APPENDIX 28

Wetland Treatment Memorandum

Technical Memorandum

Wetlands as a Post-closure Water Quality Mitigation Method
Eagle Gold Project, Yukon Territory
November 12, 2010
Stantec Consulting Ltd.
Prepared by: Jim Higgins, Ph.D., P.Eng.

SUMMARY

Stantec has substantial experience and capability in all aspects of industrial wastewater treatment, including its use for treating minewaters of all sorts, including acid rock drainage (ARD), neutral mine drainage (NMD), seepages, leachates, mill process waters, mine area stormwaters, sludges, and sanitary wastewaters associated with mine facilities. The Company can carry out assessments to evaluate the application and design of both conventional "active" physical-mechanical/chemical minewater treatment systems and natural treatment systems such as treatment wetlands based on "passive" treatment such as **constructed wetlands** (CWs) and 'semi-passive" treatment such as **engineered wetlands** (EWs).

All kinds of treatment systems will require some degree of long-term maintenance, although for passive natural ones such as CWs, maintenance may be minimal. Semi-passive minewater treatment systems such as limestone drains and EWs involve reactive media which can be "used up" during the treatment processes, and may need to be periodically replaced.

Stantec can provide a new type of semi-passive CW technology for minewater treatment involving advanced types of **engineered wetlands**, ones that allow the treatment of wastewaters containing even the most recalcitrant pollutants to very high levels of removal in treatment systems that are surprisingly small in surface area (often less than 1/10 the surface area of an equivalent CW), and can operate whatever the ambient air temperature. The EW ecotechnology is fully developed and proven, with over a hundred operating facilities using it for treating a wide variety of wastewaters including minewaters, municipal sewage, landfill leachates, biosolids and other liquid sludges, contaminated groundwaters, process waters, and glycol-contaminated stormwater runoff from cold weather aircraft de-icing operations.

EW-based wastewater treatment systems, called EW Systems, may involve primary and/or tertiary treatment steps in addition to the advanced secondary wastewater treatment of the EW cells *per se*, and are much more economic to build and operate than alternative mechanical wastewater treatment plants, and require very much less operator attention. The ecotechnology is acceptable for licensing in all jurisdictions.

EW Systems have much higher treatment efficiencies (often 5 – 30x) than CWs, use much less energy than alternative mechanical wastewater treatment plants (often as low as one-tenth as much), and can handle very much higher wastewater flow rates than can ordinary

CWs (up to ten of thousands of m^3/d). EW Systems allow the treatment of acidic and other mine drainage streams throughout summer and winter in more economic treatment systems; ones which require relatively little operator attention or maintenance, and which can easily and consistently meet stringent wastewater discharge criteria over extended periods. The following sections clarify the differences between CWs and EWs.

CONSTRUCTED WETLANDS

Modern constructed wetland technology was developed in the late 1970s and early 1980s. Many early CWs failed to achieve their designers' goals as layouts were primitive and proper engineering design principles were rarely followed. CW design evolved through several stages to rectify such limitations through the *kinds of wetland basin* (cell) types used (e.g. from ponds and artificial bogs to open water, marsh type kinds of CWs), in *morphology* (e.g. from small facilities with one or few, long irregularly shaped cells to the current multiple train, multiple rectilinear cell, low aspect ratio systems), in the *volumes of water* that they could handle (e.g. from relatively low flow rates to thousands of cubic metres per day), in *sizing methods* used (i.e., from early empirical relationships based on hydraulic and/or contaminant loadings to modern methods based on reaction kinetics), and in *engineering design* (from *ad hoc* designs to the use of formal civil and chemical design engineering techniques as developed). The technology of CWs for municipal and industrial wastewater treatment is now mature and there are tens of thousands of them in operation around the world.

Constructed wetlands usually consist of a number of individual cells (artificially-constructed basins) connected in series or parallel and surrounded by berms (dykes) of earth, rock or other materials. They contain structures (concrete control structures, weirs, separators) to ensure good hydraulic dispersion, level and rate control, and collection. For some, integral ponds and forebays may be involved, depending on the type and application. With many CWs, vegetation is specifically chosen for effectiveness with certain pollutants.

With sub-surface flow (SSF) CWs, there is no open water and pollutant removal is via a porous matrix (substrate). Although wetland vegetation may be apparent in some SSF wetlands, their surfaces are usually dry. Generally, SSF wetland cells are filled with beds of rock, gravel, or other kinds of substrates. SSF wetlands are usually much smaller in surface area than alternative open water wetlands (usually called free water surface, FWS, wetlands) for the same levels of pollutant removal, and can tolerate higher loadings. SSF wetlands are used where the wastewater being treated is highly contaminated, acidic or odorous; where a higher degree of freeze protection is desired; where the attraction of wildlife may be undesirable; and/or where ample, economic supplies of suitable substrate material are readily available.

Both largely aerobic and largely anaerobic versions of SSF CWs are available and these may be used to treat minewaters, either on their own or as polishing unit processes located after active mechanical minewater treatment plants.

In metal mine water, the removal of arsenic varies from 54% (OMA, 2005) in CWs to 99% in EWs. Most of the arsenic that is retained in the system is retained in the gravel and only a limited amount is taken up by plants. If the system is designed with hyperaccumulator plants (plant that are capable of accumulating more than 1% of their dry weight) a higher percent of removal can be expected. Stantec and its associate, Nature Works Remediation (Nature Works) are world leaders in biological technologies for removing arsenic from wastewaters.

While constructed wetlands have been shown to remove selenium by reduction to insoluble forms which are then deposited in sediments or accumulation in plants, when the source of water is the municipal waste water or agricultural run-offs, the removal rate of selenium has not been outstanding or consistent. Removal of selenium in minewaters using CWs has been reported successfully at several sites with an effectiveness that varies between 50% – 60% (Hoover, et al., 1998). Selenium removal is thought to be related to reduction to insoluble forms that are deposited (trapped) in sediments, plant selenium uptake and sequestration into plant tissues or by biological volatilization of plants. Nature Works has access to proprietary EW-based biotechnology for removing selenium from minewaters to 99% or greater.

ENGINEERED WETLANDS

Engineered wetlands (EWs) are advanced kinds of CWs in which process and/or operating conditions are more actively manipulated and/or controlled than in ordinary constructed wetlands. Constructed wetlands may be “engineered” in many ways. For example, influent streams may be varied in flow rate or periodically turned off (reciprocating or pulse flow); effluents from various points in a wetland system may be recycled to other points, ordinary substrates may be replaced with special ones having specific qualities (e.g. the ability to permanently chemically adsorb certain pollutants from wastewaters passing through them); things may be added to them (e.g. heat, chemicals, air); and/or wetland vegetation may be selected for its phytoremediating properties.

The removal of many pollutants in a treatment wetland is dependent on microbially-mediated aerobic transformations. Most of the needed oxygen for such reactions is normally supplied by wetland plants which “pump” air to microbes in their root zones. This limits the degree to which aerobic reactions such as nitrification (the biological conversion of ammonia to nitrate) can occur. Ammonia removals of from 30 to 50% are typical with ordinary (i.e., not engineered) constructed wetlands. Oxygen availability also limits the thickness of SSF CW substrates to the maximum that roots can penetrate (so also reduces the potential for passive heat retention, since thicker substrates would allow better heat retention). One way to overcome this limitation is to add air to the wetland cells. This may be accomplished by placing *mechanical aerators* in bays or open areas, or by using *submerged perforated or diffuser piping* through which air is introduced into the water or under the substrates in wetland cells. One kind of well proven, advanced EW is the **aerated vertical sub-surface flow** (VSSF) type where air (supplied by small blowers) is introduced under the gravel substrate, countercurrent to the downward percolating wastewater. Aerated wetlands can achieve high levels of removal of those contaminants susceptible to aerobic degradation (e.g. >95% for organics and 99% or more for ammonia).

An aerated SSF EW can be operated either with downflowing wastewater applied at or just below the substrate surface moving countercurrent to uprising air bubbles (i.e., **VSSF**) or with the wastewater flowing horizontally (i.e., **HSSF**) through a wetland bed in which the air bubbles rise. The result is greatly enhanced microbially-mediated oxidation. The vast superiority of this aerated SSF EW technology in removing oxidizable contaminants from wastewaters of all sorts has been demonstrated in a variety of pilot-, demonstration- and full-scale aerated SSF EWs and the technology may now be regarded as fully proven. Because the conversion of oxidizable contaminants is often rate limiting in an ordinary CW, the addition of air can sometimes dramatically reduce the size and capital cost of the system. The Aerated SSF EW technology is patented by a Stantec associate, and Stantec has rights for is use in Canada, the United States and elsewhere.

Sulphate Reduction

Mine drainage and other mining-impacted wastewater streams often contain high concentrations of sulphate, and often these, as well as dissolved metals and metalloids, can be removed by reduction to sulphides. Sulphate reduction is a biological reaction, and depends on anaerobic heterotrophic bacteria called sulphate-reducing bacteria (SRB). SRB need dissolved sulphate for their metabolism, and sources of organic carbon for biomass and energy.

The required carbonaceous material (active medium) may be provided in a liquid form (e.g. as part of solutions containing alcohols, aldehydes and/or other liquid organics) along with a wastewater being treated. Alternatively (and more usually), the active medium is provided in a solid form, forming part of a substrate matrix in vessel or basin in which the unit operation is carried out. This matrix provides a habitat for fermentative microbial populations (i.e., acid-producing bacteria [APB]), iron-reducing bacteria [IRB], iron-oxidizing bacteria [IOB], as well as SRB). The APB metabolize complex and simple organics in the carbonaceous material by a variety of anaerobic fermentation and respiration reactions, breaking downing these organic contaminants to produce compounds such as ethanol and acetate, which can be further metabolized by the SRB. There are many kinds of SRB, some of which are *Desulforvibro* species. Most SRB do not flourish at pH below 5.5 and prefer higher levels of alkalinity, with PH 6.6 being optimal, although specialty kinds can be grown to operate at lower pH.

The basic equation for the SRB-mediated sulphate reduction can be represented by:

$$2\,CH_2O \;+\; SO_4^{=} \;+\; 2\,H^+ \;\rightarrow\; H_2S \;+\; 2\,H_2CO_3^- \qquad (1)$$

where:

CH_2O represents a carbon source.

The hydrogen sulphide reacts with many dissolved metals and metalloids to precipitate them in insoluble forms. Indeed, one of the most important roles of the sulphate reduction process is in the biological removal of dissolved metals and metalloids as insoluble, precipitated sulphides as follows (illustrated for divalent cations, e.g., Zn, Cd, Hg, Ni,):

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

where:

Me represents a typical metal.

It is noted that two moles of alkalinity and one mole of acidity result from the reactions illustrated above, so the combined action of the SRB is to raise alkalinity and buffer the solution. Many metals and metalloids which form oxyanions in water (e.g. Mo, As) can also be removed as sulphides using sulphate reduction via similar kinds of reactions. Metals and metalloids which do not form sulphides under aquatic conditions (e.g. Cr, U) form oxides and hydroxides which precipitate like the sulphides during the process. Stantec and Nature Works have unique, proprietary EW-based technologies for removing many of these metals to very low levels.

Additionally, during sulphate reduction unit operations, chemically- and microbially-mediated iron reduction and oxidation reactions form compounds which complex with many contaminants, removing them from the wastewater as precipitates in the bed. (The substrate beds also filter out particulate metals and metalloids.) Other anaerobic processes (e.g. de-nitrification) may also occur in the reducing conditions of a sulphate reduction unit operation’s substrate bed.

Biochemical Reactors

SRB occur naturally in the sediments and other anoxic zones of lakes, streams and wetlands. In 1990, it was suggested that focusing the sulphate reduction mechanism might lead to a better method to treat mine drainage in a relatively passive system, especially where they contain dissolved metals and metalloids as well as other wastewater contaminants susceptible to removal under anaerobic conditions. This led to the development of a new kind of treatment system called an **anaerobic biochemical reactor** (BCR, sometimes also called an anaerobic bioreactor, ABR) in which SRB populations and activity are maximized using an anthropogenically-provided organic medium to promote bacterial growth.

BCRs, therefore, are basically specialty units for carrying out sulphate reduction and other anoxic reactions, and can be used for removing from wastewaters dissolved metals and metalloids at concentrations from thousands of ppm to a few ppb, or even lower. While sulphate reduction unit processes can be “expressed” (used) as parts of active (mechanical) wastewater treatment plants, permeable reactive barriers (PRBs), or in-ground, stand alone bioreactors, BCRs are most commonly expressed as EW cells. The latter are usually multi-layer units, made up of substrates consisting of horizontal layers of rock, sand, gravel (to improve permeability), limestone (to adjust pH), and the carbon source active material. Anoxic

BCRs cells for de-nitrification can be located upstream of anaerobic sulphate reduction cells where minewaters have high concentrations of nitrate and nitrite.

As may be seen from Equation 1 above, an adequate supply of sulphate is necessary in the wastewater being treated for the reactions to work. The carbon source can be any type of carbonaceous material (e.g., sawdust, wood chips, manure) submerged in the bioreactor's water, an added soluble carbon-based liquid material (e.g., methanol), and/or a microbially-available carbonaceous material such as compost or biosolids. Stantec and Nature Works tend to use pulp and paper mill biosolids and wood waste in their BCRs.

The organic material in a biochemical reactor not only serves as a carbon source but also physically retains precipitated metal sulphides and other precipitates. As is discussed in more detail below, if a minewater contains any significant amounts of dissolved metals and metalloids, after some period, BCR EW cells may have to be cleaned out and the carbonaceous material replaced. (Hence they are correctly referred to as "semi-passive' rather than fully "passive'.) The removed material from a BCR may be disposed of in a landfill or, where a metal of economic value is involved (e.g. Zn, Ni, U), sent for recycle. Cleaning out and replacing the substrate in a BCR is not onerous and its cost is trivial compared to the cost of operating an alternative mechanical wastewater treatment plant over the same period.

Like all microbes, SRB are sensitive to temperature and reaction rates are lower where cold water is involved. However, unlike open water algae, SRB are prokaryotes and are less affected by cold than eukaryotes. Also, they consist of varying populations of bacteria, some of which are cold-adapted and may grow in such increased numbers in colder water so as to compensate for their reduced activities at the lower temperatures. Some SRB can thrive down to temperatures as low as 2°C. Stantec and Nature Works possess special SRB formulations for a variety of situations (e.g. specific metals to be removed, low temperature situations) that they use to inoculate their BCRs to ensure superior operations.

Minewaters and other wastewaters containing dissolved metals and/or metalloids can be fed into BCRs using distributors buried in or below one of the substrate layers or, in warmer climes for downflow operation, by surface distributors or sprayers. In colder climates, buried inlet and outlet distributors can be used to direct flow up through the cells, and the unit is often buried or has a deep layer of water placed over it for freeze protection.

Successive Alkalinity Producing Systems

The SRB in BCRs require alkaline conditions for optimum growth. However many minewaters are acidic in nature (e.g. ARD). Such streams must be neutralized before they can be fed to BCRs. It is common practice at mines to use limestone to reduce the pH of ARD streams. However, if the minewater contains any significant concentrations of iron (and many do) this material quickly "armours" (its particles become coated with ochre) and of limited further utility. An alternative technology tried for acid reduction was that of anoxic limestone drains (buried beds of limestone) but these proved to be useful only in certain circumstances.

Modern practice is to use **Successive Alkalinity Producing Systems** (SAPSs). These are in-ground, semi-passive bioreactors that neutralize acidity while converting ferric iron into ferrous iron. They consist of layers of organics and limestone which are expressed as one or several EW cells in a minewater treatment system. Stantec is a leader in SAPS technology.

ENGINEERED WETLAND SYSTEMS

SSF EWs such as Aerated SSF Cells, BCRs and SAPS are usually used as the biological **secondary treatment** step of **Engineered Wetland Systems** (EW Systems). In addition to their secondary treatment EW parts, EW Systems also may include primary treatment by physical and/or chemical methods (e.g. upstream sedimentation ponds) and **tertiary treatment** by chemical or other biological methods (e.g. advanced phosphorus removal technologies). Stantec has, in conjunction with its associates, developed advanced methods for removing most minewater contaminants successfully and consistently over long periods down to very low levels meeting even the most stringent regulatory guidelines. One kind uses steel slag in place of part of the gravel in an EW cell. Another uses ferric chloride-dosed fluid bed reactors as a tertiary treatment step. Either can reduce minewater phosphorus concentrations to very low levels (<0.05 mg TP/L).

As mentioned, BCRs can readily be expressed as cells of engineered wetland systems; indeed their effectiveness is optimized by doing so. This is because all BCRs leach various materials from the organic and other components of their substrate beds (e.g. suspended solids, ammonia, nitrates, BOD), and it is essential to follow them in any type of treatment system by one or more aerobic unit operations downstream of the BCR cell(s) to remove these pollutants. The state-of-the art BCR-based EW technology used by Stantec was developed by its associate, Nature Works, which is one of the few companies that has extensive, hands-on experience in successfully cleaning up both ARD and neutral metal drainage (NMD) streams, containing them using BCR-based wetland treatment systems. With such EW Systems, ARD and NMD streams containing hundreds to thousands of mg/L (ppm) of dissolved metals (e.g. Ni, Zn, Cd, Mo, Cr) and metalloids (e.g. As, Se) can be cleaned up, removing these contaminants down to a few ppm or even µg/L (ppb) levels after treatment. Stantec and Nature Works have now successfully extended this EW ecotechnology to allow them to remediate minewaters and other wastewaters containing only a few ppm or tens/hundreds of ppb, reducing contaminants (e.g. Cu, As, Mo, Cr) down to low ppb levels and even ppt levels.

EXAMPLES OF ENGINEERED WETLANDS IN USE

Nature Works now operates a field-scale BCR-based EW system at Teck's lead zinc smelter in Trail, BC and has designed and started up full-scale facilities at the Yankee Girl mine in BC and the Park City mine in Utah. Stantec and Nature Works are/have been involved in a number of bench-, pilot-, demonstration- and full-scale field BCR-based EW projects. These include ones for removing As, Cd, Cr, Cu, Mo, Ni, Pb, Sb, Se and Zn at concentrations ranging from thousands of ppm down to low ppm levels, and from low ppm/high ppb levels down to low ppb and even ppt levels. Nature Works is working with Stantec on upgrading the Trail BC BCR-based EW System and on several other similar systems, including those for Newmont's Golden Giant Mine (Mo-contaminated tailings pond water), Hydro Quebec (utility pole storage yard runoff contaminated with copper chrome arsenate wood preservative), Ontario Graphite (tailings area runoff), and Vale (acid rock and neutral mine drainages). Nature Works' Trail BCR-based EW system (see Figure 1), which has operated summer and winter for the past six years (and during summers for several years before that), involves two BCR cells followed by three SSF wetland cells and a pond wetland cell. It is designed to treat highly metal-contaminated landfill leachate and arsenic disposal cell leachate. Effluent is spay-irrigated on a hybrid poplar plantation. This system removes dissolved zinc (up to thousands of mg/L), arsenic (up to thousands of mg/L) and cadmium (up to hundreds of mg/L) reducing their concentrations to a few mg/L (Zn) and much less than 1 mg/L (As, Cd). Sulphate ions present at the input at concentrations of up to 1,600 mg/L are reduced by about 50%. Originally designed as a demonstration-scale system to treat 20 to 25% of the smelter's leachate, it has proven to be robust enough to treat up to 125 m^3/d, and is now considered by Teck to be a back-up treatment option to their mechanical wastewater treatment plant.

Anaerobic biochemical reactor-based systems are used at a number of mines, landfills and other locations in the US, Canada and off-shore, and can now be regarded as a proven technology**.** There are a number of pilot-, demonstration- and full-scale BCR-based dissolved metal treatment systems in operation/planned, including ones at:

- West Fork Mine
- July 14 Pennsylvania Mine
- Fran Mine
- Golinsky Mine
- Alfred College Wetland Test Unit
- Fleming College Wetland Test Unit
- Lutrell Repository
- Lilly Orphan Boy
- Laval Quebec
- Park City Mine
- Trail Lead Zinc Smelter
- Yankee Girl Mine
- Golden Giant Mine
- Surething
- Fabius Coal Mine
- Wheal Jane Mine
- Haile Mine
- Elizabeth Copper Mine
- Peerless Jenny King Mine
- Burleigh Tunnel
- MSF Waste Rock
- Forest Queen

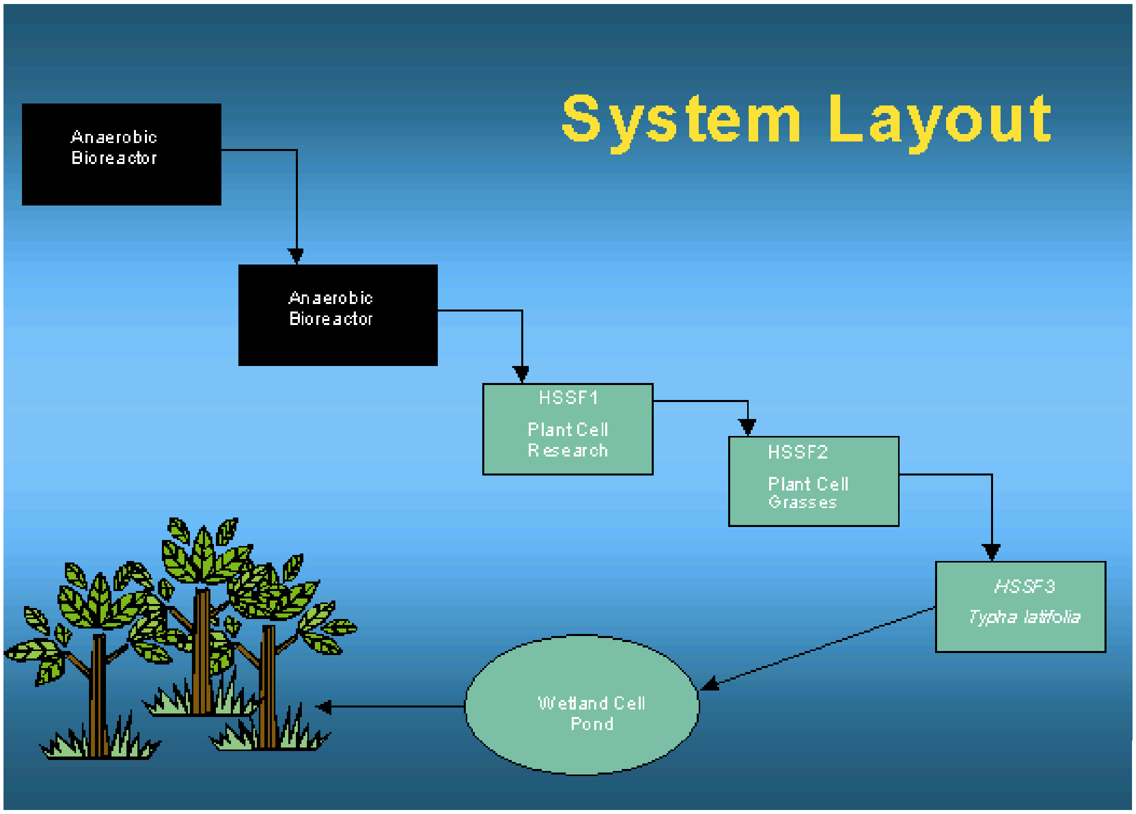

Figure 1: Diagram showing layout of final configuration of complete system installed in Trail BC for treatment of high concentrations of heavy metal contaminated leachate

For example, the full-scale BCR-based system at West Fork on the Black River in Missouri, USA is designed to treat 1,200 gpm of lead-contaminated minewater and consists of two BCRs (0.2 ha each), an aerobic rock filter (0.6 ha), an aerated pond (0.8 ha) and a polishing/settling pond (0.3 ha). It has been operating year round since 1996 and used sawdust, limestone, manure and hay in its 2 m thick substrate. It reduces lead from about 0.6 mg/L in the influent minewater down to meet NPDES effluent criteria of 0.027 to 0.05 mg/L.

Sometimes an EW system can be constructed downstream of an active treatment plant. In other cases, it is an alternative to an expensive, labour intensive, and often unreliable mechanical minewater treatment plant when it is used as the sole treatment system at a mine.

Semi-passive EW systems have another major advantage for minewater treatment that cannot be matched by mechanical treatment plants. They can be designed so that as minewater contaminant levels decline over time (as they usually do), they can be allowed to evolve into a fully passive constructed wetlands. And over much longer periods of time, such constructed wetlands can be allowed to evolve into natural wetlands, allowing full "walk-away" closure of the mine site.

NUTRIENT TREATMENT

EWs can be designed to remove nitrogen and phosphorus, as well as metals and metalloids from minewater and other wastewaters. Aerobic treatment cells (where air is introduced to the cell) can achieve high levels (99%) of ammonia removal through conversion to nitrate. Anoxic BCR cells for denitrification can be located upstream of anaerobic sulphate reduction cells where minewaters have high concentrations of nitrate and nitrite, resulting in the release of nitrogen gas to the atmosphere. This can remove at least 90% of the nitrate.

The EW system can include tertiary treatment by chemical or other biological methods for advanced phosphorus removal, which can remove more than 50% of the phosphorus. One kind uses steel slag in place of part of the gravel in an EW cell. Another uses ferric chloride-dosed fluid bed reactors. Either can reduce minewater phosphorus concentrations to very low levels (<0.05 mg P/L).

MAINTENANCE OF ENGINEERED AND CONSTRUCTED WETLANDS

As mentioned, all types of minewater treatment systems require some degree of maintenance, although with CWs and EWs the scope of maintenance will be trivial compared to that required for any kind of active treatment plant.

Well-designed CWs should not require any major maintenance over very long periods (many decades), other than periodic checking to ensure that outside environmental impacts (e.g., beavers, storm damage to berms) have not adversely affected hydraulics, vegetation or structures in any major way.

EW substrates may be used up over time and, where very high concentrations of influent minewater contaminants are involved (thousands of mg/L), may have to be replaced after some pre-defined period (i.e., 10 to 20 years). However, where much more dilute minewaters are involved (as is expected at Eagle Gold), natural replacement of the initially-supplied active media (e.g., biosolids) by senescent microbes and dead vegetation may mean that the substrate may never need replacement.

The other aspects which differentiate an EW from a CW (e.g. air blowers, pumps) may be operated for some pre-defined period after closure (see below) then turned off, allowing the EW to then evolve into a CW. And over the longest periods, so long as a source of minewater continues to flow, such a CW can be allowed to further evolve into a natural wetland requiring no further attention, a full "walk-away" situation.

For Eagle Creek, if the leach bed surface is provided with a non-barrier cover after closure (e.g. an Evapotranspiration Cover), an EW system should be considered and operated only for a relatively short period (say 5 – 10 years) before being allowed to evolve into a CW system to treat the relatively low concentration leachate. However, if a more impermeable cover is used (e.g. a multi-layer earthen barrier-type cover), then the engineered wetland mode will be needed longer term (say 10 – 20 years) to treat the resulting much more concentrated (albeit lower volume) leachate. (This is because no barrier type cover of any sort will ever prevent all meteoric water infiltration through a covered material, even on the short-term.) It too can then be allowed to evolve into a CW and eventually a natural treatment wetland.

REFERENCES

Arias C.A., Brix H. (2004). Phosphorus removal in constructed wetlands: Can suitable alternative media be identified? Liénard, A., Burnett, H. (eds.). Proceedings of the 9th International Conference on Wetland Systems for Water Pollution Control, 26-30 September 2004; IWA Publishing: Avignon, France, pp. 655-661.

Behrends L., Sikora F., Coonrod H., Bailey E., Bulls M. (1996). Reciprocating subsurface-flow constructed wetlands for removing ammonia, nitrate, and chemical oxygen demand: Potential for treating domestic, industrial, and agricultural wastewaters. Proceedings of WEFTEC '96; the 69th Annual Conference and Exposition of the Water Environment Federation; Water Environment Federation: Alexandria, Virginia, United States.

Brix H. (1999). How 'green' are aquaculture, constructed wetlands and conventional wastewater treatment systems? Water Science and Technology 40(3), 45-50.

Duncan W, Mates, A, Gould, D, Goodazi. (2004). Multistage biological treatment system for removal of heavy metal contaminants. In Waster processing and Recycling in Mineral and Metallurgical Industries, 469-484.

Gisvold B., Odegaard H., Follesdal M. (2000). Enhanced Removal of Ammonium by Combined Nitrification/Adsorption in Expanded Clay Aggregate Filters. Water Science and Technology 41(4-5), 409-416.

Johansson L. (1997). Use of LECA (Light Expanded Clay Aggregates) for the removal of phosphorus from wastewater. Water Science and Technology 35(5), 87-94.

Johns M., Lesikar B.J., Kenimer A.L., Weaver R.W. (1998). Nitrogen fate in a subsurface flow constructed wetland for on-site wastewater treatment. Proceedings of the 8th National Symposium on Individual and Small Community Sewage Systems; American Society of Agricultural Engineers: Orlando, Florida, United States, pp. 237-246.

Kadlec, R. and S. Wallace. (2009). Treatment Wetlands. Second Edition, CRC Press.

Kassenga G., Pardue J.H., Blair S., Ferraro T. (2003). Treatment of chlorinated volatile organic compounds in upflow wetland mesocosms. Ecological Engineering 19 305-323.

Noller B., Woods P., Ross, B. (1994). Case studies of wetland filtration of mine waste water in constructed and naturally systems wetlands in Northern Australia. Water, Science and Technology.29 (4): 257-265.

Ontario Mining Association. (2005). Towards greener footprints: Placer Dome's Campbell Mine Employs constructed wetland for effluent treatment, the Ontario Mining Association Reports on Significant Environmental Achievement, Foubert A (ed.)

Sun G., Gray K.R., Biddlestone A.J., Cooper D.J. (1999). Treatment of agricultural wastewater in a combined tidal flow: Downflow reed bed system. Water Science and Technology 40(3), 139-146.

Wallace S.D. (2001). Patent: System for removing pollutants from water. Minnesota, United States 6,200,469 B1.