Abstract. Current estimates of pollutant aerosol input to southern Lake Michigan are based on a single calculated emission inventory and various estimates of the fraction of emissions that enter the Lake. Alternative, but still crude, estimates of urban elemental emissions and their wet and dry deposition in the lake are made here. Observed elemental concentrations in urban air are used to calculate emissions and recently measured wet and dry deposition parameters are used to calculate deposition.

All available treatments conclude that atmospheric inputs of at least Fe, Pb, Ti, and V are sizable fractions of total lake input of these metals. This study suggests tentatively that 1) wet and dry inputs from the atmosphere are about equal, 2) between 3 and 15% of elemental pollutant emissions from Chicago and NW Indiana enter the Lake, and 3) this fraction increases with particle size.

1. Introduction

Information on the relative importance of the major environmental pathways of nutrients and toxic materials into the Great Lakes is badly needed. Such information is crucial to making intelligent decisions for the preservation of the Lakes. One of these pathways is via the atmosphere and we have pursued research to estimate wet and dry deposition of atmospheric pollutant aerosols into southern Lake Michigan. This paper presents key results.

Previous work suggested that atmospheric inputs of some nutrients (Murphy, 1974) and metals (Winchester and Nifong, 1971) comprise sizable fractions of the total inputs of these materials to the Great Lakes. However, there were large uncertainties in some of the data used in previous estimates of atmospheric input. Particularly uncertain were pollutant emission inventories and deposition rates. Furthermore, wet deposition (i.e., via precipitation) has not been estimated for most of the elements studied up to now.

This research comprised three main tasks: 1) to make a new estimate of urban emissions, using measured elemental concentrations in air, 2) to recalculate dry deposition into the southern basin of Lake Michigan, using this emissions inventory and the recent deposition velocity measurements of Cawse (1974), and 3) to estimate wet deposition into the southern basin using the scavenging ratio measurements of Gatz (1974b).

Completion of these three tasks yielded a new estimate of annual elemental inputs of Chicago and northwest Indiana pollutants to Lake Michigan. Although still relatively crude, the results provide support via an independent calculation for the
importance of atmospheric deposition to the chemical composition of the Great Lakes shown by prior research.

2. Literature Review

Recent analysis of bottom sediments (Leland et al., 1973) from the southern basin of Lake Michigan indicates that some elements are concentrated in upper layers. This suggests pollution sources, but cannot distinguish between atmospheric, stream water, or groundwater inputs.

More than a decade ago, Gorham (1958, 1961) pointed out that the atmosphere could provide significant amounts of ions to fresh waters.

Measurements of dry deposition and precipitation input to Lake Ontario (Shiomi and Kuntz, 1973; Shaw and Whelpdale, 1973) have now identified several elements for which atmospheric contributions are a significant fraction of Niagara River inputs. These include Pb (16-41% of Niagara River value), Zn (58-85%), Ni (12-15%), inorganic N (13-14%), and total P (6-14%). For Lake Michigan, Murphy (1974) estimates that 20-33% of all inputs of total P are via precipitation.

These measurements tell us the amounts of certain elements that enter lakes via the atmosphere, but the relative contribution of pollution sources and natural sources is not always clear. Furthermore, it is of interest to ask what fraction of a given city's pollution aerosols enter the lake. No one has measured atmospheric pollutant inputs specifically, but a number of estimates have been made.

Winchester and Nifong (1971) made the first estimates of pollutant inputs via the atmosphere for any of the Great Lakes. They first estimated pollution sources strengths for Chicago, Milwaukee, and Northwest Indiana. They used published data on production or consumption of materials, emission factors for particulate matter, and chemical composition of emissions for several types of sources. From consideration of the frequency of wind direction, the probable height of emission, and reasonable deposition velocities, a transfer efficiency of at least 10% was estimated and applied to estimated emissions. Winchester and Nifong concluded that the inputs of Zn, and possibly Cu, Ni, and other pollutant elements via the atmosphere may be a sizable fraction of the totals entering Lake Michigan.

More recently Robbins et al. (1972) estimated the transfer efficiency for urban and industrial pollutants from the shores of southern Lake Michigan to be at least 20%, and Skibin (1973) estimated it to be at least 25%.

These estimates of pollutant inputs to Lake Michigan are based on an admittedly crude emission inventory and estimates of transfer efficiency that were based largely on assumed deposition velocities of 1 cm s$^{-1}$. Input from precipitation scavenging has not been included in the previous estimates; it has only been acknowledged as an additional deposition mechanism. Nevertheless, these previous calculations suggest that the atmosphere can be a large source of certain elements to the Great Lakes. If this suggestion is supported by the more complete calculation that follows, the importance of atmospheric pathways will be even more firmly established.