Predicting Discharge Water Quality from Steeprock Pit Lakes in Atikokan, Ontario, Canada

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Abstract
Caland and Hogarth Pit Lakes were formed after flooding of the Steep Rock iron mines near Atikokan, Ontario, Canada. The two pit lakes continue to fill and will eventually join and empty into an adjacent river system. A model was developed to predict the water quality at outflow. At this time, the pit lakes will be approximately 400 m in depth, the oligotrophic freshwater lens in Caland will disappear, and the water will be degraded to more closely resemble the monimolimnion in Hogarth which has sulfate levels up to 2000 mg.l^{-1} . Experiments with wetland plant species determined that outflow water quality could be improved by constructing wetlands in the discharge zone. Of the four plant species examined, *Carex sp.* was able to concentrate the greatest amounts of S, Al, Cu, Fe, Ni, Sr, and Zn in its tissue and make the greatest improvement in water quality.

Key words: meromictic, sulfate, pit lakes, wetlands, plant tissue, remediation

Introduction
Caland and Hogarth pit lakes began to fill after termination of open pit operations at Steeprock Mines near Atikokan, Ontario, Canada in 1979. By 1998, the two pit lakes both had water depths of nearly 200 m but differed dramatically in their water chemistry. Caland pit lake had meromictic conditions with an oligotrophic mixolimnion extending to a depth of 30 m and monimolimnion with sulfate levels up to 450 mg.l^{-1} for 170 m. Hogarth had sulfate concentrations of approximately 1500 mg.l^{-1} and uniform water quality for its 200 m depth except for a very shallow lens at the surface. The monimolimnion in Caland was impacted by waste products from a fish farm that produced anoxic conditions below the chemocline (McNaughton, 2000). A major issue was the toxicity of Hogarth water which initially produced acute and later chronic effects with indicator organisms. As such, remediation methods were proposed that would convert the shallow west arm of the former Steeprock Lake where outflow would occur into a 620 ha wetland. The objectives of the present study were: 1) to develop a model that would describe the sequential flooding of the pit lakes until outflow; 2) to predict the water quality in the pit lakes at outlow; and 3) to determine whether wetland plants could improve the outflow water quality.

Methods
Water samples were collected with a Kemerer bottle from 2m, 18 m and 1 m off the bottom at two sites within both Caland and Hogarth pit lakes (see Fig. 1 in Conly et al –this conference). . Sampling took place in the spring, summer, and winter from 2002 – 2004. data was available from 1992, 1998, and 1999. All analyses were done at LUEL.
A GIS model was developed to forecast the filling of the two pit lakes following the procedures of Mattikalli and Richards (1996). All the GIS analyses were performed on a 10m DEM (Digital Elevation Map) file obtained from the Ontario Ministry of Natural Resources using ESRI's ArcView v. 3.0.The DEM file was clipped to include only those points contained within the flood boundaries of the two pits. Initially the pits were treated separately by creating polygons at 10m intervals. Based on the estimated rate of inflow, visual records of flooding at each point in time were generated. As flooding progressed, the pit lakes joined and were treated as a single pit.
Using the data from 1992 to 2004, repeated measures ANOVA's determined which elements varied with time. For those elements that exhibited temporal variation, regression equations were derived to predict changes over time and this change was extrapolated forward to predict the concentration of these elements at the time of outflow (2030). Elements with no temporal change were assumed to maintain their present concentration. Based on the volume in each pit prior to joining, the mass of each element was determined in each of the pit lakes. After joining and until outflow, the

concentration was assumed to be the average of the two pits. The total mass added after joining for each element was determined from the average concentration of the two pits x the added volume. Total overall mass for each element was then calculated as the total before flooding plus the added mass after flooding. Final concentrations for each element at outflow were then estimated by dividing the total volume at outflow by the total mass.

The potential for wetland plant species to remediate outflow water was determined from planting four common wetland species in mesocosms (2m diameter x 1 m depth) filled with local undisturbed sediment. Water was added to a depth of 20 cm in each mesocosm and any evaporation loss was continually replenished. Three treatments with two replicates for each treatment were used in the experiment and consisted of control (freshwater drinking supply), mixolimnion water from Caland and monimolimnion water from Caland. Each mesocosm was divided into four quadrants into each of which 10 plants from one of the four test species (*Phragmites australis, Typha latifolia, Eleocharis smallii,* and *Carex sp.*) were placed. Plant tissue was collected in the fall of 2002 and 2003, dried, and analyzed for Al, As, Ba, Be, Ca, Co, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, P, Pb, S, Sr, and Zn. Means were calculated for elemental concentrations in the plant tissue of the mesocosms. Univariate ANOVA's determined the significance of plant species, treatment, and plant species by treatment on the concentrations found in both the plant tissue. These concentrations were then used to calculate the effectiveness of plant species to remove the various elements.

Results and Discussion

The sequence of flooding for the two pits is shown by Figure 1. The two major basins (Hogarth and Caland) do not join until 2027 – 2030 and can be considered separately until then. The flooding model predicts the location of the outfall of the Steep Rock pit lakes into the west arm of Steep Rock Lake and into the rest of the Seine river system which may assist in the planning of remedial action to minimize the effects that this flooding will have on the Seine river system. The model accurately predicted that Hogarth and Roberts would join between 2000 and 2003. The two lakes actually connected in the spring of 2002.

Predicted concentrations of water quality parameters in Caland and Hogarth before and after joining are shown by Table 1. In 2027, Ca, K, Mg, Na, Mn, Ni, S, SO_4, Sr, V, and TDS were significantly higher in Hogarth compared to Caland. pH is predicted to be lower in Hogarth.

Variations in tissue concentrations varied between species and treatments (Fig. 2, for S is a good example). Higher levels of S occurred in *Carex sp.* in the deep treatment. In 2003, this pattern continued, with elevated levels of S in *Eleocharis* in the deep treatment as well. *Typha* concentrations had little variation among treatments. Although many plant species show promise in remediation, the four test species (*Carex sp., E. smallii, T. latifolia,* and *P. australis*) were chosen in this study because they occur in natural, local stands, and because the literature suggests they are effective as remediation tools in a wetland environment (Dunbabin and Bowmer 1992; Moshiri 1993; Ye et al. 1997; 1998; 2003; Batty et al. 2000; Fediuc and Erdei 2002; Panich-Pat et al. 2004; Weis and Weis 2004), and have been used to revegetate tailings under wetland conditions (McCabe and Otte 2000). The predicted amount of nutrients removed from the proposed 685 ha wetland is impressive. In the case of S, this would amount to annual removal (tonnes) of 108 for *Carex*, 0.9 for *Eleocharis*, 7.7 for *Phragmites* and 6.533 for *Typha*.

To establish a wetland consisting primarily of *Carex sp., P australis*, *T. latifolia*, and *E. smallii*, the water level in the west arm of Steep Rock Lake should be lowered to a depth ranging from 0.1 to 0.5m. This depth control could easily be facilitated by modifying the existing overflow weir situated at the South end of the West arm of Steep Rock Lake. One of the drawbacks to wetland remediation is that wetlands have a limited extraction capacity and thus require considerable area in order to be effective (Dinges 1982). Size, however, is not an issue in the case of the Steep Rock pit lakes remediation as the proposed wetland consists of approximately 620 ha. However, inflow and residence time must be considered. Moshiri (1993) describes how existing treatment wetlands use a variety of influx rates ranging from 9.5 to 1727.5 L/day/m^2 (LDM) (mean of 111.8 LDM). Wetlands where influx rates exceed 352.3 LDM often do not meet water quality standards (Moshiri 1993). Hence, while the ideal rate of influx remains undetermined, it should not exceed a rate of 352.3 LDM. With an average flow (111.8 LDM) and a size of the proposed wetland at 620 ha, a daily volume of 6.912 x10^8 L of water could be accommodated.

Figure 1 *Predicted flooding sequence within the Steeprock Pit Lakes Basin. One small pit is predicted to join with Hogarth sometime between 2000 and 2003; Caland will join with a smaller pit between 2015 and 2018. At this point there will be two visible lakes (Western and Eastern) each with two basins. The situation is expected to continue until the lakes finally join sometime between 2027 and 2030. Outflow is predicted to occur in 2030.*

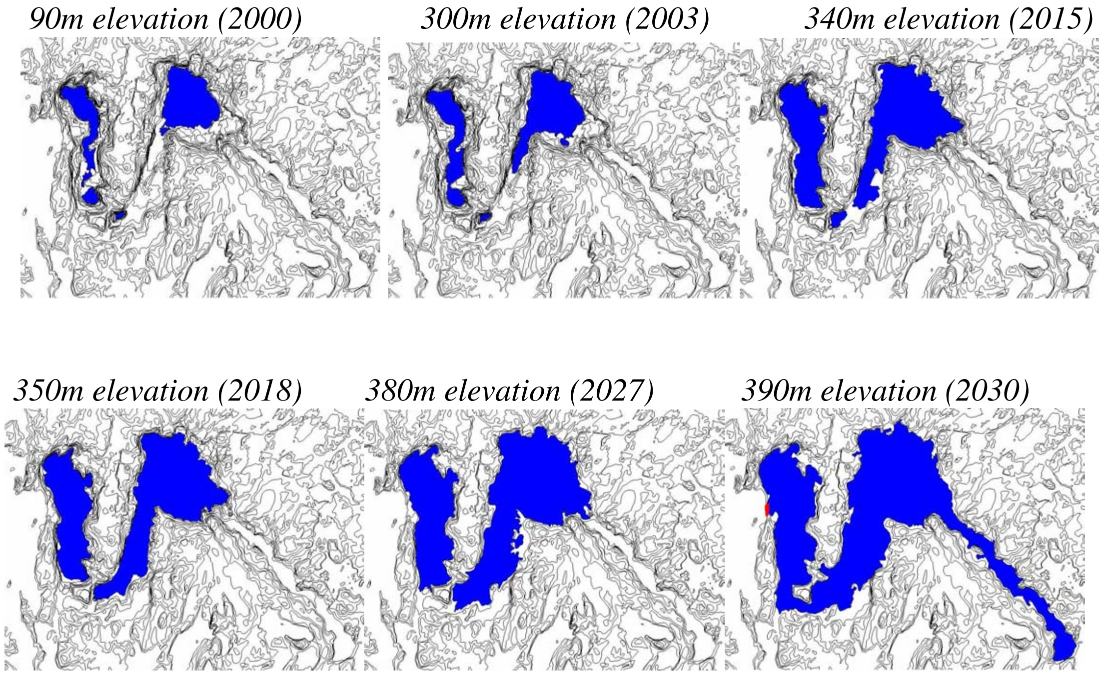
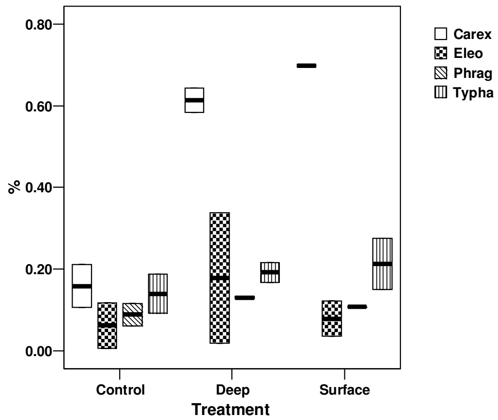


Table 1 *Predicted future concentrations of Hogarth and Caland Pit Lakes and the combined Steeprock Pit Lake at overflow. Results are given in mg.l^{-1} except for conductivity (µS/cm), alkalinity (mgCaCO$_3$/L), and pH.*

	Caland in 2027	**Hogarth in 2027**	**Flood out (2030)**
Al	0.091 ± 0.199	0.112 ± 0.281	0.099
Alkalinity	166.957 ± 10.671	152.782 ± 9.3531	161.816
Ca	115.818 ± 17.610	173.649 ± 9.6525	136.79
Cl	11.081 ± 3.494	21.761 ± 1.2492	14.954
Conductivity	985.721 ± 78.527	3043.3476 ± 67.9201	1731.913
Cr	0.006	0.011	0.008
Cu	0.113 ± 0.001		0.072
Fe	0.078 ± 0.227	0.635 ± 1.593	0.28
K	4.845 ± 0.59	6.461 ± 0.627	5.431
Mg	57.611 ± 9.295	190.623 ± 17.331	105.847
Mn	0.095 ± 0.172	0.171 ± 0.153	0.123
Na	16.083 ± 2.936	24.282 ± 1.327	19.056
NH4	0.093 ± 0.088	0.102 ± 0.103	0.096
Ni	0.009 ± 0.006	0.0018 ± 0.0113	0.006
NO3		1.036 ± 0.204	0.376
pH	7.054 ± 0.363	4.875 ± 0.2515	6.264
S (total)	112.663 ± 43.057	514.687 ± 40.821	258.456
SO4	367.656 ± 47.001	1729.1885 ± 23.1153	861.411
Sr	0.937 ± 0.0909	1.3429 ± 0.1813	1.084
TDS	750.390 ± 68.913	2305.153 ± 98.570	1314.22
TKN	0.198 ± 0.088	0.086 ± 0.066	0.157
Total P	0.012 ± 0.013	0.009 ± 0.002	0.011

TSS	1010.4001 ± 0.5965	28.170 ± 22.061	654.198
V	0.271 ± 0.167	0.631 ± 0.243	0.402

Figure 2 *Mean mesocosm plant tissue concentrations for S grown in water from the control, deep and surface treatments for 2002.*



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References

Conly, AG., Lee, P.F., Goold, A., and A. Godwin. (2008). Geochemistry and stable isotope composition of Hogarth and Caland pit lakes, Steep Rock Iron Mine, Northwestern Ontario. 10th Int. Mine Water Assoc. Congress, Karlovy Vary, Czech Republic.

Dinges, R. (1982). Natural Systems for Water Pollution Control. Van Nostrand Reinhold Co. NY.

Mattikalli, N.M., and Richards, K.S. (1996). Estimation of Surface Water Quality Changes in Response to Land Use Change: Application of The Export Coefficient Model Using Remote Sensing and Geographical Information Systems. J. of Env Manag. **48**: 263-282.

McCabe O.M., and M.L. Otte**.** (2000). The wetland grass *Glyceria fluitans* for revegetation of metal mine tailings. Wetlands 20(3): 548-559.

McNaughton, K. (2000). Limnology of two proximal pit lakes in Northwestern Ontario. M.Sc. thesis, Lakehead University.

Moshiri, G.A. (Ed) (1993). Constructed Wetlands for Water Quality Improvement. Lewis Publishers. Boca Raton Fl.

Weis, J.S., and P. Weis, (2004). Metal uptake, transport and release by wetland plants: implications for phytoremediation and restoration. Environ. Internat. 30: 685-700.