Appendix 2.6D
Permeable Reactive Barrier Treatment

TECHNICAL MEMORANDUM

To: **Ryan Todd (New Gold)** **Date:** **February 18, 2013**
Cc: **Keith Ferguson**
From: **Sung-Wook Jeen & Alan Martin** **Project #:** **A302-3**
Subject: **Blackwater Gold Project – Considerations for Subsurface Passive Treatment using Permeable Reactive Barriers and Vertical Flow Biological Rectors**

1. Introduction

This memorandum provides an evaluation of subsurface passive treatment systems to be considered as part of mitigation planning for the proposed tailings storage facility (TSF) at New Gold's Blackwater Project. Specifically, information is provided in support of permeable reactive barriers and vertical flow biological rectors as a means to potentially treat seepages from the TSF.

In mine-related settings, passive treatment systems are often designed to neutralize acidity and remove metals in drainage waters. Such systems do not require continuous chemical inputs because they are sustained by naturally-occurring chemical and biological processes (Hedin *et al*., 1994). In general, passive treatment systems are best suited for the treatment of waters with low acidity (<800 mg $CaCO_3$/L), low flow rates (<50 L/s) and therefore low acidity loads, where the key chemical outcomes are low metal concentrations and circumneutral pH. Over the past years, a variety of passive treatment systems have been developed, and there now exists a large body of literature with respect to the effectiveness of passive treatment systems for acidic and neutral-pH mine drainage (*e.g*., Watzlaf *et al*., 2004; Johnson and Hallberg, 2005; Skousen and Ziemkiewicz, 2005; Taylor *et al*., 2005; Rose, 2010). Although the majority of the literature addresses the treatment of coal mine drainages, the data are also relevant for the treatment of drainages for metal mines (Gusek and Figueroa, 2009).

Considerations for the utility of passive treatment at the Blackwater Gold project are based on three fundamental criteria:

- Availability of proven and demonstrable techniques for effluent treatment;
- Robustness and longevity; and
- Ability to operate with minimal intervention over the long-term.

It is expected that seepages from the TSF at New Gold's Blackwater Project will maintain circumneutral pH, with elevated concentrations of Zn, Cd, and sulfate, and seepage flow rates ranging from 10 to 50 L/s. Based on the criteria above, and well as on the anticipated mine water conditions at the Blackwater Gold Mine, two passive treatment systems are considered in this memo: 1) permeable reactive barriers (PRBs); and 2) vertical flow biological reactors (VFBRs).

In overview, passive treatment systems such as PRBs and VFBRs are designed to provide a sequence of chemical reactions or biological processes that convert mobilized metals and complexes contained in the leachate into immobile or inert compounds. In this regard, passive treatment systems require consideration of several variables, including: influent water chemistry, flow rate, volumetrics of the treatment cells, anticipated residence times, and effluent water quality targets. It is recommended that the ultimate configuration should rely on the results of laboratory and/or pilot-scale testing.

The purpose of this memorandum is to provide a basis from which to assess the potential applicability of PRBs and VFBRs at the Blackwater Gold Project. In the sections to follow, each of these system types are described with respect to key several variables, including:

- Metal removal mechanisms/removal rates;
- Effectiveness/longevity;
- General design/construction;
- Flow capacity; and
- Cost.

2. Passive Treatment Options

2.1 Permeable Reactive Barriers (PRBs)

In the mining sector, PRBs are typically designed to intercept plumes of mine-influenced groundwater that show elevated concentrations of trace elements and often low pH (Figure 1). For the Blackwater Project, it is anticipated that seepages from the TSF will be circumneutral, and therefore treatment will be focused on the removal of trace elements of concern (*e.g.*, Cd, Zn) and possibly sulfate. The use of PRBs involves installing an appropriate reactive material into the aquifer, so that contaminated water flows through the reactive zone. The reactive material induces chemical transformations that remove the contaminants through physical, chemical, or biological processes (IRTC, 2005). In particular, PRBs containing organic carbon (*e.g.*, sawdust, spent brewing grain, compost, and peat) promote the removal of dissolved constituents in mine-drainages under natural groundwater flow conditions by creating conditions suitable for microbially-mediated sulfate reduction (Eqn. 1) and the subsequent precipitation of metal sulfide minerals (Eqn. 2) (Benner *et al.*, 1997; Blowes *et al.*, 2000; Guha and Bhargava, 2005):

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

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

where CH_2O represents an organic carbon substrate, Me^{2+} is a divalent metal (such as Fe, Cd or Zn), and MeS is a sparingly soluble amorphous metal sulfide (*e.g.*, FeS_2, CdS, ZnS). Because sulfate reduction generally occurs in excess compared to the amount of metal sulfide precipitation that occurs, and given that sulfate reduction liberates bicarbonate alkalinity at neutral pH, the net result is generally a decrease in the overall acidity of the treated water. Although the amelioration of acidity is not necessarily a prerequisite function for a PRB at the Blackwater site, metal removal by adsorption onto organic carbon and by metal hydroxide/carbonate precipitation may be enhanced due to alkaline conditions in the PRB (Gibert *et al.*, 2005). In most cases, sulfate reduction and subsequent metal sulfide precipitation should provide sufficient attenuation to achieve water quality targets for elements such as Cd and Zn. Sulfate removal rates strongly depend on the organic carbon source, but for most forms of organic carbon, the sulfate removal rate is typically 100 mg/L per day of residence time (David Blowes, personal communication).

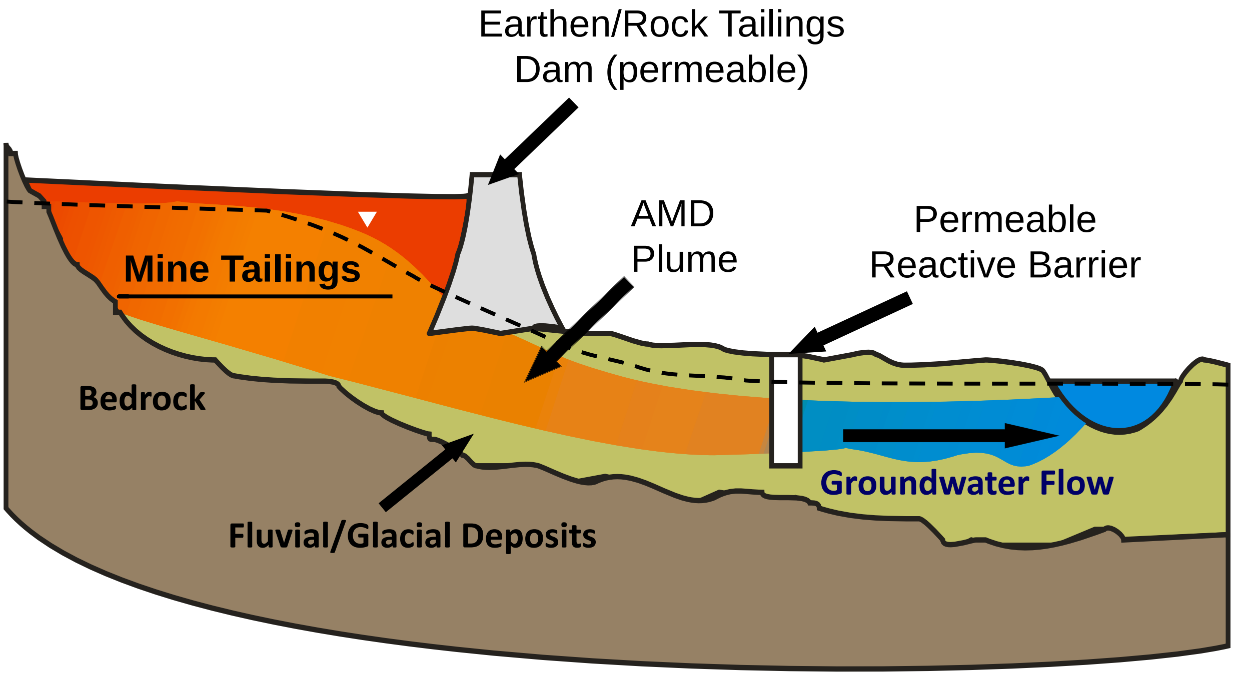

Figure 1: **Schematic of a permeable reactive barrier (PRB).**

Laboratory, pilot and full-scale trials have demonstrated the potential for treating mine drainages using PRBs containing organic carbon. As a working example, a full-scale PRB for the removal of mine-related contaminants was installed at the Nickel Rim Mine near Sudbury, Ontario (Benner *et al.*, 1997, 1999). The PRB was successful in treating mine-influenced water showing slightly acidic pH ($5<pH<6$) and elevated concentrations of sulfate (1000-4000 mg/L), Fe (200-1000 mg/L) and Ni (up to 30 mg/L) over a period of 5 years. A pilot-scale PRB to remediate sulfate-rich groundwater containing elevated Cu, Ni, Zn, Cd, and Co was also installed in Vancouver, British Columbia (Ludwig *et al*., 2002). The reactive material was compost-based, and was installed in a guar-gum slurry trench. The trench dimensions were 10 m in width, 6.7 m in depth and approximately 2.5 m in thickness in the general direction of groundwater flow. Cd concentrations decreased from 15.3 μg/L to 0.2 μg/L while Zn concentrations decreased from values in excess of 2 mg/L to <0.1 mg/L. Groundwater velocity estimates were as high as 1 m/day (total flow ≅ 0.3 L/s) and the input concentration of sulfate was approximately 1000 mg/L. A full-scale PRB was constructed at the same site between November 2000 and February 2001. It is the largest organic-based PRB yet installed and is approximately 400 m in width, as much as 15 m in depth, and 2.5 to 5 m in thickness (Mountjoy and Blowes, 2002).

In addition to compost-based PRBs, granular zero-valent iron (ZVI)-based PRBs have also been proven to be highly effective for the removal of heavy metals through reaction with ZVI surface corrosion products (Blowes *et al.,* 2000; Wilkin and McNeil, 2003). ZVI surface corrosion products reported to form include ferrous hydroxides, Fe(II/III) (hydr)oxides (*e.g.*, green rust and magnetite) and ferric (hydr)oxides. Mixed Fe(II/III) (hydr)oxides such as green rust have been shown to be highly effective in removing heavy metals from solution (Wilkin and McNeil, 2003).

Recently, PRBs containing both organic carbon and ZVI have gained attention (Lindsay *et al.*, 2008; Guo and Blowes, 2009). ZVI is a strong reductant and, when mixed with organic carbon, sustains conditions suitable for growth and activity of sulfate reducing bacteria (SRB). This is partly due to the acid consuming nature of the reduction of water during anaerobic corrosion of ZVI, which can generate neutral or alkaline conditions (preferred by SRB). Eqn. 3 describes the anaerobic corrosion of ZVI:

$$Fe^0 + 2H_2O \rightarrow Fe^{2+} + H_2 + 2OH^- \qquad (3)$$

Hydrogen gas released in this reaction may be used by SRB in addition to organic carbon as an electron donor (Lovley and Goodwin, 1988). The surfaces of commercially produced granular iron materials are moderately corroded. These iron oxide surfaces are well suited for the adsorption of metals from mine waters (Wilkin and McNeil, 2003). Dissolved metals may also precipitate or co-precipitate with corrosion products that form on the surfaces of the ZVI. As a result of these properties, mixtures of organic carbon and ZVI may offer improved potential for the removal of dissolved metals from water, over use of organic carbon alone. In 2002, a pilot-scale PRB system containing a combination organic carbon and ZVI was installed at a former fertilizer plant in Charleston, South Carolina (Ludwig *et al.*, 2009). Performance monitoring showed effective treatment of As, Pb, Cd, Zn, and Ni from concentrations as high as 206 mg/L, 2.02 mg/L, 0.32 mg/L, 1,060 mg/L, and 2.12 mg/L, respectively, entering the PRB, to average concentrations of <0.03 mg/L, < 0.003 mg/L, < 0.001 mg/L, < 0.23 mg/L, and <0.003 mg/L, respectively, within the PRB. Effective treatment of As (from ~20 mg/L to < 0.01 mg/L) by another pilot-scale PRB combining organic carbon and ZVI has been demonstrated at a gold mine in Ontario, Canada (Bain *et al.*, 2007).

The economics of PRBs are tied to the longevity of the media and long-term hydraulic capture in the system. Longevity of reactive barriers may be limited by the chemical characteristics of the barrier, including the total mass of reactive material and the rate of reaction within the barrier. Potential processes leading to decreased reaction rates include consumption of reactive material, declining reactive surface area resulting from the precipitation of secondary minerals on reactive surfaces, clogging and development of preferential flow paths (Blowes *et al.*, 2000). Barrier life may also be limited by physical changes to the barrier, including decreases in porosity and permeability. In general, the longevity of PRBs is anticipated to be 15-20 years (IRTC, 2011). Given that PRBs are contained within the subsurface environment, they are minimally influenced by atmospheric temperature, and have been shown to function well in cold-interior climates (e.g., (Benner *et al*., 1997).

2.2 Vertical Flow Biological Reactors (VFBRs)

Vertical flow biological reactors (VFBRs) are operated on the same basic principles as PRBs in terms of biochemical reaction mechanisms. Differences relate to configuration, engineering and water management (Figure 2). A vertical flow biological reactor is a particular design of a general class of passive treatment systems similar to vertical flow wetlands (VFWs) or reducing and alkalinity producing systems (RAPSs). A vertical flow biological reactor is constructed in a geomembrane-lined facility and typically constructed with the following structure, from the bottom upward in the direction of flow:

- Foundation, which may comprise an excavation into natural substrates;
- Geo-membrane liner to provide containment and minimize downward seepage;
- Influent distribution system (perforated pipe) laid in gravel matrix;
- Reactive substrate layer, comprising permeable matrix with reactive amendment (*e.g.*, sawdust, spent brewing grain, compost, peat, ZVI);
- Effluent collection system, consisting of perforated pipe; and
- Vegetative soil cover.

Post aeration prior to discharge to the receiving environment may also be required to oxygenate the effluent and oxidize parameters that may be elevated in the suboxic outlet flow (*e.g.*, ammonia, ferrous iron, hydrogen sulfide). This can be achieved via the draining of treated effluents by gravity to an aerobic leach field (Figure 2).

In a VFBR system, influent waters are forced upward through a permeable reactive matrix where reactions, identical to those described above for PRBs, take place. In this manner, a primary difference of VFBRs to PRBs is the nature of the hydraulic gradient. For PRBs, the gradient and flow direction are dictated by natural groundwater flow paths. For VFBRs, the upward flow path is afforded by containment (lined system) and water pressure. Given the imposed hydraulic containment of VFBRs, they are less dependent on natural substrate features in comparison to PRBs, which operate most effectively for well-constrained groundwater flow paths. This offers increased flexibility for VFBR placement.

Similar to PRBs, VFBRs operate by producing reducing conditions that promote metal removal via sulfide precipitation. The organic component also provides sites for metal adsorption. In some cases, effluent pH can be expected to decrease as a result of acidity generated through the oxidation of Fe(II) and precipitation of Fe(III) hydroxides. If required, circum-neutral surface water and groundwater collecting in the outer perimeter of the VFBR can be introduced into the effluent drain to contribute sufficient alkalinity to promote circum-neutral pH conditions.

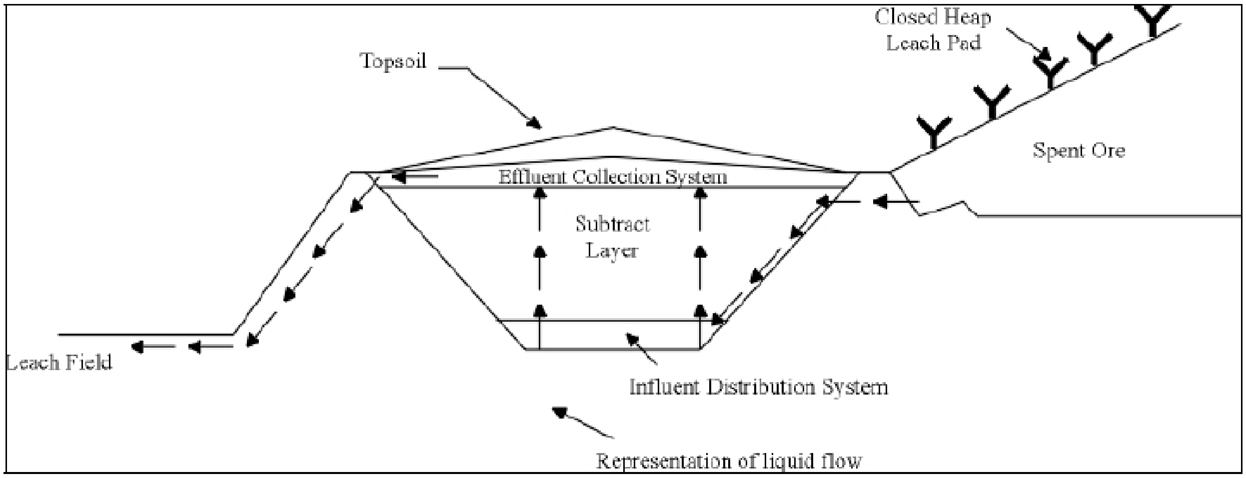

Figure 2: Schematic cross-section of a vertical flow biological reactor.

Case study information is more limited for VFBRs in comparison to PRBs. More information is available on general vertical flow wetlands or anaerobic sulfate reducing biological reactors (*e.g.*, Sobolewski, 2005; Gusek *et al.*, 2008). One example of a VFBR system is that constructed at a closed cyanide heap leach facility at the Santa Fe Mine in Mineral County, Nevada (Cellan *et al.*, 1997). The system was designed for a minimum 20 days residence time and a peak flow rate of 2.8 L/s to treat weak acid dissociable (WAD) cyanide (CN), sulfate (SO_4), nitrate (NO_3), mercury (Hg), and selenium (Se). Monitoring results indicated that all of the contaminants of concern were removed sufficiently from the effluent to meet mandated discharge criteria. No cost information was available for this treatment system.

A similar but downward-flow vertical biochemical reactor (BCR) was operated between September 2008 and October 2009 at a gravel pit adjacent to the Colorado River in western

Grand Junction, Colorado (Walker and Golder, 2010). A single 4,380 cubic foot (124 m^3) pilot-scale BCR was constructed to afford flow rate of 2-24 gpm (0.13-1.5 L/s) to treat selenium-contaminated surface water. The vertical-flow reactor media contained 30% sawdust, 30% wood chips, 10% cow manure, 10% hay, and 20% limestone. The pilot BCR achieved maximum selenium removal rates of 98% with a hydraulic retention time of 2.4 days and a minimum effluent Se concentration of 0.0005 mg/L from the average influent concentration of 0.034 mg/L. Total capital cost for this pilot system was $39,200 ($15,000 for engineering, $8,000 for materials, and $15,700 for labor). A rough order-of-magnitude capital cost for a full-scale BCR for this site, with 1 acre (~4,000 m^2) surface footprint to treat flow of 225 gpm (1 acre-ft per day or ~14 L/s), was estimated to be $900,000.

Given the nature of the effluent collection and distribution system, VFBRs are potentially more susceptible to atmospheric influences (e.g., temperature) compared to PRBs, and therefore care must be taken in the design of VFBRs in cold climates. Like PRBs, VFBRs may require maintenance and rehabilitation during their life, although maintenance requirements for the latter may be more onerous given the nature of the distribution and collection systems. With improper design, VFBRs are susceptible to clogging with suspended sediments. Elevated TSS in influent waters can result from poor design of the effluent collection and distribution systems, or from the oxidation and precipitation of Fe and Mn within aerobic portions of the VFBR. In general, total suspended solids (TSS) levels should be reduced to levels <50 mg/L in the influent to maximize performance and life span of the system. Like PRBs, Fe and/or Al precipitates accumulation can lead to short circuiting and reduced rates of reaction (Rose, 2010). Saturated conditions must be maintained for VFBRs to be effective. In this regard, water elevation within the VFBR must be controlled to minimize the potential for re-oxidation of reduced species (e.g., metal sulfides).

3. Design and Construction

The design of sub-surface passive treatment systems depends on several variables, including topography, hydrology, hydrogeology, influent water quality, and desired effluent water quality. Residence time, flow rate, and depth of flow are critical considerations in the design stage. Required residence time depends upon contaminant types, degradation/removal rates, and treatment goals. Site conditions must also be evaluated to assess the suitability and potential effectiveness of the proposed system. In general, site-specific data requirements include:

- Water balance information;
- Influent characteristics (major ions, TSS, trace elements, *etc*.);
- Treatment targets; and
- Site suitability features

- Hydrogeologic conditions
- Available area
- Site topography
- Soils data and depth to the bedrock
- Availability of construction materials
- Availability of reactive media
- Climatic conditions
- Presence of sensitive downstream environments

3.1 Permeable Reactive Barriers (PRBs)

Construction of PRBs involves digging of a trench or pit in the flow path of the contaminated groundwater plume, filling the void with reactive materials (*e.g.*, a mixture of organic solids, ZVI and possibly limestone gravel) that are sufficiently permeable to allow the unimpeded flow of groundwater, and finally landscaping of the disturbed surface.

The site characterization data needed for PRB design are extensive. In particular, data gathering on a smaller scale is necessary for placement of a PRB, including the complete vertical and horizontal delineation of the groundwater plume and characterization of hydrogeologic, geochemical, geotechnical, and microbiological conditions. Work associated with PRB design includes treatability studies (e.g., lab-based column testwork) and groundwater modeling.

The most common PRB design is the continuous PRB configuration. In such a system, the reactive media is distributed across the width and vertical extent of the groundwater contaminant plume. Properly designed and constructed, continuous PRBs have minimal impact on natural groundwater flow. Theoretically, PRBs do not need to be keyed into a low-permeability layer, as long as the permeability of the PRB is as same as or greater than the aquifer. However, it is good practice to key the PRB into an underlying low-permeability layer (e.g., bedrock, or clay-rich till) if one is present, or to a sufficient depth to ensure complete plume capture and as a safeguard in the event the permeability of the PRB is compromised. Ensuring sufficient permeability of the reactive matrix is one of the design considerations for PRBs. Installation methods include unsupported excavation, supported excavation, continuous trenching, and biopolymer trenching.

The flow capacity of PRBs depends on parameter concentrations of the influent water, metal removal rates for reactive materials, and associated residence time. The highest flow rate that a PRB can be applied to is up to about one pore volume a week (*i.e.*, 7 days of residence time) (David Blowes, personal communication). The largest PRB currently in use globally (*i.e.*, 400 m in width, 15 m in depth, and 2.5 m in thickness; Mountjoy and Blowes, 2002) operates at a flow rate of ~10 L/s. Theoretically, if land and resources are available, a bigger PRB capable of treating higher flow rates is feasible. This is illustrated in Figure 3, which shows flow rate as a function of PRB thickness, assuming residence times of 7 and 14 days. The data assume a 1000 m width and 15 m depth of the barrier, and an active pore volume of 40%. Based on a residence time ranging from 7 to 14 days, a 1 m-thick PRB can afford flow rates of approximately 5 to 10 L/s.

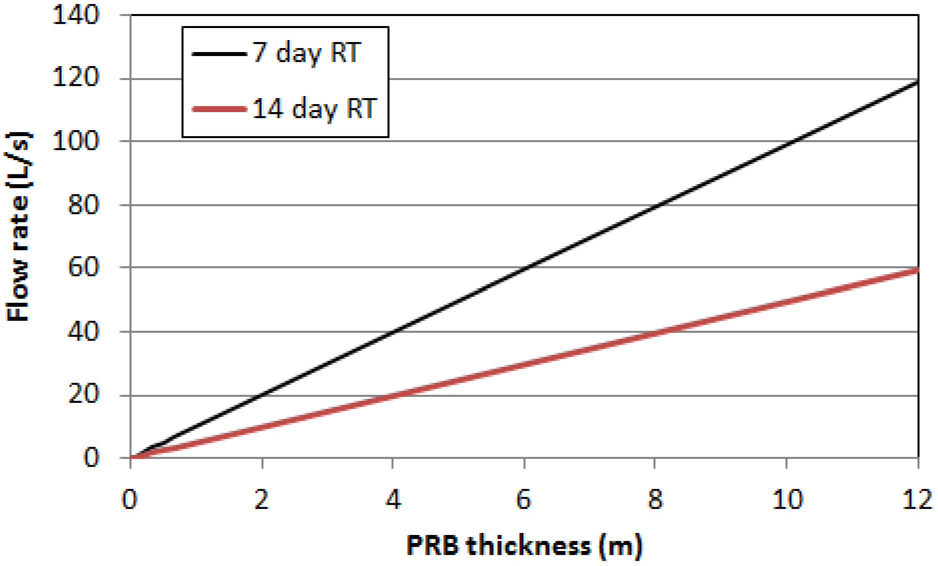

Figure 3: **Flow capacity for PRBs as a function of thickness, assuming residence time (RT) of 7 and 14 days. Data assume a 1000 m width and 15 m depth of the barrier and an active pore volume of 40%.**

3.2 Vertical Flow Biological Reactors (VFBRs)

There is not one uniform standard substrate design or standard depth for the construction of VFBRs, but the general design includes the following specifications:

- Area/depth – Sizing of the facility is dependent on the range of flow volumes that will report to the system;
- Organic substrate – Combination of cellulosic (wood chips, hay) and organic waste (manure, peat) should have sufficient hydraulic conductivity to ensure that the system can handle design flows. Additions of organic materials may be required periodically to maintain treatment efficiency;
- Gravel/limestone – To maintain permeability (*e.g.*, hydraulic conductivity of 10^{-3} to 10^{-4} m/s) and provide alkalinity, if necessary;
- Liner – Preferably, the base and sides of the vertical flow system will be constructed of compacted material with a low hydraulic conductivity to prevent influent water from seeping through the sides and short-circuiting the treatment system; and

- Drains –The network configuration will be dependent on the actual configuration of the vertical flow system, but, should have sufficient coverage to encourage vertical flow through the entire vertical cross section.

Similar to PRBs, flow rate is critical to sizing VFBRs. Further, VFBRs perform best over time when receiving a consistent influent flow rate. Flow velocity should be low (less than 0.15 m/s) to provide sufficient contact time to attain target removal rates (Burton and Tchobanoglous, 1991). In general, a residence time of 7-14 days is recommended. Flow depths vary from system to system depending on the above factors. Based on a residence time ranging from 7-14 days, a 2 m depth of the active vertical flow bed, and an active pore volume of 40%, flow rates of approximately 6.6 to 13.2 L/s per hectare are achievable (or average of ~9 L/s/ha based on residence time of ~10 days). This is illustrated in Figure 4a, which shows flow as a function of surface area for water residence times of 7 and 14 days. VFBRs can be constructed to support the upward flow of waters through a permeable reactive matrix that may be up to 4 m thick. Increased depth of the reactive bed allows for greater unit flow yields per area (Figure 4b).

4. Cost

The main costs of PRBs are related to the site characterization, design, and construction. While the initial installation cost may be substantial, there is little expense thereafter to maintain or operate the barrier (*i.e.*, no active energy costs, nor need for employees to monitor and maintain the system). Generally, the cost factors that should be evaluated for a PRB installation include the following:

- Site characterization
- Design
- Construction
- Purchase and installation of reactive media
- Licensing fees
- Operation and maintenance (O&M) costs
- Annual monitoring and reporting costs
- Media replacement/rejuvenation

Capital and operating costs for PRBs vary from site to site depending on the size of the barrier, barrier design, reactive material used, and physical and chemical characteristics of the contaminated groundwater plume. Usually the capital costs are similar to a pump-and-treat system, but operating costs are much lower. Of many factors, the media costs are generally the greatest. Sources of organic carbon are highly variable; thus, cost estimates rely heavily on treatability studies for design. While limited information is available with regard to the construction costs of operational-scale PRBs, materials and installation costs for the PRB at the Nickel Rim mine site (15 m long, 3.6 m deep, and 4 m wide) were approximately $30,000

(Benner *et al.*, 1997), corresponding to approximately $42,600 in 2013 dollars (allowing for inflation according to the Consumer Price Index at the Bureau of Labor Statistics, U.S.

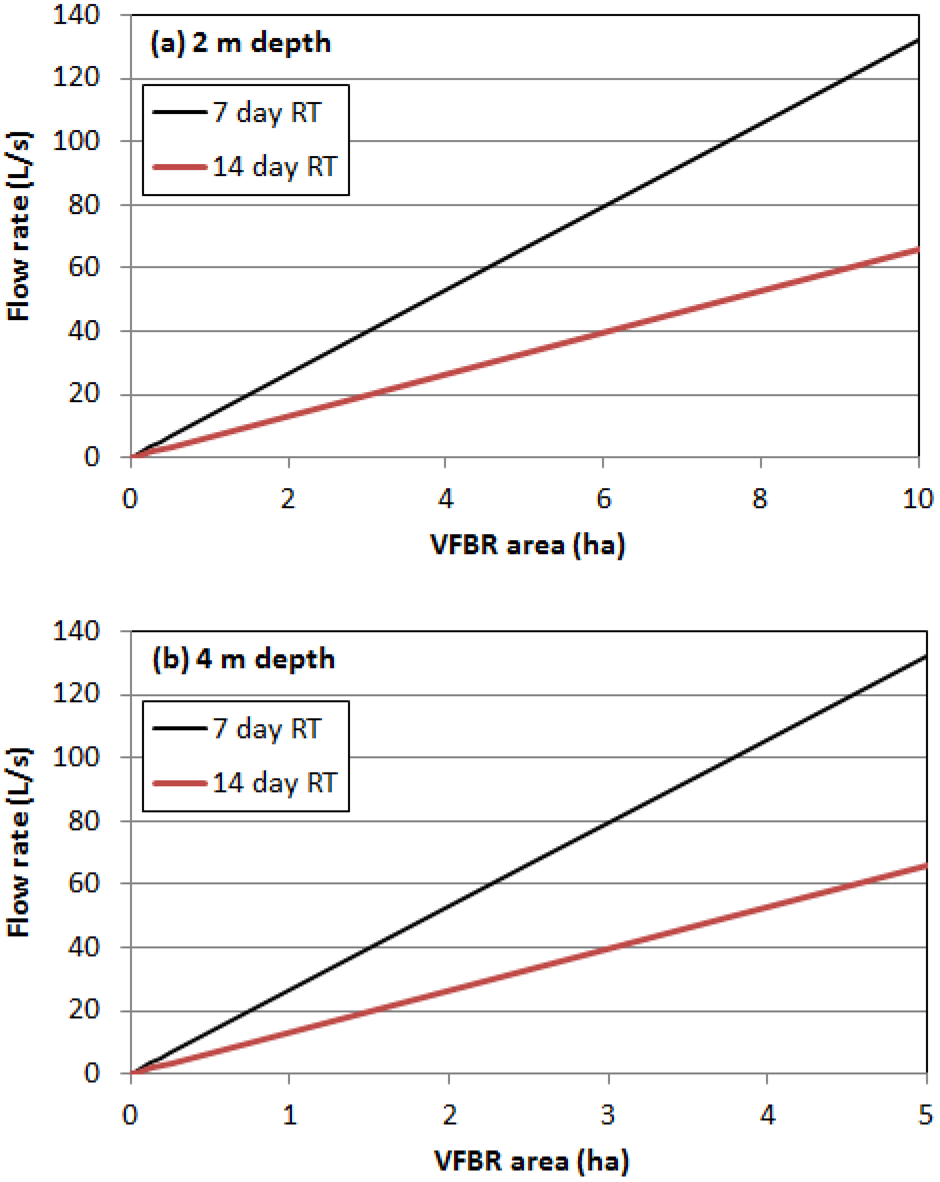

Figure 4: **Flow capacity for vertical flow biological reactors as a function of surface area, assuming residence time (RT) of 7 and 14 days. Data assume a (a) 2 m and (b) 4 m depth of the active vertical flow bed and an active pore volume of 40%. Note the difference in scale for VFBR area between (a) and (b).**

Department of Labor; http://www.bls.gov/cpi). This includes the cost for construction, materials, and the reactive mixture, but does not include costs for design, operation, monitoring and periodic maintenance. Approximately half of that cost was incurred for materials and the other half for installation. Based on this information, the unit capital cost for the Nickel Rim site was calculated to be approximately $140 per cubic metre of PRB volume ($197 in 2013 dollars).

Using the unit capital cost approximated from the Nickel Rim site, capital costs for constructing PRBs were estimated assuming residence time of 7 days (Figure 5). Cost adjustments were made to normalize project costs in relation to the date when the costs were incurred (*i.e.*, calculated in 2013 dollars). According to the estimation, capital costs for the PRB with a volume of ~7,500 m^3 to handle a flow of ~5 L/s (residence time of 7 days), are estimated at $1,470,000 (range of $740,000 to ~$2,960,000; Figure 5). The assumed -50% and +100% ranges represent uncertainties associated with the unit capital cost estimation. Annual monitoring and reporting costs are estimated to be $27,000 to $42,000/year (ITRC, 2011).

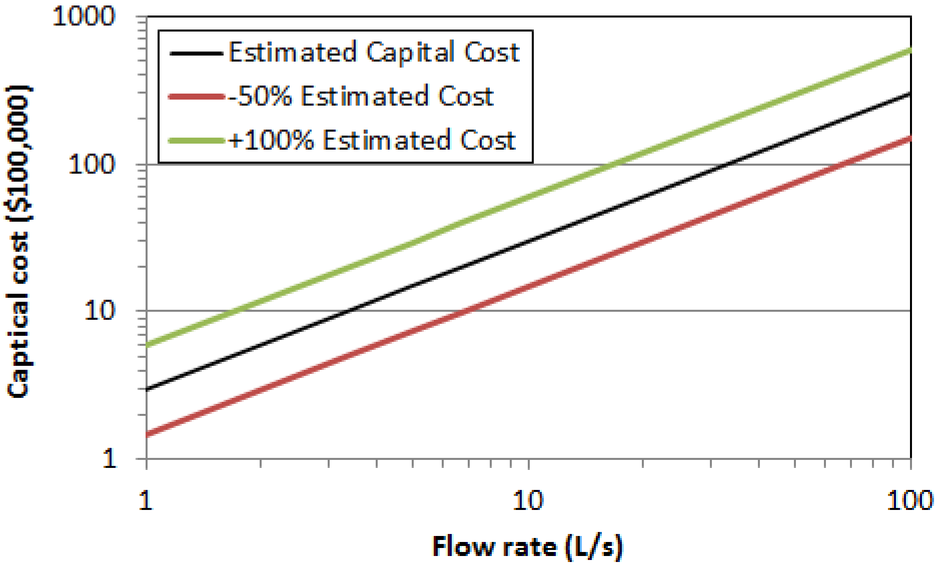

Figure 5: Estimated capital cost for Permeable Reactive Barriers as a function of flow rate.

Factors that affect the costs of VFBRs include required land area, pre-treatment requirements (*e.g.*, TSS removal), water management infrastructure, topography, soil type, land use and site complexity. In general, VFBRs are considered to be more expensive to construct than surface wetland systems because of the engineered media and the likely requirement for a liner. VFBRs require less land and plants, but more piping and a better control of flow. Other site-specific factors such as water chemistry, treatment goals, and source and availability of construction media can also influence the cost.

Typical cost factors for VFBRs can be proportioned as follows:

- Land cost: 3%
- Clearing and grubbing: 4-5%
- Excavation and earthworks: 15-25%
- Liner: 12-25%
- Media: 50-55%
- Miscellaneous: 10-12%
    - Site investigation
    - Inlet structures
    - Outlet structures
    - Fencing
    - Piping, pumps, etc.
    - Engineering, legal, and contingencies

Similar to PRBs, the media costs are usually the greatest of these factors. The unit capital cost for VFBRs is estimated at approximately $127 per cubic metre of VFBR volume (Jack Adams, personal communication). Based on this, capital costs for 1 ha system, with a volume of ~7,500 m^3 to handle a flow of ~5 L/s (residence time of 7 days), are estimated at $950,000 (range of $475,000 to ~$1,900,000; Figure 6). Annual maintenance, monitoring, and operational costs are estimated at ~2.5% of the construction costs, or roughly $25,000 per hectare per year (USEPA, 2000).

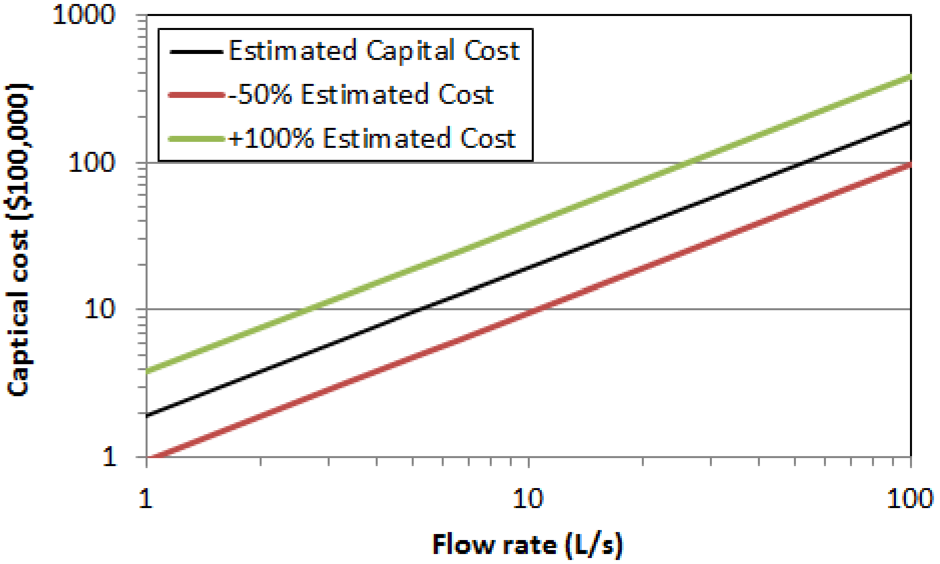

Figure 6: Estimated capital cost for Vertical Flow Biological Reactors as a function of flow rate.

5. Summary

This memorandum provides generic information about passive treatment systems that could be considered for treating seepage from the the proposed TSF at New Gold's Blackwater Project. Actual design and installation of passive treatment systems should be determined based on site specific conditions. Accurate site characterization and water balance calculations should be conducted to determine feasibility and capacity of passive treatment systems that can afford the anticipated seepage from the TSF. Factors affecting the choice and design of passive treatment systems include seepage chemistry, flow rate, mass loading, target remediation goals, and availability of land and local organic sources. In this regard, the feasibility of passive treatment should be assessed through a combination of laboratory-scale testing, pilot-scale field verification and hydrogeologic/geochemical modelling. It should also be noted that replenishment of the reactive materials or installation of additional reactive materials (*e.g.*, in front of an existing PRB) may be required as the reactivity and treatment potential of the passive treatment systems may decrease over time. The spent PRB reactive materials may be left in place if no significant changes in redox conditions are expected, while spent materials from VFBRs can be considered stable as long as they are stored under permanently saturated conditions. A general comparison of PRB and VFBR systems is summarized in Table 1.

Table 1:
Comparison of Permeable Reactive Barriers and Vertical Flow Biological Reactors

Variable	**PRBs**	**VFBRs**
Parameters treated	Acidity, SO_4, NO_3, As, Cd, Co, Cu, Fe, Ni, Pb, Se, Zn	Acidity, SO_4, NO_3, As, Cd, Co, Cu, Fe, Ni, Pb, Se, Zn
Effectiveness	Proven effective	Effective, but requires more performance data
Flow capacity	0.025-0.05 L/s/m (up to 10 L/s)[1]	~9 L/s/ha
Longevity	15-20 years	10-20 years
Proven at full scale	Multiple examples	Few examples
Materials	Coarse granular material, reactive amendment	Coarse granular material, reactive amendment
Liner	Not required	Required
Site characterization requirements	High	Moderate
Water management infrastructure requirements	Low	Moderate (distribution/collection systems)
Requirement for secondary treatment	No	In some cases post aerobic treatment is required
[2]Flexibility with regards to placement location	Low	High
Maintenance requirements	Low	Moderate (water management infrastructure)
Likelihood of success	High	Moderate to High
Cost	High installation cost, low maintenance cost	Moderately high installation cost, relatively low maintenance cost

[1] 10 L/s represents the highest flow for the largest PRB currently in use, but higher flows are feasible.

[2] Location for PRB dictated by location of TSF and underlying hydrostratigraphy. Greater flexibility is afforded for location of VFBRs.

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