AN INNOVATIVE, LONG TERM DRY COVER TREATMENT SYSTEM TO MANAGE TAILINGS MANAGEMENT AREA PERCOLATE

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Abstract

The **Kearney Graphite Mine**(the Mine) has been inactive in a care and maintenance state since 1994. There now are plans to reactivate this Mine and this will require the preparation of a closure plan before it can proceed. The tailings generated at the Mine are mildly acid-generating and provision must be made for the management of precipitation infiltrating through them after the eventual closure after a new operating period. This will involve the diversion of as much meteoric water as possible, the placement of a **dry phytoremediation cover** over the tailings, and down-gradient treatment of any water that still does percolate through using an **Engineered Wetland** (EW) treatment system.The dry cover will be a tree-vegetated, non-barrier kind of cover known as an **Evapotranspiration (ET) Cover**. Meteoric water that infiltrates through this cover will be treated in the multiple-redundant, aerobic/anaerobic EW system which will consist of a **sedimentation pond**; a **successive alkalinity producing system;** an anaerobic **biochemical reactor**; and an **aerobicwetland**.It will be designed to operate with minimal attention even under the severest winter conditions and will be capable over the longest periods of evolving into a fully passive "walk away" system.

Key Words: constructed wetlands, engineered wetlands, evapotranspiration covers, graphite, mine tailings area reclamation

Cover Systems

Acid-generating wastes such as tailings from mine sites may be managed by storing them long term under water, either in lakes or under tailings ponds behind dams. However, lake disposal of tailings is controversial and the long term maintenance of artificial tailings ponds may be difficult. Accordingly, mining firms are increasingly looking to dry covers for the long term reclamation of areas containing potentially acid-generating wastes such as mine tailings. Dry cover systems are designed to greatly reduce or eliminate the downward infiltration and migration (percolation) of meteoric water from the surfaces into covered and re-vegetated waste materials below them, thereby reducing the amount of contaminated leachate requiring treatment.They also promote the surface runoff of water uncontaminated by contact with the underlying materials, prevent direct exposure to the materials, minimize erosion, and provide sustainable and aesthetically-pleasing solutions at closed mine sites (EPA 1989, 2003).

There are various kinds of dry covers: **Barrier Covers** using geomembranes, impermeable materials such as clay,or multi-component earthen layers, and **Alternative Covers**including simple vegetative covers and ones involving phytoremediation technology calledET covers. ET covers are intermediate between water covers and barrier-type dry covers as to the amount of excess water that will need to be treated with themand there is less provision to eliminate infiltration through them (EPA 2003, Zahn *et al*. 2006).

The recommended design approach for an ET cover includes:

- Targeting woody and herbaceous vegetation assemblage;
- Defining the precipitation interception and transpiration characteristics of the cover's proposed vegetation;
- Calculating the long-term angle of repose of the material to be covered (e.g., tailings);
- Determining the availability and physiochemical characteristics of proposed substrate media;
- Calculating the water storage/holding capacity of the substrate material(s);
- Determining the slope of the ET cover and its relationship to overland flow material erodibility; and
- Integrating the above input variables into a comprehensive water balance model that maximizes evapotranspiration and runoff while reducing infiltration.

Alternative Covers such asVegetative and ET covers may use one or more layers of substrates, and may be further categorized into monolayer and capillary versions. Monolayer (sometimes referred to as monolithic or monofill) covers involve a single layer of soil or other growth medium (e.g., compost, wood waste, excavated topsoils) in which the plants are grown. A capillary-type Alternative Cover consists of a layer of finer-grained material similar to that of a monolithic cover but overlying a layer of coarser material such as sand or gravel. The differences between the unsaturated hydraulic properties between the two layers minimize percolation into the lower layer (EPA, 2003). With either monolayer or capillary covers, under the saturated conditions of large precipitation or snowmelt events, there will be some infiltration into the underlying material (and the waste), but the cover material quickly will reach field capacity (i.e., saturate), allowing the un-contaminated excess water to flow off the cover for separate management (e.g., passage through a stormwater system).

The kinds of vegetation which are planted on barrier-type dry covers are usually selected not to have deep roots which might penetrate the cover material and provide routes for the influx of water into the underlying waste. This practically limits cover vegetation to kinds of grasses, and necessitates long term maintenance programs to prevent deeper rooting vegetation such as trees and bushes from colonizing the cover surface. This is a special problem for the closure of mines located in forested areas where trees are the natural vegetation. With ET covers, the penetration of roots through the cover material, and even into the underlying wastes, is not a problem, as in most seasons except winter the plants will evapotranspire much of it, and in any case down-gradient water treatment systems used with them are sized to deal with such infiltration. Accordingly, with ET covers, woody plants native to the area of a mine can be used.Vegetative Covers are already very widely used in Ontario and elsewhere to reclaim waste rock and tailings areas at many minesites (Tisch 2007, Lock et al. 2010). The Canadian Land Reclamation Association and the Mining and Mineral Sciences Laboratories of the Natural Resources Canada (CANMET) have been leaders in testing and installing covers of this sort for some time, particularly in the Sudbury, ON area (CANMET 2007).

ET covers are usually more economic to install and maintain than are barrier kinds of dry covers. The main considerations for selecting an ET cover are climate; underlying mine material to-be-covered (i.e., its physical and chemical properties); the availability and cost of suitable cover materials; the physical, chemical and agronomic properties of these cover materials; and the kind(s) of plants with which it is intended to initially vegetate the cover. As natural succession will inevitably change the kinds of plants growing on a cover, this aspect too must be considered when designing an ET cover. ET covers are natural complements to downstream constructed wetland (CW) systems treating the water that does infiltrate through them.

Constructed and Engineered Wetlands

Mine drainage from tailings and waste rock piles at mine sites can be major sources of surface water and groundwater pollution. These mine drainage streams can be difficult to handle because of their natures (turbid, variable flow rates, sometimes very high flow rates, low or high pHs, high levels of sulphates, high levels of dissolved metals, etc.). Active treatment of mine drainage in conventional, on-site wastewater treatment facilities may be effective while the mines are in operation, but can be expensive to maintain after mine closure. An alternative is passive treatment in a CW(Aube *et al.* 2006).

The use of CWs for the treatment of industrial wastewaters such as mine drainage began almost as soon as they began to be used for municipal wastewater treatment (Kadlec&Wallace2008). Early mining industry designers first attempted to build open water wetlands vegetated with *Sphagnum* moss (Brown *et al.* 2002), but these were unsuccessful and were quickly supplanted by simpleaerobic wetlands vegetated with cattails (*Typha* spp.). These early types of 'free water surface' wetlands (kinds of open water, artificial marshes) proved useful for treating low flows of moderately contaminated coal mine drainage that was net alkaline, but were limited for other uses (Brown*et al.*2002). Aerobic wetlands were quickly supplemented by anaerobic wetlands. These are ones that encourage some sub-surface flow (SSF) in an organic substrate as well. Anaerobic wetlands can treat small flows of acid rock drainage (ARD) with higher iron and dissolved oxygen contents than can aerobic wetlands. Later designs added layers of alkalinity-generating limestone to the organic substrates.

In CWs, aerobic and anaerobic conditions can occur simultaneously in the same basins (cells), and in them the metals of concern in mine drainage can be precipitated either as (oxy)hydroxides or as sulphides. The most important metal removal processes involved are redox reactions, complemented by others such as precipitation; by the sorption of metals by algae, bacteria, plant debris, organic substrates, and/or oxides/hydroxides; and by plant uptake. Accordingly, if conditions in CWs can be optimized, various heterogeneous chemical reactions (accompanied by filtration, coagulation, and/or flocculation processes) can be exploited to remove contaminants from any mine drainage passing through them.

CWs are used at many mine sites for treating various process, sanitary, and leachate flows, especially for final polishing applications. Before the end of the 20th Century over 1,000 CWs had been built to treat mine drainage alone (Skoussen 1998). These passive treatment systems are attractive because they are economic to build & operate, and can continue to operate with relatively little attention long after mine decommissioning (Kadlec& Wallace, 2008). However, such CWs have many limitations, including the relatively large surface areas they require; their limited, overall contaminants' removal levels (only 40 - 60% for many pollutants); their sometimes erratic treatment capabilities; their inability to handle some mine drainage contaminants (e.g., some dissolved metals); and their poor (or non) operabilities during winter. However, there is a kind of treatment wetland that can surmount these limitations.

Engineered wetlands are special, advanced kinds of constructed wetlands in which operating conditions are more actively monitored, manipulated and controlled than is the norm with ordinary CWs (Higgins *et al.*, 1999). CW systems may be "engineered" in many ways. For example, the influent streams of vertical sub-surface flow CWs may be varied in flow rate or periodically turned on and off to draw air into the granular substrate; effluents from various points in a wetland system may be recycled; ordinary substrates may be replaced with special ones having specific qualities (e.g., the ability to permanently sorb certain pollutants from wastewaters passing through them); things may be added to flows through the wetlands (e.g., heat, chemicals, air); and/or wetland vegetation may be selected for its phytoremediating properties (Higgins 2000). EWs generally have much smaller surface areas than ordinary CWs (often less than one-tenth the size), have much higher treatment efficiencies (often 5 – 30X), and can handle much higher wastewater flow rates (up to tens of thousands of m^3/d) (Wallace *et al.* 2006).EWs can be categorized as semi-passive in comparison to the passive operations of ordinary CWs.

Engineered wetland systemsare multi-cell (and often multi-train) ones in which physical, chemical, and biological processes are carried out in separate cells (basins) in serieswhere the secondary wastewater treatment component involves aerobic and/or anaerobic EW cells. Many kinds of methods for treating mine drainage such as limestone drains can be used ("expressed") as cells in an EW system. EW systems are much more versatile than ones involving ordinary CWs; can treat even the most recalcitrant contaminants; allow very high removals (95%+) in relatively small areas; and can operate under more extreme conditions of contamination, flow rate and environmental conditions. EW systems can and do operate throughout the severest winter conditions, regardless of ambient air temperatures (Higgins & Mattes 2003).

Treatment of Excess Meteoric Water at Closed Mines

There will alwaysbe some meteoric water infiltration into, and groundwater flowing under, reclaimed tailings and waste rock accumulations at closed mines regardless of the kinds of dry covers used over them. Where the covered wastes are acid-generating, this water may become ARD and, as it usually cannot be allowed to accumulate, it will have to be collected and treated adjacent to or downstream from the reclaimed site. ARD treatment may be carried out by active, semi-passive or passive methods. Such treatment can involve neutralizing the ARD and precipitating out its dissolved metal contaminants. Conventional aerobic treatment can be carried out passively by adding slaked lime.This raises the pH,allowing iron to precipitate as (oxy)hydroxides (ochre) which gives the distinctive orange coloration where mine drainage containing dissolved iron becomes exposed to air. Where lime is added to ARD to raise the pH and precipitate out iron, the resulting floc will alsoco-precipitate some other dissolved metals.

Often, active treatment processes are used at operating facilities, while passive and semi-passive systems are preferred for facilities that are no longer in operation, yet still continue to generate ARD (Skoussen 1998, Brown *et al*. 2002). Passive systems are generally much cheaper than semi-passive systems, which in turn are again much more economic to build and operate than active ones.

Early on in the mining industry it was known that beds of limestone could be used to raise the pH of ARD. However, mine drainage often contains both ferrous and ferric iron, and the latter will precipitate if the pH of ARD is raised under oxic conditions. This then will armour (coat) the surfaces of any limestone particles, inhibiting or stopping further neutralization reactions. To counter this tendency, limestone beds can be buried in the ground (anoxic limestone drains[ALDs]) to exclude oxygen while the pH is being raised. The ARD then flows out into a later basin open to the air (e.g., a pond or CW) where the ochre can precipitate without causing armouring. ALDs can readily be expressed as cells of an EW system and work reasonably well where there are relatively low proportions of ferric iron in the waters being treated, and the streams are essentially oxygen-free.

The problem with ALDs is that most acidic mine drainage contains some ferric iron and it is difficult to exclude all oxygen from them. To address this problem, a compost (anaerobic) wetland can be combined with an ALD in a single basin in a system called a **Successive Alkalinity Producing System** (SAPS). With a SAPS, acidic minewater flows into the headspace of a basin where a layer of water on top ensures anoxic conditions in the SAPS cell below (Brown *et al*. 2002, Wildeman*et al*. 2005). It then percolates down through a compost/support medium (e.g., gravel) substrate wherein any ferric iron is reduced to the ferrous form, before the drainage enters a lower limestone bed. In this lower bed, alkalinity is added and the pH is raised towards circum-neutral values without risking the precipitation of ochre or the armouring of the limestone particles. As with ALDs, the neutralized minewater (now an neutral mine drainage, NMD) from a SAPS can oftenthen be released into an open basin where the ferrous iron will quickly oxidize to ferric iron which will hydrolyze to produce an amorphous ochre sludge which will then settle out.

Alternatively, a SAPS cell in an EW system can be followed by an **anaerobic biochemical reactor** (BCR, once called an anaerobic bioreactor, ABR).BCRs represent a rapidly developing new ecotechnology for removing contaminants such as these dissolved metals as well as sulphates and other reducible contaminants from mine drainage passing through them (Mattes *et al.* 2002, Duncan *et al.* 2004). They consist of closed substrate beds involving active media mixed with support materials such as sand, gravel and limestone. The active medium can be any type of carbonaceous material (e.g., sawdust, manure, municipal compost and/or biosolids). BCRs allow the iron and other dissolved metals in a wastewater being treated to be precipitated under anaerobic conditions as sulphides and hydroxidesdue to sulfate reduction effected by sulphate-reducing bacteria (SRB)(Steed *et al*. 2000). The basic equations for SRB-mediated sulphate reduction in a BCR (or an anaerobic wetland) can be represented by:

$$\mathbf{2CH_2O + SO_4^{=} \rightarrow H_2S + 2\,HCO_3^{-}} \qquad (1)$$

where CH_2O represents a carbon source. The hydrogen sulphide quickly reacts with the dissolved metals in the water (e.g., Fe, Zn, Cd, Ni) to precipitate them as relatively insoluble metal sulfides.

$$\mathbf{Me^{2+} + H_2S \rightarrow MeS + 2\,H^{+}} (2)$$

WhereMe is a typical dissolved divalent metal cation in mine drainage. Similar SRB-mediated reactions with dissolved metals that form oxyanions (e.g., As, Se, Mo, Cr) allow their removal as sulphides or hydroxides in BCRs as well (Higgins & Mattes 2003, Higgins *et al*. 2007).

BCRs are most commonly used semi-passively and while they can involve stand-alone units, they also can readily (and more effectively) be expressed as cells of EW systems (Higgins *et al*. 2007). Mine drainage can be fed into BCRs using distributors buried in or below substrate layers or, in warmer climates for downflow operation, by surface distributors or sprayers. In colder climates, buried or water-submerged inlet and outlet distributors can be used to direct flow through the reactors. Precipitated metal sulfides and other precipitates accumulate in the BCR's substrate beds and/or in downstream filters (e.g., CWs). Designs usually provide enough active media in the substrate to allow operations for 5 – 20+ years.Where a mine drainage being treated in a BCR contains enough dissolved metal that has an economic value (e.g., zinc), the substrate beds can later be "harvested" to recover the metal for re-use.

As may be seen from Equation 1, an adequate supply of sulphate is necessary in the ARD for the reactions to work. Like all microbes, SRB are sensitive to temperature, and reaction rates are lower where colder water is involved. However, SRB consist of varying populations of bacteria, some of which are cold-adapted and can thrive down to temperatures as low as 4 ºC, with increased numbers of bacteria compensating for the lower reaction rates (Fortin *et al.* 2000).

The Kearney Graphite Mine

The Kearney Graphite Mine is an industrial minerals facility located southeast of Graphite Lake near the Town of Kearney, ON and includes an open pit quarry, a mill, a waste rock disposal area, and a tailings management area (TMA) with associated water management facilities. Its product is flake graphite, a valuable industrial mineral used in refractory materials, powder metallurgy, flame retardants, battery anodes, brake pads and fuel cells. TheMine previously operated during the period from 1989 to 1994, and has been in a state of temporary suspension since then. Its new owner, **Ontario Graphite Limited,** proposes to re-start production for a further seven-year operating period. Graphite-containing ore will be excavated from the quarry and trucked to the mill where it will be crushed to the consistency of sand and undergo a series of flotation processes to separate out the graphite flakes which will then be dried and bagged for sale. During mining operations, the tailings, which have the consistency of, and look like, coarse sand, will be pumped as a 30% slurry into the TMA which is located in a long narrow valley south of the mill. Figure 1 shows an aerial photograph of the Mine with the existing (pictured) and future (after continuing operations) extent of its tailings management area indicated (green lines).The tailings are structurally different from the usually much finer, often thixotrophic tailings produced by metal mines. Indeed, the tailings have structural characteristics such that heavy equipment can easily drive on their dry surface.

Figure 1: The Kearney Graphite Mine

The open pit quarry is currently filled with water and will be dewatered before production re-commences. The far south end of the TMA is enclosed by a rockfill, permeable tailings dam. The water contained in the slurried tailings separates out in an ephemeral tailings pond in front of the tailings dam. During operations, water will percolate through the tailings dam and subsequently drain into a polishing pond down-gradient, from which it will be recycled to the mill. The mining process is relatively innocuous as the Mine's tailings are only weakly acid-generating and, as produced, are basic in nature, being buffered initially by carbonates in the ore.They will only develop mild acid-generating properties if exposed to oxic conditions after extended periods. This has occurred during the current temporary suspension, and the water in the tailings pond is now acidic (pH ~ 3) and contaminated with iron. Currently, seepage permeatingthrough the tailing dam collects in the downstream polishing pond and has to be limed under an existing certificate of approval prior to discharge to the downstream receiving waters.

Following reactivation and after the additional seven-year operating period, quarrying and milling operations at the Mine will cease, and itwill be converted in a safe and environmentally sound manner from an operating mine to a closed site. The mill and all of its buildings and associated equipment will be removed. The open pit quarry will be allowed to fill with water naturally to form a small pit lake (as it already has done during the current temporary suspension period). On closure, any tailings pond will be drained into the downstream polishing pond; the water in the polishing pond will be treated by liming and discharged; and the polishing pond will then be drained. Two rock-filled channels will be constructed at the toes of the hillside slopes along the sides of the final TMA and these will direct clean, un-contaminated meteoric water falling on the hillsides above it away from the tailings and down separate channels to discharge in the down-gradientSouth Pond that serves as the Mine's receiving waters.

An ET cover will be placed over the dry tailings after closure. It will consist of a monolayer at least 0.5 m thick of composted biosolids and other organic waste materials (e.g., excavated soil, chipped brush) collected before closure. The ET cover's surface will be sloped to allow excess water (once the cover becomes saturated and achieves field capacity during precipitation events) to flow into the two peripheral channels. The ET cover will be first hydoseeded with grasses and then vegetated with local trees and other woody plants at 2000 trees/ha and occupy a total tailings surface area of 94 ha.

The design features of the ET cover will include:

- Clean, un-contaminated meteoric (stormwater) water falling on the hillsides of the valley in which the TMA is located will be prevented from contacting the tailings by building the perimeter ditches to intercept it on both sides of its valley;
- The final surface of the TMA will be sloped towards the west and east (i.e., towards the ditches) to optimize overland flow, while minimizing dry cover material erosion and infiltration;
- The remaining surface of the Tailings Management Area (after subtracting that part of the original surface converted to ditches) will be covered with a monolayer ET Cover;
- The ET cover's substrate will consist of composted and un-composted organic material which will be accumulated during the new operating period before closure (plus any sludge and evacuated soil recovered during decommissioning/EW System construction);
- The ET Cover will be planted with trees local to the area such as red and white pine;
- The Thornthwaite and Mather (1957) water balance model was used to estimate and optimize dry cover vegeation, types, slopes and substrate material water storage/holding capacity. Based on water balance modeling it is estimated that 50% of the annnual preciptation of 1032 mm will evapotranspire over the dry cover area, 40% will runoff and 10% of all incipient precipitation (275 m^3/d on average) will infiltrate/recharge to the sub-surface; and
- Based on climate normals, 266 m^3/day was estimated to recharge through the tailings and percolate through the tailings. Utilizing a factor of safety estimate of 1.1, the downstream receiving system treating tailings leachate was designed for a daily volume of 300 m^3/day.

After closure, any excess meteoric water seeping from the re-vegetated tailings area will be treated in a down-gradient**Engineered Wetland System**. The EW system proposed to treat any potentially contaminated, possibly acidic water passing through the covered and re-vegetated tailings management area after closure will consist of four cells in series:

- **Sedimentation Pond**
- **Successive Alkalinity Producing System (SAPS) Cell**
- **BCR Cell**
- **Aerobic Wetland Cell**

Figure 2shows the locations for the four EW system cells. Although water passing through the ET cover after closure is not expected to be as acidic or metal-contaminated as the water currently collected in the existing tailings pond, for very conservative design it has been assumed that it will be. Water from the EW system will be continuously discharged and will meet stringent new effluent criteria. This will be confirmed by the off-site pilot-scale testing of the EW system during the period when the Mine is being reactivated.

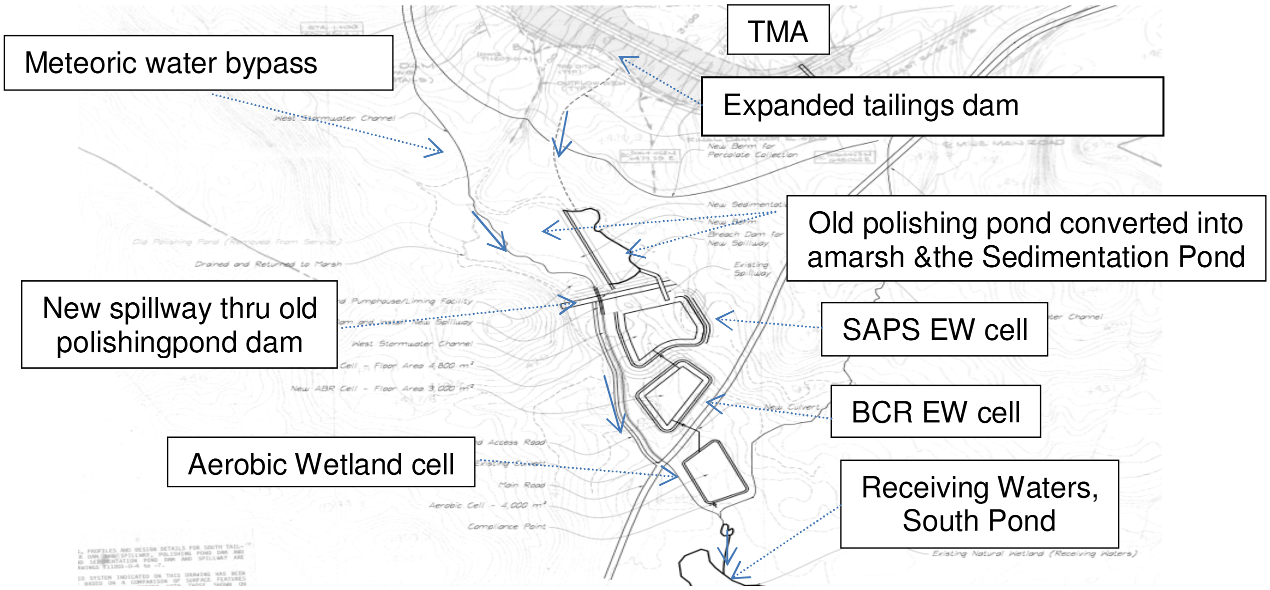

Figure 2: Location for the EW System at the Kearney Graphite Mine

The purpose of the 5.5 m deep first cell of the EW system, the**Sedimentation Pond** (which will be constructed after closure in a portion of the old polishing pond's footprint), will be to allow a portion of any ferrous iron in the water (which will be sourced from an anaerobic environment deep in the tailings above the dam) to oxidize to ferric iron and precipitate out as ferric oxyhydroxides(also carrying down part of any other dissolved metals in the water). This precipitate can be expected to settle out in the new 30,000 m^3Sedimentation Pond, which will have an average residence time of about 100 days at design flow rates.

The second cell of the EW System will be a **SAPS EW cell** and water from the Sedimentation Pond will flow into it via an existing channel and spillway. Should the water leaving the upstream Sedimentation Pond still contain any ferric iron and/orbe acidic, the SAPS's purpose will be to convert the ferric iron to ferrous iron while raising its pH to circum-neutral levels. The 4,700 m^2 surface area SAPS will consist of a one-meter deep surface layer of water; an underlying gravel lens; a layer of compost; and a lower layer of limestone gravel. Water will flow down through this EW cell and effluent from it will enter the next cell (the BCR) into its bottom without surfacing. The residence time for water in the limestone layer of the SAPS cell will be at least five days and sizing was determined using equations developed by Jage*et al*. (2001).

The next (third) cell of the EW system after the SAPS will be theanaerobic **Biochemical Reactor**. The purpose of the BCR will be to remove any residual dissolved metals in the water using biological sulphate reduction and other reactions. This 3,000 m^2 BCR will be a specialized, vertical sub-surface flow (VSSF) EW cell. Feedstock to it will flow by gravity from the SAPS in an upflow manner. In calculating the surface area of the BCR, two empirical formulae proposed by Gusek and Wildeman (1997) were considered. The BCR will involve several layers: an initial(lower) lensing layer of gravel; a layer ofcomposted biosolids mixed with sand and limestone; a layer of sand; and an overlying layer of deep water. The reactive media used in the substrates of the EW system's BCR are well-proven and characterized paper mill biosolids that have been demonstrated effective in other projects. As hydraulic considerations governed design, the amounts of these materials used will be sufficient for hundreds of years and no future replacements will be necessary.

For designing the BCR, it was important that several important requirements were met (Neculita*et al.*, 2007). These were: 1) having a near neutral pH in influent water (effected by the upstream SAPS cell); 2) having available carbon (active medium) from a suitable organic source (chipped and composted wood waste and paper mill biosolids); 3) providing a solid matrix onto which the SRB can establish suitable micro-environments (the sand and gravel support components of the substrate); 4) ensuring that an anaerobic environment will be present (again, caused by the upstream SAPS cell); 5) confirming that there was enough sulphate in the water being treated to ensure that the SRB in the BCR will be able to outcompete methanogens for available carbon (there is); and 6) providing a design that will physically retain the metal sulphides that will be produced (it will).The design of the BCR was based on an understanding of the microbial activity taking place, augmented by an understanding of aquatic chemistry and metal sulphidesolubilities. Although there are formulas that are important factors in designing aBCR, successful design also depends on experience, the type of substrate provided, and the engineering that is used to control water flow to reduce or eliminate plugging and short circuits. There is considerable "art" involved in the selection of BCR morphology, operating conditions, and substrate materials in order to ensure trouble-free, long term operations.

The final cell of the EW System will be a 4,000 m^2**aerobic wetland cell**, essentially an open, horizontal flow, CW basin used topolish the treated water after it passes through the upstream SAPS and BCR cells. Water will enter the aerobic wetland from the upstream BCR's effluent stoplog outlet structure. Effluent from the Aerobic Wetland will overflow via a stoplog control structure into an adjacent stormwater channel. The purpose of the Aerobic Wetlandwill be to remove any oxidizable materials (e.g., BOD, ammonia) remaining in the water being treated, either sourced from the original water infiltrating the ET cover, or entering the treatment train due to the breakdown of organic parts of substrates in the upstream SAPS and BCR cells.

The EW system is designed to operate 365 days per year regardless of ambient air temperatures. Visually, only the last cell will show traditional "wetland" morphology as it will be vegetated with transplanted harvested cattails taken from around the Mine site. The Sedimentation Pond will be just that, a deep pond. The operating parts of the two middle cells, the SAPS and the BCR, will be submerged under deep overlying water layers which will protect their microbial populations and prevent freezing from reaching them in winter. They will appear to be two ponds with emergent wetland vegetation around their peripheries and floating wetland vegetation in them. Unlike alternative mechanical wastewater treatment technologies which are capital and operationally intensive, and produce difficult-to-manage sludge by-products, the EW system will not do so. It will be relatively economic, will operate by itself, and will require only minimal care and attention after closure. In addition, it is designed so that over the longer term it can evolve into a completely un-attended natural wetland system.

Table 1 presents the Design Basis for the EW System. As mentioned, influent contaminant concentrations are based on worse case, existing tailings pond conditions which are not expected to occur after the completion of mining. However, they are assumed to ensure conservative design.

Table 1: Design Basis for the EW System

Parameter	Units	Influent to Sedimentation Pond	Sedimentation Pond Outlet	SAPS Outlet	BCR Outlet	Aerobic Wetland Effluent
pH	unitless	2.5	2.5	6.5	7.0	7.0
Acidity	mg/L as $CaCO_3$	150	150	<5	<5	<5
BOD	mg/L	5	5	15	30	<15
TSS	mg/L	20	5	20	30	<15
TP	µg/L	40	30	100	300	<300
Ammonia as N	mg/L	0.3	0.3	1.0	2.0	<0.02
Sulphate	mg/L	500	500	450	400	400
Al	mg/L	8	<1	<1	<1	<1
Alkalinity	mg/L as $CaCO_3$	3	3	~100	>100	>100
Co	µg/L	50	40	30	<1	<1
Cu	µg/L	30	25	20	<5	<5
Fe	mg/L	50	25	20	<0.03	<0.03
Mn	µg/L	3	3	3	3	3
Ni	µg/L	25	20	15	<10	<10
Zn	µg/L	400	350	<20	<20	<20

The technologies of the ET cover and cells of the EW System are fully proven, with successfully-operating examples in Canada, the United States and offshore.

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