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When preparing materials budgets for watersheds containing lakes, the spatial and temporal interchange between large compartments within the whole system must be considered. This paper addresses the lakes of the Integrated Lake-Watershed Acidification Study (ILWAS) and their role in our mass balance calculations for the period of winter stratification of 1978-1979, and presents data on lake metabolism.

Snow accumulation is one mechanism by which strong mineral acids are temporarily stored in the watersheds of regions receiving acidic precipitation. On melting, 50-80% of the pollutant load may be released in the first 30% of the meltwater.[1] Acids may also be stored elsewhere in a watershed, including in various soil layers (where biological activity may generate acids, in addition to acids derived from precipitation) and in the waters of lakes. Furthermore, biological processes within lakes may result in an accumulation of carbon dioxide which can add to the total amount of acid in the lake by forming bicarbonate, depending on the lake pH.

Stratification of ILWAS Lakes

In winter stratified lakes, acids associated with snowmelt may move across the surface of the lake under the ice cover and be discharged from the system.[2] But mixing of inflowing stream water into lakes during winter stratification is strongly influenced by lake and watershed morphometry. The basin topography and large ratio of lake surface to watershed area, 1:69 (Table 1), of Sagamore Lake results in a single stream carrying 89% of the drainage from the 4965 Ha watershed. Both Woods and Panther Lakes are smaller, shallower, froze earlier and were more firmly stratified than Sagamore Lake (Table 1). Both of the smaller lakes have several small inlet channels through which snowmelt-water enters so that water moves across the epilimnion with little advection to the hypolimnion. Woods Lake's hypolimnetic (1-6m) pH in winter was 4.5-5.1, while Panther's (1-5m) was 6.4-6.6. The respective epilimnetic pH values were as low as 4.2 and 5.0. This acidic water was confined to the top 1m or less of the lakes.

Table 1.

Physical Characteristics of the ILWAS Lakes

	Panther	Sagamore	Woods
Elevation, m	562	586	615
Watershed Area, Km^2	1.24	49.65	2.07
Lake Surface Area, Km^2	0.18	0.72	0.23
Surface:Watershed, Ratio	1:6.9	1:69	1:9.0
Volume, $10^6 m^3$	0.709	7.54	0.813
Mean Depth, meters	3.51	11.6	4.22
Flushing Time in days $\frac{\text{volume}}{\text{mean annual flow}}$	230	65	180
Winter Hypolimnetic Volume, $10^3 m^3$	542	3940	616
Winter Hypolimnetic Area, $10^3 m^2$	150	480	160

During the winter of 1978-1979, three episodes of melting occurred which brought large amounts of acid through the lake systems. The first was in early December and affected Woods Lake only. The next episode was in early January when warm temperatures and rain caused melting which dropped the pH in the surface waters of all three lakes. The final episode was the spring thaw in March and April.

The spring melt at Sagamore Lake brought strong inlet stream discharge, up to 14 m^{-3} sec^{-1}, with pH as low as 4.6. This water mixed to 6m depth, depressing epilimnetic pH from 6.0 in early March to 4.2-4.8 in mid-March to mid-April, and exposing the entire littoral zone to this acidic water (with potential biological consequences, as discussed by Hultberg).[3] Sagamore's pH was 5.2 in the epilimnion and 5.6 in the hypolimnion just before ice-out. With clearing of the lake surface and spring circulation, pH for the entire water column was 5.2. Inlet stream pH at this time was near 5.0. Water column pH at spring circulation was thus due to prior input of acids by stream discharge to the epilimnion, mixing of hypolimnetic water of higher pH and input of lower pH stream water to the mixing system.

Hypolimnetic Metabolism

While thermal stratification allows materials entering a lake via stream flow, or from the melting snow pack on the lake surface, to pass through the epilimnion, stratification also prevents much advection of materials to or from the hypolimnion. Since hypolimnetic water is essentially cut off from exchange with the epilimnion, the hypolimnion may be treated, approximately, as a closed reactor. The accumulation of dissolved inorganic carbon (DIC) and uptake of dissolved oxygen (O_2) provide information on the rates of heterotrophic activity in the whole lake, as discussed by Ohle.[4] Consumption of O_2 on an areal basis measured in the period 21 Jan.-16 Mar. (Table 2) was greater in Sagamore than in the other lakes. The initial hypolimnetic O_2 mass for Sagamore, Woods and Panther, respectively, were 1.4, 3.0 and 1.2 moles $O_2\ m^{-2}$, and the dissolved inorganic carbon concentrations (DOC) of the hypolimna were 0.6 $mM^{\ell-1}$ in Sagamore and 0.3 $mM^{\ell-1}$ in the other two lakes.

Table 2.

Changes in O_2, CO_2 and the respiratory quotient RQ in the hypolimnia during winter stratification. The time period was 52 days in Woods and Sagamore and 49 days in Panther.

	$-\Delta O_2$ $mM\ m^{-2}\ d^{-1}$	ΔCO_2 $mM\ m^{-2}\ d^{-1}$	RQ
Woods	6.4 ± .6	10.2 ± .7	1.6 ± .1
Sagamore	10.4 ± 1.2	11.7 ± 1.5	1.1 ± .1
Panther	6.4 ± 0.7	11.8 ± 1.5	1.8 ± .1

The ratio of CO_2 released (calculated from DIC) to O_2 taken up, the respiratory quotient (RQ) is a useful indicator of the extent to which anaerobic decomposition contributes to the metabolism of lakes.[4,5] RQ values of 0.5 to 1 (average 0.85) are expected for completely aerobic respiration.[4] Values greater than this indicate contributions by anaerobic processes to lake metabolism.[4,5,6] Woods and Panther lakes had essentially identical RQ values while Sagamore's RQ was much lower. These differences reflect the similarity of initial O_2 and DOC concentrations and mean depths (Table 1) of Woods and Panther, and their differences from Sagamore. The effect of respiration in the sediments on the O_2 deficit and DIC accumulation of shallow lakes can be expected to be greater than in the deeper lake and this is reflected in the RQ values.

It has been suggested that lake acidification will inhibit microbial activity, reduce the biomass of benthic invertebrates, and lead to an accelerated accumulation of organic debris in lakes, and that neutralization will reverse these processes. Much evidence supports these ideas.[7,8,9,10] Data on the hypolimnetic metabolism of the ILWAS lakes during the winter of 1978-1979 do not indicate an inhibition of community respiration due to acidification. On the other hand, the data and discussion presented here do not include an analysis of the sources or stocks of reduced carbon within the lakes. Carbon inventories are currently being made for the three lakes and will be included in future analyses so that whole-lake metabolic processes can be more accurately compared among the lakes.

References

1. Johannessen, M. and A. Henriksen. 1978. Chemistry of snow meltwater: changes in concentration during melting. Water Resources Res. 14:615-619.

2. Henriksen, A. and R. F. Wright. 1977. Effects of acid precipitation on a small acid lake in southern Norway. Nordic Hydrology 8:1-10.

3. Hultberg, H. 1976. Thermally stratified acid water in late winter, a key factor inducing self-accelerating processes which increase acidification. pp. 503-517 in Dochinger, L.S. and T.A. Seliga (Ed.). Proc. First Internat. Symp. on Acid Precipitation and the Forest Ecosystem. USDA For. Serv. Gen. Tech. Rep. NE-23.

4. Ohle, W. 1956. Bioactivity, production and energy utilization of lakes. Limnol. Oceanogr. 1:139-149.

5. Hutchinson, G. E. 1957. A treatise on Limnology. Vol. I. John Wiley and Sons, New York.

6. Rich, P. H. 1979. Differential CO_2 and O_2 benthic community metabolism in a softwater lake. J. Fish Res. Board Can. 36:1377-1389.

7. Andersson, I., O. Grahn, H. Hultberg, and L. Landner. 1974. Jamforande undersokning av olika tekniker for alterstallande av forsurade sjoar. Institute for Water and Air Research, Stockholm. STU Rept. 73-3651.

8. Grahn, O., H. Hultberg and L. Landner. 1974. Oligotrophication--a self-accelerating process as in lakes subject to excessive supply of acid substances. Ambio 3:94-94.

9. Hendrey, G. R., K. Baalsrud, T. Traaen, M. Laake and G. Raddum. 1976. Acid precipitation: some hydrobiological changes. Ambio 5:224-227.

10. Scheider, W., J. Adamski and M. Paylor. 1975. Reclamation of acidified lakes near Sudbury, Ontario. Ontario Ministry of the Environment, Rexdale, Ont. Canada.