OPTICAL BACKSCATTER MEASUREMENTS OF TAILINGS RESUSPENSION IN A MINE TAILINGS POND

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ABSTRACT

The mining industry in Canada and others parts of the world uses shallow water covers to control and, in some cases, prevent acid generation from sulphide-bearing mill tailings. These covers reduce diffusive oxygen flux into the tailings to very low values resulting in reduced oxidation. At some sites, however, wind induced waves can erode and resuspend tailings in areas under shallow water cover, due to generation of shear stresses higher than the critical shear stress of the tailings. The paper presents and discusses the results of field measurements at a mine tailings site located near Elliot Lake, Ontario. Details of instrumentation platforms installed in the tailings pond are presented. Total suspended solids (TSS) concentrations measured using optical backscatter sensors are also presented. In general, the results show good correlation between wind activity and TSS concentrations. The highest TSS concentrations were observed when winds were strong and in the direction of the major axis of the tailings pond (northwest to southeast). The maximum wind speed observed on two separate monitoring periods ranged from 9 to 11 m/s and the corresponding maximum TSS concentrations were 11 to 85 mg/L. A separate study confirmed that the suspended solids included tailings eroded from the bed. These findings suggest that tailings resuspension should be a consideration in the any tailings area management plan.

RĔSUMĔ

L'industrie minière au Canada et d'autres pays du monde utilise des couvertures aquatiques de faible profondeur pour contrôler et, dans certains cas, empêcher la génération acide des résidus miniers contenant du sulfure. Cettes couvertures réduisent le flux diffusif de l'oxygène dans les résidus miniers à valeurs très basse qui réduisent l'oxydation. Cependant, les vagues induites par le vent peuvent éroder et remettre en suspension les résidus miniers aux secteurs où le couverture aquatique est profonde en raison de la génération des tensions de cisaillement plus haut que la tension de cisaillement critique des résidus miniers. Le papier présente et discute les résultats des mesures au terrain au parc à résidus miniers situé près de Elliot Lake, Ontario. Les détails des plateformes d'instrumentation installées dans le parc à résidus sont présentés. Les concentrations des solides totals en suspension (TSS) mesurées à l'aide des sondes optiques de rétrodiffusion sont également présentées. En général, les résultats montrent la bonne corrélation entre l'activité de vent et les concentrations de TSS. On a observé les concentrations de TSS les plus élevées quand les vents étaient forts et dans la direction de l'axe principal du parc à résidus (nord-ouest au sud-est). La vitesse de vent maximum observée deux périodes de surveillance séparées s'est étendue de 9 à 11 ms et les concentrations maximum correspondantes de TSS étaient de 11 à 85 mg/L. Une étude séparée a confirmé que les solides en suspension ont inclus des résidus miniers du fond. Ces résultats suggèrent que le resuspension des résidus miniers devrait être une considération importante dans le plan de gestion d'un parc à résidus miniers.

1. INTRODUCTION

Disposal of mine tailings under shallow water cover is a common and effective method for reducing sulphide oxidation and the subsequent release of heavy metals to the environment (Pederson et. al. 1997, Yanful and Catalan, 2002). A number of authors have conducted studies on the oxygen consumption and water quality impacts of resuspended tailings (Yanful and Catalan, 2002, Li et. al, 1997). Adu-Wusu et al. (2001) found that bottom shear stresses due to wind-generated waves were a major factor in the resuspension of flooded uranium mine tailings at shallow depths.

During the last two decades, a lot of effort has been devoted to furthering understanding, of the role of sediments in lake systems (Håkanson, 1977, 1982; Sheng, 1979; Jonsson, 1980; Lick, 1982; Aalderink et al., 1984; Carper and Brachmann, 1984; Kenny, 1985; Bengtsson et al., 1990). The resuspension of sediments by wind action can lead to temporary increase in turbidity and enhance material cycling into the water column. The transport of tailings particles can be a major problem, as tailings are a major contaminant and, in addition, due to their relatively large surface to mass ratio they have large adsorptive capacities. An increase in the total suspended solids at effluent discharge points might mean an elevated concentration of heavy metals being desorbed into the receiving waters.

There has been very little work done on the influence of wind generated waves on sediment resuspension and its effect on water quality in mine tailing ponds (Yanful and Catalan, 2002; Adu-Wusu et al., 2001, Mian and Yanful, 2001, Mian and Yanful, 2002, Mian and Yanful 2003). Due to their small fall velocities, fine-grained particles (in the silt and clay size range) are easily transported by flows. An understanding of the dynamics of these particles in shallow tailings ponds is important since they may repeatedly settle to the bottom and be resuspended throughout the water column. Calmano et al. (1994) found that resuspension of river sediments at a pH of 7.5 rapidly oxidized constituent pyrite and other metal sulphides, resulting in the release of toxic and heavy metals. In the case of tailings ponds, resuspension by wave action can increase the oxidation of sulphide bearing tailings and also enhance heavy metal cycling by bringing sedimentary heavy metals into the water column.

Sediment resuspension is a function of several factors. The process begins with energy delivered to the water surface through wind action. The amount of energy depends both on the wind velocity and fetch. The friction created initially between the wind (moving air) and the pond surface (motionless water) produces small surface deformations or ripples that progressively build into waves, as the wind continues to blow. Below the surface water moves in circular eddies, the energy of which dissipates with depth. When a wave moves into water with depth less than one half its wavelength, the wave is said to "feel" the bottom (Carper and Brachmann 1984). Yanful and Catalan (2002) observed that bottom shear stresses produce a direct force on the sediment bed and are responsible for erosion and resuspension. The amount of scour or resuspension would depend on the magnitude of stress and the type of bottom sediments. From experimental studies Wu (1975) described wind induced flow in ponds and lakes as countercurrent flow. Similarly, Baines and Knapp (1965) and Lawrence et al. (1991) noted that the wind induces a shear stress at the surface of the tailings pond, which in turn drives a surface drift current in the direction of the wind and a return current near the tailings bed. Lick (1986) and Yang (2001) noted that wave action is generally dominant in shallow waters, whereas return currents are more important in deeper waters.

Mian and Yanful (2003) measured wave height in two tailings ponds and concluded that wave heights and hence bottom shear stresses increased with increase in wind speed. Also, Mian and Yanful (2004) analyzed four years of total suspended solids (TSS) data at the outlet of a mine tailings pond. These authors concluded that the shear stresses generated by wind induced waves in the shallower regions of the tailings pond likely resuspended tailings particles and transported them to the deeper areas of the tailings pond and the effluent outlet. However, in the studies conducted in mine tailings ponds either grab samples of TSS concentrations were taken (Mian and Yanful, 2004) or sediment traps were installed and left in place over several weeks (Adu-Wusu et al., 2001). Where these studies established the importance of a number of factors such as wind speed and direction, fetch, and wind-wave and current generated bottom shear stresses and gave quantitative estimates of net sediment resuspension, they were not able to show a clear relationship between transient wind events and corresponding changes in TSS concentrations.

The present study was thus initiated in response to the need of collecting time series measurements of TSS concentration and the corresponding wind data in mine tailings ponds. It also provides an example of how TSS concentrations vary in shallower than 1 m water cover depths. Measurements were made during October 2003 to November 2003. Design details of platforms fabricated for housing TSS measuring sensors and data loggers inside the tailings pond are presented. Initial results of some time series measurements at a shallow water cover depth (0.75 m) are discussed. Finally, some conclusions are drawn based on the results provided.

2. SITE LOCATION

The study site was the Quirke Cell No. 14 tailings pond, which is part of the Quirke Waste Management Area (QWMA) owned by BHP Billiton and located approximately 16 km north of the city of Elliot Lake, Ontario, Canada. The Quirke mine was a low-grade uranium mine that operated from 1956 to 1961 and from 1968 to 1990. The Quirke ore deposit was classified as low grade (0.1 % or less $U_3 O_8$ content) and contained 5-10 % pyrite, 0.11 % U_3O_8, 0.02 % ThO_2, and 0.056 % rare earth elements such as yttrium, cerium, and neodymium. Approximately 95 % of the uranium ore was removed in the milling process. Therefore, the tailings had low radioactivity, however, they are acid generating due to their pyrite content (SENES Consultants Limited, 1989). The QWMA is 192-ha in area and is divided into five cells, 14 to 18, by internal dams. From Cell 14 in the western section to Cell 18 in the east, the tailings surface drops approximately 15 m. Final flooding of all cells was completed in 1995. Figure 19 illustrates the five cells at QWMA. All the cells except Cell 14 are currently being stabilized with lime against acidity generated from previously oxidized tailings. Cell 14 is the largest of the cells and covers an area of 64-ha. Before flooding, the tailings beaches were tilled with lime and re-graded to provide a minimum water cover depth of 0.6 m (Golder Associates Limited, 1993). Cell 14 is bound by Dams K1 and K2 to the west and Dam L to the north. Site visits conducted during 1999 to 2002 showed that the minimum water cover depth in the cell fluctuates between 0.3 m in summer to 0.65 m in winter. Figure 1 shows a map of Quirke Cell 14.

3. MATERIALS AND METHODS

3.1. Time History of TSS Concentration

To measure variation of suspended tailings concentration with time, commercially available OBS-3 sensors were obtained from D&A Instrument Company, USA. The OBS-3 measures suspended solids concentrations with a backscatter method. The sensor consists of a high intensity infrared emitting diode (IRED), a detector (four photodiodes), and a linear, solid state temperature transducer. The IRED produces a beam with half-power points at 50˚ in the axial plane. The detector integrates IR scattered between 140˚ and 160˚. Visible light incident on the sensor is absorbed by a filter. The OBS-3 sensors were connected to a CR10X data logger (Campbell Scientific Inc., Logan, UT, USA). The sensors were programmed using PC208W (Campbell Scientific Inc., Logan, UT, USA). TSS measurements were made every 10 minutes.

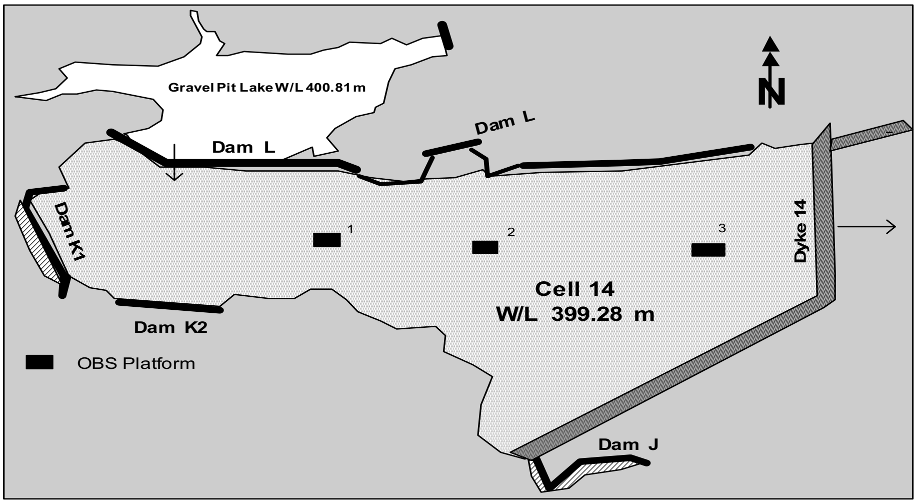

Fig 1. Site Map of Quirke Cell 14

3.2. Location of Stations and Installation of OBS Sensors

From previous studies (Adu-Wusu et al., 2001; Mian and Yanful, 2003) it was observed that for the range of wind speeds occurring at Quirke Cell 14 site, the wave induced shear stresses exceeded the critical shear stress for erosion of tailings at shallower than 1 m water cover depths. To select the station for TSS measurements, a bathymetric survey was conducted at the site using a survey rod. From visual observation and consideration of the dominant wind direction at the site, three stations were selected such that winds would have a maximum fetch to blow. Depth of water cover at the selected stations ranged from 0.75 m to 1.2 m. The locations of the stations are shown in Figure 1. A motorized boat was used to access each station, and an OBS carrying survey staff was installed manually in the tailings. To keep the data logger and other equipment safe 1.5 m x 1.5 m platforms were designed. Figure 2 shows a photograph of the platform together with a data logger assembly and the solar cell for powering the equipment. In the present paper results from only one OBS sensor installed at 0.75 m (fixed at 10 cm height above the tailings surface at all times) are presented.

3.3. OBS-3 Calibration

The OBS sensor was calibrated using Quirke Cell 14 tailings prior to installation. Initially, the probe was immersed in a bucket full of distilled water such that the sensor was submerged at least 5 cm in the water. The tailings sample from Quirke cell 14 was mixed thoroughly and the total solids content of the mixture was determined using Standard Methods (Method 2540 B with wet weight substituted for sample volume in the calculations). Five to ten equal increments of the mixture were then weighed with the total dry weight needed to produce the maximum concentration expected at the monitoring site. The tailings were then added in increment and a stirring motor was used to mix the tailings thoroughly. The output voltage was then recorded for each increment. Samples were also withdrawn for suspended solids analysis after each increment. The output voltages during each increment were then plotted against the total solids data and fitted with a polynomial curve as shown in Figure 3. This calibration curve was then used to convert voltage outputs from the OBS sensor to total solids concentrations at the tailings site.

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Fig 2. Photograph of the platform and data logger assembly installed at 0.75 m of water cover depth

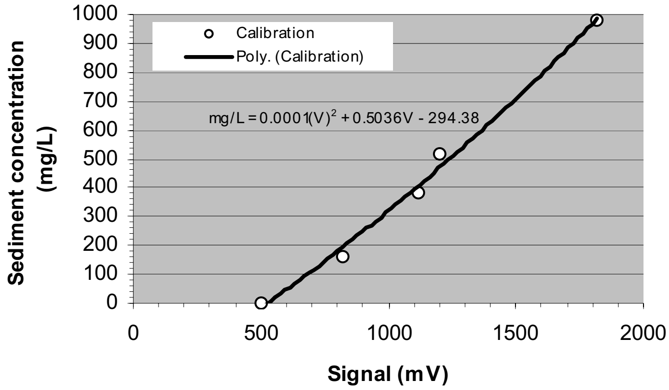

Fig. 3 OBS 3 calibration curve

3.4. Wind Measuring Technique

The movement of material in tailings ponds is mostly caused by waves and currents (Yanful and Catalan 2002). Yang (2001) showed that tailings resuspension is caused mainly by wave action under shallow water wave condition, while under intermediate and deep-water wave conditions counter currents contribute to erosion and resuspension as well. The major controlling factor for tailings transport is thus the speed, duration and frequency of winds (Catalan and Yanful 2002; Mian and Yanful 2001). At the Quirke Cell 14 site, a Young Wind Monitor model 05103-10 RM linked to a data logger type CR10WP (Campbell Scientific Inc., Logan, UT, USA) was used to measure wind speed and direction. The wind monitor was mounted 10 m above the water surface in the tailings pond and in an area that was not sheltered by topography. Wind speed and direction were measured every hour.

4. RESULTS

Partheniades (1965) observed that sediment entrainment rate increased rapidly for shear stress greater than the stress needed to initiate noticeable entrainment, that is, the critical shear stress. Bengtsson et al. (1990) also showed that when the bottom shear exerted, for example, by waves exceeds the critical shear stress for initiation of sediment motion, the bottom is scoured. Mian and Yanful (2004) showed, through the analysis of suspended sediment concentrations in a tailings pond, that concentrations tend to increase with wind speed and/or fetch inf the tailings pond. Figure 4(a) shows the TSS concentrations measured every 10 minutes at a water cover depth of 0.75 m for Julian days 299-301. Figure 4(b) shows the corresponding hourly averaged wind speed and directions. The data show that the TSS concentrations follow the same trend as the wind speed, that is, suspended sediments concentrations increase with wind speed, as would be expected. Also, the highest concentrations occur when the winds in same direction as the major axis of the pond (northwest to southeast). The maximum wind speed during this period was 9 m/s and the maximum concentration was 11.4 mg/L.

Similarly, for the period during Julian days 310 and 312, the TSS concentrations followed an increase in wind speed. During this period very high winds of 11 m/s blowing along the major axis of the tailings pond were observed. The TSS concentrations during this period reached a maximum of 85 mg/L. The same trend was observed for the period Julian days 316-318.

A general observation from Figures 4-6 is that when the wind speed and, hence, the total bed shear stress (inferred from wind waves and return currents) increases, the spikes in TSS pattern increase, and when the bed shear stress dissipates the spikes decrease. It can also be seen that TSS concentrations peaks tend to continue even after the wind shear has dissipated, indicating that sediment will remain in suspension after the wind ceases. In case of storms of longer durations these resuspended sediments would be transported by currents to the effluent outlets and might result in effluent TSS concentrations higher than the Federal Effluent Guideline of 15 mg/L.

The average wind speed in case of Figures 4-6 is 5.5 m/s. Wind speed is the most important factor in controlling the size of waves and hence the magnitude of the bottom shear stress (Yanful and Catalan 2002; Catalan and Yanful 2002; Mian and Yanful 2001). Bengtsson et al. (1990) noted that unless the water body (for example, a lake) is very large and the storm is of a short duration, the wave conditions are determined by the wind speed and the fetch and not by the storm duration.

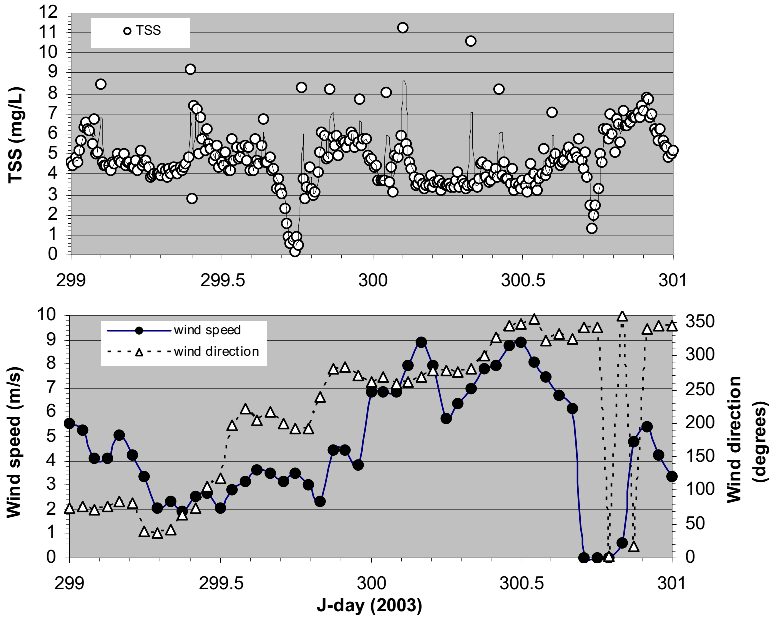

Fig 4. (a) Time series of TSS concentration at 0.75 m of water cover depth for Julian days 299-301 (b) Wind speed and direction for Julian days 299-301 (October 25-27, 2003)

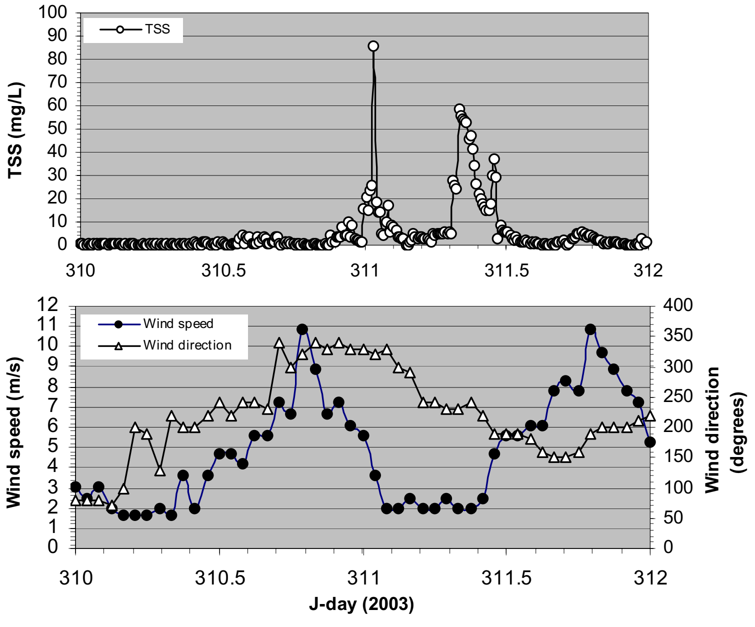

Fig 5. (a) Time series of TSS concentration at 0.75 m of water cover depth for Julian days 310-312 (b) Wind speed and direction for Julian days 310-312 (November 5-7, 2003)

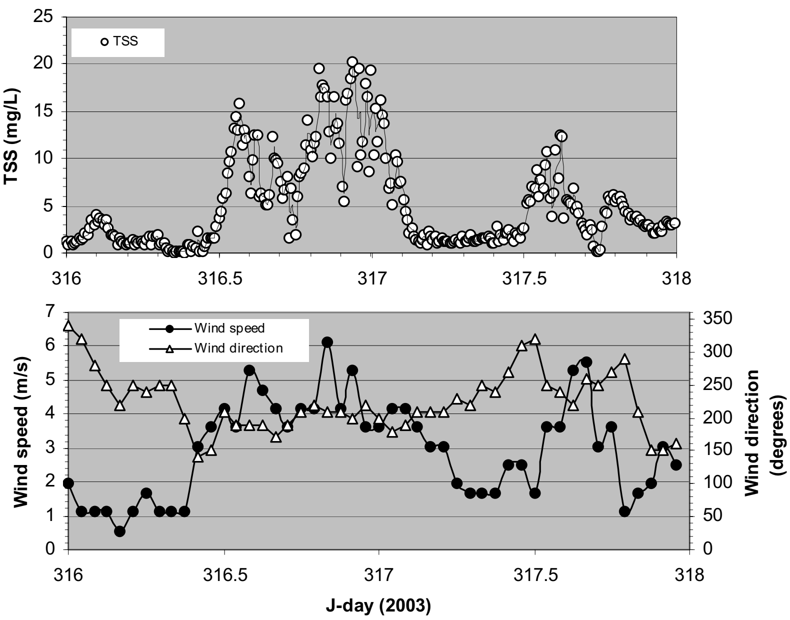

Fig 6. (a) Time series of TSS concentration at 0.75 m of water cover depth for Julian days 316-318 (b) Wind speed and direction for Julian days 316-318 (November 11-13, 2003)

The U.S. Army Coastal Engineering Research Centre (2002) noted that the time required to accomplish fetch-limited waves over shorter fetches is given by the relation:

[1] $$t_{x,u} = C \frac{x^{0.67}}{u^{0.34} g^{0.33}}$$

where $t_{x,u}$ is the time required for waves crossing a fetch of length *x* under a wind velocity of *u* to become fetch limited, *g* is the acceleration due to gravity (ms^{-2}), *x* is the straight line fetch over which the wind blows (*m*) and *C* is a constant equal to *77.23* (U.S. Army Coastal Engineering Research Center 2002)). For the Quirke Cell 14, with a fetch, $F = 1500\ m$ and average wind speed, $U = 5.5\ ms^{-1}$, $t_{x,u}$ is calculated to be 45 minutes. Thus a wind of 5.5 ms^{-1} must blow for at least 45 minutes along the major axis to resuspend the bottom tailings at a water cover depth of 0.75 m. Winds of speed and duration much higher than this value are anticipated at the Quirke Cell 14 site throughout the year, and it is most likely that they would cause resuspension as indicated by elevated suspended solids concentrations shown in Figures 4-6.

6. CONCLUSIONS AND PRACTICAL IMPLICATIONS

The design of shallow water covers for mine tailings ponds is generally based on empirical approaches that are intended to eliminate or minimize subsequent resuspension of tailings (Yanful and Catalan, 2002). Field evidence (Adu-Wusu et al., 2001; Catalan and Yanful, 2002), has however, shown that using these empirical methods to implement a minimum depth of water over tailings did not eliminate resuspension and particle entrainment into the water cover. The main problem with resuspension is that it can compromise the quality of effluent discharged from the flooded tailings by increasing turbidity and also exposing tailings to greater contact with oxygen in the water cover.

Fundamental work on the prediction of resuspension in flooded mine tailings is limited. The mode of erosion of fine-grained sulphide tailings in the field is quite complex and depends on a number of factors such as flocculation and degree of consolidation, near bed turbulence, in-situ tailings structure, and surface cementing action of iron-oxyhydroxides present in oxidized tailings and the chemistry of the pore and eroding fluid.

Adu-Wusu et al. (2001) measured resuspended tailings mass in the Quirke Cell 14 tailings pond by using sediment traps. Mian and Yanful (2003) showed that from wind-wave measurements at the Quirke Cell 14 that the wind generated shear stresses exceeded the critical shear stress from erosion of the Quirke Cell 14 tailings at depth shallower than water cover. Winds from varying directions will tend to have different effect upon the resuspension and sedimentation fluxes at various locations. On very stormy days such as Julian day 311 (November 6, 2003) where the concentrations were as high as 87 mg/L in the water column, it was observed that stormy conditions existed for more than 6 hours, with constant wind speeds of 8-11 m/s and blowing in the direction of maximum fetch. It is inferred that, on such stormy days, tailings particles would remain in suspension, once resuspended and may never settle but could be transported laterally to the effluent discharge point, resulting in high effluent concentrations. It would thus not be surprising to find high suspended solids in the effluent on such days.

Prediction of suspended solids concentrations based on the wind data in tailings ponds could help in the design of new ponds and management of existing ones. In the case of the design of new tailings pond, knowledge of the dominant winds speeds and their directions and predicted tailings concentrations (you cannot use an OBS sensor if there is no tailings pond) could help in deciding the layout of the longer axis of the tailings pond, thus helping in minimizing possible future problems. In case of existing mine tailings ponds, tailings stability could be reevaluated. For example, if the suspended sediment concentration increases to the point where effluent from the pond cannot be discharged, flocculants may then be added to the tailings promote aggregation of fines and settling of suspended solids. Also, by knowing the suspended solids concentrations based on various wind speeds, their direction, and times of occurrence during a year, dredging operations can be conducted before hand and a certain minimum depth of water cover maintained over the tailings to prevent possible high effluent concentrations.

7. FURTHER RESEARCH

Although the present study was able to estimate suspended tailings concentrations at a water cover depth of 0.75 m in the Quirke Cell 14 site, additional research is needed to fully understand the problem of resuspension in tailings ponds. A study is needed to measure the time series of suspended solids concentrations at various water cover depths. Additional research is also needed to confirm that the currents in the tailings pond are small enough not to cause resuspension of the tailings. A more comprehensive and reliable evaluation of sediment transport in the tailings pond would require careful field measurements of current velocity. Further experiments also need to be conducted to fully understand the erosion and deposition characteristics of the cohesive tailings particles. Dependence of the nature of tailings particles on consolidation time, water content, temperature, clay mineral content and salt concentrations also needs to be understood.

8. ACKNOWLEDGEMENTS

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9. REFERENCES

Aalderink, R.H., Lijklema, L., Breukelman, J., W. van Raaphorst and Brinkman, A.G. 1984. Quantification of wind induced resuspension in a shallow lake. *Wat. Sci. Tech.* 17, pp. 903-914.

Adu Wusu, C., Yanful, E. K. and Mian, M. H., 2001. Field Evidence of Resuspension in a Mine Tailings Pond. *Can. Geotech. Journal,* August 2001.

Bianes, W.D. and Knapp, d. J. 1965. Wind driven water current. Journal of the Hydraulic Division, ASCE*,* **91**(2): 205-221.

Bengtsson, L., Hellstrom, T., and Rakoczi, L., 1990. Redistribution of Sediments in Three Swedish Lakes. *Hydrobiologia,* Vol. 192, pp. 167-181

Calmano, W., Förstner, U., and Hong, J. 1994. Mobilization and scavenging of heavy metals following resuspension of anoxic sediments from the Elbe River, in *ACS symposium series 550. Environmental geochemistry of sulphide oxidation (*Ed: C.N. Alpers and D.W Blowes). pp. 298-321 (American Chemical Society, Washington D.C.:USA)

Carper, L. G. and Bachmann, W. R., 1984. Wind resuspension of sediments in a prairie lake. *Can. J. Fish. Aquat. Sci.,* Vol. 41, pp. 1763-1767.

Catalan, L. J. J. and Yanful E. K. 2002. Sediment Trap Measurement of Suspended Mine Tailings in a Shallow Water Cover. *ASCE, Journal of Environmental Engineering*. Vol. 128, No. 1, pp. 19-30.

Golder Associates Limited. 1993. Interim assessment of the hydrological performance of Cell No. 14, Quirke Mine Waste Management Area. Golder Associates Limited, Mississauga, ON.

Håkanson, L. 1977. The influence of wind, fetch and water depth on the distribution of sediments in Lake Vänern, Sweden. *Can. J. Earth Sci.* 14: 397-412.

Håkanson, L. (1982). Lake bottom dynamics and morphometry – the dynamic ratio. *Water Resource. Res*., Vol. 18, 1444-1450.

Jin, K.-R., and Wang, K.-H., 1998. Wind generated waves in Lake Okeechobee. *Journal of the American Wat. Res. Assoc.,* Vol. 34 (5), pp. 1099-1108.

Johnson, T. C. 1980. Sediment redistribution by waves in Lakes, Reservoirs and Embayments. In: Stefan, H. (Ed.) Proceedings of Symposium on Surface Water Impoundments, ASCE, Minneapolis, Minnesota, Paper No. 7-9, pp. 1307-1317.

Kenny, B.C. 1985. Sediment Resuspension and Currents in Lake Manitoba. *J. Great Lakes Research.* 11, pp. 85-96

Lawrence, G.A., Ward, G.A., and Mckinnon, P.R.B. 1991. Wind-wave induced suspension of mine tailings in disposal ponds. A case study. *Can. J. Civ. Eng.,* 18(6), 1047-1053.

Li, M., Aube, A., and St-Arnaud, L. 1997. considerations in the use of shallow water covers for decommissioning reactive tailings. Proceedings of the 4th International Conference on Acid Rock Drainage, Vancouver, B.C. Canada, Vol. 1, pp. 115-130.

Lick, W. 1982. Entrainment, Deposition, and Transport of Fine-Grained Sediments in Lakes. *Hydrobiologia*, Vol. 91, pp 31-40.

Lick, W., 1986. Modeling the Transport of Fine Grained Sediments in aquatic Systems. *Sci. Tot. Environ*., Vol. 55, 219-228.

Mian, M. H. and Yanful, E.K. 2001. Wind Induced Erosion and Resuspension in Two Mine Tailings Ponds Due to Wind Waves. *In: Proceedings 2001 An Earth Odyssey. 54th Canadian Geotechnical Conference, Calgary, Alberta, Canada, Sep 16-19.*

Mian, M. H. and Yanful, E.K. 2002. Analysis of Suspended Sediements Concentrations in a Mine

Tailings Pond. *Ground and Water: Theory to Practice. Proceeding of the 55th Canadian Geotechnical and 3rd Joint IAH-CNC and CGS Groundwater Speciality Conferences, Niagara Falls, Ontario, Oct 20-23* (Ed: D. Stolle, A.R. Piggott and J.J. Crowder) pp. 433-440 (Southern Ontario Section of the Canadian Geotechnical Society: Canada)

Mian, M. H., and Yanful, E.K. 2003. Tailings erosion and resuspension in two mine tailings ponds due to wind waves. Advances in Environmental Research, 7(4): 745-765.

Mian, M. H., and Yanful, E.K. 2004. Analaysis of wind driven resuspension of metal mine sludge in a tailings pond. Journal Environ. Eng. Sci., 3: 119-135.

Partheniades, E. 1965. Erosion and Deposition of Cohesive Soils. *J. Hyd. Div., ASCE,* 91:1, pp. 105-139.

Pedersen, T.F., McNee, J.J., Flather, D., Sahami, A., Mueller, B., and Pelletier, C.A. (1997). Geochemistry of submerged tailings in Buttle Lake and the Equity Silver tailings pond, British Columbia, and Anderson Lake, Manitoba: What have we learned? *Proc. 4th Int. Conf. on Acid Rock Drain.,* Vancouver, Canada, Vol. III, 991-1005.

Sheng, Y. P. and Lick, W. 1979. The transport and resuspension of sediments in a shallow lake. Journal of Geophysical Research, 84(C4): 1809-1826.

US Army Coastal Engineering Research Center, 2002. Coastal Engineering Manual (CEM). US Army Coastal Engineering Research Center, Washington, D.C

Wu, 1975. Wind-induced drift currents. J. Fluid Mech., 68:49-70.

Yang, Y. 2001. Wind induced countercurrent flow in shallow water. Ph.D. thesis, University of Western Ontario, London, Ontario, Canada.

Yanful, E.K. and Catalan, L.J. 2002. Predicted and Field-Measured Resuspension of Flooded Mine Tailings. *ASCE Journal of Environmental Engineering*, 128**:**341-351.