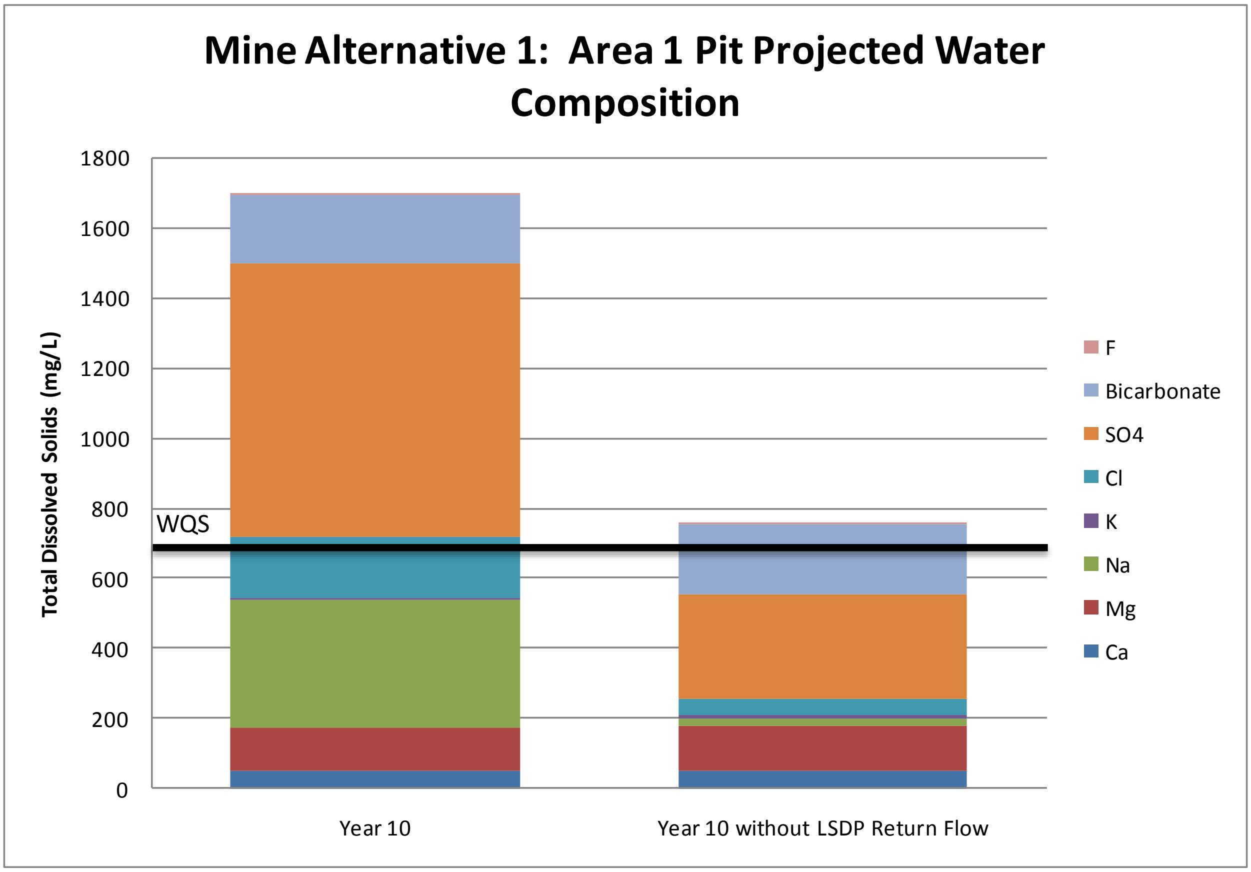
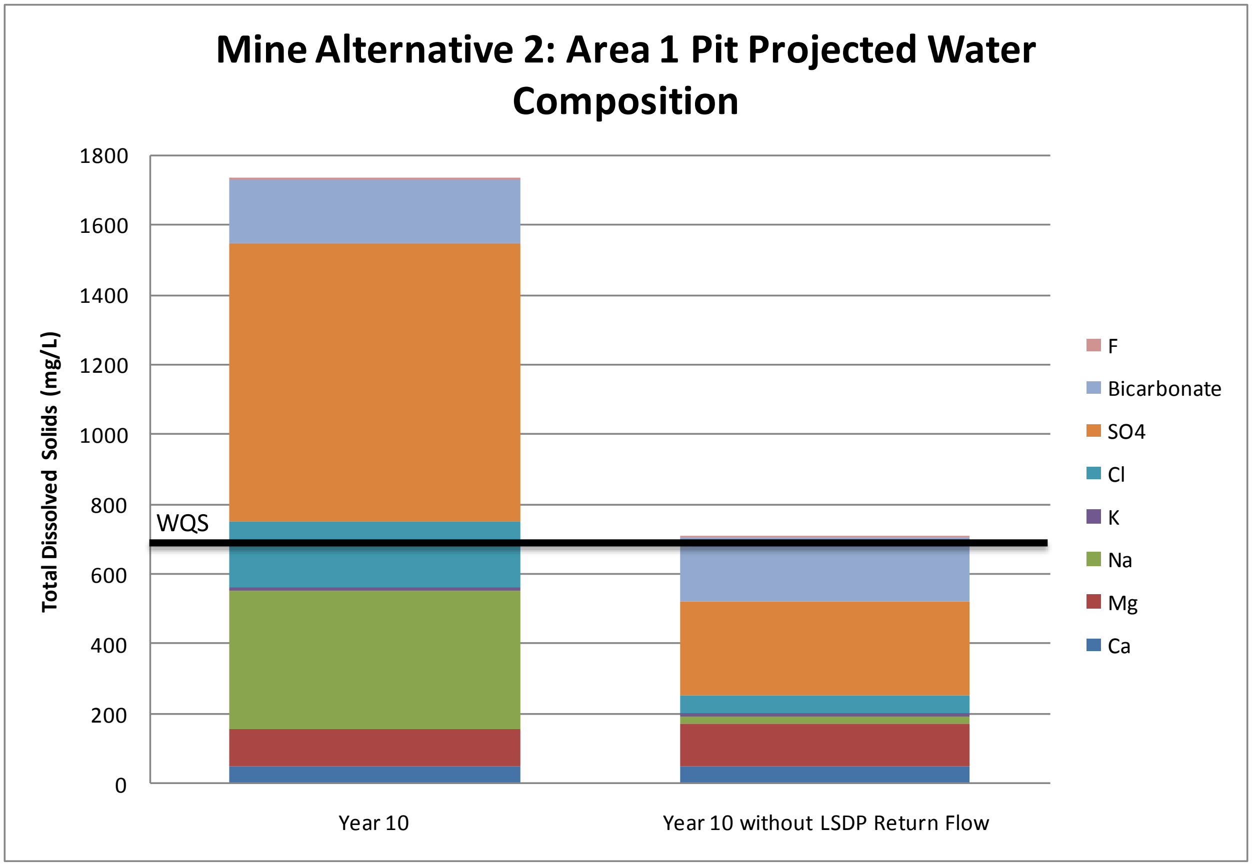
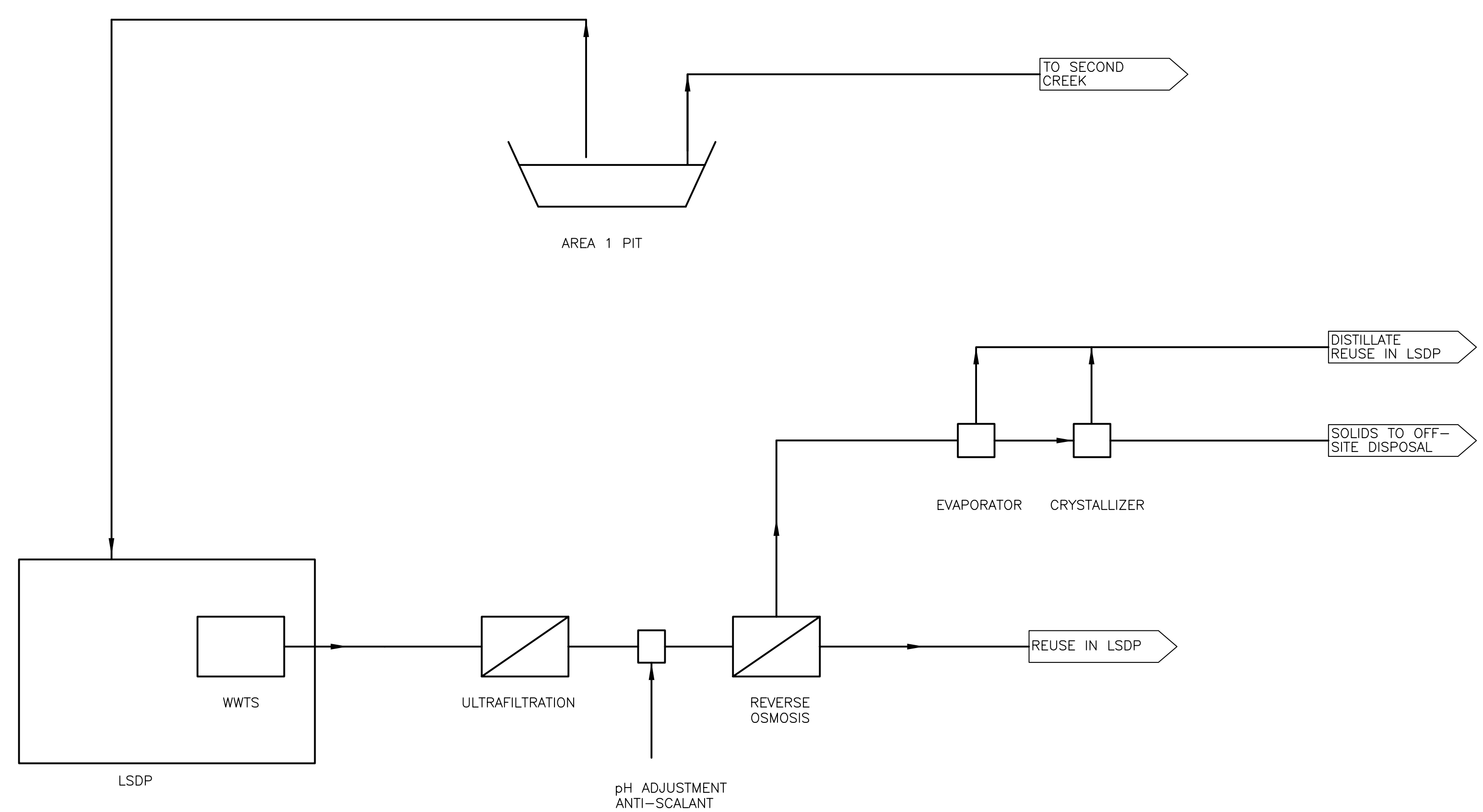


Figure 3. Area 1 Pit Year 10 Water Quality – Mine Alternative 2





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MESABI NUGGET

FIGURE 4: LDSP REVERSE OSMOSIS WITH ZLD

CONCEPTUAL PROCESS FLOW DIAGRAM

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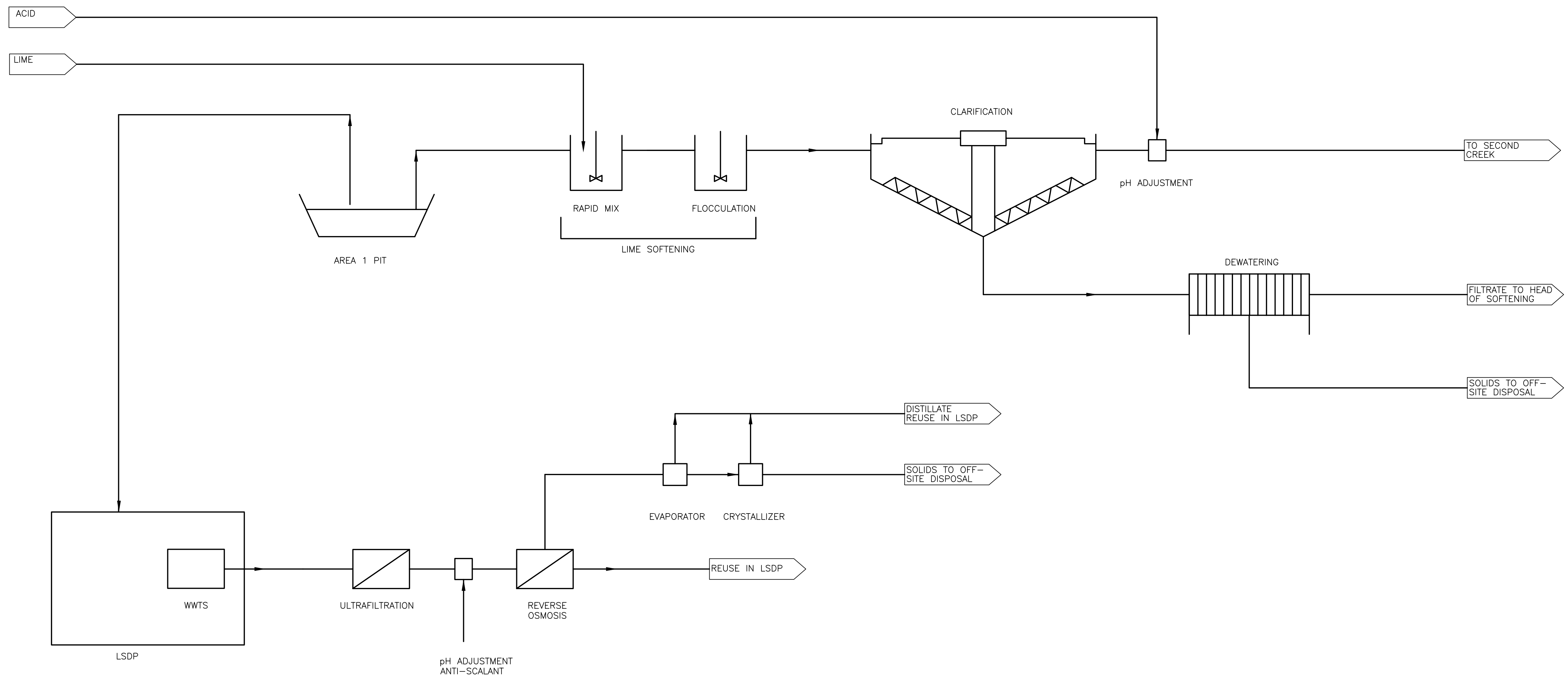
REV. No.



CADD USER: Amanda Sachi FILE: P:\MPLS\23 MN\69\2369B65 MESABI NUGGET PHASE II\WASTEWATER NPDES\WATER TREATMENT EVALUATIONS\AREA 1 PIT\AREA 1 - ALT 1 - 4 CAD FIGURES SEPTEMBER09\ALTERNATIVE 2 FIGURE 9-21-09.DWG PLOT SCALE: 1:2 PLOT DATE: 9/29/2009 12:20 PM

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FIGURE 5: ZLD WITH LIME SOFTENING

CONCEPTUAL PROCESS FLOW DIAGRAM

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DWG. No.
REV. No.

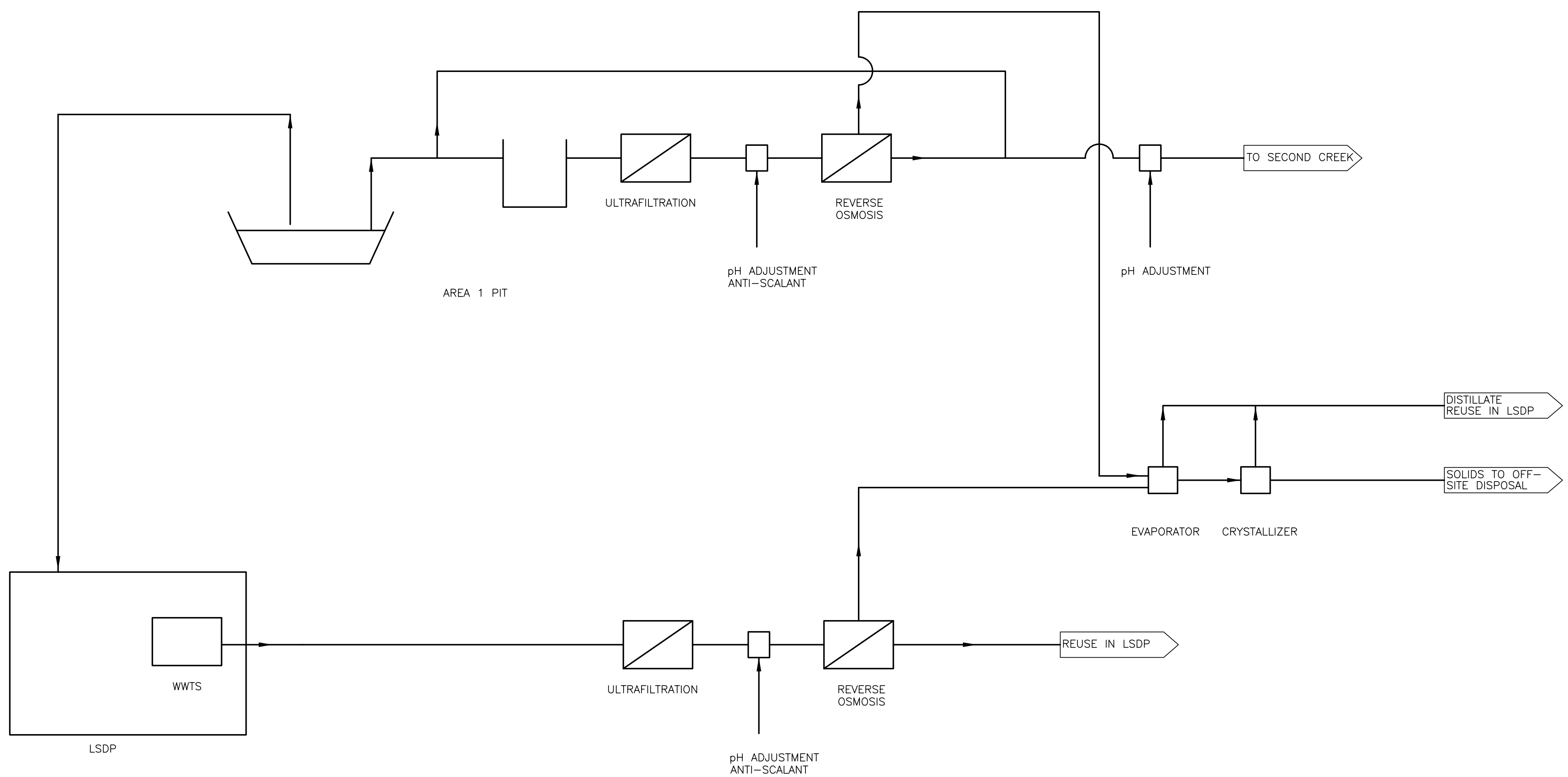

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FIGURE 6: ZLD WITH MEMBRANE SOFTENING

CONCEPTUAL PROCESS FLOW DIAGRAM

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CLIENT PROJECT No.

DWG. No. REV. No.

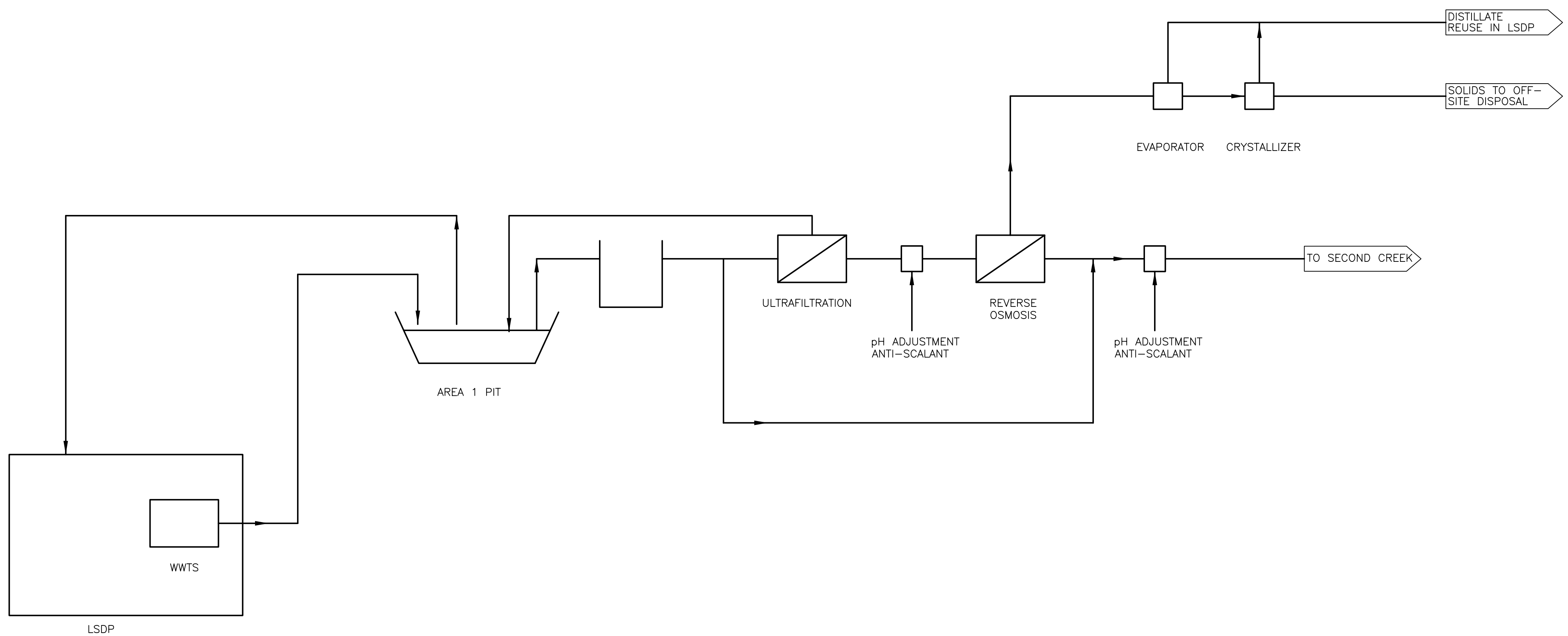

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FIGURE 7: MEMBRANE TREATMENT AND PIT DISCHARGE

CONCEPTUAL PROCESS FLOW DIAGRAM

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DWG. No. REV. No.

CADD USER: Amanda Sachi FILE: P:\MPLS\23 MN\69\2369B65 MESABI NUGGET PHASE II\WASTEWATER NPDES\WATER TREATMENT EVALUATIONS\AREA 1 PIT\AREA 1 – ALT 1 – 4 CAD FIGURES SEPTEMBER09\ALTERNATIVE 4 FIGURE 9-21-09.DWG PLOT SCALE: 1:2 PLOT DATE: 9/29/2009 12:21 PM

Appendix A

Equipment Supplier Information

GE Infrastructure
Water & Process Technologies

Paul DiLallo

M 414-403-1897
T 262-200-2111
paul.dilallo@ge.com

May 21, 2009

Lisa Andrews
Barr Engineering Company
4700 West 77th Street
Minneapolis, MN 55435-4803

Lisa:

Please find below information for the ZLD system relating to Area 1 Pit.

Equipment Scope

Ultrafiltration System
- 500 gpm (feed) system, 95% recovery
- Feed Pumping System
- ZeeWeed Membrane Racks
- Piping and Valve Skid
- Membrane Air Scour System
- Backwash System
- Cleaning System
- Permeate Storage Tank and Distributions Pumps

Reverse Osmosis System
- 450 gpm (permeate) system, 80% recovery
- Cartridge Filters
- Chemical Injection Systems
- Feed Pump
- RO Skid – Membrane Housings, Membranes, Piping, Valves, Controls
- Cleaning System
- Permeate Storage Tank and Distribution Pumps

Brine Concentrator
- 88 gpm feed
- Feed tank
- Feed pump/motor
- Feed tank mixer/motor
- Acid pumps/motors
- Feed / distillate heat exchanger
- Deaerator vessel with packing
- Evaporator vessel
- Recirculation ducts with expansion joints
- Vapor ducts with expansion joints

- Distillate pump/motor
- Distillate tank
- Recirculation pump/motor
- Vapor compressor/motor
- Seed recycle system (not shown on PFD)
- Seed tank
- Seed tank mixer/motor
- Seed pump/motor
- Start-up boiler
- Control system – PLC type with CRT operator interface
- Field instrumentation and controls

Crystallizer

- 20 gpm feed
- Crystallizer vapor body and mist eliminator
- Crystallizer Heater
- Solids separation device (centrifuge)
- Recirculation pump / motor
- Feed pump / motor
- Centrate tank
- Centrate tank mixer
- Centrate pump / motor
- Themocompressor units
- Crystallizer product condenser
- Crystallizer product condensate pump
- Prime condensate tank
- Prime condensate pump
- Antifoam pumps / motors
- Caustic pumps / motors
- Control system – PLC type with CRT operator interface
- Field instruments
- Control valves

Building Requirements

A footprint of approximately 10,000 square feet is required for the ZLD system. Approximately 8,000 square feet is required to be housed in a building. Approximately half of the building will need to be two-stories. The other half can be single-story. The evaporator vessels will be mounted outdoors. Brine concentrator evaporator height is approximately 90 feet.

Capital Cost

Estimated capital cost for the ZLD system is $7.0 MM. This estimate is for equipment only and is based on the scope of supply outlined above.

Operating Costs

Estimated operating cost for the ZLD system is approximately $550,000 per year. Operating costs include power, chemicals, membrane and filter replacement for the UF and RO systems and power and chemicals for the brine concentrator and crystallizer.

If you have any questions or require additional information, please don't hesitate to contact me.

Sincerely,
GE Infrastructure
Water & Process Technologies

Paul DiLallo
GE Water & Process Technologies

cc. Fred Lichtner
Troy Eddy