Flooding as a Reclamation Solution to an Acidic Tailings Pond and Open Pit; 15 Years Later

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Abstract

The SolbecMine (Quebec, Canada) was in operation from 1962 to 1970, although the mill was active until 1977. The tailings pond received mill refuse from 1962 to 1977. Over 2.5M cubic meters of sulfide tailings from the mill were deposited in a natural pond.Local sampling conducted by government authorities had confirmed the presence of acid rock drainage (ARD). A 1987 characterization report of the tailings pond proposed flooding of the tailings as the most appropriate solution to the problem. A series of experiments and studies was conducted from 1989 to 1993 to test the efficiency and viability of flooding as a solution. The work required to achieve flooding was planned, designed and carried out from 1994 to 1996. Afterthe flooding was completed, the quality of the water cover and groundwater surrounding the tailings pond was monitored as part of the MEND program (Mine Environment Neutral Drainage program). Analysis of ten parameters for more than 50 samples revealed that the flooding solution was effective. Results showed that the covering waters met all requirements outlined in "Directive019surl'industrieminière" (Quebec Environment and Wildlife Department) as well as those of the Quebec drinkable water regulation. The site has now been covered with water for 15 years and has performed according to design. The former tailings pond has become a valued recreation area; land lots have been purchased around the "lake", and vacation homes have been built. The mine site had become a popular area for walking all year round.

Key Words: acidic drainage, acid potential, prediction, water cover

Introduction

The Solbec site is located in the Eastern Townships region of Quebec, about 200km east of Montreal (Figure1) between LakeAylmer and Lake St-François. The Solbec mine and mill were located approximately 3 km from the Lake Aylmer, a sought-after vacation site near the village of Stratford.

The Solbec mine was inoperation from 1962 to 1970 by the Sullivan Group. At that time, over than 1.9M tonnes of copper, zinc and lead sulphide ores were mined in a sericite schist gangue. The on-site concentrator operated from 1962 to 1977, processing not only the Solbec ore but also more than 2.9M tonnes of similar ores from the Cupra, Weedon and Clinton mines, all located in the same area. The Solbecorebody was a massive sulphide deposit. Predominant sulphide minerals included pyrite (FeS_2), sphalerite (ZnS), chalcopyrite ($CuFeS_2$), and galena (PbS). A total of 4.9M tonnes of massive sulphides were processed in the concentrator; the overall average grade was 2.17% Cu, 0.60% Pb, 3.52% Zn, 0.44 g/t Au, and 41 g/t Ag.

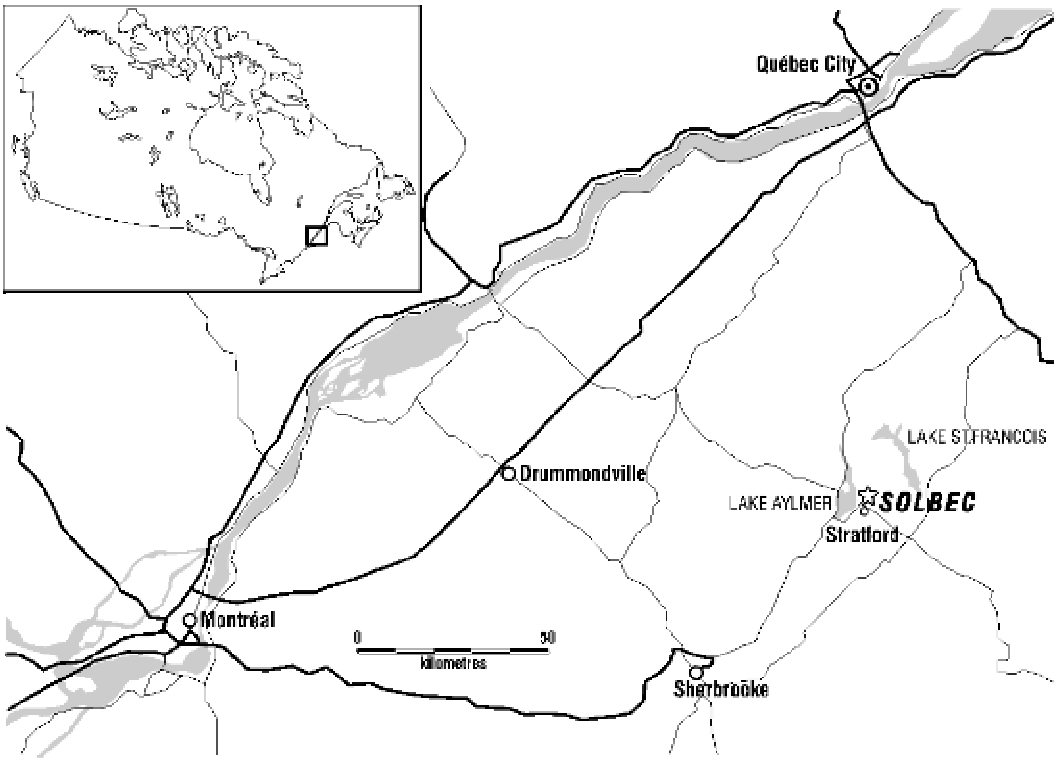

Figure1. Map showing the location of the Solbec site

The mine tailings were deposited in a 66-hectare site located in a swampy basin 3km north of theconcentrator. The tailings contained residual values of quartz, chlorite, sericite, plagioclases andminor fractions of calcite, dolomite, jarosite, magnetite and limonite. The total tailings volume was estimated at2.5M m^3 or 4.9M tonnes. At closure, about 20 hectares of the pond were submerged at the northern end and the water had a pH ranging between 3.0 and 3.5. In 1987, metal concentrations in the water wereapproximately 3 mg/L for zinc, 1 mg/L for copper and 10 mg/L for iron; other metals concentrations were not significant. The emerged surface of thetailings hadoxidized to a depth ranging from a few millimetres, in the section close to thewater pond to 50 cmat the south end of the tailings pond.Thetailingspond drainedintoan unnamed creekthat flowsinto a streamentering a ditch along the ThirdRange of the township which thenempties intoLakeAylmer. The mine and mill site also drains into an unnamed creek, this one flowing into the Bernier River and then into Lake Aylmer (Figure2).

Figure2. Natural drainage of Solbec site (mine and tailings pond)

Post Decommissioning Regulatory Involvement

In October 1983, the Quebec Department of Environmentcreated a special group known as GERLED (Grouped'étude et de restauration des lieuxd'élimination des déchetsdangereux) to inventory and categorize sites where hazardous waste have been disposed of. Under to the present Quebec regulation, mine tailings are no longer managed as hazardous waste, but in 1983, Quebec's environmental regulations were not as developed and all abandoned mine tailings and waste piles were identified on the GERLED list Sites were then classified as follows according to risk level for to public health and the environment.

Table 1.Risk Levels Classification according to GERLED

Category	Risk Potential	
	Public Health	Environment
1	Medium to High	High
2	Low	Medium
3	None	Low

Beginning in 1972, the quality of surface water at several stations in the vicinity of the Solbec Mine began to be monitored by regulatory agencies. The data indicated that acidic flows from the open pit were adversely affecting the water quality of the East Creek that flows into the Bernier River which in turn flows into Lake Aylmer. In 1985, while reviewingthe databases, GERLED gave the Solbec mining complex (consisting of the Solbec Mine and the Solbec tailings disposal area) Category 1 classification–a site presenting a high risk of contamination to the downstream environment.

In 1986, the Quebec Natural Resources department became aware of the need for characterization andthe developmentof a reclamation plan sponsored a study**.** The report proposed flooding as the optimal solution from both an economic and an environmental perspective and recommended that field and laboratory experiments be performed to test the efficiency and viability of this option (Centre de RecherchesMinérales, 1987).

Cambior Inc. became involved in October 1987, following the acquisition of Sullivan Mines Inc. The reclamation of the remaining infrastructure and the characterization of the two sites (Solbec mine and mill and Solbec tailings pond) began in 1988. Various experiments aimed at testing the flooding option to attenuate the acidic drainage from the tailings pond began the following year.IAMGOLD acquired Solbec sites through the acquisition of Cambior in 2006.

Flooding Experiments

The first experiments to examine flooding of oxidized tailings as a reclamation solution for the Solbec tailings site were conducted in 1989. Ten-centimetrediameter columns testing various depths of water cover were monitored in the laboratory for ARD for a period of eight weeks. On-site, 1.22-m long cylinders were sunk into the tailings to the level of the water table to simulate in situ flooding. These were monitored for 17 weeks. The results showed that acidification can be stopped by flooding once the interstitial water is replaced.

In 1990, a 3m x 3m test basin was built with piezometers located in the various layers to simulate and study flow conditions in the pond and to confirm that the circulation of interstitial water was an important element in inhibiting acid generation. Along with a technical-economic feasibility study, monitoring took place over a 15-week period. The geological and geotechnical characteristics of the site were found to be favourablefor construction of dams and long-term water retention. The ground bearing capacity was reported to be good and since it was demonstrated that the tailings were deposited on a bed of peat overlaying an impermeable till zone, the long-term water retention capacity seemed realistic.

In 1991, a third phase of experiments was conducted to determine the efficiency and technical feasibility of flooding as a means to reclaim the Solbec tailings site. This consisted in ensuring that the water cover could be maintained in the long term (i.e. establishing a potential water balance) testing the bearing capacity of the ground under the dams, identifying borrow pits with potential fill material of low hydraulic conductivity and observing the physical-chemical and microbiological evolution of the interstitial water in the tailings. The flooding option was consequently maintained and confirmed. With the construction of two dams, the water could accumulate from a 5 km^2 watershed in a 1.2 km^2 basin for 18 months before any overflow occurred and an annual water surplus of approximately 3 Mm^3 was anticipated. However, the results from the testing basins were unexpected; the acidification process was still ongoing in the oxidized tailings. Thus, oxidation product leaching arose as a consequence of flooding the oxidized tailings.

In 1992, a fourth phase was undertaken. To offset the leaching of the oxidation products from the oxidized tailings, limestone was added to the testing basins in an attempt to neutralize and stabilize the previously

acidified water. In December 1993, flooding of the pond after the addition of lime was recommended as the reclamation method.

The next study attempted to assess the depth of water required to inhibit acid generation given wave action and the possible re-suspension of particles. However the model used had been designed for longer fetch and higher wind speeds. In addition, the tailings grain size under study was typical only of the pond's central zone and was finer than the average. Therefore the results were taken as a guideline only. Analysis of the results of the study had initially led to recommending a minimum water depthabove the reactive tailings of 1.34 m or 0.74 m if the tailings were to be covered with sand. With respect to the tailings' grain size in areas where the future shallow water zones were to be located, a one-metre water cover was determined to be adequate.

Another study aimed to assess the quantity of lime to be used and its application method (Karamand Guay, 1994). The resulting recommendation was to apply 118 tons/ha to an average depth of 15 cm. The final investigation studied the effect of flooding on microbiological activity (Karamand Guay, 1994). In the laboratory it was found that maintaining the non-oxidized tailings under water prevented colonization by *Thiobacillusferrooxidans*-type bacteria, while artificial flooding of un-oxidized and oxidized tailings combined with lime inhibited microbial activity without destroying cell viability. The authorsexpected an effective decrease in the populations over time,however no fieldwork has yettested this prediction.

The work conducted from 1990 to 1993 was part of the MEND program and the detailed reports are available.

Reclamation Work

Flooding of the tailings pond, with a minimum cover of 1m of water, was possible with the construction of two dams: a main dam 396m long and 9 m high and a second dam 192 m long and 2.5-m high. The long dam was classified as a high-capacity and class C dam on the basis of the risksto persons and property;class A being the most exposed class on an A to D vulnerability and consequence scale.

Work began in August, 1994 with the clearing of 27 ha of land. This area included mine and mill site, access roads, thedam'ssites and a portion of the area to be flooded

At both dam sites, the overburden was stripped and the bedrock was blasted to level the base of the dams. The bedrock was then cleaned and fractures were cemented. The dams were built with an impermeable till core. At the upstream side, the core was covered with an impermeable liner, while at the downstream side, the core was entirely covered with liner and a filter bed. The slopes were completed with gravel and were covered in riprap.

At the north end of the main dam, a 4 m wide concrete spillway was built to handle a 1 in 100 year flooding event.

To minimize the height of the dams, about 50,000 m^2 of tailings located at the south end of the pond were smoothed toward the center of the impoundment.

Before flooding, the whole surface of the tailings was limed. In the water-covered area, hydrated lime ($Ca(OH)_2$) was dumped in the water. In the uncovered area, calcite dust and granules ($CaCO_3$) were used as a neutralizing agent and incorporated into the tailings by plowing to a depth of 300 mm. It was found to be a difficult operation resulting in irregular distribution and excess of neutralizing agent according to Karamand Guay's 1994 calculation. An average of 230 tons/ha of material was applied.

The Solbec mine and mill site were decommissioned between 1977 and 1979 by the owner of that time. The decommissioning work completed included:

- the demolition of surface structures and backfilling of foundations to grade;
- the contouring of waste dumps and the grading of former building sites; and
- the capping with 0.2 m layer of soil of mine waste followed by seeding (but with no success).

In 1988, in conjunction with the works at the Solbec tailings pond, reclamation of the Solbec mining and milling site was reinitiated. Sulphide waste rock had been left on surface; exploitation of the surface pillar had left an open trench (glory hole) where the accumulated waters had a pH below 5. It was soon determined that the pit had been partially filled in. Approximately 10,000 m^3 of tailings had apparently been disposed in the pit during the last few weeks of mill operation in 1977. It was subsequently calculated that the pit lake surface area was 14,300 m^2 and the residual volume of the pit above the tailings was 360 000 m^3 of which 180 000 m^3 was water.

All the oxidized and non-oxidized suphides remaining on-site were therefore transported to the trench and limed.At the completion of the wastes relocation program the level of waste in the pit was 2 m above the original water table elevation. Fortunately, a 1m water cover could be maintained over the wastes by constructing a water retaining dyke across the south end of the pit and fitted with only one overflow. The former glory hole was then arranged as a water pond that can accommodate aquatic birds and the overflow of the new pond drained by gravity through underground canalisation towards biofilters, constituted of ashes and bacterial inoculums, before its discharge to the environment (Figure 3). The biofilters also treat drainage from the areas of the site where ARD waste rock dumped in the pit had been collected.

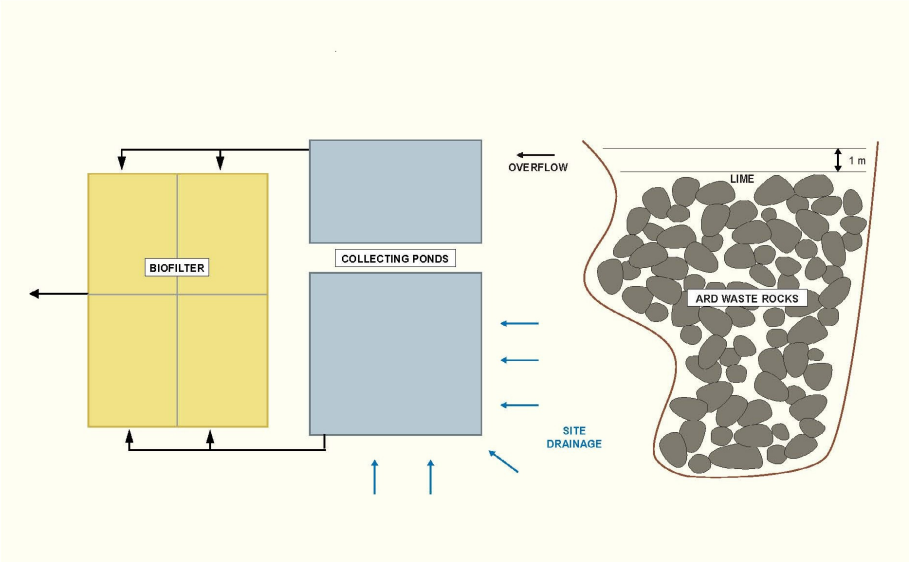

Figure 1. Water from pit to biofilters (from Amyot, 2003)

The biofilter,known as Mediaflex technology, was designed to reduce the metal concentrations.The biofilter has an average capacity of 650 m^3/d, but can handle higher rates during high water periods. The maximum capacity is somewhat greater than 800 m^3/d.

Two basins were set up to accumulate water before entry into the biofilter during heavy downpours and spring thaw. Since the filters were designed to operate by ascending flow, the system of pipes is not visible. The filters are passive and need no start-up procedures. As soon as the waters thaw in spring, they are operative.

Besides the reclamation of the tailings pond and of the pit-site, Cambior collaborated with Ducks Unlimited to set up a walking path and a public nature trail. Duck Illimited is a non profit group which conserves, restores and manages wetlands and associated habitats for North America's waterfowl.

Work ended in November 1994. Complete flooding of the tailings to their highest elevation (329 m) was achieved in September 1995. In February 1996, the 330 m water elevation mark was reached during a mild period, and the first overflow from the basin occurred.

Monitoring

The environmental monitoring program following the flooding of the tailings pond (1994-1998) was developed as part of the MEND program. It examined aspects such as the quality of the pond water cover,the quality of the groundwater and effluents from the three sites, the quality of receiving water down to Lake Aylmer,the water balance, the effect of waves and ice on sediments, bank erosion and beach creation, the evolution of the microbiological populations as well as dam stability and integrity.

The watermonitoring programwhich included more than 50 sampling stationsand analyzed more than10 parameters was in place from 1996to the end of 2002. In 2003, MDDEP (Quebec Environment Department) acknowledged the good performance of the reclamation works and indisputable restoration of the two sites; it allowed water monitoring to be discontinued in April, 2003. Today, the remaining dam stability and integrity follow-up is performed by the S.M. Group and Aquagéniemonitors the efficiency of theMédiaflex filters.

Results

The tailings were completely flooded by the fall of 1995 and in February 1996, an effluent was reported at the spillway (1m over the tailings) where covering water had been sampled before the flooding. The anticipated fill period of 18 months was as expected. A new equilibrium was established in the pond. The summary of results from 1996 to 2002 as well as data from a recent 2011sampling are presented below (figures4and 5).

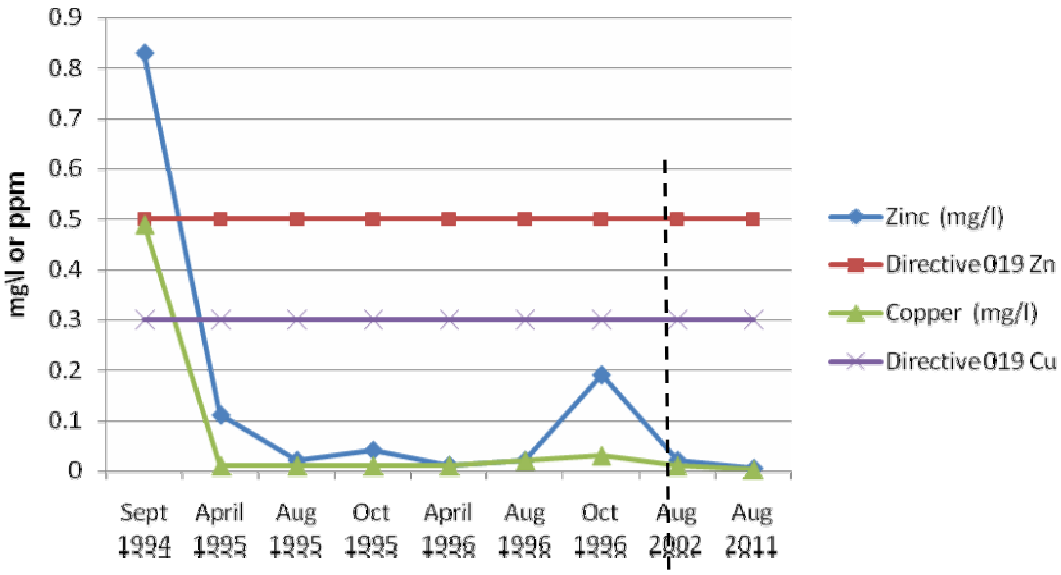

Figure 4. Tailings pond covering water copper and zinc concentrations

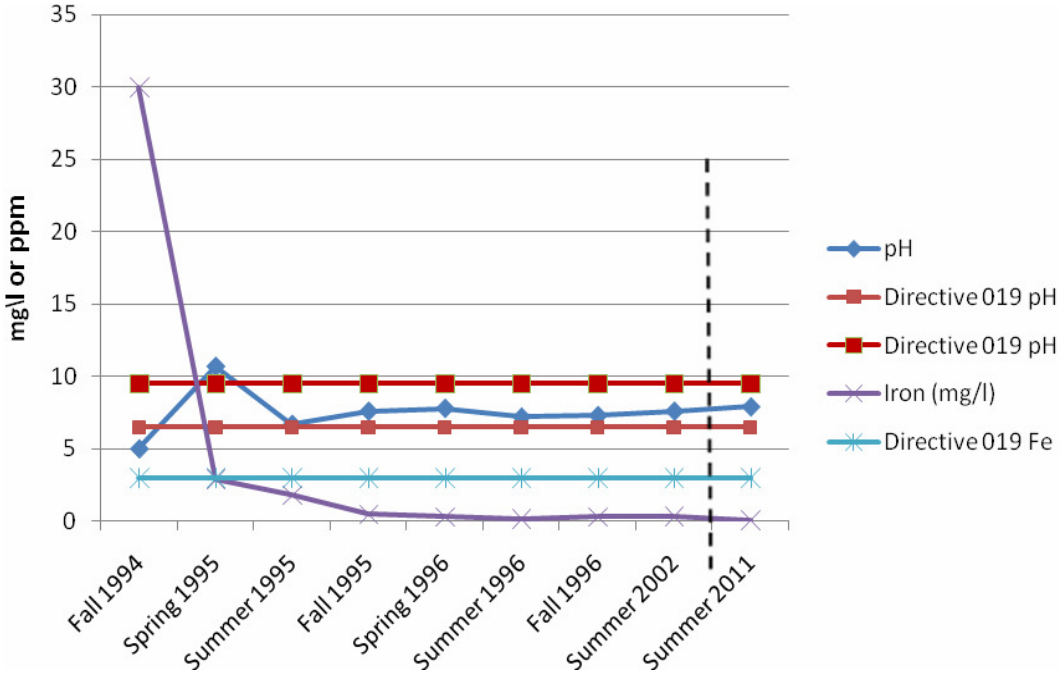

Figure 5. Tailings pond covering water pH and iron concentrations

Two important factors must also be considered. The surface area of the reservoir drainage basin is 500 ha(5 km2). The total precipitations measured in the region ranged between 1.1 and 1.2 meters per year and had an average pH around 4.4. The second important factor is the liming of the pond and tailings before flooding. Limestone dissolves slowly and strongly influences the quality of the water cover.

To date, several hydraulic, hydrogeological, wave action and ice impact studies confirmed that the risk of tailing re-emergence or re-suspension is not significant. In fact, 210 consecutive days of drought are

apparently needed for evaporation and exfiltration to cause the tailings to re-emerge. On the other hand, 64 km/h winds blowing along the basin axis would be required to re-suspend the tailings (Consultants S.M. Inc., 1998).Furthermore, neither the cover nor the semi-solid waters beneath the ice cover reach the tailings.

The covering water rose from a slightly acid pH in the fall of 1994 to very alkaline levels in the spring of 1995 following the thaw, once the lime began to dissolve. It subsequently hovered around neutral.Following the complete flooding of the tailings in the fall of 1995 and the gradual saturation of the tailings, the 1996 spring campaign detected slightly acid pHs (6.1) in the layer of oxidized tailings. More neutral pH's were observed the following summer.No anomalies were seen in the pHs measured in the water for any of the other stratigraphic units.

In 2009, a compilationstudy on the effectiveness ofrestoration methodthat wasusedto restoretheSolbec tailings pond, near ThirdCreek, wasconductedas a master degree memoir atLaval University(De Coninck, Arnaud Sydney Philippe, 2003).Therestoration methods, which were implemented for the tailings pondin the 1990, wereprovedto be effective.Recently, in 2010, brown bullheads (*Ameiurusnebulosus*)captured from the lake developed on the former tailings pond had mercury level was measured in the tissue and the results were all well below the Canadian consumption guideline (AECOM, 2010).

As for the reclamation of the glory hole, the removal of iron and zinc by the biofilter was about 90% from 1996 to 1998. In 1999, the yield dropped to 75%, and has since stabilized at 65% as showed by the following graphs (Figures6and 7). Better performances occur during summer and cold water gives lesser performance.

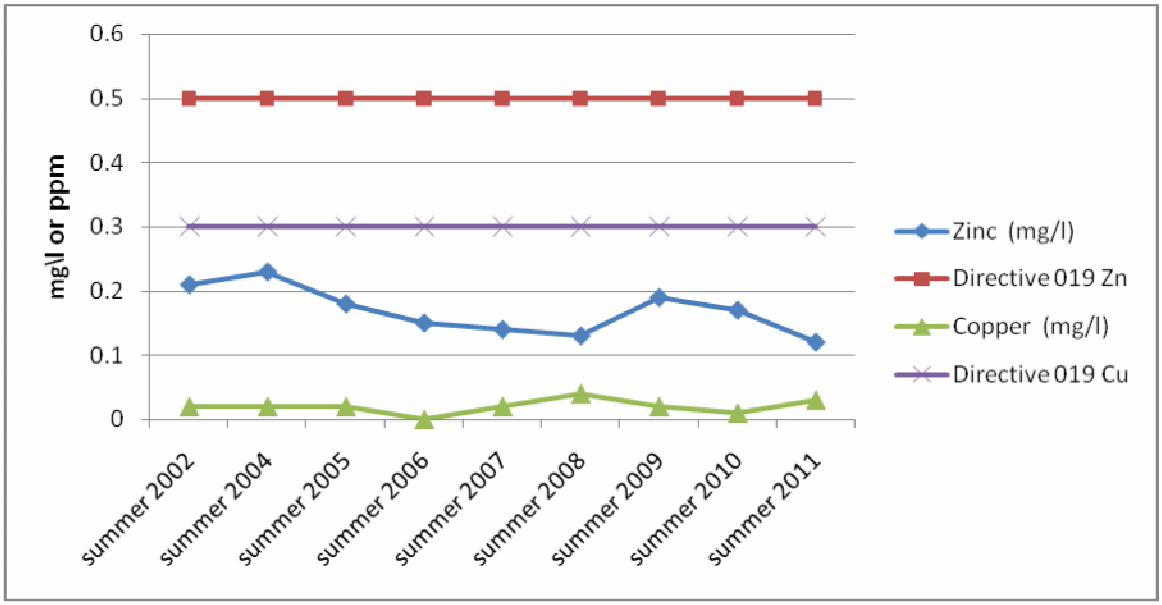

Figure 6. Overflow of Mediaflex filter zinc and copper concentrations

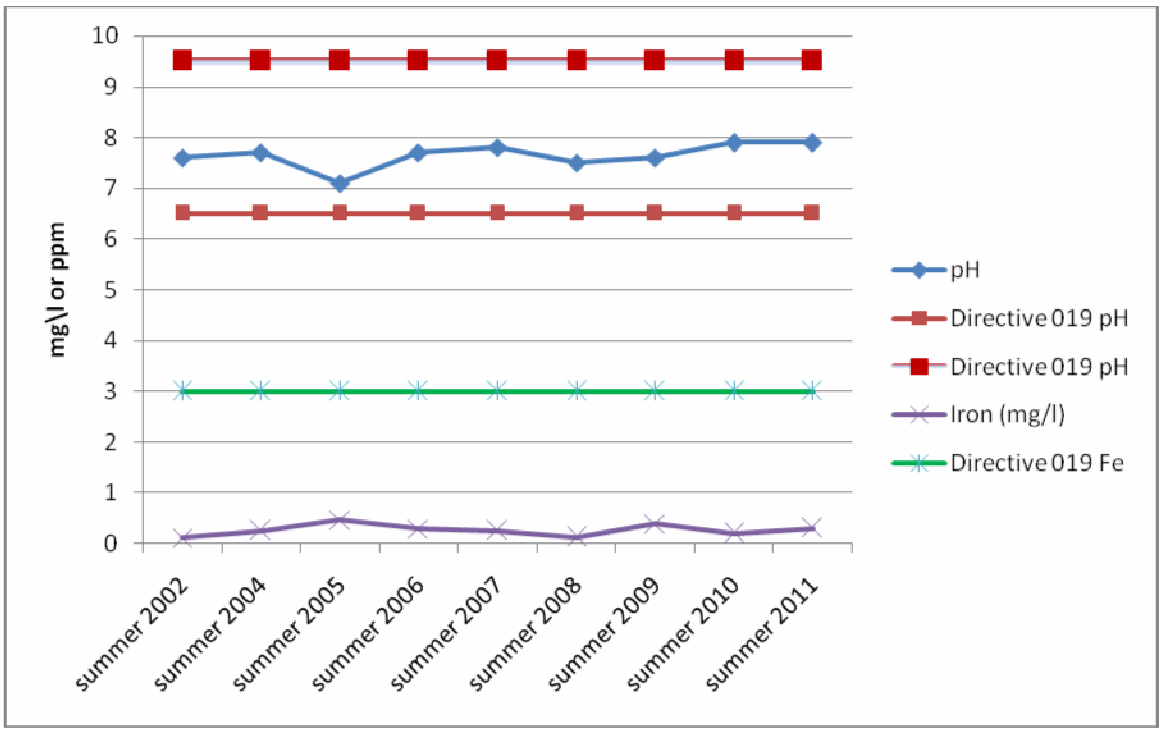

Figure 7. Overflow of the Mediaflexfilters pH and iron concentrations

Conclusion

The results from the various sampling campaigns showed that flooding of the Solbec tailings pond was successfulin inhibitingacid mining drainage. Water samples meet the various quality criteria and the site had been recolonized by native flora and fauna.

The covering waters meets all requirements outlined in Directive019 (Quebec government environmental criteria for the mining industry) as well as those of the Quebec Regulation respecting Quality of Drinking Water. All the results to date therefore show that flooding was effective in attenuating the generation of AMD at the Solbec tailings site.

Since July, 2009, IAMGOLD have been acorporate member of the Lac de laHéronnière lotowners association. This partnership can only be beneficial for both parties, i.e. the company responsible for the creation of the lake and its sustainability and the Association, responsible for good usage of the land and the waterbodyby its members. The Dam Safety Act requires perpetual monitoring for the stability of the long dam;this requirement prevents IAMGOLD from being releasedof the former tailings pond liability from Quebec Department of Natural Resources as per the Mining Act. Our responsibility is thus full and whole.

In conclusion, the pond site has returned to its natural state; native plants have reappeared and amphibians, herons, various ducks species and even white-tailed deerare seen regularly. The private owners of Solbec sites surface landtook advantage of this added value to their land by subdividing and selling the land lotswhere some 20summer residences now surround the body of water.

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