APPENDIX 20

Mine Water Treatment Technical Memorandum

Technical Memorandum

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INTRODUCTION

This memo provides a planning-level conceptual outline of treatment for the mine water from the proposed Eagle Gold project. The treatment of sanitary wastewater from the mine camp is not addressed here. This memo focuses on active treatment system technology for high flowrates. Passive and/or semi-passive treatment systems may be appropriate for the long-term mine post-closure period and for lower flowrates.

Active treatment will be provided for combined net discharge originating from open pit and waste rock areas through sediment control ponds; and the net process water from the CN heap leach operation which will have undergone pretreatment to detoxify CN by oxidation using hydrogen peroxide. The details of the CN detoxification are provided elsewhere. These streams will be channeled through the Feed Pond and to the proposed mine water treatment system.

WATER CHARACTERISTICS AND TREATMENT GOALS

The projected flowrate to be treated during the mining operation is projected to range between 500,000 m^3/yr and 2,500,000 m^3/yr, with an average of 1,500,000 m^3/yr. The treatment system will operate 150 days per year, with an average flowrate of 10,000 m^3/d or 420 m^3/h; and a maximum flowrate of 618 m^3/h. To address flowrates higher than this during extreme wet-weather conditions, operational flexibility will be designed into the treatment system, as discussed in a subsequent section.

A summary of the projected characteristics of the water from the Feed Pond to be treated are provided in Table 1.

Table1: Projected Feed Pond Water Characteristics

Parameter	Expected Feed Pond Conditions			
	Mean (mg/L)	Median (mg/L)	Max (mg/L)	Concentration (mg/L) on July 2024 with Max flow through MWTP of 445,000 (m^3/month)
Fluoride	0.9929	0.7431	2.4000	2.1130
Sulphate	848	221	2800	2401
Aluminum	0.8342	0.2500	2.6000	2.2160
Antimony	0.5528	0.1969	1.7000	1.4679

Parameter	Expected Feed Pond Conditions			
	Mean (mg/L)	Median (mg/L)	Max (mg/L)	Concentration (mg/L) on July 2024 with Max flow through MWTP of 445,000 (m^3/month)
Arsenic	1.7478	0.3347	6.0000	5.1230
Cadmium	0.0017	0.0010	0.0080	0.0033
Chromium	0.0079	0.0046	0.0303	0.0046
Copper	0.0387	0.0192	0.1119	0.0971
Iron	0.4396	0.3946	1.5966	0.6536
Lead	0.0545	0.0092	0.1900	0.1620
Manganese	0.2939	0.1324	1.5240	0.5512
Mercury	0.0001	0.0001	0.0004	0.0003
Molybdenum	0.0773	0.0526	0.2000	0.1746
Nickel	0.0703	0.0134	1.0462	0.0221
Selenium	0.0632	0.0111	0.2239	0.1910
Silver	0.0084	0.0014	0.0300	0.0255
Uranium	0.1389	0.0591	0.6852	0.3194
Zinc	0.1733	0.0381	0.5712	0.4887
Ammonia, Total			**46**	
Nitrate-N	2.9			

For the purpose of modeling effects on water quality, the mine water treatment end of pipe effluent criteria have been set assumed at two times the downstream Water Quality Guidelines or Site Specific Water Quality Objectives to provide a conservative measure. Table 2 summarizes the projected constraints for discharge of the treated water.

Table 2: Assumptions for Effluent Quality for the Mine Water Treatment Plant

Parameter	Concentration (mg/L)	Comment
Sulphate	200	Two times higher than BC WQG of 100 mg/L
Fluoride	0.4	Two times higher than BC WQG of 0.2 mg/L
Aluminum, D	0.2	Two times higher than BC WQG, dissolved (0.10 mg/L) rather than total
Antimony, T	0.04	Two times higher than BC WQG of 0.02 mg/L
Arsenic, T	0.04	Two times higher than a SS WQO for Haggart Creek
Boron, T	2.4	Two times higher than CCME WQG
Cadmium, T	0.0006	Two times higher than draft CCME WQG (2010) of 0.0003
Chromium, T	0.0178	Two times higher than CCME WQG
Copper, T	0.006	Two times higher than CCME WQG

Parameter	Concentration (mg/L)	Comment
Iron, T	2.0	Two times higher than BC WQG (2008) for total iron of 1.0 mg/L and also considering the BC WQG for dissolved iron of 0.35 mg/L
Lead, T	0.008	Two times higher than CCME WQG
Manganese, T	0.1	Two times higher than BC WQG for drinking water, 0.05 mg/L
Mercury, T	0.00005	Two times higher than CCME WQG
Molybdenum, T	0.146	Two times higher than CCME WQG
Nickel, T	0.22	Two times higher than CCME WQG
Selenium, T	0.004	Two times higher than BC WQG of 0.002
Silver, T	0.0002	Two times higher than CCME WQG
Thallium, T	0.0016	Two times higher than BC WQG of 0.008 mg/L
Uranium, T	0.03	Two times higher than draft CCME WQG
Zinc, T	0.06	Two times higher than CCME WQG
Cyanide (free)	0.01	Two times higher than CCME WQG
Phosphate	0.2	Preliminary SS limit for Haggart Creek based on eutrophication
Ammonia, T	11.2	Two times higher than CCME WQG, adjusted for temperature and pH based on aquatic toxicity
Ammonia, T	1.0	Potential SS limit based on eutrophication
Nitrate	5.8	Two times higher than CCME WQG
Nitrate	0.4	Potential SS limit based on eutrophication

NOTE:
Effluent Discharge Criteria are two times higher than WQG or a SS WQO

Total ammonia guidelines for aquatic toxicity are based on pH and water temperature; here projected to be 7.0 pH units and 10 degrees Celsius during the warmest month. Total ammonia targets during other colder months will be lower, equating to approximately 23 mg/L during the coldest discharging month. The eutrophication-based limits for Phosphate and Nitrate are preliminary, and will be examined more closely in subsequent evaluations.

POTENTIAL TREATMENT TECHNOLOGIES

Combinations of several treatment techniques are considered in order to meet the discharge requirements. Some limited bench-scale testing has been conducted to date. Additional treatability testing will be performed to refine and finalize the treatment system selection.

Conventional acid mine drainage treatment using lime addition, coagulation and settling, will not be sufficient to meet the projected discharge requirements. However, that treatment technology may be appropriate as an initial pretreatment step, to reduce particle loading on downstream treatment units. The low concentration targets for arsenic, cadmium, copper, selenium, and mercury will require advanced treatment technologies. Additional testing is planned to more accurately quantify the concentration of mercury, which has a very low target level.

The chemical coagulation, flocculation, and solids separation steps that are appropriate for initial removal of metals are also effective for precipitation of Phosphates. When typical coagulants such as Ferric Chloride or Alum are used in conjunction with settling and/or filtration, it is possible to remove Phosphorous down to concentrations of 0.2 mg/L and possibly somewhat lower; but that is the borderline limit.

Many treatment technologies have been used and tested to achieve low concentrations of the target metals listed, as well as ammonia and nitrate. Such technologies have included co-precipitation on iron hydroxide floc, biological and abiotic sulfide precipitation, selective chelation ion exchange (IE), electrochemical ion exchange, ultrafiltration, reverse osmosis (RO), electrobiochemical reactors; ozonation (for oxidation of ammonia and metals); and others. A technique finding increased application involves enhanced settling of coagulated precipitates on mobile sand media to increase overall particle density and settling velocities. The Actiflo® system is an example of this. Use of such enhanced solids separation techniques provides more flexibility in treating variable flowrates at lower cost.

The solubility product constants (K_{sp}) for most metals as sulfides are generally several orders of magnitude lower than the K_{sp} values for the corresponding metal hydroxides. That fact led to the recognition of sulfide precipitation as a more effective precipitation water treatment technique several decades ago. Sulfide precipitation may be accomplished in conjunction with the controlled biological reduction of sulfate to sulfide; or through the abiotic addition of inorganic chemicals. Metal sulfide precipitates are often initially very fine, with slow crystal growth rates. Because of that, sulfide precipitation often requires more precise application of coagulants and polymers to be successful. Use of sulfide sludge blanket contact clarification, in which a slurry of excess ferrous sulfide precipitate is maintained in controlled suspension as a sludge blanket, has been used in an ion exchange application. In that approach, because other metals have sulfide K_{sp} values much lower than that of iron sulfide, other metals become precipitated as sulfides in exchange for iron returning into solution.

Phosphorous may be removed through biological treatment techniques or by physical/chemical techniques. Ammonia oxidation to nitrate and conversion of nitrate to strippable gaseous nitrogen forms may be accomplished through biological treatment techniques (with aerobic and anaerobic steps in series). Ammonia oxidation and nitrate removal can also be removed by physical chemical techniques.

Biological systems such as biological sulfide reduction, ammonia oxidation, and nitrate removal would require provision of carbon, which would have to be added. Biological removal of nitrate would also require addition of carbon and nutrients, and maintenance of anaerobic conditions; and would not be as flexible for rapid changes in pollutant flux. In addition, biological treatment systems would require addition of heat to maintain the water within a temperature range suitable for effective microbial growth and activity. For these reasons, for the large flowrates of this project, biological treatment systems are not considered a primary candidate solution. There may be a role for biological treatment systems, including possible engineered wetlands, for long-term low-flowrate maintenance in the post-mining period.

For chemical precipitation techniques, particularly those based on precipitation of metals as hydroxides, oxides, and carbonates, the pH of optimum removal (minimum solubility) is different for different metals. For discharges requiring removal of a large number of metals, such as projected for the Eagle Gold project, this could complicate precipitation and might in fact require serial precipitation and settling steps if precipitation is used as a major component of the overall treatment train. If precipitation and settling are used largely as a pretreatment to reduce solids loading on downstream units such as IE or RO, it may be possible for a single-pH precipitation concept to play a feasibly appropriate role.

Ion exchange is effective not only for removal of metals, but also for removal of Ammonia, Nitrate, and Phosphate (with zeolite ion exchange being applicable for the latter). It will probably be necessary to use different IE resin column banks in series, with each bank designed for a specific group of inorganics. IE resin columns may be cationic, anionic, non-ionic or a combination.

The potential effects of ammonia and other ligands in forming metal complexes will be addressed through additional testing during preliminary and final design of the treatment system.

Stantec reviewed a number of treatment technologies and related published literature. A 2009 study evaluated the effectiveness of nanofiltration (represented by Alfa Laval NF-99) and reverse osmosis (represented by AlfaLaval RO98HT) at removing metal ions from mine wastewater. Results indicated rejections higher than 95% for polyvalent metal ions and sulphate (Rieger, Steinberger, Pelz, Hasender, & Hartel, 2009).

MSE Technology Applications prepared a report for US EPA comparing several technologies for removing selenium (and a number of other metals). Technologies evaluated in that study included ferrihydrite precipitation/adsorption, catalyzed cementation process and biological selenium reduction (BSeR). All three technologies were able to achieve target removal of metals, with BSeR process being the most consistent and economically feasible. (MSE Technology Applications, Inc., 2001).

A paper published in the Mine Water Environment journal (2008) listed As and Se removal rates by various technologies, and compared them to that of a Sulphate-reducing bioreactor. The bioreactor achieved target removal levels; however, it seemed to be partly inhibited by H_2S. (Luo, Tsukamoto, & Zamzow, 2008). Table 3 below shows the comparison table for As and Se reoval.

Table 3: Arsenic and Selenium Removal by Different Methods (Luo, et al, 2008)

Removal Methods (As)	Maximum Removal (%)	Removal Methods (Se)	Maximum Removal (%)
Ion exchange	95	Ion exchange	>80
Activated alumina	90	Alumina adsorption	>80
Reverse osmosis	>95	Reverse osmosis	>80
Modified coagulation/filtration	92	Fe^{3+} coagulation/filtration	40 to -80 Se^{4+}
Modified lime softening	80	Lime softening	40 to -80 Se^{4+} <40 Se^{6+}
Electrodialysis reversal	85	Ferrihydrite adsorption	80 Se^{4+}

ZENON Environmental Inc. (ZENON) of Canada successfully demonstrated their alumina adsorption with Microfiltration technology to remove arsenic from process waters from the ASARCO East Helena, Montana lead smelter and from the TVX Mineral Hill Mine 1300 foot Portal water located in Jardine, Montana. (MSE Technology Applications, Inc., 2001)

All of the treatment technologies result in a residual sludge stream that will require management. Sludge management steps may involve mechanical or controlled atmospheric dewatering, and controlled disposal in a designed disposal area.

PROJECTED WATER TREATMENT CONCEPT FOR THE EAGLE GOLD PROJECT

Based on the information reviewed, it is projected that a mine water treatment system involving steps equivalent to the following will be effective for the Eagle Gold project:

- pH adjustment by addition of lime, sodium hydroxide, and or other reagents
- Addition of coagulants such as ferrous chloride
- Blending of granular floc seed material such as sand
- Flocculation in a slow-mix reactor
- Enhanced sedimentation in a rapid-settling configuration such as an inclined plate separator
- Withdrawal of the settled sludge and recovery of the floc seed sand by means of a cyclone separator (such as the Actiflo® process)
- Selective chelation ion exchange in closed vessels
- Ultrafiltration
- Reverse osmosis
- Final pH adjustment and possibly recarbonation using carbon dioxide prior to discharge to the receiving stream.

Backwash and regeneration waste streams will be generated. Due to the relatively high flowrate and the level of treatment, it will probably be necessary to provide dewatering to feasibly allow secure long-term sludge disposal on the site in controlled covered disposal cells. Consideration will be given to the feasibility of incorporating dewatered treatment system sludge into designed landfill facilities for waste rock and other material, with appropriate cover design to minimize future exposure to moisture and air and minimize the potential for re-mobilizing pollutants that have been removed from the mining operation liquid stream by the treatment system.

A hydraulic retention of approximately 20 minutes would be required for each stage of the chemical conditioning processes, including coagulation and pH adjustment. A maximum surface overflow rate (SOR) of 4.17 $m^3/m^2/hr$ would be applied for the sedimentation tank at peak flowrates; this may be increased, depending on treatability testing. A maximum hydraulic loading rate of approximately15 $m^3/m^2/hr$ would be applied for the ion exchange units.

To address extreme high wet-weather flowrates, operational flexibility will be designed into the treatment system. For certain units such as IE banks, multiple parallel units will be provided. Filters and IE units will be designed to undergo more frequent backwashing and cleaning cycles during times of higher loading. For gravity settling units, the use of enhanced coagulation/settling systems such as Actiflo® will allow high hydraulic loading rates. Higher flowrates will not always correspond to higher flux rates for target pollutants. The details of the balance between increased sizing of treatment units (as a capital cost) versus greater frequency of backwashing and cleaning (as an operational cost) will be developed during engineering design.

Treatment vessels may be constructed of steel or reinforced concrete. Reinforced concrete is generally more suitable for partial burial, achieving some ground insulation. Installation of steel tanks would allow faster construction. A detailed cost comparison will be done in conjunction with subsequent detailed design efforts.

A building will be constructed to shelter critical treatment components such as chemical make-up and feed systems, controls, ultrafiltration, IE and RO equipment. Some components such as flocculation and settling tanks, may be located outside, with insulation as appropriate to operate in shoulder season weather.

It may be appropriate to consider other alternatives involving biological treatment or ground recharge. Mixing of untreated or partially treated sanitary wastewater with the mine water may allow for more cost-effective biological treatment of the mine discharge water, for example by the design of a biological sulfide reduction system. However, such biological treatment would in all likelihood still need to be followed by the advanced polishing steps listed above. It may also be possible to implement a system of recharge of treated mine water to the ground, to minimize the treatment for some parameters such as Nitrate. Determination of the feasibility of that approach would require a comprehensive modeling of the groundwater recharge system, to determine whether the ground conditions are suitable for a feasible recharge system.

Final selection of the details of the appropriate treatment train will be made following treatability testing. Testing will include focus on effective pH control strategy, chelation IE resins, and solids separation dynamics.

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