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Nitrogen Cycling in Lake Superior and the Effects of Climate Change

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Background

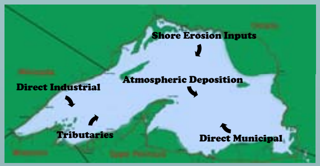
Figure 1: Map of Lake Superior and surrounding geographic areas

• The Lake Superior basin encompasses portions of the Upper Peninsula of Michigan, Ontario, and several counties in northern Wisconsin and Minnesota.

• Lake Superior is a special resource in that it is the largest and cleanest of all the Great Lakes, with long spans of shoreline that have not experienced the same agricultural development, urbanization, and pollution as the other Great Lakes. Among fresh water lakes, it is the World's largest lake measured in surface area and second in volume.

The Nitrogen Sources and Cycling

Figure 2: Lake Superior Nitrogen Sources



Placement of titles do not reflect the location of where nitrogen sources on Lake Superior solely exist. Map credited to Superior Trails.

Sources

The amount of nitrogen in lake water corresponds to local land use. Nitrogen may come from fertilizers and animal wastes on agricultural lands, human waste from sewage treatment plants or septic systems, and lawn fertilizers used on lakeshore property. Nitrogen may also enter a lake from surface runoff, groundwater sources, or from atmospheric deposition (car emissions, etc.) in the form of nitrogen oxide (NOx).

Historically, the trend in loading on Lake Superior is probably anthropogenic and due almost entirely to an increasing rate of atmospheric deposition (Bennett, 1986).

Cycling:

Nitrogen exists in lakes in several forms, namely nitrate (NO_3^-) plus nitrite (NO_2^-), ammonium (NH_4^+), and organic plus ammonium (Kjeldahl nitrogen). Decomposing organic matter releases ammonia, which is converted to nitrate if oxygen is present. All inorganic forms of nitrogen (NO_3^-, NO_2^-, NH_4^+) can be used by aquatic plants and algae. Nitrogen may also be lost from the lake to the atmosphere by deniftrication, this only occurs if oxygen is depleted, allowing nitrate to be converted back to nitrogen gas (N_2).

Figure 3: Total NOx emission sources in the State of Michigan.

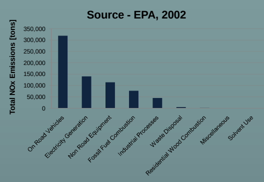
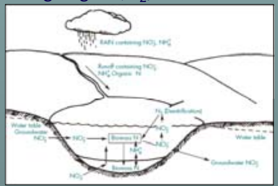


Figure 4: Nitrogen cycling diagram in a lake



Wisconsin Department of Natural Resources (WDNR). Understanding Lake Data

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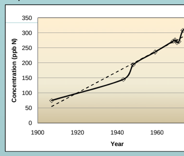
Project Abstract

• Increasing nitrate concentrations in Lake Superior have been well documented over the last decade (Bennett 1986, Sterner et al. 2007). Recent studies suggest that atmospheric deposition alone cannot account for the observed increases in nitrate concentrations and that the N-cycle within the lake is more complex than previously assumed (Finlay et al. 2007). Quantifying nitrogen fluxes will help determine a more complete N-cycle within the lake so we may better understand its future.

Figure 5: Spring nitrate concentrations in Lake Superior



Source: The Nitrifying of Lake Superior by E.B. Bennett (1986).

UPDATE! [NO_3^-] in Lake Superior has continued to rise since 1980, though possibly at reduced rates (Sterner et al. 2007).

Research Objectives for N-cycling in Lake Superior

1. Determine whether current influxes and effluxes of nitrogen (N) support the hypothesis that the lake is at steady state.
2. If it is not at steady state, document the rate of change in inventory resulting from current loadings and sinks.
3. If a mass balance can be achieved on current inputs, use the history of N concentrations to hindcast the historical loadings that must have existed.
4. Compare estimated historical loadings with information on NOx emissions, N atmospheric deposition, population and sewage N inputs, etc…
5. Construct a model of internal cycling on weekly to monthly time step to reconcile observations of "short" N residence time in lake (and large burial flux required), complete biological processing of N in lake, seasonal changes in N species concentrations.

The Effects of Climate Change

• Given the expected trends in world population, demand for food, agriculture practices and energy use, anthropogenic nitrogen fluxes are likely to increase. In addition, humans may likely be responsible for doubling the turnover rates not only of the terrestrial nitrogen cycle but also of the nitrogen cycle of the entire Earth. (Gruber and Galloway, 2008)

Figure 6: Map of Great Lakes.

Source: Map from the United States Protection Agency

• Given the correspondence between high ocean denitrification rates and high atmospheric CO_2 levels, it has been suggested that changes in the marine nitrogen cycle could influence observed variations in the concentration of atmospheric CO_2. However, a recent assessment concluded that it is unlikely that changes in the marine nitrogen cycle were the key drivers for the past changes in CO_2 levels, although they probably contributed to it. (Gruber and Galloway, 2008)

• While effects of climate change on Lake Superior have not been conclusively shown, it will be interesting to examine recent trends in N cycling processes to determine future impacts. Understanding how the N cycle is affected by climate change will be of benefit to help predict future concentrations.

Potential Losses Due to Increasing N-inputs

• Because Lake Superior is phosphorus-limited, excessive N inputs can result in enhanced denitrification rates, enhanced N_2O emissions, shifts in algal species and subsequent changes in food web structure, changes in vegetation in N-limited coastal wetlands and estuaries, decreases in biodiversity, and fishery losses.

International Joint Commission (IJC)'77

• The United States and Canada created the IJC because they recognized that each country is affected by the other's actions in lake and river systems. The two countries cooperate to manage these waters wisely and to protect them for the benefit of today's citizens and future generations.

• The first comprehensive study of Lake Superior was completed in March 1977 by the IJC in the Upper Lakes Reference Study to summarize water uses and related water quality problems for the Lake. A mass balance which included all measured inputs and outputs for total nitrogen (as N) was provided, and may be seen in Table 1 below.

Table 1: Lake Superior Material Balance for Total Nitrogen (As N)

Source	Total Nitrogen Loadings in Tonnes Per Year (ton/yr)				
	Direct Municipal	Direct Industrial	Tributary		Total
			Sampled	Unsampled	
Michigan	50	65	4,050	1,470	5,635
Wisconsin	149	6	3,060	3,070	6,285
Minnesota	50	39	7,230	551	7,870
Ontario	249	456	14,700	2,420	17,825
Atmospheric Inputs					56,000
Shore Erosion Inputs					1,600
Total Inputs					95,215
Total Outputs (via the St. Marys River)					21,900
Accumulation (ton/yr)					73,315

Conclusion

Figure 7: Map of Lake Superior

Source: Map of Lake Superior provided by NASA satellite imagery

• Historical atmospheric deposition of N inputs were almost certainly responsible for an increased NO_3- concentration in Lake Superior.

•Recent studies suggest that atmospheric deposition alone does not account for increasing NO_3^- concentrations. (Finlay et al. 2007)

• Further research of climate change and its impacts on the N cycle will help scientists model changing processes and predict future trends in the N cycling process of Lake Superior.

References Available Upon Request