Normétal Mine Tailings Storage Facility HDPE Cover: Design Considerations and Performance Monitoring

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Abstract
Synthetic materials such as geomembranes can be used as alternate materials in the construction of dry cover for acid-generating tailings impoundments. The Normétal Mine, in northwestern Quebec, has been reclaimed in 2005-2006 using a HDPE geomembrane to prevent oxidation and water infiltration through the tailings. In this paper, the author presents some historical background and the main reclamation features of the site. The results of the 5-year post-reclamation environmental monitoring program are presented and used to assess the performance of the reclamation plan. It is shown that the cover succeeds its function of protective layer by stopping the migration of tailings and that the discharge rate of contaminants in the environment has decreased since the implementation of the cover.

Key Words: acidic drainage, dry cover, HDPE liner, seepage collector drain, fertilizing residual materials

Introduction
Ten Mtons of copper and zinc sulphide ore were extracted by underground mining at Normétal Mine from 1929 to 1975. Discovered in 1923, the orebody was sporadically exploited from 1929 to 1937. The production rates went from 250 tpd in 1937 to 900 tpd in 1956 and until the mine closed in 1975. Abana Mines, Normétal Mining Corp., Kerr-Addison and Exploration Minière Normétal have been the successive owners of the property. Currently, Xstrata Zinc is the manager of the site and in charge of the environmental monitoring.

The tailings storage facility (TSF) was expanded during the mine lifespan. Three different impoundments were successively built. Impoundment no.1 was built next to the plant site and was later expanded to the east to create impoundment no.2, which together increased the TSF footprint to 21 ha (Figure 1). A third and final expansion phase of the TSF, impoundment no.3, took place to the north creating a 33 ha basin. Impoundment no.3 is separated from the southern impoundments by a Central Ditch to facilitate the surface water management towards the Des Méloizes River, which flows downstream of the impoundments along the eastern limit of the property.

The original closure plan called for the demolition of all buildings and other mining/processing facilities, the flattening of the downstream tailings dam slopes to ±5H:1V, and for a final grading of the whole site surface. Placement of a 30-cm thick layer of sand in addition to grass seeding and grey pine tree planting completed the reclamation work carried out by Kerr-Addison between 1980 and 1985. However, this revegetation failed to prevent erosion of the sand cover which eventually resulted in soil erosion and tailings spill onto the shores and riverbed of the Des Méloizes River.

This paper presents the main reclamation works carried out in recent years to reduce the effect of the TSF on the surrounding environment. In fact, in the early 2000's, Noranda / Falconbridge and the Quebec Ministry of Natural Resources agreed on a series of reclamation works aiming at:

- Stopping the migration of tailings;
- Improving progressively the water quality in the Des Méloizes River;
- Providing recreational uses of the site by the local population.

Results of the site environmental monitoring are presented and the overall performance of the cover system is then discussed.

Cover Implementation

The reclamation works of the TSF required a site preparation, the installation of a buried seepage collector drain system, and the placement of a cover constituted of a HDPE geomembrane and a soil layer.

Clean-up of spilled tailings and other reactive materials

The grey pine trees planted after the initial closure of the site in the mid 1980's and the bordering vegetation had to be grubbed and the area cleared prior to start the reclamation works. All materials capable of generating acid mine drainage (AMD) and lying outside of the TSF footprints were recovered and stored in a single pile in the southwest quadrant of tailings impoundment no.3 (Figure 1). These materials included tailings spilled from the impoundments towards the Des Méloizes River and acid-generating waste rockfill recovered from the former plant site.

Construction of the buried seepage collector drain system

Two drains were installed at the downstream edge of the tailings impoundments to intercept, collect, and convey to a single discharge point the acidic drainage seeping at the toe of the impoundments (Figure 1). The drains consist of a 15-cm perforated HDPE drainage pipe overlain by three successive layers of filter-graded crushed stone materials topped with tailings.

The southernmost drain is 1,250 m long and collects the seepage from impoundments nos. 1 and 2 (Figure 1). It consists of two segments meeting at their lowest point at the northeast corner of impoundment no.2. The north segment starts at the western limit of impoundment no.1 and runs eastward collecting successively the seepage from an adit at the former plant site and the seepage at the north toe of impoundments nos. 1 and 2. The south segment starts at the west end of impoundment no.2 and runs along the toe of the impoundment until it meets the north drain segment. The northernmost drain is 1,150 m long and collects seepage from impoundment no.3. It consists of two segments also meeting at their lowest point at the southeast corner of the impoundment. The south segment collects seepage at the toe of the south slope of impoundment no.3 while the east segment runs southward along the toe of the east side of the impoundment.

The seepage evacuation system consists of four manholes connected together with 25-cm HDPE pipes whose invert elevations are such that they are permanently flooded by at least one meter of seepage water. Figure 2 shows the arrangement of the four manholes.

Installation of the Cover

Once the area prepared and the drain system installed around the impoundments, the surface was graded in preparation for the placement of the geomembrane. A 1.5 mm thick HDPE liner was installed over the 54 ha surface area of the three tailings impoundments. This polyethylene has good resistance to chemical exposure, low cost and ease of seamability (Haug and Pauls 2002). Smooth liner was installed on top of the impoundments while texturized liner was used on the slopes and anchored in native soils beyond the buried drain. A 0.5 meter thick layer of clayey silt was placed as a single lift on top of the geomembrane liner. This clayey silt layer aims to provide a physical protective cover for the geomembrane and a substrate for plant growth. On slopes, the liner is protected by a 30-cm thick layer of clay overlain by a 30-cm thick layer of rockfill. Compaction was obtained solely by the frequent passage of heavy equipment at the time of placement. Finally, the surface of the soil cover was amended with 300 T/ha of fertilizing residual materials consisting of a mix of municipal sewage sludge (60%), bark (35%) and fly ash (5%). Seeding consisted of fescue, yellow sweetclover, birdsfoot trefoil and red clover.

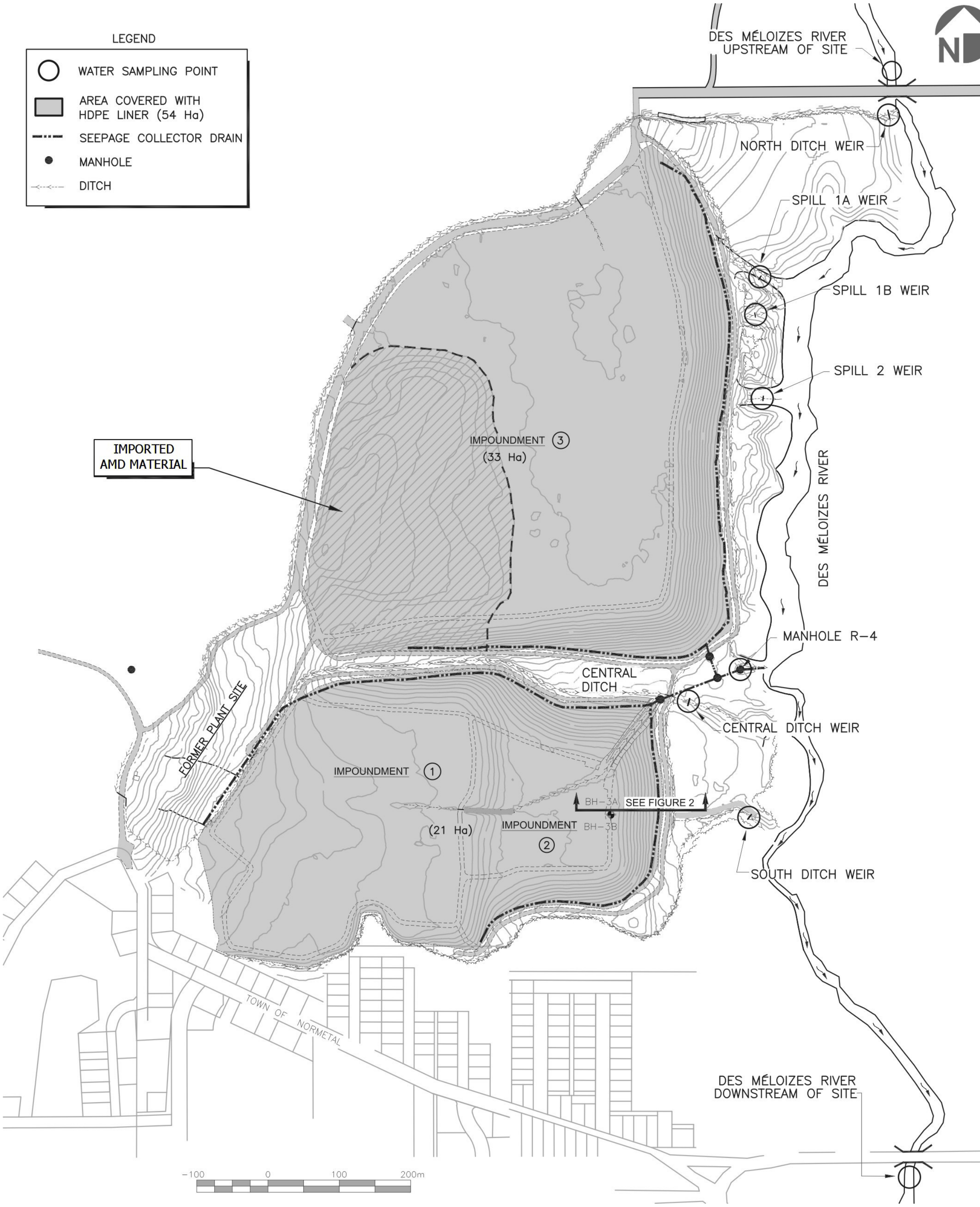

Figure 1. Location plan of Normétal mine tailings impoundments

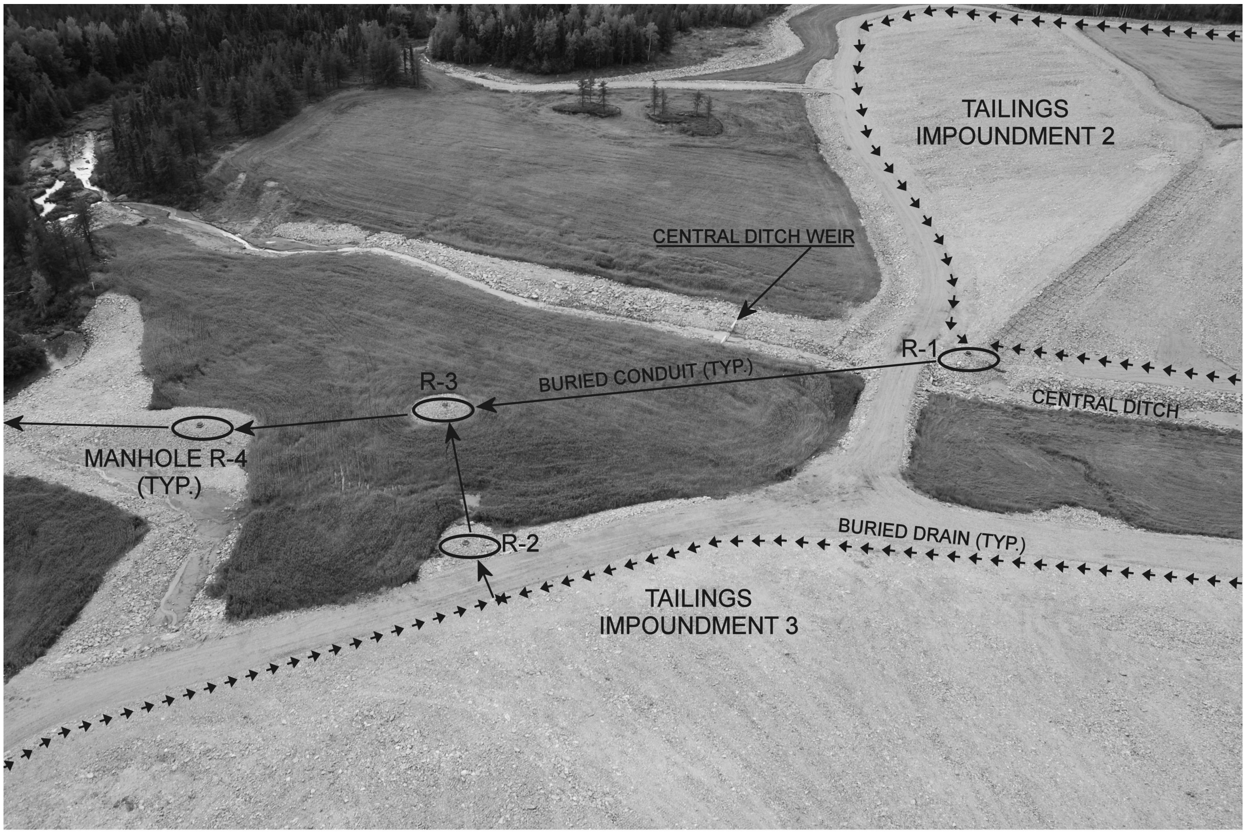

Figure 2. Aerial view to the south of manholes and location of seepage collector drains.

Environmental Monitoring Program

The current monitoring program aims at assessing the performance of the reclamation plan by measuring temporal variations in the metal discharge into the Des Méloizes River. Six monitoring points for water sampling were initially specified in the original Certificate of Authorization. However, during the construction works, three additional monitoring points were added to accommodate changes in the surface drainage pattern from the original design. The location of the monitoring points from north to south is as follow (Figure 1):

- Des Méloizes River, upstream of site
- Concrete weir of North ditch
- Wood weir of Spill 1A
- Wood weir of Spill 1B
- Wood weir of Spill 2
- Manhole R-4
- Concrete weir of Central ditch
- Concrete weir of South ditch
- Des Méloizes River, downstream of site

The original plan was to direct all seepage collected by the buried drain system to one discharge point, located downstream of manhole R-4. However undetected variations in the topography of the original ground created preferential pathways for water seepage under the buried drain. In fact, prior to construction of the buried seepage collector drain system, over sixty test pits were dug to define the elevation of the original ground. This was done in order to define the position of the invert profile of the drains to be set below the original ground level. Nevertheless, several depressions along the east toe of impoundment no.3, likely erosion gullies carved by surface water prior to the construction of the tailings impoundments, remained undetected. Efforts were made to seal the gullies when observed at the time of construction but these gullies still currently allow some seepage under the buried drain. Three weirs, identified as Spill 1A, Spill 1B and Spill 2, were hence installed to measure the contribution of these gullies to the metal loadings in the Des Méloizes River.

Sampling for metal loadings measurements emitted from the site was carried out in accordance with the *Guide d'échantillonnage à des fins d'analyse environnementales*, 2e édition, MDDEP, 2001. Each sample was collected in a 1-litre bottle with no preserving agent and a separate 250- or 500-ml bottle containing acidic water for measuring metals concentrations. Because surface water was not filtered, the reported concentrations represent total metal concentrations. The metal assays specified by the Certificate of Authorization are As, Cu, Fe, Ni, Pb and Zn. Conductibility and pH are also monitored.

In addition to the water sampling, three monitoring campaigns are carried out annually to evaluate the drawdown of the water table in the covered tailings and to inspect the performance of both the surface drainage system and the vegetation cover. Previous work carried out on site required the installation of standpipe piezometers on both impoundments nos. 2 and 3. However, piezometers on impoundment no.3 were defective at the time of construction and only those on impoundment no.2 are still operational and used to assess the drawdown of the water table in the tailings covered with the geomembrane.

Results

Water table drawdown in tailings

Figure 3 is a cross section of the east slope of tailings impoundment no.2 at the location of piezometers BH-3A and BH-3B. The filter tip of BH-3B lies in tailings just above the base of the stack. The filter tip of BH-3A is in a sandy gravel stratum, 8 meters below the original ground surface (base of tailings).

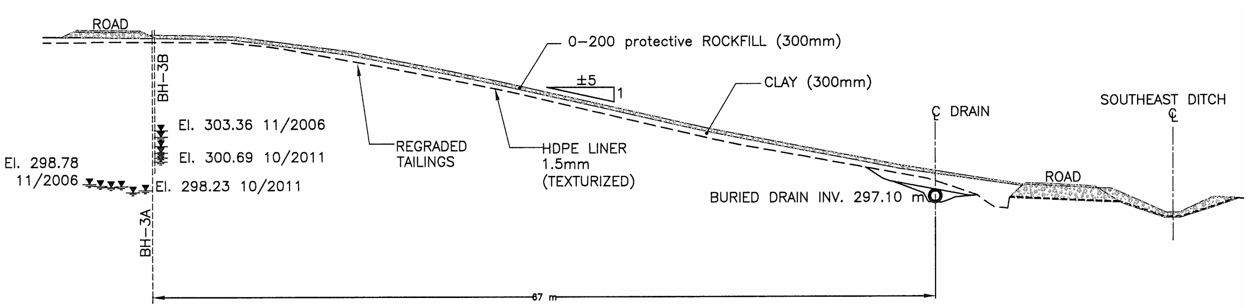

Figure 3. Cross section showing the monitoring wells BH-3A and BH-3B and the seepage collector drain.

Results of drawdown measurements acquired up to November 2011 in piezometer BH-3B are presented in Figure 4 and are compared to those made for a similar project, the Poirier Mine site, reclaimed in 1998-2000 with a geomembrane cover (Lewis and Gallinger 1999). The drawdown rate measured in the Normétal tailings impoundment no.2 is slightly higher than the rate measured at Poirier in the first 5 years after the tailings were covered with a HDPE geomembrane.

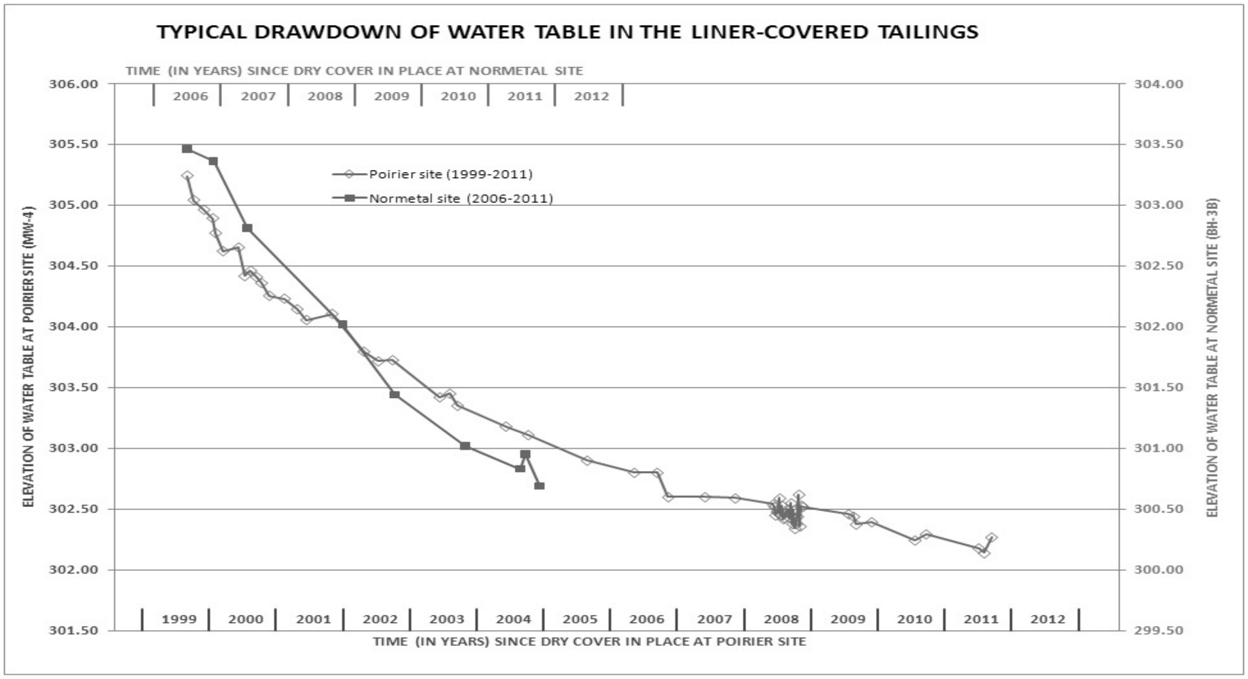

Figure 4. Typical drawdown rates at Poirier and Normétal sites

Metal loadings emitted from the site

Results of the water quality and flow monitoring campaigns carried out since the end of the reclamation works in 2006 are presented graphically in Figures 5 to 9. Since the flow rates are measured only three times a year (spring, summer and fall), the total loading or concentration of metals being rejected in the environment cannot be calculated. We can only propose an analysis based on the variation of discharge rates.

Relative magnitude of the Different Metals

The relative magnitude of the six metals currently monitored in the Des Méloizes River is shown on Figure 5a. Iron, accounting for 96.4% of the total metal loadings, is by far the most predominant metal found in the receiving environment. Zinc accounts for 3.4% of the total loadings whereas the four remaining measured metals account together for only 0.2% of the measured values.

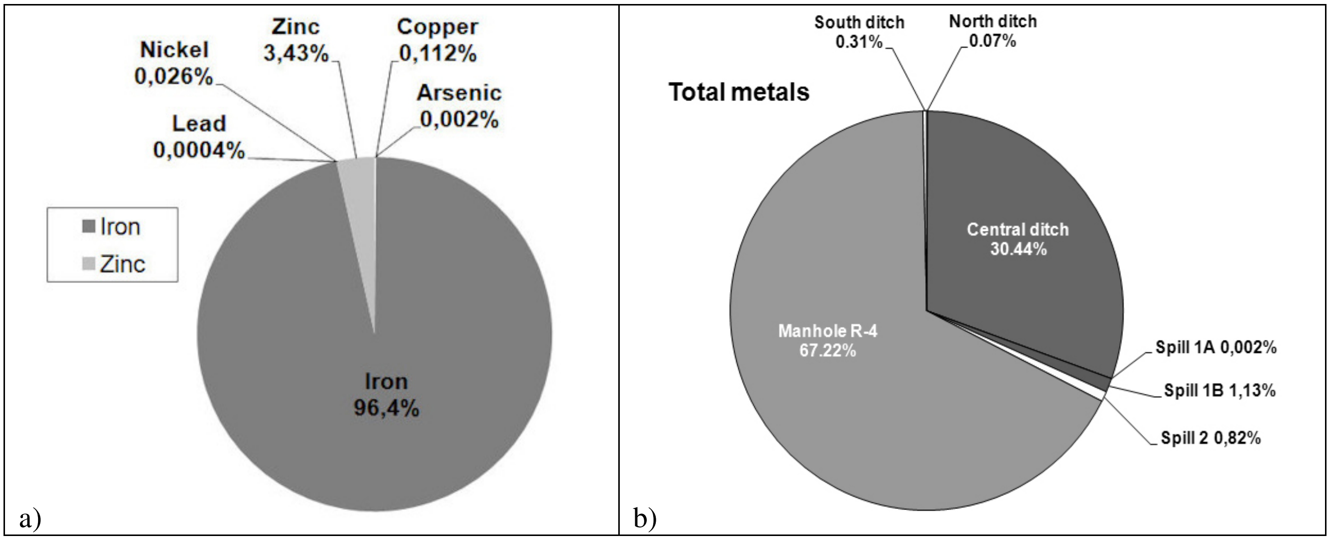

Figure 5. a) Distribution of metals being discharged in the Des Méloizes River and b) contribution per sources

Contribution from the discharge points

The contribution of metal ions from each drainage source reaching the Des Méloizes River depends on the seepage rate and the metal concentrations leaking in the seepage. Figure 5b shows the relative contribution to total metal loadings from all seven discharge points being monitored on site. Manhole R-4 and the Central ditch account together for almost 98% of all metals being discharged in the Des Méloizes River. The seepage collected in the easternmost 250 m long segment of the Central ditch as measured at its weir contains almost half the total metal load (30.44%) that is collected in the 2400 meters long buried drains collecting seepage from all 3 impoundments and being discharged through manhole R-4 (67.22%).

The average concentrations of Fe and Zn as measured in water samples collected from Manhole R-4 and Central ditch between November 2006 and October 2011 (15 samples each) are presented in Table 1.

Table 1. Average concentrations of Fe and Zn

Manhole R-4 (undiluted seepage)			**Central Ditch (diluted seepage)**		
Fe	Zn	Zn/Fe ratio	Fe	Zn	Zn/Fe ratio
2075 mg/L	27.8 mg/L	0.013	382 mg/L	31.2 mg/L	0.082

Since the seepage recovered in the Central Ditch is exposed to rainwater, it is expected to be more diluted than the seepage collected in the drain and sampled in Manhole R-4. Despites the dilution expected from the surface water reaching the Central Ditch, the Zn concentration in the seepage into the Central ditch is higher (31.2 mg/L) than in the seepage collected by the buried drains reporting to Manhole R-4 (27.8 mg/L). This leads to suggest that the seepage chemistry is definitely not homogeneous across the tailings basins.

Relative contribution of sources of Fe and Zn

The metal composition of the seepage evaluated at the seven sampling points is not constant throughout the reclaimed site. Figures 6a and 6b show the relative contribution of each source to iron and zinc loading, respectively. Manhole R-4 is the main contributor of iron (68.58%) and the Central ditch is the main contributor of zinc (71.45%).

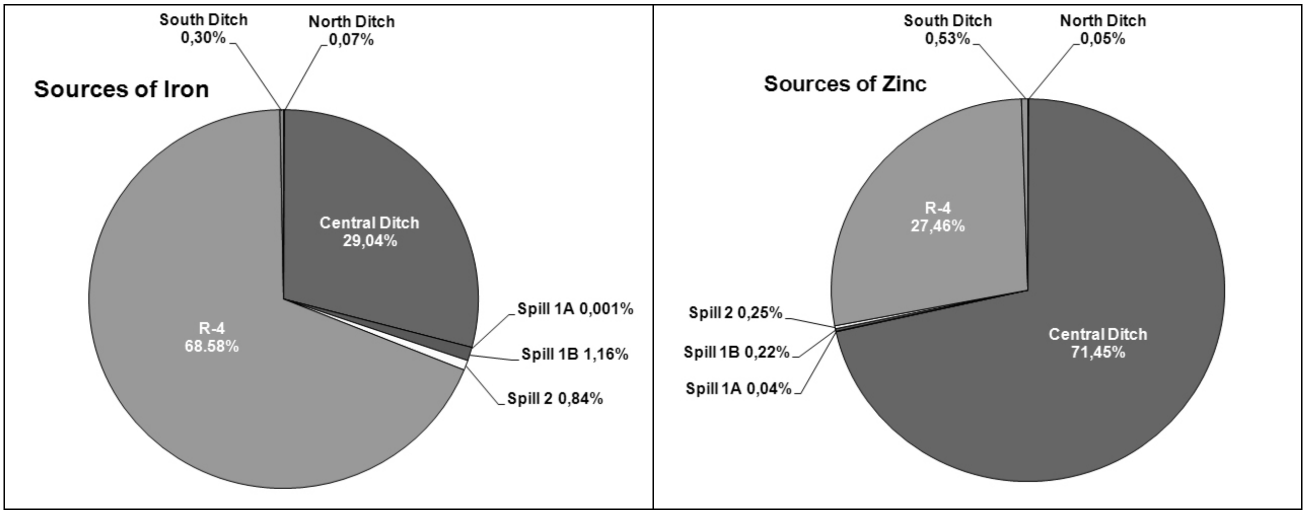

Figure 6. Sources of iron a) and zinc b) and their relative contribution.

Variation of metal discharge rates in time

One of the main objectives of a reclamation plan is to reduce the impacts of mine tailings on the environment and as quickly as possible. Graphs shown in Figures 7, 8 and 9 present the efficiency of the reclamation plan to reduce metal discharge since the implementation of the monitoring program in 2007.

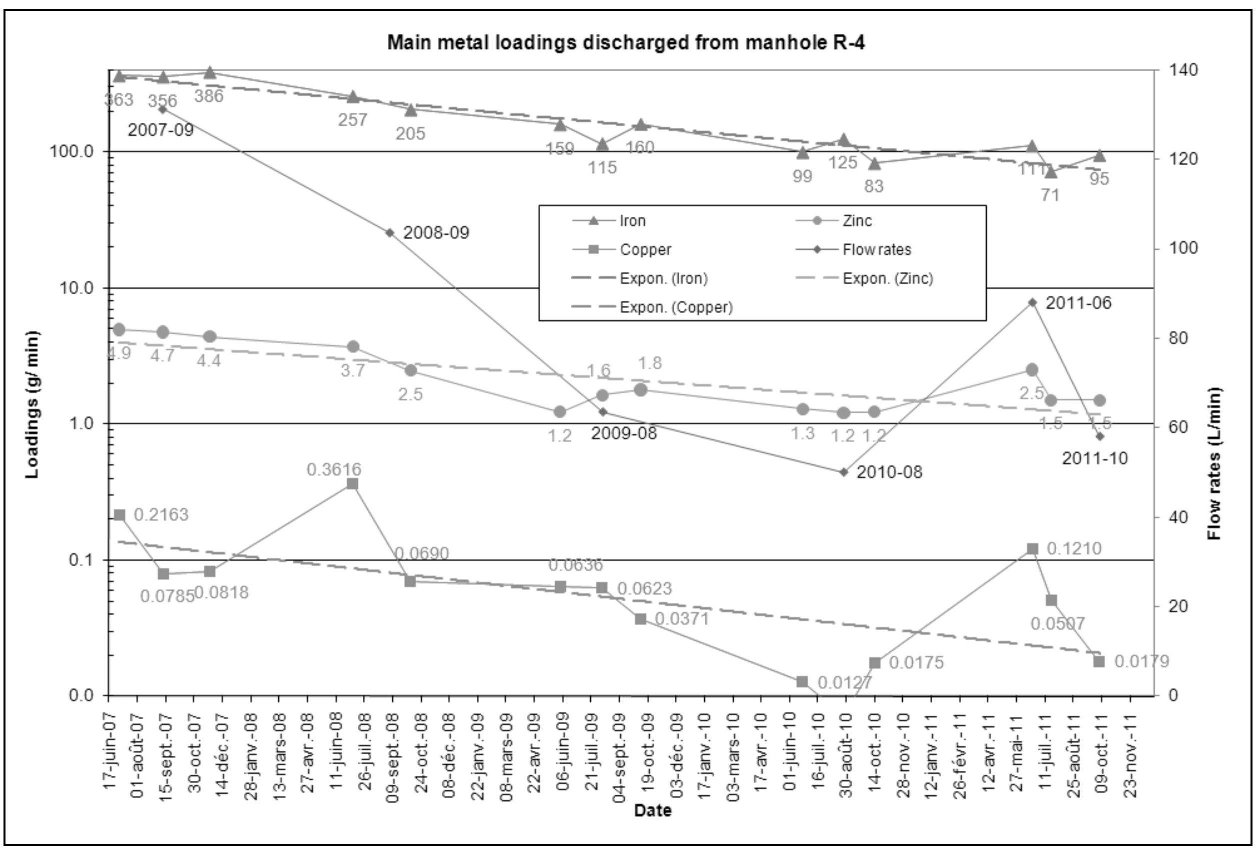

Figure 7. Variation in time of the main metals discharged from manhole R-4

Figure 7 shows metal discharge rates measured in manhole R-4, the main contributor of discharged metals. The trend lines shown as a dashed line for each of the three metals are the “best fit” curves obtained by regression using the LAB Fit Curve Fitting Software. All three metals show a decrease in their discharge rate by more than 70% over the last four years.

Before 2011, the flow rate at manhole R-4 was measured only once a year, always during the “Summer” campaign in either August or September. Sampling was done three times a year and discharge rates were calculated assuming a constant flow rate during all three campaigns. The year 2011 was an exception with two measurements of flow rate instead of one, but no measurement during the second half of the summer as in the previous years: the first measurement of flow rate was in June and the second one in October. Seasonal fluctuation in the flow rate was identified for the first time in 2011. The high flow measured in June might be a consequence of a recharge from the spring freshet: a hypothesis that should be validated with more frequent measurements in 2012.

Figure 8 and 9 show the variations of metal loadings in the Central ditch and into the Des Méloizes River. The Central ditch exhibits a pattern similar to manhole R-4: a decrease in metal discharge rates greater than 58% since 2007. Flow rates are not measured in the Des Méloizes River: the data shown on Figure 9 are the sum of discharge rates measured at the seven sampling points. As expected from the results in Figures 7 and 8 for the main contributors, Fe, Zn and Cu discharge rates in the Des Méloizes River decreased respectively by 76%, 64% and 71% between 2007 and 2011.

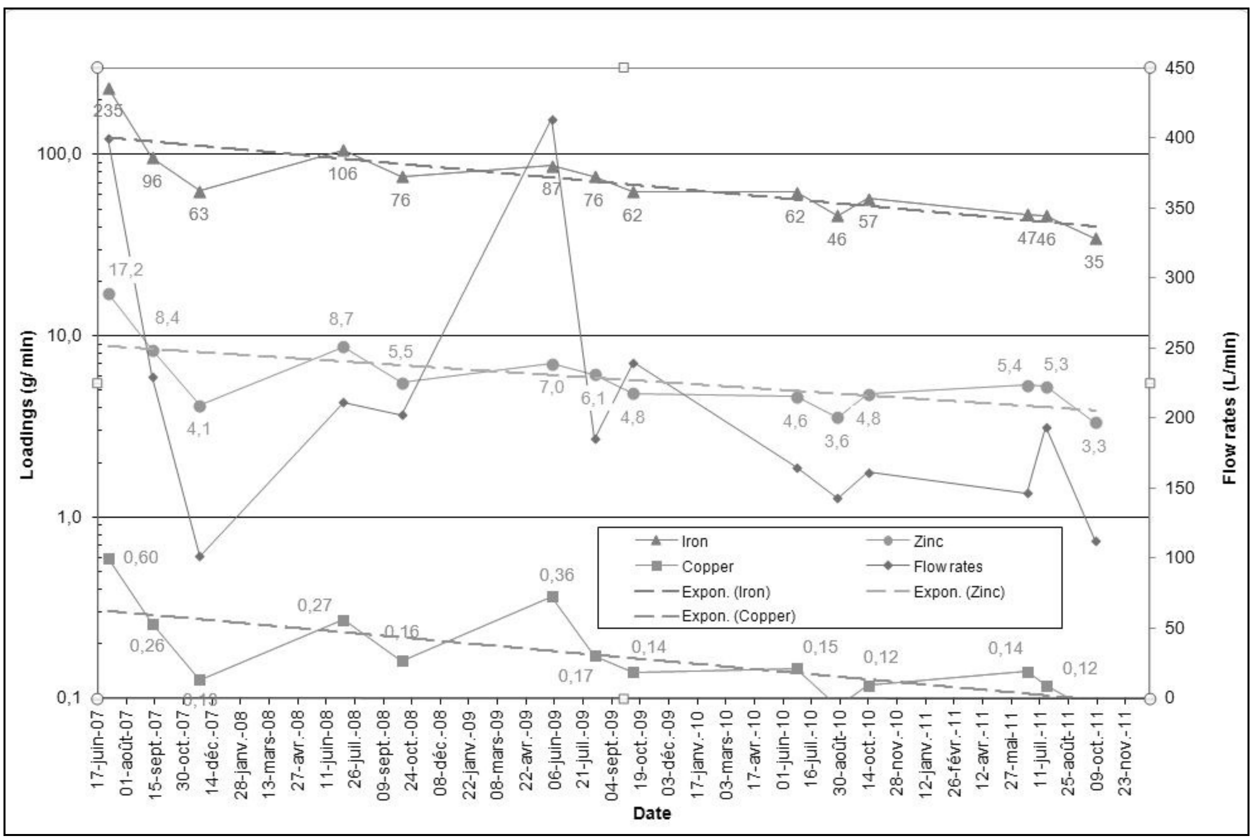

Figure 8. Variation in time of the main metals discharged from the Central ditch

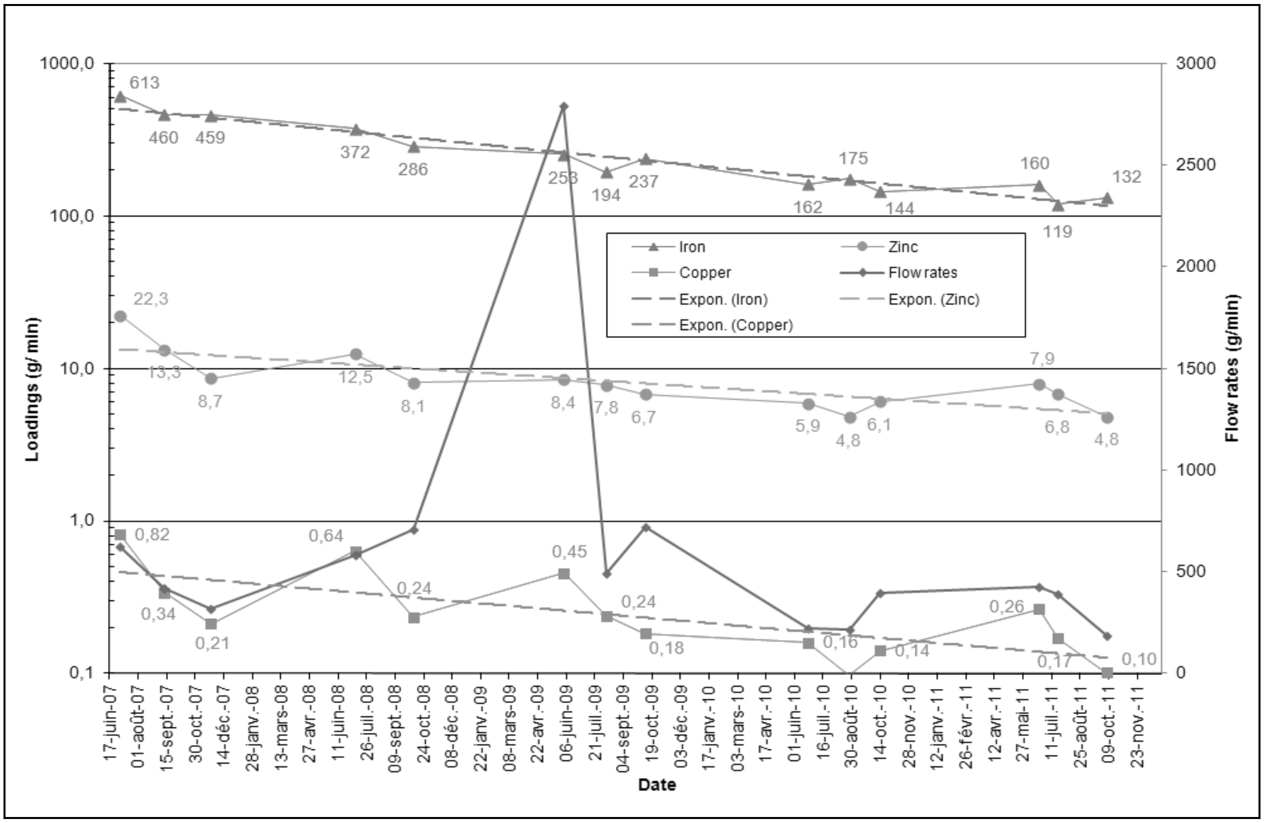

Figure 9. Variation in time of the main metals discharged into the Des Méloizes River. Best-fitted trend lines show that iron loadings decreased from 500 to 120 g/min (-76%), zinc decreased from 14 to 5 g/min (-64%) and copper decreased from 0,45 to 0,13 g/min (-71%) between 2007 and 2011.

Cover Performance

No evidence of erosion was found on the cover or in the ditches at the toes of the impoundments and hence no traces of tailings are observed in the tributaries of the Des Méloizes River. This is a first indication that the cover succeeds its function of protective layer stopping the migration of tailings. Additionally, the geomembrane used at the Normetal site acted as a successful hydraulic barrier to control water infiltration into the acid generating waste pile. This is the most obvious factor that led to the efficient drawdown of the table as the water infiltration recharging the tailings stack is essentially reduced to an insignificant amount. Moreover, the grain size distribution of the tailings is fairly coarse which implies that the permeability is relatively high and facilitates also a rapid drawdown of the water.

The water table height has a significant impact on the overall success of the reclamation works to improve progressively the water quality in the Des Méloizes River. The seepage collected in the Central Ditch and effluent from manhole R4 will continue to affect the water quality downstream of the site as long as the tailings will not have been completely drained. However, if this trend of drawdown of the water table persists in the future, resulting in an observed annual reduction of 25% per annum, we can presume that the discharge rate of contaminants in the environment will be negligible at about 1% of its post-construction level by 2023, 16 years after the end of construction.

Regarding the recreational use of the site by the residents of Normetal, some of them have already used part of the site to fly model aircrafts and to snowglide. Projects are currently being submitted to Xstrata who granted funds to help implement popular projects.

Conclusion

This paper presented a case of successful reclamation of a site storing AMD generating material using a geomembrane cover. As a result of the reclamation plan implemented between 2005 and 2007, all the mine tailings at the Normetal site are now covered by an impervious geosynthetic liner and protected by a thick layer of clay supporting a dense, self-sustaining grass cover. This combination of materials makes the engineered cover very resistant to natural erosion processes, ensuring that the tailings remain permanently confined.

Revegetation works were completed in 2007 and now most of the surface of the cover is overlain by dense vegetation populated by migrating birds. Overall, the water quality of the Des Méloizes downstream of the site has continued to improve due to a significant reduction in loads of iron and zinc emitted from the site. Decreases in loads of iron and zinc are particularly eloquent and the results of the monitoring program carried out to date indicate a progressive improvement of the water quality by about 25% *per annum*. Since 2007, the charges of iron and zinc emitted by the site have decreased by 76% and 64%, respectively.

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