Modeling copper transport in the sediments of Torch Lake, Houghton County, MI
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Introduction
Torch Lake was inundated with copper mine tailings from 1886–1966. Copper concentrations in the sediments continue to pose a significant risk to the benthos. The U.S.EPA has chosen the “No Action” alternative for the lake, but several studies have questioned whether the sediments of Torch Lake are undergoing natural remediation. While copper concentrations in the water column have decreased since the end of mining operations, sediment copper concentrations have not declined.

Copper in the mine tailings primarily exists as readily soluble carbonate and oxide forms, whereas a large fraction of copper in the post-mining sediment is associated with organic matter. This suggests that diffusion of copper in pore waters may be transporting labile copper from the mine tailings upwards, where it is complexed with organic matter in the post-mining sediment. The objective of this study was to develop and apply a mathematical model to the sediments of Torch Lake to investigate the cause of the persistently elevated copper concentrations in surficial sediments, and to estimate the time required for natural sedimentation processes to return these concentrations to an acceptable level.

Methods
A series of sediment cores were taken from Torch Lake in 2004 and 2005 (Figure 1). Cores were dated using 14C and 13C and analyzed for solid-phase and porewater total copper concentrations, bulk density and porosity, and organic matter content. A 1-D numerical model was developed using an Evolution frame of reference relative to the sediment-water interface in which compaction is treated as an advective process (Figure 2). The spatial derivatives associated with advection and diffusion are represented by second-order finite difference approximations and solved using Euler integration. Copper adsorption is represented by a Langmuir isotherm.

Results/Discussion
Visual inspection of Torch Lake cores reveals a clear distinction between mine tailings and post-mining sediment (Figure 3). The two sediment types are also visible in bulk density profiles (Figure 4). The discontinuity was utilized to facilitate “PPF Dating.” Pore-water contamination rates are low, 0.014-0.025 g cm-1 yr-1 (5-9 mm yr-1), as compared with mineral-adsorption rates of 1.2 g cm-2 yr-1.

Copper concentrations in the sediment continue to pose a significant risk to the benthos (Figure 4). All Cu concentrations are significantly higher than the MAAQ銆併 Square Foot Effect Level (PEL) of 197 µg L-1.

Because Cu profiles reveal near-constant concentrations throughout the post-mining sediment, a Langmuir isotherm was selected to represent Cu partitioning in the model. Adsorption parameters were determined based on data from this and previous studies (Figure 5). The numerical model provides a good fit to measured copper concentrations (Figure 6). The model predicts a rapid decrease in solid-phase copper concentrations in surficial sediment (uppermost 1-2 cm). Finer sampling resolution would be required to verify this prediction.

Conclusions
Torch Lake has made little progress towards recovery in terms of solid-phase Cu concentrations. Though Cu fluxes from the sediments to the lake have been attenuated, Cu concentrations in the post-mining sediment remain nearly 2x greater than those in the mine tailings, and an order of magnitude greater than the PEL.

Because pore water diffusion is delivering copper to the post-mining sediment from a very large pool, no significant reductions in solid-phase copper concentrations will be noticed in the foreseeable future.

References
6. Torch Lake sediment flux and metals analysis study Houghton Co., MI. 2006. Great Lakes Environmental Center, Traverse City, MI.

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