Spatial water quality distribution in the water cover used to limit acid mine drainage generation at the Don Rouyn site (QC, Canada)

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ABSTRACT

Highly sulphidic (approximately 85% pyrite) and potentially acid generating mine tailings were subaqueously deposited into the old Don Rouyn quarry pit between 1997 and 2000. The site, covering an area of approximately 7.7 ha, is located in Rouyn-Noranda, Quebec. Various *in situ* measurements and laboratory tests were performed during the summer of 2005 to study tailings erosion and resuspension, and to characterize water quality in the water cover and ground water around the pit. *In situ* measurements include water cover depth, vertical profile and spatial distribution of pH, temperature, dissolved oxygen, electric conductivity and redox potential. Laboratory analyses performed on water (groundwater and water cover) samples include alkalinity, acidity, potassium, elementary analysis and suspended particles. Physical, mineralogical and chemical tailings properties were also determined. Collected data are presented and interpreted. Results show no tailings erosion or resuspension under the site conditions. Moreover, no water contamination was observed during testing. Groundwater, water cover and effluent water quality meet Quebec's regulations. Additional studies are planned to assess the long-term efficiency of the water cover.

RÉSUMÉ

Des résidus miniers très sulfureux (environ 85% de pyrite) et potentiellement générateurs du drainage minier acide ont été déposés dans l'ancienne carrière de Don Rouyn entre 1997 et 2000. Ce site qui couvre une superficie d'environ 7.7 ha est localisé à Rouyn Noranda au Québec. Plusieurs mesures in situ et tests de laboratoire ont été effectués durant l'été 2005 pour étudier l'érosion et la remise en suspension des résidus, et pour caractériser la qualité de l'eau dans la couverture aqueuse, et dans les eaux souterraines autour de la carrière. Les mesures in situ comprenaient les profondeurs de la couverture, le profil vertical et la distribution spatiale du pH, de la température, de l'oxygène dissous, de la conductivité électrique et du potentiel d'oxydoréduction. Les analyses au laboratoire quant à elles ont porté sur l'alcalinité, l'acidité, l'analyse élémentaire et la mesure des matières en suspension. Les propriétés physiques, minéralogiques et chimiques des résidus ont également été déterminées. Les données collectées sont présentées et interprétées dans cet article. Les résultats ont montré une absence d'érosion et de remise en suspension sous les conditions actuelles du site. De plus, aucune contamination de l'eau n'a été observée durant la période de l'étude. La qualité des eaux souterraines, de l'eau de la couverture et de l'eau de l'effluent respecte aisément les exigences de la réglementation sur l'eau au Québec. Des études additionnelles sont prévues pour étudier la performance à long terme de l'efficacité de la couverture hydrique.

1 INTRODUCTION

The main environmental problem associated with surface storage of mine tailings is acid mine drainage (AMD), because it causes water contamination and can seriously affect the environment. This phenomenon occurs naturally when sulphide minerals in the tailings oxidize when exposed to air and water. Chemical equations describing such oxidation reactions are provided in the literature (e.g. Aubertin et al. 2002). Among the preventive methods for AMD production in wet climates, reducing the oxygen supply to tailings appears to be the most effective. This can be achieved using water cover because the oxygen diffusion coefficient is 10,000 times lower in water than in air. This technique was used at the Don Rouyn site to limit AMD generation. The Don Rouyn site is a flooded former quarry located 4 km west of Rouyn-Noranda (QC, Canada). Approximately 700,000 m^3 of tailings from Gallen Mine ore treated in the Horne Smelter concentrator having very high pyrite content was deposited underwater between 1997 and 2000. The artificial reservoir has a surface area of about 7.7 ha. Piezometers were installed around the pit to monitor interactions between the water cover and the surrounding environment. An overflow spillway crest controls the water level in the pit.

A water cover is a complex, dynamic system subjected to several factors such as tailings erosion and resuspension, oxygen migration, oxidation of sulphidic tailings by dissolved oxygen (DO), release of dissolved metals, water exchange with the surrounding environment, etc. These factors can influence water deposition efficiency and affect the water quality of the water cover. Several studies on these aspects have been conducted to develop appropriate design tools for water covers (e.g. Adu-Wusu et al. 2001; Catalan and Yanful 2002; Yanful and Catalan 2002; Coastal Engineering Research Center 2002; Peacy and Yanful 2003; Yanful and Mian 2003; Samad and Yanful 2004; Mian and Yanful 2004). Nevertheless, it is important to monitor changes in water quality to ensure effective short-, medium- and long-term performance of AMD control measures. At the Don Rouyn site, long-term prediction of the water quality was performed by Catalan (1998) before the tailings were completely deposited. The study concluded that, given a water cover thickness of 1 m, the effluent could not permanently comply with the mine industry's Directive 019 in force in Quebec. Since the tailings were first deposited at the Don Rouyn site, the Horne Smelter has regularly monitored water quality parameters in the effluent and piezometers.

Water cover efficiency is one of the research projects under the Industrial NSERC Polytechnique-UQAT Chair on Environment and Mine Wastes Management. The Don Rouyn site was retained as an experimental site partly because of the very high pyrite content in the tailings. Preliminary investigations were performed in July 2005 to study the spatial variability of water quality at the Don Rouyn site. Various field and laboratory tests were performed on water and tailings samples taken from the site. This paper describes this investigation and presents the main results.

2 STUDY DESCRIPTION

2.1 Field investigation

The field investigation conducted on 20 July 2005 consisted of measuring water depths below the level of the overflow spillway crest at 64 points throughout the water cover (Fig. 1) using a contact disk attached to the end of a tape measure. Vertical pH profiles and dissolved oxygen (DO) concentrations were then measured in 10 stations at vertical intervals of 20 cm. Locations of the measurement points are shown in Figure 1. Water and tailings were also sampled. Twenty water samples were taken from 10 stations in the water cover (Fig. 1), including a sample near the water cover surface and a sample near the water-tailings interface. Surface samples were taken with a beaker at a depth of about 5 cm for immediate on-site parameters measurement, and with a 1 litre HDPE bottle for laboratory analysis. All bottles were fully filled to limit free void containing oxygen. Bottom samples near the tailings surface were taken with a transparent acrylic horizontal sampler bottle (Alpha model, Wildlife Supply). With a capacity of 2.2 litres, the horizontal bottle allowed sampling of representative water at the desired depth for in-place parameters measurement and laboratory analysis (lab samples were transferred in a 1 litre HDPE bottle). The rest of the volume taken near the tailings surface was also stored in 1 litre HDPE bottles for analysis of solid suspended materials.

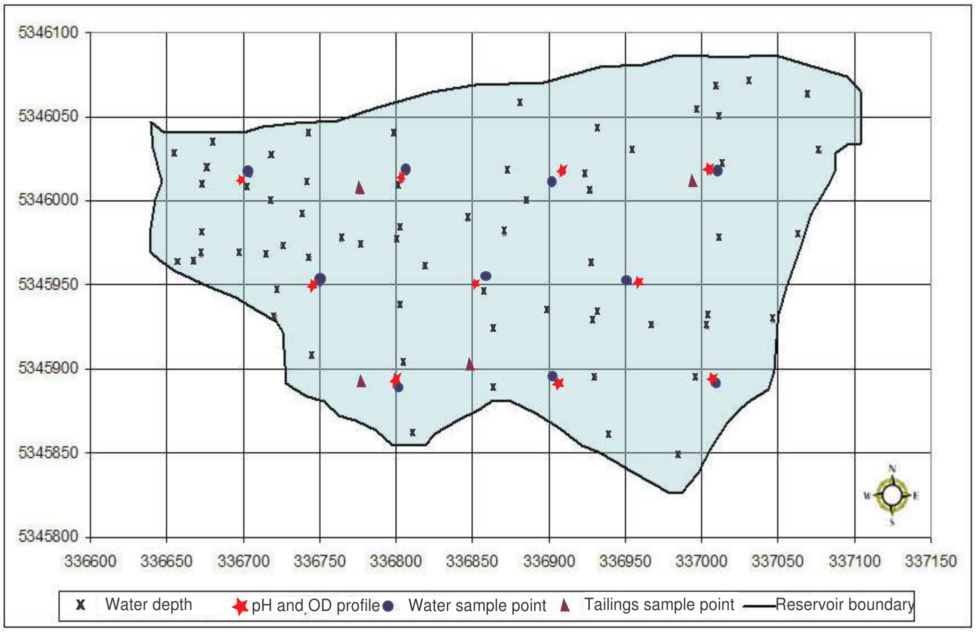

Figure 1. Locations of measurement and sampling points for water cover (NAD 83 SCOPQ coordinates)

Water sampling was also performed on 21 July 2005 in piezometers F2, F3, F5 and F6 (piezometer F4 was destroyed during aggregates operations) located around the pit, as indicated in Figure 2. Near-surface sampling equipment (S) and near piezometer bottom sampling equipment (B) were installed in each piezometer. However, some of the equipment did not work properly, and samples were therefore taken near the surface for F2, F3 and F6 and near the bottom for F3 and F5.

The on-site parameters measured were pH and temperature (using a YSI pH100 probe, YSI Environmental), dissolved oxygen (DO) (using a polarographic electrode, YSI EcoSense® DO200, YSI Environmental), electric conductivity (using a 4075 Traceable® Expanded-Range conductimeter, Control Company) and redox potential (using a CPS 12 platinum electrode, Endress & Hauser).

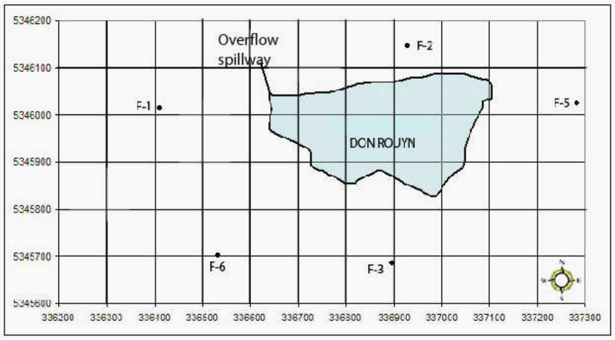

Figure 2. Locations of the 5 piezometers at the Don Rouyn site (NAD 83 SCOPQ coordinates)

In addition to the water samples, tailings samples were taken from the site at 4 locations, as presented in Figure 1. Attempts were made to extract intact tailings cores using an ABS pipe with a length of 2.5 m and a diameter of 3.81 cm. The top of the pipe was hermetically sealed as the tube was driven through the water cover to minimize the volume of water entering the pipe. Once in contact with the tailings, the top of the pipe was opened and driven as far into the tailings as possible. The pipe top was again sealed to take advantage of the suction effect during removal. Once the pipe was completely removed from the water, the bottom was immediately sealed and the tube was transported to the laboratory in an inclined position to limit core degradation. The tailings core was then immediately extracted from the pipe and prepared for analysis.

2.2 Laboratory analysis

Water samples were analyzed for alkalinity by titration in sulphuric acid (H_2SO_4 0.02 N until pH 4.5), and for acidity by titration in a strong base (sodium hydroxide NaOH 0.02 N until pH=8.3). Potassium was measured by a selective electrode in potassium (27502-39, Cole-Parmer), and an elementary analysis of 25 elements was performed by ICP-AES. Sulphate content was also determined by calculation from the concentration in total sulphur, using molar mass ratios. Concentration of suspended particles was also measured in the various water samples collected after filtration of a known sample volume through a 0.45 µm filter. The concentration of suspended particles is obtained by the mass difference between the filter weighed before filtration and the same filter weighed after filtration and drying at ambient temperature for 4 days.

Grain size distribution of tailings was determined using a Malvern Mastersizer laser granulometer to obtain grain size volume distributions for diameters from 0.05 to 900 µm. Solid grains density of tailings was also determined using an Accupyc 1330 Helium pycnometer (Micromeritics). An elementary analysis of the tailings for 25 elements was also performed using inductively coupled plasma-atomic emission spectroscopy (ICP-AES). Mineralogy of the solid materials was determined by x-ray diffraction (XRD). Mineral phases were identified using EVA and quantified using TOPAS (Bruker AXS).

3 RESULTS AND DISCUSSION

3.1 Water cover depths

The results of the water depth measurements below the level of the overflow spillway crest at 64 points distributed across the water cover indicate average depth of 1.23 m, median depth of 1.16 m, minimal depth of 0.81 m, maximum depth of 2.81 m, and a standard deviation of 0.29 m. The surface distribution of water depth is shown in Figure 3. A water cover with a thickness of 1.0 m was assumed sufficient in the original design.

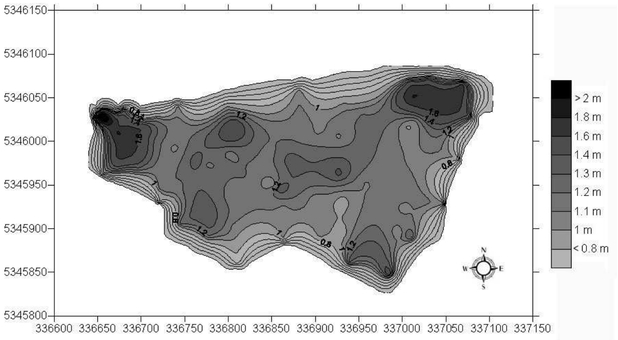

Figure 3. Surface distribution of water depth below the level of the overflow spillway crest (NAD 83 SCOPQ coordinates).

3.2 Tailings characterization

3.2.1 Grain size distribution and density of solid grains of tailings

Figure 4 presents the grain size distribution curves for the 4 tailings samples.

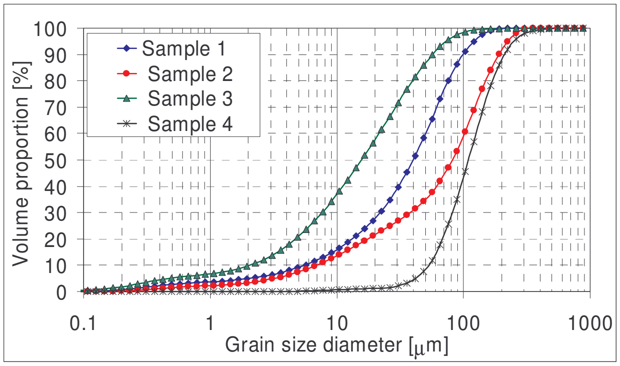

Figure 4. Grain size distribution curves for the 4 tailings samples

The curves show significant heterogeneity in the tailings grain size. Diameters d_{10}, d_{50}, d_{60} and d_{90} are given in Table, where d_x corresponds to x% volume on the cumulative grain-size distribution curve. The mean diameter d_{50} is 62 µm for the 4 samples. This table also shows the densities of the solid grains of tailings, with values from 4.43 to 4.80 and an average of 4.68. These results are close to the density of solid grains of pure pyrite, at 5.01 g/cm^3 (Landry et al. 1995), indicating the large proportion of pyrite in the tailings.

Table1. Tailings grain size and density of solid grains

Sample	Diameter				Density
	d_{10} [µm]	d_{50} [µm]	d_{60} [µm]	d_{90} [µm]	ρ_s [g/cm^3]
1	5.6	39.9	50.5	99.6	4.80
2	6.9	82.2	103.0	189.8	4.68
3	2.1	15.7	21.6	56.4	4.43
4	53.0	110.2	127.0	213.1	4.80
Mean	16.9	62.0	75.5	139.7	4.68

3.2.2 X-ray diffraction

Samples of dried tailings were analyzed. The main mineralogical components are presented in Table 2. Pyrite content varies from 86% to 96% for the 4 samples, with an average of 92%. The high pyrite content can also be observed visually in the dried tailings samples. A mineralogical analysis performed by Catalan (1998) 2 years before the tailings were completely deposited at the site obtained a pyrite content of about 76%. From the results, the finest tailings sample (Nr 3) shows the lowest pyrite content and the coarsest sample (Nr 4) shows the highest pyrite content.

Table 2. Mineralogical analysis of tailings by X-ray powder diffraction (XRD)

Sample	Quartz	Pyrite	Chlorite	Muscovite
1	2.25	95.59	2.14	0.02
2	5.63	91.86	2.37	0.14
3	6.84	85.90	7.03	0.23
4	2.01	95.23	2.63	0.14
Mean	4.18	92.15	3.54	0.13

3.2.3 Elementary analysis of tailings

Table 3 shows the results on the 4 samples for 4 main elements (Fe, Al, S and Zn), clearly indicating the strong dominance of Fe and S. Sample 4 contains the most Fe and S and sample 3 the least. These results corroborate the pyrite content results presented in Table 2. The elementary analysis of tailings by ICP-AES nevertheless contains an error: S content is underestimated and Fe content is overestimated (Mermillod-Blondin 2006). The corrected average for the 4 samples of tailings is 43.2% instead of 51.2% for Fe, and 44.2% instead of 35.6% for S. From the average value of total sulphur measured by ICP-AES, the average calculated pyrite content is 82.9%. This value is lower than the mean value measured using XRD (i.e. 92.15%).

Table 3. Mineralogical analysis of tailings by ICP-AES

Sample	Fe	S	Al	Zn
1	52.2	36.1	0.35	1.01
2	52.4	34.9	0.65	0.47
3	46.6	32.7	1.35	0.68
4	53.6	38.6	0.36	0.33
Mean	51.2	35.6	0.68	0.62

3.3 Erosion and resuspension

Tailings erosion and resuspension occurs when the total shear stress at the water-tailings interface (τ_{tot}) induced by waves (τ_w) and the countercurrent flow (τ_{cc}) ($\tau_{tot} = \tau_w + \tau_{cc}$) is higher than the critical shear stress of tailings (τ_{cr}). Equations to calculate τ_{cc}, τ_w and τ_{cr} are given in the literature (e.g. Adu-Wusu et al. 2001; Yang and al. 2000; Catalan and Yanful 2002; Peacy and Yanful 2003; Yanful and Mian 2003; Mian and Yanful 2004) and are not described here. Total bottom shear stress is calculated using wind speed U, fetch F (which depends on wind direction) and water cover depth. The wind speed and direction used were obtained from Environment Canada's National Climate Archives (Environment Canada 2005) using data collected at two meteorological stations located in the Rouyn-Noranda area (Rouyn WUY and Rouyn A YUY situated at about 2.5 km and 25 km from the site Don Rouyn, respectively). The hourly wind speed *U* at the sampling day is shown in Figure 5. From 8:00 to 18:00, U varied between 2.5 m/s and 7.2 m/s. The fetch was 392 m at a direction of 301° (direction of the dominant winds).

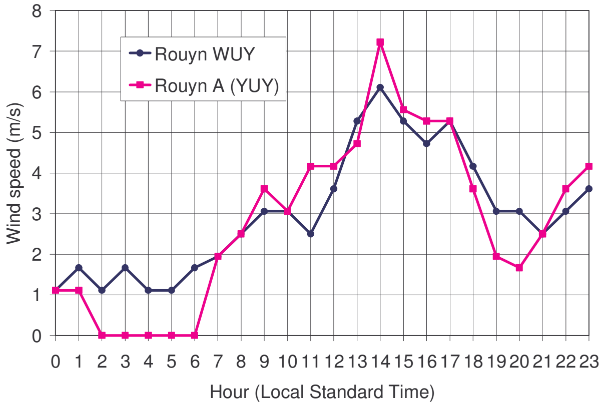

Figure 5. Hourly wind speed on 20 July 2005

When deep water conditions prevail for the site Don Rouyn (when the ratios of water depth and calculated wavelengths are found to be higher than 0.5), the evolution of calculated total bottom shear with wind speed is shown in Figure 6 for three different water cover depths: the measured minimum and median thicknesses of 0.81 m and 1.16 m, as mentioned in section 3.1, and the 1.0 m thickness, assumed as sufficient in the original design. Critical shear stress was estimated using the average diameter d_{50} and the average density of the solid grains of tailings. The value obtained is 0.15 Pa (see also Fig. 6).

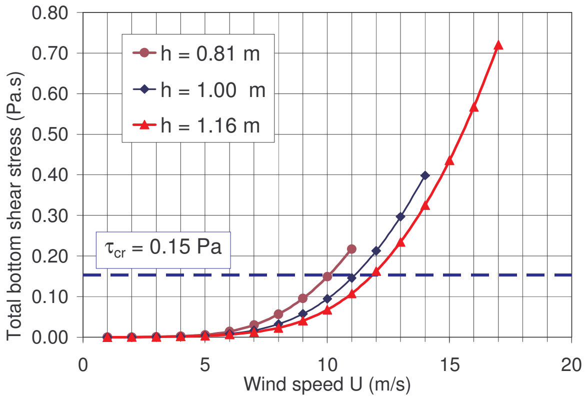

Figure 6. Total bottom shear stress and critical shear stress versus wind speed for different water cover depth.

Even for the maximal wind speed of 7.2 m, the bottom shear stress remains weaker than the critical shear stress of tailings of 0.153 Pa for the three thicknesses, meaning that tailings erosion and resuspension didn't occur on sampling day (on 20 July 2005). However, the average concentration of suspended materials determined for 10 samples taken near the water cover bottom was 3.3 mg/l. Although this value falls well within the acceptable average concentration of 15 mg/l, as defined by Directive 019, the difference observed between the predictions and measurements cannot be explained at this time. Wind speed measurement at the site and further water sampling for suspended sediments analyses are planned. These extra steps will help to better interpretate the tailings erosion and resuspension data.

3.4 Water quality in the water cover

3.4.1 On-site parameters measurement

At the 10 stations where vertical pH and DO profiles were determined, pH varied from 8.1 to 8.3, for an average of 8.2. For OD, the average was 7.8 mg/l and all values were from 7.6 to 8.1 mg/l, with the exception of one value of 7.2 mg/l. No significant pH or OD variation was therefore observed with depth or surface distribution. As the water temperature during the measurement ranged from 25.7 to 26.3°C for an average of 26.1°C, saturated DO concentration is about 8.2 mg/l (Rooney and Daniels 1998). This is slightly higher than the measured values, but the water in the water cover can be considered close to saturation state for DO.

The results for 5 parameters (pH, DO, temperature T, conductivity and Eh) measured on freshly sampled cover water are presented in Table 5. The pH and DO results confirm the above-presented results. pH varies from 8.1 to 8.3 for the 10 surface and 10 bottom water samples. The average is again 8.2, falling well within Directive 019, which requires a pH from 6.0 to 9.5. DO concentrations range from 7.8 to 8.2 mg/l, for an average of 8.1 mg/l for surface and bottom samples. These values are slightly higher than those measured for the vertical DO profiles, probably due to the colder water temperature during sampling, at about 23°C. Saturated DO concentration is about 8.7 mg/l at 23°C (Rooney and Daniels 1998).

Table 5. pH, DO, temperature (T), conductivity (Cond) and Eh measured in the field on water sampled near the water cover surface and bottom

Sample	pH [-]	DO [mg/l]	T [°C]	Cond [µS/cm]	Eh [mV]
Surface					
Mean	8.2	8.1	23.1	507	392
Median	8.2	8.1	23.0	499	398
Minimum	8.1	8.0	22.6	492	345
Maximum	8.3	8.2	23.6	558	414
Bottom					
Mean	8.2	8.1	23.1	495	402
Median	8.2	8.1	23.0	491	410
Minimum	8.1	7.8	22.4	476	367
Maximum	8.3	8.2	23.9	515	418

Electric conductivity was recorded at from 476 to 558 µS/cm, with very slightly lower values for the bottom samples. The overall average is 501 µS/cm. Electric conductivity gives a good estimate of water salinity, which is not very high in this case. In mining effluents containing some acid mine drainage, conductivities from 4800 to 14,000 µS/cm are often found, and sometimes as high as several hundreds of thousands (Aubertin et al. 2002). The water conductivity in the Don Rouyn water cover was therefore below what is typically found in AMD contaminated effluents.

In contrast to the electric conductivity, redox potential was slightly higher in bottom samples than surface samples. Overall values are from 345 to 418 mV, for an average of 397 mV. These values are too weak to be considered potentially AMD generating.

3.4.2 Laboratory analyzed parameters

The laboratory analysis results are presented in Table 6. Acidity (Ac) and alkalinity (Alc) show no variation across samples, with an acidity of about 3 $mgCaCO_3/l$ measured for all samples and alkalinity measured at 40 $mgCaCO_3/l$. The difference between acidity and alkalinity is negative, which indicates that, in the current conditions, there is no risk for the cover water pH to become acid.

Sulphate concentrations (SO_4^{2-}) range from 200 to 202 mg/l, for an average of 201 mg/l. To compare, one year after the tailings were completely deposited, the water cover at the Health Steele Mine (New Brunswick), Catalan and Yanful (2002) showed sulphate concentrations from 1190 to 1300 mg/l. Given the concentrations measured at the Don Rouyn site, the water meets Quebec's quality criterion for surface water, which is 500 mg/l.

Table 6. Chemical contents measured in the laboratory by ICP-AES in 10 water samples taken near the surface of the water cover and 10 samples taken near the bottom of the water cover

Sample	Ac	Alc	K^+	Al	As	B	Ba	Be	Bi	Ca
	[mgCaCO$_3$/l]		[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]
Surface										
Mean	3	39	1.99	0.024	<0.03	<0.005	0.022	<0.007	<0.02	91.3
Median	3	39	2.02	0.024	<0.03	<0.005	0.022	<0.007	<0.02	91.3
Minimum	3	39	1.81	0.017	<0.03	<0.005	0.021	<0.007	<0.02	90.7
Maximum	3	40	2.05	0.033	<0.03	<0.005	0.024	<0.007	<0.02	91.6
Bottom										
Mean	3	40	1.99	0.025	<0.03	<0.005	0.022	<0.007	<0.02	91.4
Median	3	40	1.95	0.025	<0.03	<0.005	0.021	<0.007	<0.02	91.2
Minimum	3	39	1.93	0.014	<0.03	<0.005	0.021	<0.007	<0.02	90.4
Maximum	3	40	2.30	0.039	<0.03	<0.005	0.023	<0.007	<0.02	92.4

	Cd	Co	Cr	Cu	Fe	Mg	Mn	Mo	Na	Ni
	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]
Surface										
Mean	<0.001	<0.002	<0.001	<0.01	-	7.75	0.013	0.051	3.82	<0.004
Median	<0.001	<0.002	<0.001	<0.01	0.008	7.76	0.013	0.051	3.83	<0.004
Minimum	<0.001	<0.002	<0.001	<0.01	<0.005	7.70	0.013	0.043	3.78	<0.004
Maximum	0.003	<0.002	<0.001	<0.01	0.138	7.78	0.014	0.060	3.85	<0.004
Bottom										
Mean	<0.001	<0.002	<0.001	<0.01	-	7.76	0.013	0.052	3.82	<0.004
Median	<0.001	<0.002	<0.001	<0.01	0.006	7.76	0.013	0.051	3.79	<0.004
Minimum	<0.001	<0.002	<0.001	<0.01	<0.005	7.73	0.013	0.048	3.74	<0.004
Maximum	0.001	0.003	0.001	0.01	0.058	7.78	0.014	0.058	4.10	<0.004

	P	Pb	SO_4^{2-}	Sb	Se	Si	Ti	Zn
	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]
Surface								
Mean	<0.08	<0.07	201	<0.03	<0.07	0.271	<0.004	0.082
Median	<0.08	<0.07	201	<0.03	<0.07	0.269	<0.004	0.082
Minimum	<0.08	<0.07	200	<0.03	<0.07	0.258	<0.004	0.076
Maximum	<0.08	<0.07	202	<0.03	0.07	0.294	<0.004	0.089
Bottom								
Mean	<0.08	<0.07	201	<0.03	<0.07	0.263	<0.004	0.121
Median	<0.08	<0.07	201	<0.03	<0.07	0.262	<0.004	0.083
Minimum	<0.08	<0.07	200	<0.03	<0.07	0.247	<0.004	0.074
Maximum	<0.08	<0.07	202	<0.03	<0.07	0.286	<0.004	0.473

No significant spatial variations were noted for potassium and the 25 elements analyzed by ICP-AES, with the exception of iron, which varies from a minimum lower than the detection limit (0.005 mg/l) to a maximum of 0.138 mg/l. This is still a low concentration, because the median value for iron is 0.008 mg/l. For zinc, values range from 0.074 to 0.089 mg/l, with the exception of a surprising value of 0.473 mg/l. This value is the only one that approaches the threshold for effluents, stipulated in Quebec's mining industry Directive 019 at 0.50 mg/l. Concentrations of elements As, B, Be, Bi, Ni, P, Pb, Sb and Ti are below their respective detection limits for 20 water samples. For Cd, Co, Cr, and Cu, the great majority of samples have concentrations lower than their detection limits, and otherwise concentrations approach the limit. Concentrations of Ba, Mn and Mo are also very low, as well as Al, although the latter is present in the tailings. Al is almost insoluble in water with pH higher than 6.

3.5 Groundwater characterization

Results of the parameters measured in the field in piezometers F2, F3, F5 and F6 are presented in Table 7. Significant differences between these results are found, especially for DO concentration and electric conductivity, which vary from 2.6 to 8.0 mg/l and from 295 to 1153 µS/cm, respectively. These differences are linked neither to piezometer locations nor sampling positions (near the surface of the bedrock or near the bottom of the piezometer). Compared with the results obtained for cover water, pH in the piezometers is closer to neutrality or else very slightly acidic. DO, temperature and redox potential are lower than in the cover water. Electric conductivities are lower in F2, F5 and F6 and higher in F3 compared to the water cover.

Table 7. pH, DO, temperature (T), conductivity (Cond) and Eh measured in the field on water sampled near the surface (S) and near the bottom (B) in piezometers

Piezometer		pH [-]	DO [mg/l]	T [°C]	Cond [µS/cm]	Eh [mV]
F2	S	7.2	3.8	14.2	295	237
F3	S	6.4	2.6	19.2	1027	171
F3	B	7.3	4.6	14.5	1153	216
F5	B	7.3	8.0	13.2	455	375
F6	S	7.1	6.1	14.6	332	204

Table 8. Chemical contents measured in the laboratory by ICP-AES in groundwater samples taken from piezometers placed around the water cover

Groundwater		Ac [mgCaCO$_3$/l]	Alc [mgCaCO$_3$/l]	K$^+$ [mg/l]	Al [mg/l]	As [mg/l]	B [mg/l]	Ba [mg/l]	Be [mg/l]	Bi [mg/l]	Ca [mg/l]
Piezo F2	S	15	137	0.699	0.020	<0.03	<0.005	0.018	<0.007	<0.02	46.5
Piezo F3	S	247	381	2.48	0.065	<0.03	0.017	0.118	<0.007	<0.02	169
	P	42	320	1.30	0.010	<0.03	<0.005	0.134	<0.007	<0.02	196
Piezo F5	P	22	225	0.321	0.018	<0.03	<0.005	0.005	<0.007	<0.02	88.6
Piezo F6	S	18	126	0.853	0.015	<0.03	<0.005	0.033	<0.007	<0.02	65.3

		Cd [mg/l]	Co [mg/l]	Cr [mg/l]	Cu [mg/l]	Fe [mg/l]	Mg [mg/l]	Mn [mg/l]	Mo [mg/l]	Na [mg/l]	Ni [mg/l]
Piezo F2	S	<0.001	<0.002	<0.001	<0.01	<0.005	5.20	0.398	<0.003	2.01	<0.004
Piezo F3	S	0.001	0.066	0.016	<0.01	26.5	24.9	38.2	0.009	9.61	0.020
	P	<0.001	<0.002	<0.001	<0.01	<0.005	39.9	0.280	0.003	9.79	<0.004
Piezo F5	P	<0.001	<0.002	<0.001	<0.01	<0.005	12.3	0.042	<0.003	3.34	<0.004
Piezo F6	S	<0.001	0.002	<0.001	<0.01	<0.005	5.88	0.297	<0.003	3.10	<0.004

		P [mg/l]	Pb [mg/l]	SO$_4^{2-}$ [mg/l]	Sb [mg/l]	Se [mg/l]	Si [mg/l]	Ti [mg/l]	Zn [mg/l]
Piezo F2	S	<0.08	<0.07	9.11	<0.03	<0.07	6.61	<0.004	<0.02
Piezo F3	S	<0.08	<0.07	179	<0.03	<0.07	5.36	<0.004	0.036
	P	<0.08	<0.07	149	<0.03	<0.07	9.30	<0.004	0.029
Piezo F5	P	<0.08	<0.07	41.0	<0.03	<0.07	5.95	<0.004	0.024
Piezo F6	S	<0.08	<0.07	50.6	<0.03	0.085	5.82	<0.004	<0.02

The results of the parameters measured in the laboratory are presented in Table 8. Distinctive results are obtained for piezometer F3, with some concentrations much higher than for the other piezometers. Concentrations are high for Ca, Mg and Na, explaining the higher electric conductivity. Compared with the cover water, the groundwater has fairly higher acidity and alkalinity, whereas sulphates and zinc concentrations are lower. In terms of groundwater protection, most values meet threshold concentrations, with the exception of manganese in 4 piezometers at concentrations 764 times higher than the F3-S limit. The latter piezometer also presents an iron concentration 88 times higher than the limit and a pH of 6.4, or slightly lower than the recommended lower limit of 6.5. Selenium is also present in large amounts in piezometer F6-S. This value can not be explained at the moment. Further investigations are planned to identinfy the source of Se.

4 CONCLUSION

Field and laboratory investigations performed in summer 2005 to study the spatial distribution of the water quality in the water cover at the Don Rouyn site allowed to draw the following conclusions. The tailings under the water cover are highly sulphidic (average pyrite content above 90%). The average height of the water cover below the level of the overflow spillway crest is around 1.16 m. Hydrodynamic calculations found an overall low probability of tailings resuspension under normal site conditions. A water cover with a thickness greater than 1 m would therefore appear to be sufficient to avoid sulphidic tailings erosion, resuspension and oxidization with exposure to the dissolved oxygen in the cover, which is close to saturation level. Results also indicate vertical and horizontal homogeneity of the water quality parameters in the water cover. At the time of the study, no contamination was found. The cover water falls well within the requirements of Directive 019 for Quebec's mining industry. Groundwater sampled in piezometers around the water cover site also meet most of the threshold concentrations established for purposes of groundwater protection. This study therefore confirms the excellent efficiency of the water cover as a preventive measure for AMD production.

However, the results presented represent a preliminary phase of a project aiming to determine the long-term efficiency of the water cover. Several investigations remain to be carried out, including an analysis of the quality of interstitial waters in the tailings and monitoring of seasonal variations in water quality at the site. In fact, the information supplied by the Horne Smelter indicates a seasonal variation in pH and Zn concentration. These variations have already resulted in application of ponctual corrective measures consisting of applying lime milk to the site.

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