ANALYSIS AND COMPARISON OF NORTHEASTERN NEW YORK STATE ATMOSPHERIC PHOSPHORUS DEPOSITION RATES

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ABSTRACT

Bulk atmospheric phosphorus deposition rates were calculated for seven areas of northeastern New York State. Data for this analysis were obtained from the atmospheric deposition monitoring program of the U.S. Geological Survey for 12 years in the period 1968-81. Annual deposition rates were low and comparable to those for other rural areas. The rates were generally below 25 $mg \cdot m^{-2} \cdot yr^{-1}$, in agreement with published values from similar areas in the Northern Hemisphere. In winter the rates tended to be low; in spring and summer they tended to be high. From the reviewed data and calculations, overlake atmospheric deposition rates of around 18 $mg \cdot m^{-2} \cdot yr^{-1}$ should be the rule for the northeastern New York State region, including Lake George.

INTRODUCTION

Intense interest in atmospheric transport and deposition of sulfur and nitrogen compounds is now associated with concern about acid precipitation. Transport and deposition of phosphorus, though currently a less popular concern, is important in the calculation of accurate nutrient budgets for lakes. Nutrient budgets, in turn, play important roles in decisions concerning lake management. This report deals with the range and variation in phosphorus atmospheric deposition rates in northeastern New York State. Specifically the analysis was designed to establish a probable range for deposition rates to the surface of Lake George as well as other lakes in northeastern New York State. Temporal and spatial variations in deposition rates over a 12-yr period were sought for this purpose.

The data for this analysis were accumulated since 1968 by the U.S. Geological Survey (USGS) at up to seven locations in northeastern New York State. Data for two years (1972 and 1973) were unavailable, as phosphorus in precipitation was not analyzed during this period.

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METHODS

The USGS reported areal phosphorus depositions (USGS 1970-73, 1975-79, 1981) at seven stations in northeastern New York State (Figure 1). One of these stations (Lake George) was in operation for only 2 years but provided both bulk and dry/wet collector data for 1980. Delmar and Chazy were changed from single- to dual-collector stations in 1981. The remaining stations (Hinckley, Canton, Stillwater Reservoir, and Albany) provided only bulk collector data dovering periods from 1 to 11 years.

The opening of a bulk collector is usually 1.5 m above ground level and protected by a windshield. Until 1977 a straight-sided glass funnel 165 mm in diameter collected the airborne materials and funneled them into a polyethylene receiving bottle. The bottle and funnel were enclosed in an insulated box. Since 1977 a polyethylene funnel has been used in conjunction with a Teflon reservoir. Until 1977 a fritted glass disk or plug of glass wool filtered out large particulate materials to prevent contamination of the samples. The disk was replaced at the end of each collection period (about 1 month). Since 1977 the disks have been eliminated. The funnel is heated during cold weather to aid in full collection of snow, and a vapor lock is included to prevent evaporation of more than 2-5% of the precipitation.

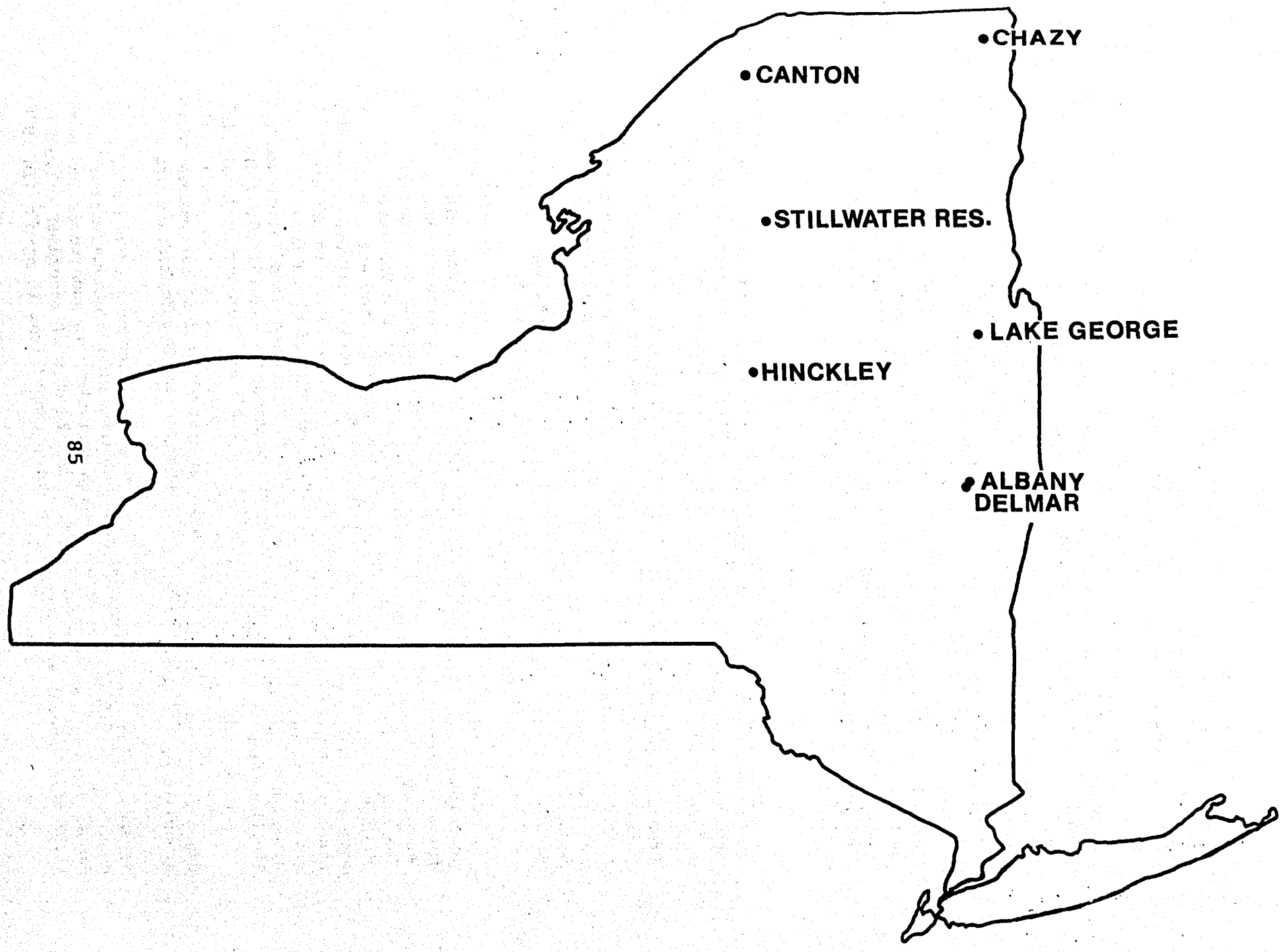
Galloway (1975) notes problems with plastic and glass components of deposition samplers. The effects of the modifications (from glass to plastic funnels, from polyethylene to Teflon receiving bottles, and omission of fritted-glass or glass-wool filters) are unknown, but they are thought to minimize sampler errors. Biologic sources of error are probably much more important (see Discussion).

An Aero Chemetrics Model 101 dry/wet collector with openings 2.5 m above ground level was used in Lake George Villege in 1980. Additional dry/wet collectors were set up at the Delmar and Chazy stations during the 1981 water year in addition to the bulk collectors. The dry/wet collectors have polyethylene sampling vessels 286 mm in diameter with a 13-liter capacity (USGS 1981).

Chemical analysis for phosphorus used the molybdate blue technique. After acid-persulfate digestion the soluble phosphate reacted with ammonium molybdate to form a blue phosphomolybdate complex (Skougstad et al. 1979). This method has a 1 $\mu g \cdot dm^{-3}$ detection limit. Duplicate analyses of split samples by the USGS and the New York State Department of Health laboratories showed excellent agreement (Sutherland et al. 1982). For wet deposition samples in 1981 an annual deposition rate of 14.35 $mg \cdot m^{-2}$ was calculated from USGS data and a rate of 14.12 $mg \cdot m^{-2}$ from Department of Health data.

Annual deposition rates ($\underline{D}$) were calculated (in $mg \cdot m^{-2}$) as

$$D = \frac{\Sigma P \cdot C \cdot 10}{\Sigma t} \cdot 365$$


CHAZY
CANTON
STILLWATER RES.
LAKE GEORGE
HINCKLEY
ALBANY
DELMAR

where $\underline{P}$ is the precipitation (in cm) during the collection period $\underline{t}$ (in days) and $\underline{C}$ is the concentration of phosphorus ($mg \cdot liter^{-1}$). For analysis of dry fall samples P = 1.56 cm, the height occupied by the 1 liter of water used to wash out the collector.

Logarithmically transformed annual deposition estimates were used for statistical analysis. Calculated atmospheric depositions had high variances and a skewed distribution among stations and years. Application of the Tukey test (Snedecor and Cochran 1967) showed significant nonadditivity of the estimates ($F = 11.987$; 1,39 df; $P < 0.005$). The regression coefficient pointed strongly to logarithmic transformation of the data as being the most appropriate.

The transformed data were analyzed for variation among the years represented in the data, as well as among the locations of the stations. Analysis of variance and the least-significant-difference test (Steel and Torrie 1960) were used to compare and contrast the geometric means.

RESULTS

Differences among stations. Statistically different phosphorus bulk deposition rates ($F = 4.827$; 6,41 df; $P < 0.005$) were found for the seven locations (Table 1). Delmar, with 2 years of record, had a high mean rate of 111 $mg \cdot m^{-2} \cdot yr^{-1}$, significantly higher ($P < 0.05$) than the nearby Albany site, with a 10-yr record (28 $mg \cdot m^{-2} \cdot yr^{-1}$). Probable contamination of the Delmar bulk samples is suggested by a parallel dry/wet result for 1981 of 21 $mg \cdot m^{-2} \cdot yr^{-1}$, lower than the mean for the Albany station. For this reason the bulk data from the Delmar station were excluded from most of the following analyses. Exclusion of the Delmar bulk data results in a lesser but still significant difference among the six remaining stations ($F = 2.997$; 5,40 df; $P < 0.025$).

Chazy, with a 7-yr record, had a significantly lower bulk deposition rate (7 $mg \cdot m^{-2} \cdot yr^{-1}$) than most other stations. Rates for all stations except Stillwater Reservoir (4 years of record) were significantly greater than that for Chazy at the 95% level. The low overall deposition rate for Chazy results from estimates in January and April in 1978 and 1979. These estimates were extremely low in comparison to the other 5 years of record and to other published deposition estimates. Omission of these two estimates brings the mean for Chazy to 13 $mg \cdot m^{-2} \cdot yr^{-1}$ and eliminates any significant differences among the stations ($F = 1.651$; 5,38 df). The Chazy data for these two years were excluded from further analysis.

Analysis of the remaining data suggests that long-term mean deposition rates for phosphorus in northeastern New York State are around 18 $mg \cdot m^{-2} \cdot yr^{-1}$.

Variation over time. When the data from all stations were combined, no significant between-year variations in phosphorus deposition could be detected within the 12 years of record ($F = 1.341$; 11,32 df). Annual mean deposition rates ranged from 10 $mg \cdot m^{-2}$ (in 1978)

to 33 $mg \cdot m^{-2}$ (in 1970).

Table 1

Differences in phosphorus bulk atmospheric deposition between stations in northeastern New York State

Location	Record (years)	Bulk Deposition ($mg\ P \cdot m^{-2} \cdot yr^{-1}$)[a]
Delmar	2	111[b]
Albany	10	28
Lake George	2	25
Canton	12	18
Hinckley	11	16
Stillwater Reservoir	4	12
Chazy	5 (7)[c]	13 (7)[c]

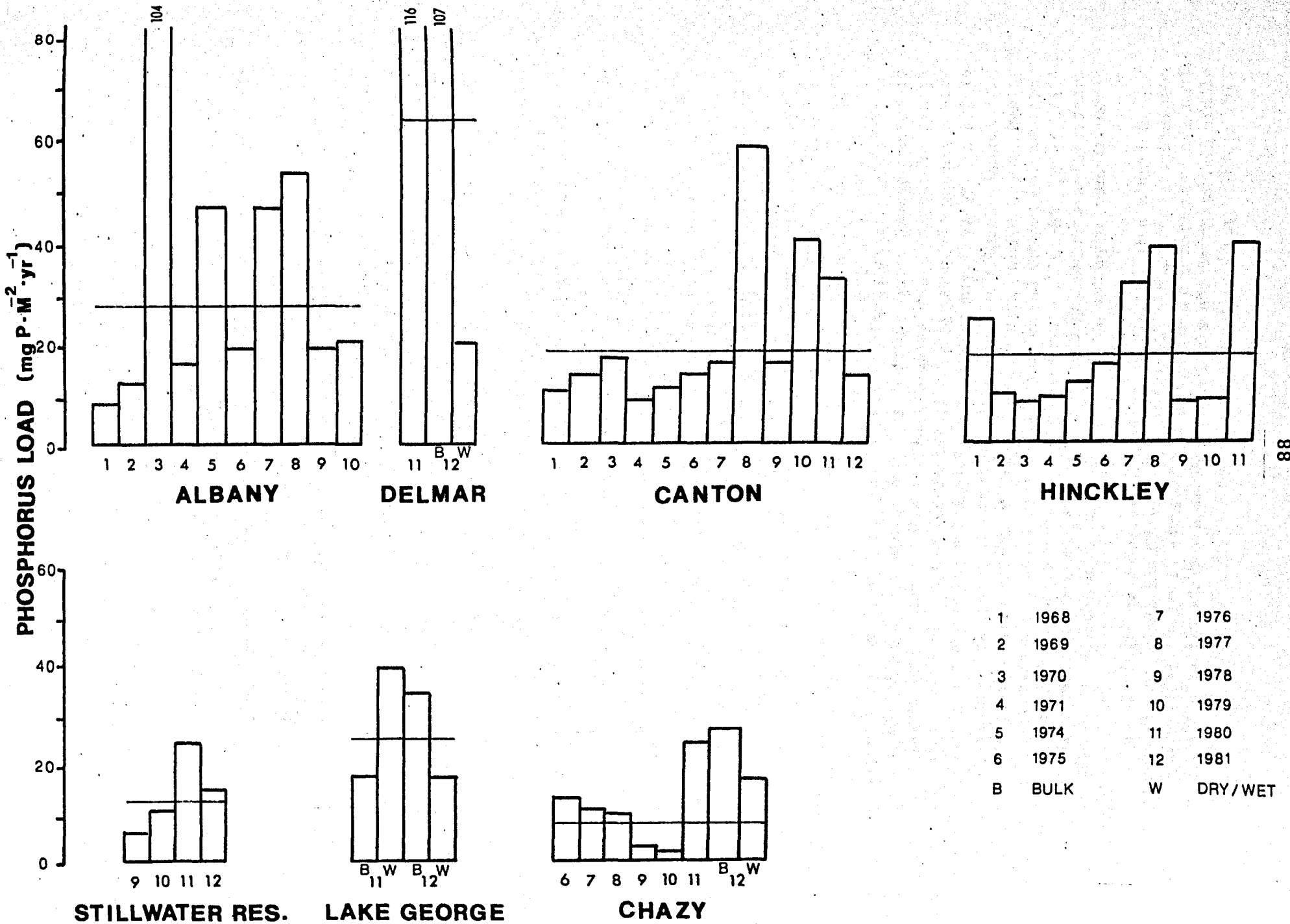
[a] Geometric means

[b] Presumably contaminated (see text)

[c] Presumably the 7 mg $P \cdot m^{-2}$ annual deposition rate for 1978 and 1979 are erroneous

Year-to-year variation at individual stations showed occasional high mean annual rates (Figure 2). These peaks were largely the result of sample contamination events in all but one or two monthly values during the peak years. At the Albany station in 1970 a rate of 104 $mg \cdot m^{-2} \cdot yr^{-1}$ was calculated. This large value was due to two high monthly deposition values of 1.608 and 0.326 mg, in contrast to values around 0.040 mg during the other 10 months. Other peaks at this station, which may reflect lesser contamination, occurred in 1974, 1976, and 1977. These peaks appear to have some relation to construction work during the expansion of parking facilities at the Albany County Airport, where the samplers were located.

Delmar's bulk deposition estimates (included in Figure 2 for completeness) exceeded 100 $mg \cdot m^{-2} \cdot yr^{-1}$ in 1980 and 1981. The estimates from the nearby dry/wet collector for 1981 was 21 $mg \cdot m^{-2} \cdot yr^{-1}$, well within the range of the six lowest estimates for the Albany station.



1	1968	7	1976
2	1969	8	1977
3	1970	9	1978
4	1971	10	1979
5	1974	11	1980
6	1975	12	1981
B	BULK	W	DRY/WET

This discrepancy suggests contamination of the bulk sampler and argues for exclusion from further analysis.

Similar higher peaks were observed less frequently and less dramatically at the Canton (1977) and Hinckley (1976, 1977, 1980) stations. Low values were obtained for the Chazy station. These values of 1.4 and 2.2 $mg \cdot m^{-2} \cdot yr^{-1}$ for 1978 and 1979 respectively are lower than any published values in the rest of the world.

In general, considerable year-to-year variation at individual stations was observed, probably due in large measure to random contamination. Only two instances of probable sampler problems were found (at Chazy). These observations suggest that a multiyear and multistation approach should be used in estimating annual deposition rates.

Within-year differences in deposition rates were found when the depositions were expressed as rates by month for the five stations (Figure 3). Canton showed significantly low rates in February and a tendency for high rates in June and August. Lake George, with only 2 years of data and incomplete annual records, was not scrutinized for monthly or seasonal differences.

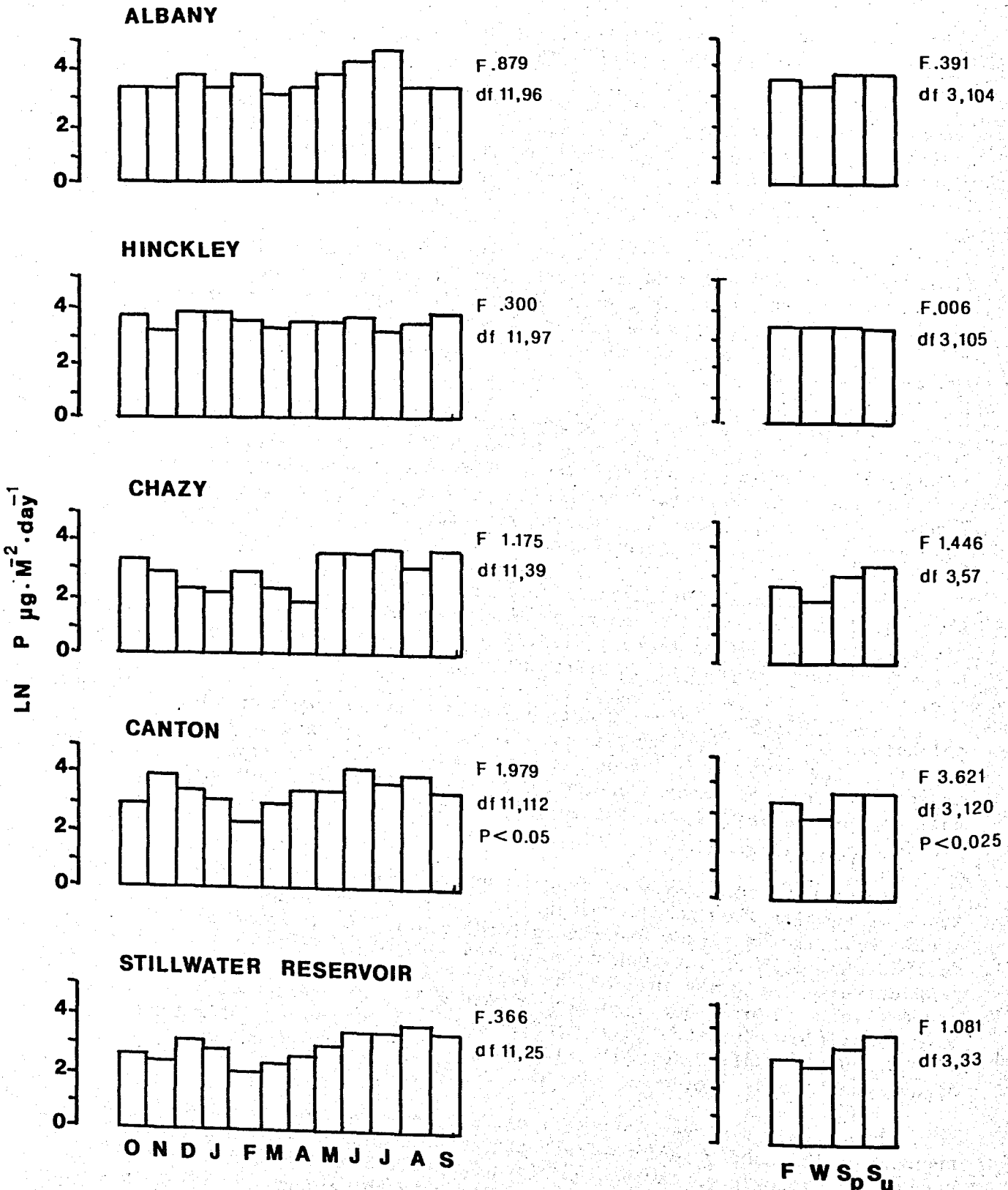
When the monthly estimates are grouped by season (Figure 3), the winter is seen to have generally lower deposition rates, although this was statistically significant only for Canton. Spring and summer rates appear to be generally higher.

Sampler effects. Some investigators have used dry/wet or wet collectors to segregate chemical depositions into dry- and wet-fall classes. The USGS, in an effort to compare bulk, wet, and dry aspects of chemical depositions, used dry/wet collectors along with bulk collectors at two stations in 1980 and at two more stations in 1981.

Preliminary comparison of deposition estimates for the two types of sampler show good agreement for two of six pairings (Table 2). The data from the Mendon Ponds station (near Rochester) in 1980 show bulk and dry/wet rates of 144 and 101 mg $P \cdot m^{-2} \cdot yr^{-1}$ respectively. At Chazy in 1981 the results were 24 and 17 $mg \cdot m^{-2} \cdot yr^{-1}$ respectively. Four other comparisons were widely divergent, with bulk deposition estimates significantly higher than dry/wet estimates ($F = 8.379$; 1,10 df, $P < 0.025$). The bulk mean rate of 104 was much higher than the dry/wet mean rate of 30 $mg \cdot m^{-2} \cdot yr^{-1}$.

These results suggest that (i) either the height of the sampler opening or its configuration affect the recorded depositions and (ii) occasional biologic contamination probably creates artifactually higher deposition rates in collectors closer to the ground.

Probable contamination by bird feces, insects, and other sources was inferred. When one high monthly estimate was excluded


ALBANY
F .879
df 11,96
F .391
df 3,104
HINCKLEY
F .300
df 11,97
F .006
df 3,105
CHAZY
F 1.175
df 11,39
F 1.446
df 3,57
CANTON
F 1.979
df 11,112
P < 0.05
F 3.621
df 3,120
P < 0.025
STILLWATER RESERVOIR
F .366
df 11,25
F 1.081
df 3,33
LN P µg·M⁻²·day⁻¹
0
2
4
O N D J F M A M J J A S
F W Sp Su

from each divergent sample, the recalculated rates showed only an insignificant difference between the two sampling systems ($F = 0.544$; 1,10 df). Thus single contamination events by biologic or other agents during an annual monitoring period may cause considerable overestimation of phosphorus and other deposition rates.

DISCUSSION

Deposition estimates for northeastern New York State are in the lower portion of the range of estimates for other parts of the Northern Hemisphere (Tables 3, 4). The mean for Hubbard Brook, New Hampshire (9 $mg \cdot m^{-2} \cdot yr^{-1}$), based on 2 years of data (Likens et al. 1977), is similar to the overall estimate for Chazy (7). Thus 7-9 mg $P \cdot m^{-2}$ may represent a lower boundary for annual phosphorus depositions. The mean for the Great Lakes (21) is close to the mean for northeastern New York State (18). The northeastern New York State estimates are generally exceeded only by those for Oklahoma (Sober and Bates 1979); Gainsville, Florida (Hendry and Brezonik 1980); and other areas with agricultural or urban impacts. Aerial transport of particles from denuded areas and paved areas contributed to these high deposition rates.

By the use of geometric means, dictated by significant nonadditivity (Snedecor and Cochran 1967), normality is approached in the data analysis. Judging from the long-term results, many of the high values are thought to reflect sample contamination events. Agricultural and road-dust sources of sample contamination from an agricultural land use area were thought to be typical factors influencing the 60 $mg \cdot m^{-2} \cdot yr^{-1}$ deposition rate for phosphorus to Lake Carl Blackwell, Oklahoma (Sober and Bates 1979). Culturally derived dust may be a typical source of higher values in urban land use areas (Randall et al. 1978, Goettle 1978, Malmquist 1978, and others references in Tables 3 and 4). Placement of samplers away from roads and cultivated areas will keep these contamination sources and the resulting data variance to a minimum.

Aulenbach et al. (1980) presented an estimated atmospheric phosphorus deposition rate of 75 $mg \cdot m^{-2} \cdot yr^{-1}$ to the surface of Lake George. This amount would represent 58% of the total loading of this important nutrient to the lake surface from uncontrollable sources. The estimate was derived from work by Gibble (1974), who sought to determine wet deposition over a 1-yr period (1972-1973). Additional work by Siebecker (1979) during a 3.5-month period in 1978 sought to add the dry fraction to the wet deposition measured by Gibble. For this Siebecker constructed a 1-m^2 pan sampler of polyethylene sheeting, sealed with silicone cement and containing 1.5 liters of water. For 40% of the period the device was exposed at only 1 m above ground. To avoid dust contamination from a nearby dirt road the device was moved to the roof of a one-story structure. Siebecker does not report a quality-control protocol for his device. Together the data from Gibble and Siebecker provided a bulk atmospheric deposition estimate of 75 $mg \cdot m^{-2} \cdot yr^{-1}$, exceeding both the estimate of 10-33 $mg \cdot m^{-2} \cdot yr^{-1}$ by years (1968-1981) and the estimate of 12-28 $mg \cdot m^{-2} \cdot yr^{-1}$ by station for the USGS data set. Indeed, the Aulenbach et al. estimate exceeds most of

those published for other areas of the world.

Table 2

Atmospheric phosphorus loading (L_p) estimates (mg $P \cdot m^{-2} \cdot yr^{-1}$) from bulk for variable percentages of a water year and from dry/wet collectors

Location	Year	Bulk		Dry/Wet			
		L_p	%yr	Total	Wet	Dry	Dry/Wet
Mendon Ponds	1980	144	34	101	10	91	9.1
	1981	102	82	31	12	19	1.6
Delmar	1981	107	92	20	13	7	0.5
Chazy	1981	24	91	17	14	3	0.2
Lake George	1980	273	32	39	16	23	1.4
	1981	125	90	17	10	7	0.7
Edited bulk data (one high monthly estimate omitted)							
Lake George	1980	18	17				
	1981	34	81				
Mendon Ponds	1981	35	73				
Delmar	1981	59	84				

Maguire (1963) suggested that the height of the opening above ground and the type of ecosystem in which the collectors are placed are significant factors in sample contamination from biologic activity. Containers closer to the ground had much higher and more diverse communities than more elevated containers. Collectors with openings well above ground or forest canopies and constructed to discourage birds from perching may yield background phosphorus depositions for northeastern New York State of less than 18 $mg \cdot m^{-2} \cdot yr^{-1}$.

Both aquatic and terrestrial biota utilize soluble phosphorus for uptake and metabolic functions. Distinctions between dry and wet deposition are therefore questionable for terrestrial systems and especially for lakes. Dry deposition on a lake surface is immediately wetted, so the biologic or physical solubility of the constituents is of primary concern.

Table 3

Comparison of United States atmospheric phosphorus loadings from the literature

Location	mg $P \cdot m^{-2} \cdot yr^{-1}$ Geometric Mean	Range	Reference
Oklahoma: Stillwater	60		Sober and Bates 1979
Florida: Gainesville	120		Hendry and Brezonik 1980
Gainesville		10-100	Brezonik 1975
Coastal	31		
Urban	48		
Rural	27		Hendry et al. 1981
Agricultural	66		
Ohio: Cincinnati	20		Weibel 1969
Connecticut: Thomaston	29		Pearson and Fisher 1971
Wisconsin: Central	102		Kluesner 1972
Great Lakes:			
Superior	13	5-73	
Michigan	18	5-84	
Huron	9	3-21	Allen and Halley 1980
Erie	25	7-180	
Ontario	24	6-100	
Huron	24		Delumyea and Petel 1978
Ontario		13-19	Shiomi and Kuntz 1973
Michigan - North	22	19-33	Eisenreich et al.
South	36	22-56	1977
New Hampshire: Hubbard Brook	8	3.6-13.1	Likens et al. 1977
New York: Lake George	75		Aulenbach et al. 1980
Finger Lakes	43	15-117	Likens 1972
Other than NE	23		USGS 1970-79, 1981
Northeast	18		This analysis

Table 4

Comparison of world atmospheric phosphorus loadings from the literature

Location		mg $P \cdot m^{-2} \cdot yr^{-1}$ Geometric Mean	Range	Reference
Canada				
Various		17	5.6-44.3	Scheider et al. 1979
Alberta:	Edmonton	114?		Caiazza et al. 1978
Ontario:	Haliburton	35	29-42	Scheider et al. 1979
	Haliburton	77		Dillon 1974
	Algonquin Pond	35		Scheider 1978
	Ranger Lake	9		Foster 1974
	Rawson Lake	31	24-53	Schindler et al. 1976
	Clear Lake	31	27-39	Schindler and Nighswander 1970
	Harp Lake	74		Nicholls and Cox 1978
	Lake St. Nora	37		Gomolka 1975
Europe				
Scandinavia		17	6-34	Melanen 1978
Finland			6.0-22	Malmquist 1978
Sweden:	Various	10		Sand-Jensen and Sondergaard 1981
	Göteborg	28		Malmquist 1978
England:	Various		12-100	Allen et al. 1968
	northern	80		Gore 1968
Switzerland		15		Goettle 1978
Germany:	Munich		40-80	Goettle 1978

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Figure legends

1. Location of the USGS atmospheric deposition monitoring stations in northeastern New York State.

2. Atmospheric phosphorus deposition estimates at seven USGS monitoring stations by year (including the Delmar and Chazy results which were rejected from further analysis).

3. Monthly and seasonal variation in atmospheric depositions of phosphorus ($\mu g \cdot m^{-2} \cdot day$) at five USGS monitoring stations, 1968-1981.

DISCUSSION

Stross - To what do you attribute Siebecker's estimate being two times that of Aulenbach's?

Woods - The methods of collection were different. Siebecker used a lake surface simulator - 24 hour wet pan collector