THE

ONTARIO WATER RESOURCES

COMMISSION

Yield of Phosphorous in the Eastern Lake Ontario Region

1968

THE YIELD OF PHOSPHORUS
IN EASTERN
LAKE ONTARIO REGION

by

Dr. Syed S. Ahmed Rizvi

S. E. Salbach, P. Eng.

Water Quality Surveys Branch

1968

Ontario Water Resources Commission

YIELD OF PHOSPHORUS IN EASTERN LAKE ONTARIO REGION

Dr. Syed S. Ahmed Rizvi [1]

and S. E. Salbach [2]

ABSTRACT

The yields of phosphorus were estimated from four selected Eastern Lake Ontario region watersheds. These streams drain mainly agriculture and pasture lands to Lake Ontario. The variation of concentrations, flows and yields for the four watersheds were calculated and plotted for comparison on a monthly basis over the four year study period. Mathematical equations for forecasting of concentration levels were developed and tested for statistical significance. The mean monthly yields were also plotted to assess on a quantitative basis during the calendar year, the variation of the discharge of phosphorus to Lake Ontario. About 40 to 50 per cent of the annual yields were found to be released during the months of February, March and April. A step-wise regression analysis was used for developing the relationship between concentration, yield and land use for this region. Three year annual yields of phosphorus from the four watersheds ranged between 237 to 810 lbs/mi^2-yr. The methodology presented could be used on other water quality data.

---

[1] Asst. Prof. of Eng., S. G. W. Univ., Montreal and Consult. Eng., WQSB, OWRC, Toronto, Ontario. September, 1968.

[2] P. Eng., WQSB, OWRC, Toronto, Ontario.

INTRODUCTION

In recent years, the Great Lakes have received widespread attention from public and private groups who were concerned about the increasing evidence that through direct waste discharges and tributary drainage, the Great Lakes are becoming excessively enriched with nutrients - nitrogen and phosphorus. This report presents the findings of an analysis of nutrient data for four streams tributary to Lake Ontario in the north-eastern part of the Province of Ontario. The objectives of the analysis were to determine the yield of total phosphorus from forest and pasture land and to develop a forecasting equation based on streamflows and/or other independent variables. The nutrient data used for this analysis was obtained by the Ontario Water Resources Commission as part of a regular water quality monitoring program of lakes and streams in the Province of Ontario.

The region under study is drained by four streams, the Moira River, Salmon River, Napanee River and Wilton Creek and for the purpose of this report is referred to as Eastern Lake Ontario Region (Figure 1). The selected area has essentially similar socio-economic, physical, and climatological features.

PHYSIOGRAPHY AND LAND USE

The general physiography is outlined in Figure 1. The region has four primary soil divisions as follows:

In the northern part of the region the Canadian Shield predominates. It is composed of Pre-cambrian granite outcrops but glacial scouring has caused numerous small deep bank lakes. Shelf depressions are usually filled with marsh or scrub, and vegetation is sparse. There is little or no agriculture in the area.

Bordering the Canadian Shield to the south is the till moraine, an area of rough land. The underlying bedrocks of the till moraine are sedimentary limestones of the Black River group. The moraines of the area are characterized by angular fragments and blocks of limestone. The surface is extremely rough and mainly used for raising cattle and a few flocks of sheep. Crossing this moraine belt are the Moira tributaries which cut up to 100 ft into the bedrock. A number of these valleys are blocked by glacial drift; thus isolating long narrow lakes and swamps.

The Napanee Plains (clay and limestone plains) are flat to undulating south-east of the till moraine area. While the soil is only a few inches deep over most of the region some deeper glacial till occurs in the stream valleys and toward the north. Alluvial deposits exist in the valleys. There are also a few scattered drumlins of the long thin type. The greatest elements of relief are provided by the Salmon and Napanee rivers. They cut the rockplain to a depth of 50 to 100 feet. In this area hay and oats are the most prevalent crops and cattle and poultry are in notable number.

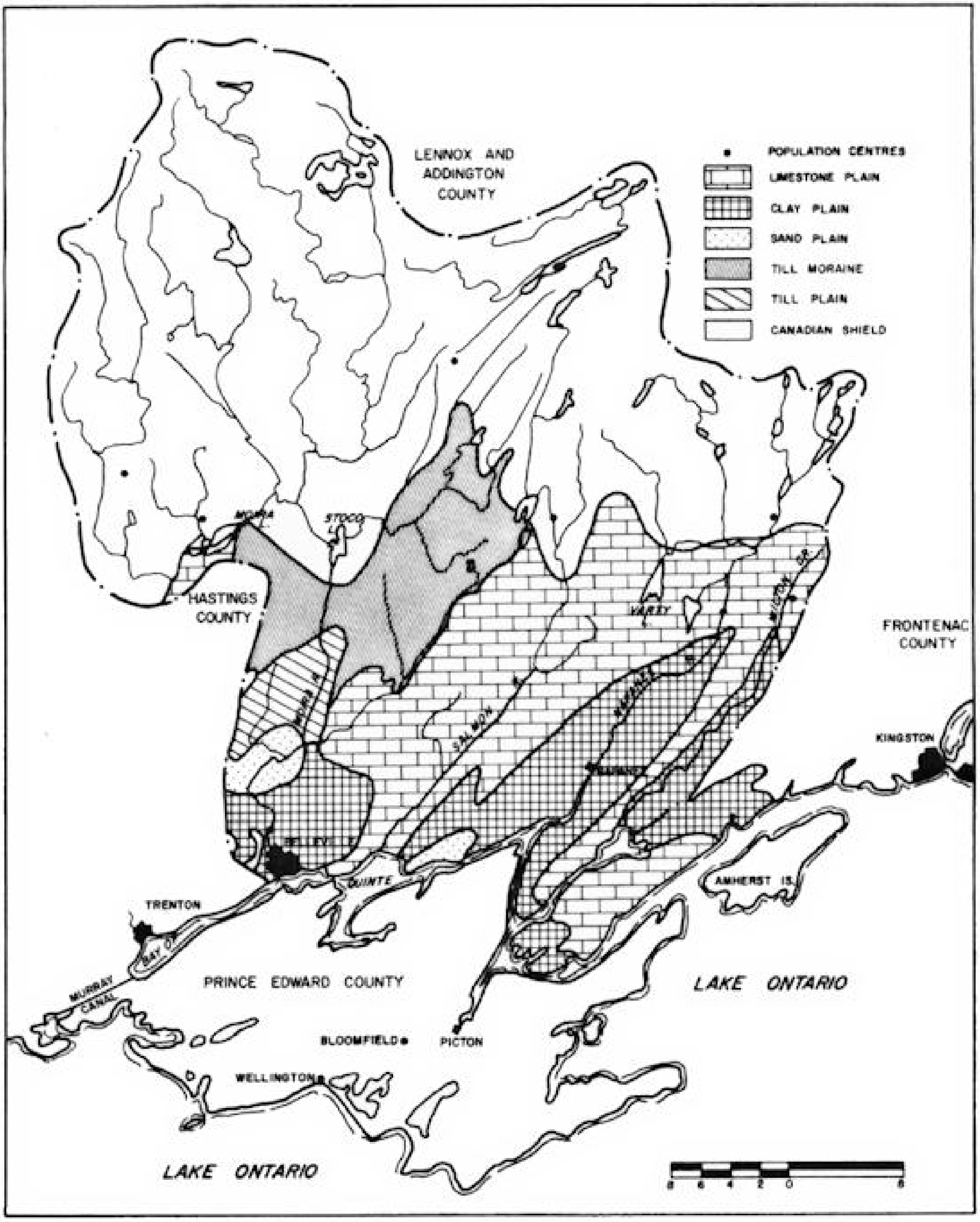

FIG. 1. Physiographic Regions.

To the west, north of Belleville are the till and sand plains. This area is part of the Iroquois plain which extends along the north shore of Lake Ontario into the Niagara fruit belt. The region is identified by cliffs, boulder pavements and shallow soils. Even though rurally populated the till and sand plains have very little agriculture.

Drumlins exist scattered in the eastern part of the region, west of the Moira River. This is composed of Grand ridge and poor soils (clays). Along the northern edge, the drumlins are small, scattered and imperfectly formed. Along the southern edge (north of Trenton) the drumlins are very large and some outstanding specimens exceed 200 feet in height with 25 per cent slopes. The whole area is accompanied by wet swampy hollows. Land use is mainly for animal grazing and hay and oats are grown.

The land use and other information are presented in Table 1 and also shown in Figures 2 and 3. Industrial and urban development is small, and as this analysis shows, represents an insignificant proportion of total discharge of phosphorus from the watersheds to Lake Ontario. Forest and pasture land are by far the most predominant land uses in the area of the four watersheds. The largest urban area is Belleville with 6.4 square miles in the Moira River basin. Napanee is the only municipality served by a water pollution control plant. The discharge of the treatment plant enters the Napanee River just prior to confluence with Lake Ontario.

TABLE 1. Characteristics of Four Selected Watersheds In Eastern Lake Ontario Region.

Watersheds	Area (sq. mi.)	Estimated Pop.		Major Land Use charge (sq. mi.)	Total Effluent Discharge above sample point (IMGD)	No. of Industries (1)	Municipal Treatment Plants (M)	Mean Discharge (1000 ft^3/day) During Study Period
		Rural	Urban					
Moira River	1,040	10,000	3,600	urban 9.1 woodland 693 pasture & forage land 261.6	M - 0.6 I - 2.7	10	3	85102.6
Salmon River	344	10,000	-	urban 3.68 woodland 203 pasture & forage land 112.34	I - 0.025 (seasonal operation)	1	0	28624.9
Napanee River	300	1,100	7,600	urban 3 woodland 165 pasture & forage land 129.7	M - 0.9 I - 0.9	2	2	24935.0
Wilton Creek	4.34	3,000	-	urban 0.5 woodland 10.9 pasture & forage land 38.1	I - 0.03	2	0	3647.4

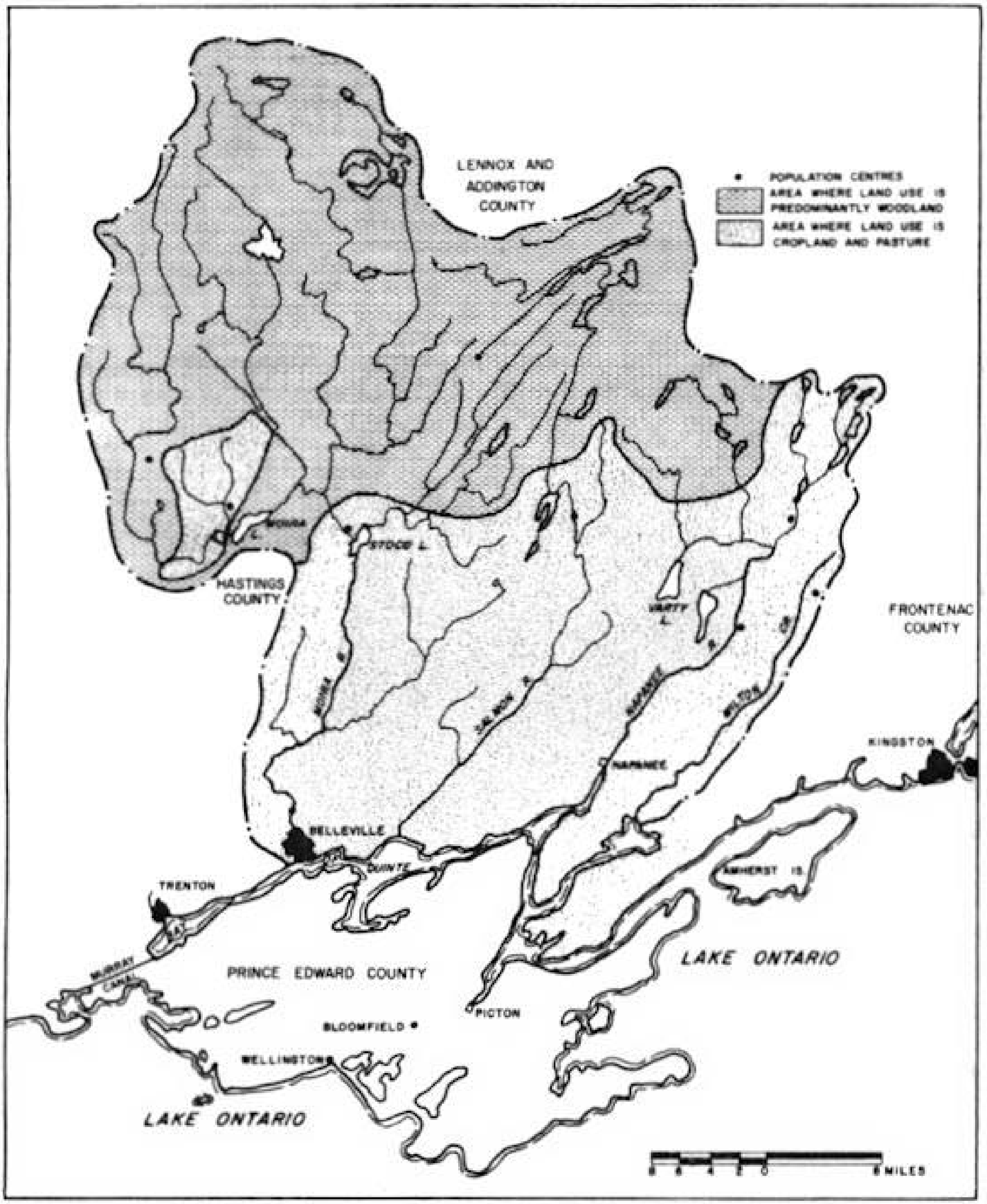

FIG. 2. Land Use.

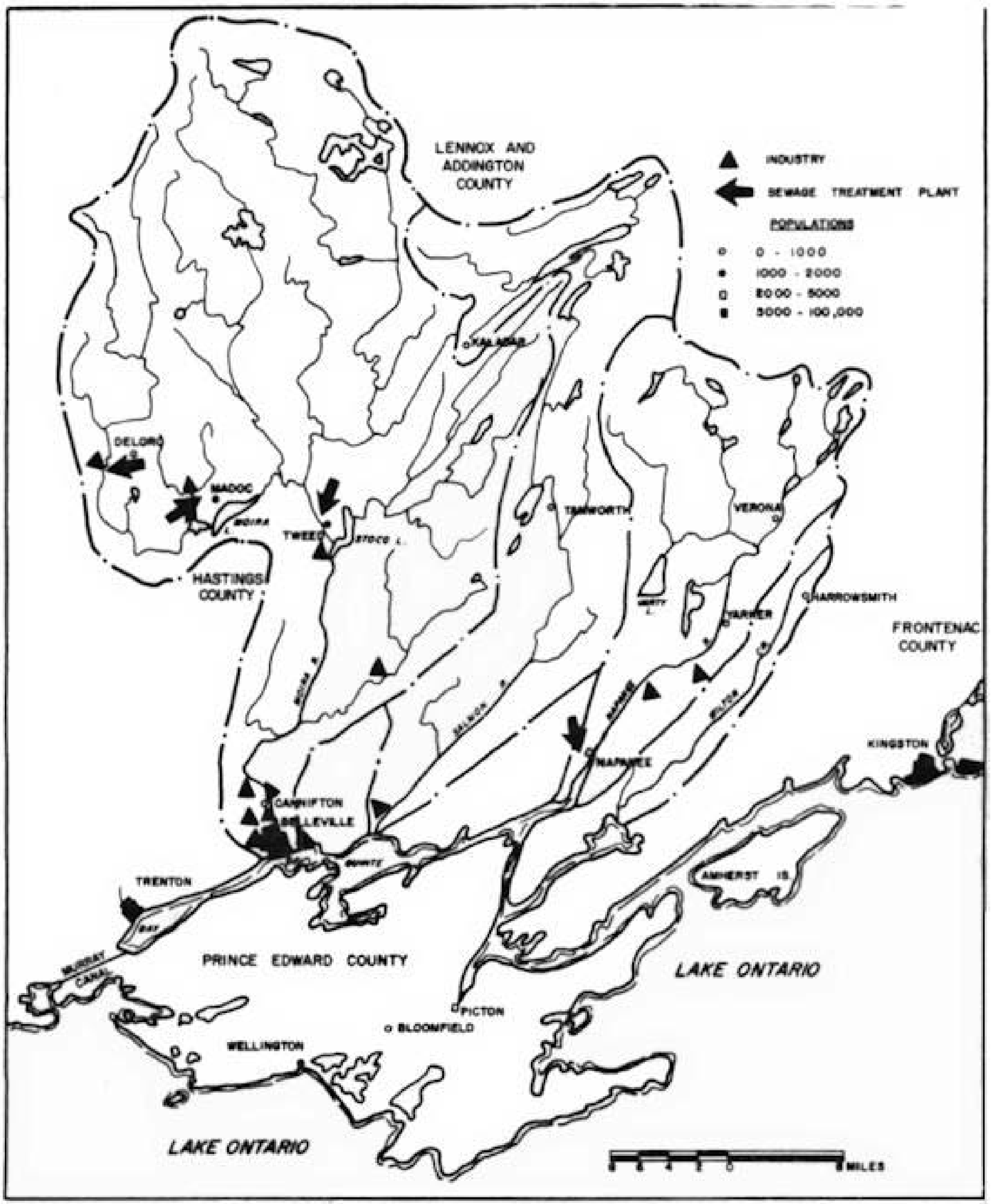

FIG. 3. Industries, Sewage Treatment Plants, Centres of Population.

METHOD OF ANALYSIS OF PHOSPHORUS DATA

The water quality data were collected near the mouth of the four streams on a monthly or bimonthly basis during the study period (October 1964 to September 1967). Streamflow information was obtained for the days of sampling from the Canada Department of Energy, Mines and Resources. On an average about twenty-four samples were collected on each stream during the study period. The samples were obtained on random days, and thus represent a random series.

For all the samples collected the total phosphorus concentration level (mg/L), was measured, using standard methods (A.P.H.A. 1960) (1). In Table 2, the annual yields based on mean concentrations and mean flows for the samples collected during each water year (October 1 to September 30) are presented.

Figures 4, 5, 6 and 7 show the variations of the phosphorus concentration levels on sampling days as well as the flows (ft^3/m^2-day) and yields of phosphorus (lbs/m^2-day) for the four streams. These graphs give an indication of the relationship between the three variables, if present. In any attempt to correlate these variables statistically, however, one must keep in mind that the yield is not an independent variable since it is a product of the concentration and flow.

In Figure 8 the average monthly yields were plotted for each of the four streams. Mean monthly yields (lbs/month) are based on mean monthly concentrations and the mean monthly flows (ft^3/day) for the study period. Before the regression analysis was tried for different variables, simple log relationships between concentration and flows were plotted, however, these graphs are not presented here as they did not show any significant relationship.

In Figure 9, the ranges between yearly maximum and minimum concentration and mean values have been plotted for the four streams. Figure 10 shows the range between maximum and minimum yields.

TABLE 2. Mean Concentration Level Mean Flow and Annual Yield of Phosphorus From Four Watersheds in the Eastern Lake Ontario Region.

	Mean Concentration (mg/L)			Mean Flow (cfs/mi^2)			Avg. Annual Yield (lb/mi^2-yr)		
	1964-65	1965-66	1966-67	1964-65	1965-66	1966-67	1964-65	1965-66	1966-67
Moira River	0.22	0.19	0.138	0.7165	1.048	1.077	310.7	392.4	292.9
Salmon River	0.22	0.09	0.087	0.7994	1.052	1.038	346.5	186.6	177.9
Napanee River	0.74	0.42	0.195	0.786	1.073	1.027	1146.3	888.1	394.6
Wilton Creek	0.24	0.17	0.189	0.7823 [e]	1.099	1.037	369.7	368.1	386.1

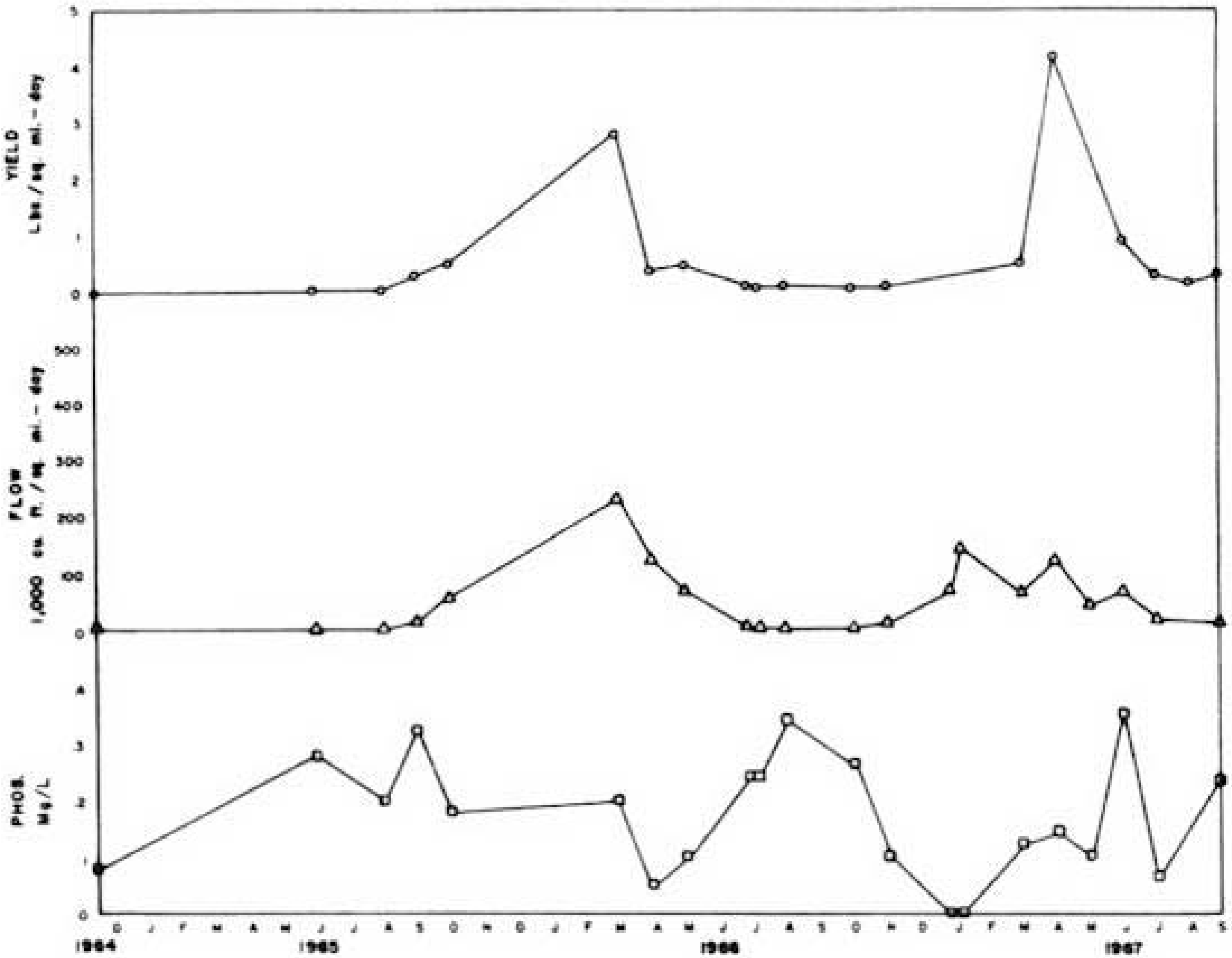

FIG 4. Moira River: Variation of Phosphorus, Flow, Yield During Study Period 1964 - 1967.

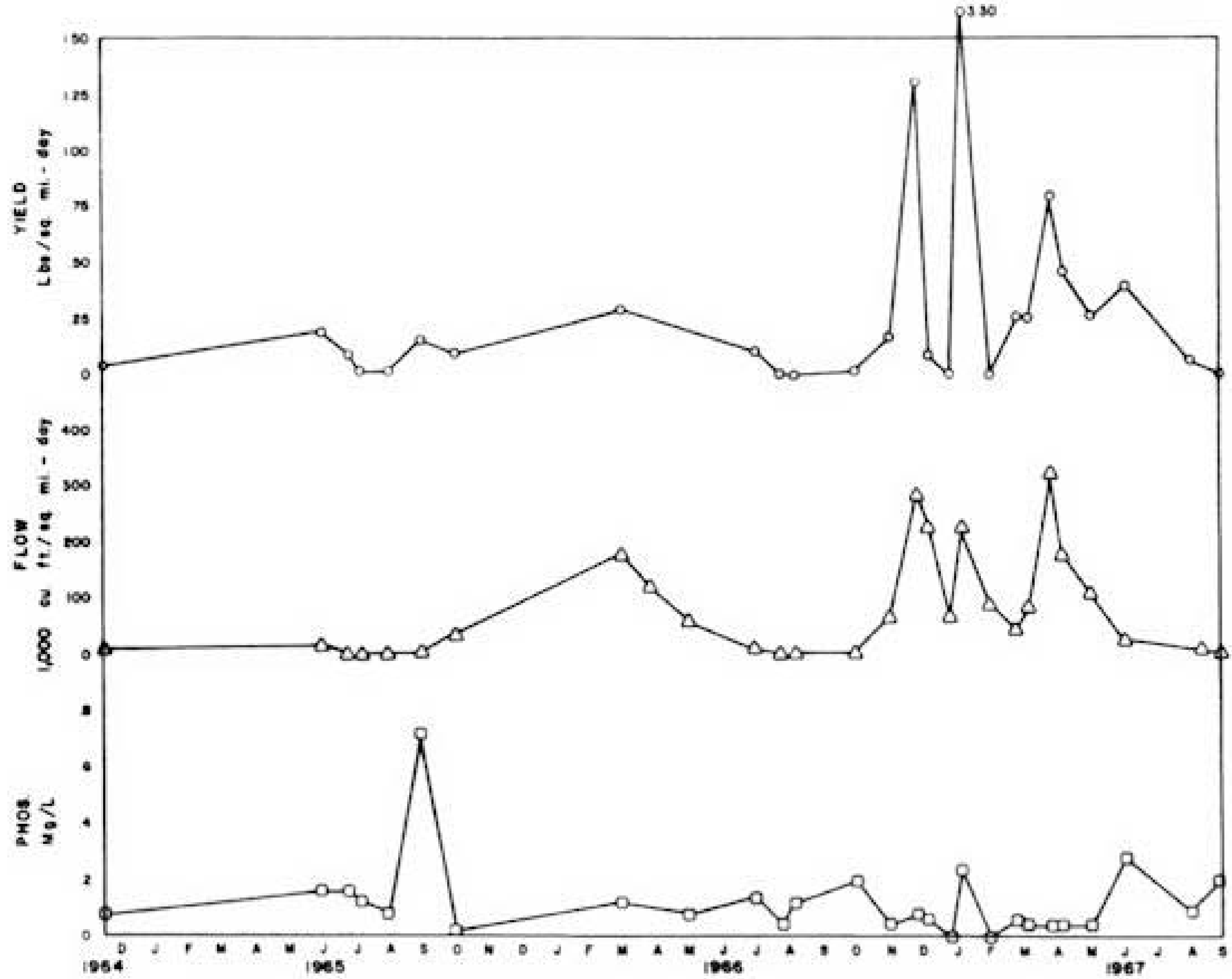

FIG. 5. Salmon River: Variation of Phosphorus, Flow, Yield During Study Period 1964 - 1967.

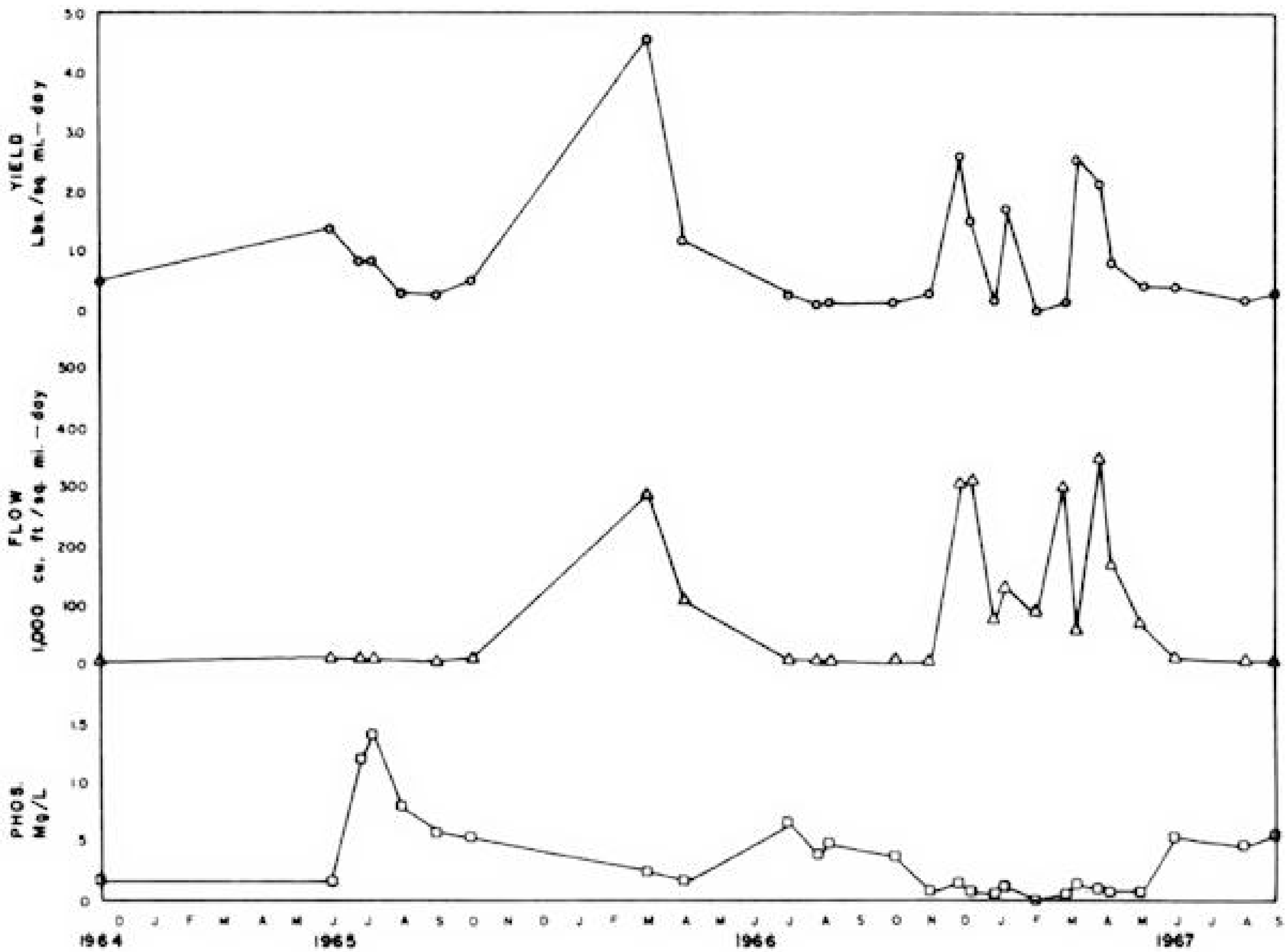

FIG. 6. Napanee River: Variation of Phosphorus, Flow, Yield During Study Period 1964 -1967.

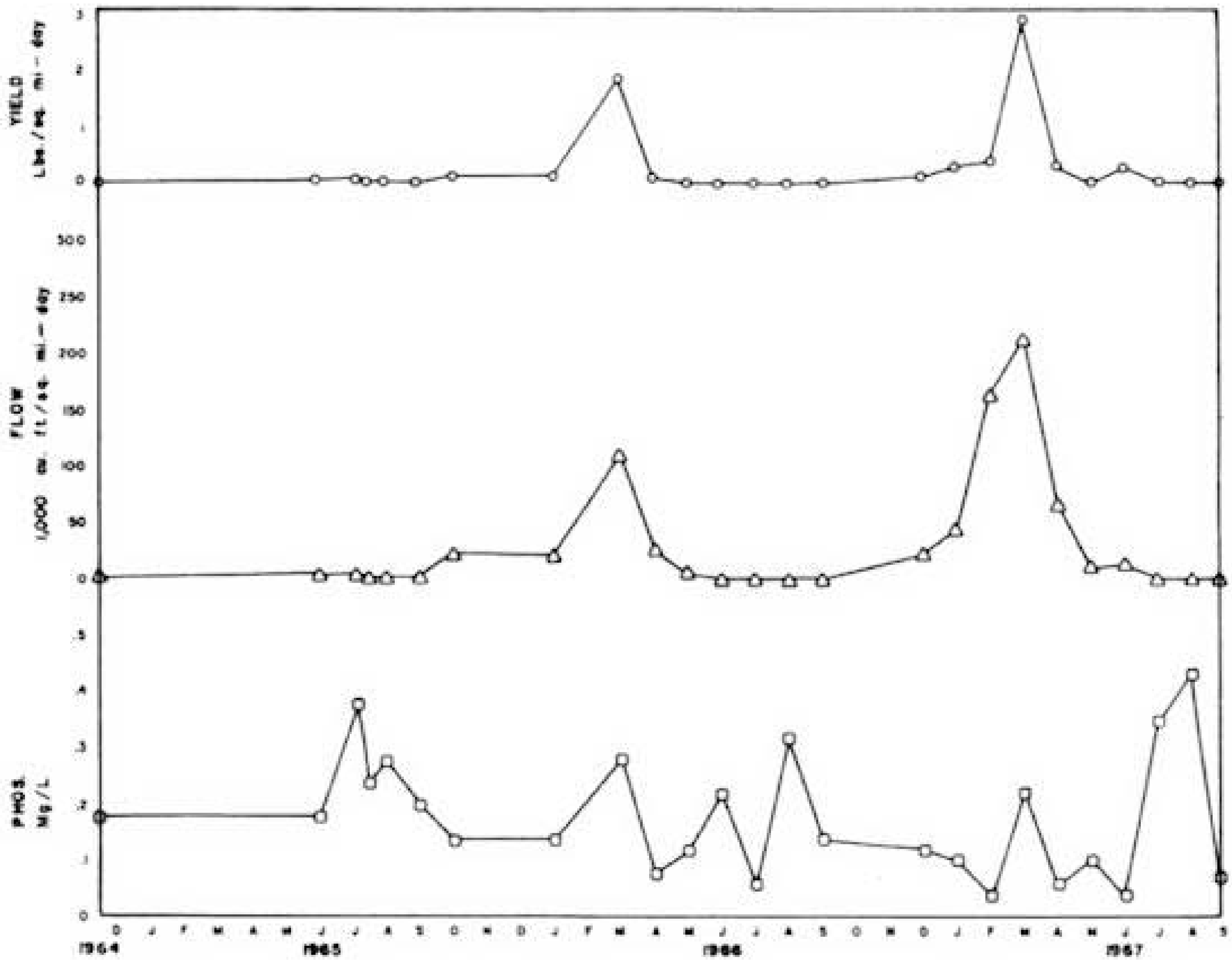

FIG. 7. Wilton Creek: Variation of Phosphorus, Flow, Yield During Study Period 1964 - 1967.

DISCUSSION

A number of researchers in the past have drawn attention to the importance of land drainage as a significant source of phosphorus to surface waters. In 1966, Owen and Johnson (2) showed a statistically significant relationship between the yield of phosphorus (lbs/mi^2-day) with flows (ft^3/mi^2-day) and developed an equation which allowed forecasting of phosphorus yield for streams. However, the relationship is somewhat questionable since yield and flow are not independent variables. For a regression analysis, it is essential that random samples be obtained from the values of the dependent variable (y) for those values of the independent variable (x) included in the study. Also when (y) is a multiple of x then variation in x will not explain the true variation in y because the effect of the variable x has been included in the variable y. The yield which is a product of concentration and flow cannot be correlated with flows.

Figures 4 to 7 show that total phosphorus content (mg/L) fluctuated markedly in some months. In general, the fluctuations did not associate with changes in flow (ft^3/mi^2-day) and appeared to indicate no direct or inverse relationship between phosphorus concentrations and flows. This relationship was verified by calculating the coefficient of correlation between the two variables and the required critical values for the coefficient of correlation at the 5 per cent level of significance (Table 3). By comparing the calculated and required values in this table it is apparent that at that significance level, no relationship exists between concentration levels and flows. This appears to indicate that streamflow is not an important factor for forecasting the phosphorus concentrations in these four streams.

An attempt was also made to correlate the concentration with temperature (°C) of the sample water, and the dissolved oxygen (DO) (mg/L) in the sample. This was done by using the technique of stepwise multiple regression analysis. However, no significant statistical relationship was found, and the equation is therefore not included in this report.

Figure 8 shows the seasonal variation of the mean monthly yield (PO_4 lbs/mi^2-day) of phosphorus for each watershed. All four watersheds show great fluctuations in phosphorus yields between periods of high and low streamflows. About 18 to 25% of the annual yield was discharged from these streams during the two months of December and January. About 40 to 50% of the annual yield was discharged during February, March and April as compared with only 3 to 22% for the period of May to September. By comparison, Engelbrecht and Morgan (3) found that only approximately 6% of the total annual yield from a predominantly agriculture watershed was discharged during a period of April to September. Some seasonal variation in yield is intermediate while some is high.

Sawyer (4), in his study of Madison Lake, describes a mean annual yield of phosphorus from agriculture drainage of this area equivalent to about 700 PO_4 lbs/mi^2-yr Smith (5) found a yield of 114 PO_4 lbs/mi^2 from agriculture drainage during a period of April through December. Engelbrecht and Morgan (6) estimated that approximately 665 PO_4 lbs/mi^2-yr was of land drainage origin on an Illinois water-shed of 4,220 square miles. In the study of Eastern Lake Ontario Region, the mean yield of phosphorus as PO_4 was found to be 332 lbs/mi^2-yr from the Moira, 237 lbs/mi^2-yr from the Salmon, 810 lbs/mi^2-yr from the Napanee and 375 lbs/mi^2-yr from Wilton Creek.

The four watersheds studied here have little industry and urban area. The Napanee River receives the effluent from the sewage treatment plant serving the Town of Napanee which increased the yield of phosphorus for this watershed to 810 lbs per square mile per year (lb/mi^2-yr). With the phosphate input from the Napanee water pollution control plant deducted, the phosphorus yield from this watershed reduces to

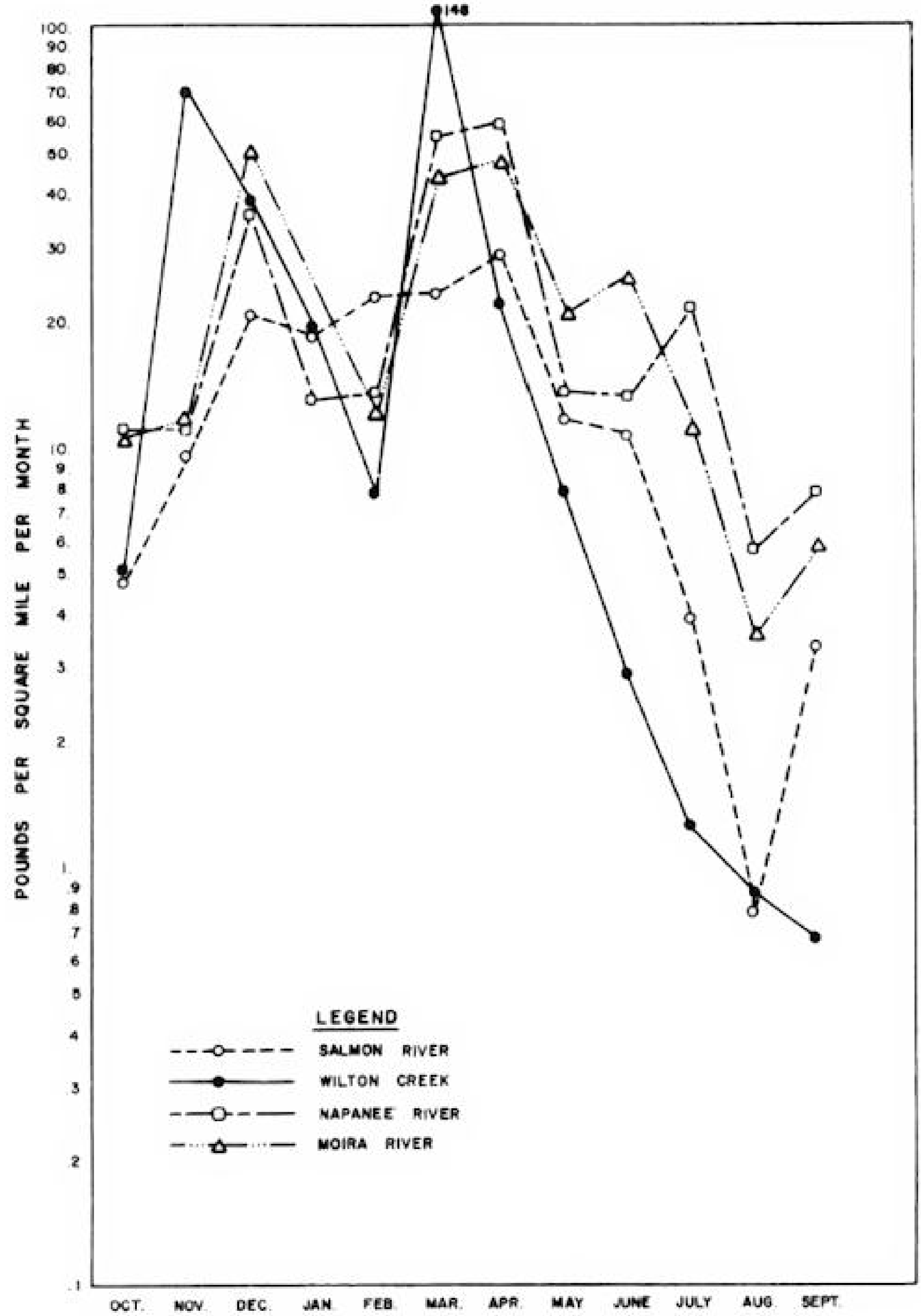

FIG. 8. Comparison of Mean Monthly Phosphorous Yield For Selected Watersheds.

654 lbs/mi^2-yr. No attempt was made to investigate in detail the reason for having high yield at Napanee, however, a visual observation and discussion with local people indicates that this high value may be due to the flooding of lands and existence of Depot lakes on the river, and also because of effluent coming from paper industry into the stream. From the knowledge that land use in the four streams is predominantly forest and grazing, it can be apparently concluded that drainage from these two land uses provides the main source of phosphorus to the rivers in this region throughout the year.

The bar diagrams in Figure 9 indicate the maximum, minimum, average concentration values based on study period (1964-67), While the available data does not allow to comment on developing trends at this time, it is evident that with more data such bar diagrams are useful in establishing long term trends in the variations of the yield of phosphorus from the area under study or elsewhere.

The equation obtained from the multiple regression analysis relating phosphorus yield to major land uses on four streams is shown in Table 3. The land uses for this region are forest, horticulture, urban, pasture and grazing land. The cursory examination appears to indicate a relationship between phosphorus concentration and horticultural and urban land uses on the four watersheds. However, as only four streams were considered, the number of observations for this multiple regression was limited to four, and any attempt at regression analysis having more variables than observations would be meaningless, (the number of degrees of freedom would be negative). Therefore, after the addition of two variables the multiple regression was terminated. Although the multiple correlation coefficient is high, $r = 0.959$, it is below the critical $r_c = 0.999$ required at a 5 per cent level of significance. It is, therefore, concluded that with the data used no significant relationship can be established between phosphorus yield and land uses and the established forecasting equation does not produce reliable results. The same holds true for other equations based on simple regression analysis for the four streams (Table 3).

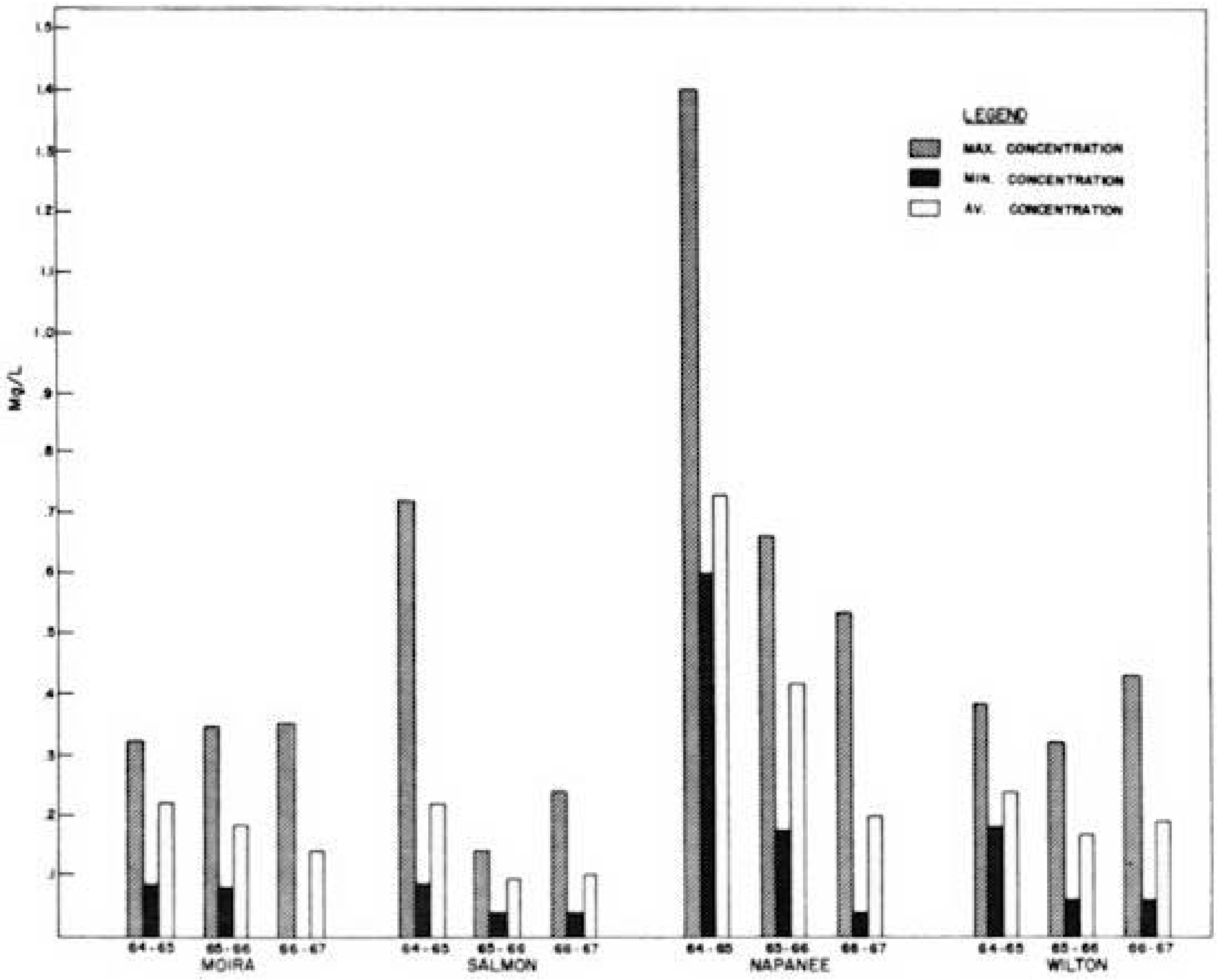

FIG. 9. Yearly Maximum , Minimum, Average Concentration of Total Phosphorous 1964 - 67.

TABLE 3. Coefficient of Correlation Between Phosphorus Concentration (mg/L), y, and Flow ($ft^3/m^2/day$), x, for Four Watersheds in the Eastern Lake Ontario Region.

Watershed	Estimating Equation	Computed Correlation Coefficient (r)	Critical Value of r at 5% Level of Significance Req'd
Moira River	$y = 0.191 - 0.024x$	0.292	0.423
Salmon River	$y = 0.146 - 0.028x$	0.262	0.367
Napanee River	$y = 0.459 - 0.121x$	0.439	0.367
Wilton Creek	$y = 0.216 - 0.041x$	0.269	0.396
Whole Region	$y = -0.78 + 0.832x_1 + 0.296x_2$	0.959	0.999

where y = Phosphorus Concentration
x_1 = urban, and
x_2 = horticulture areas

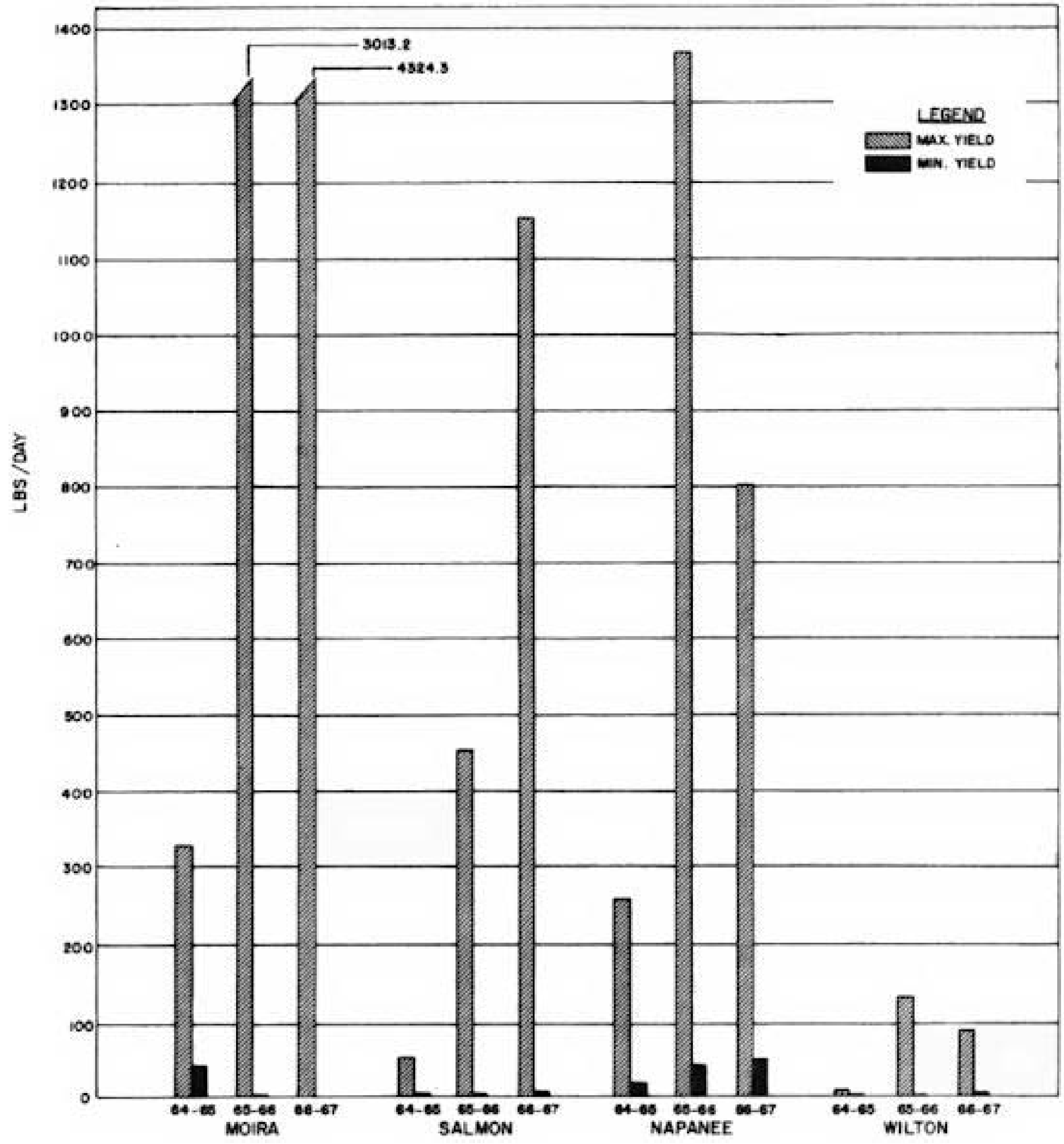

FIG. 10. Comparison of Maximum, Minimum Yield of Phosphorous on Yearly Basis.

SUMMARY AND CONCLUSION

Concentration levels of total phosphorus in four major streams of eastern Lake Ontario region were investigated. The watershed of all these streams is predominantly wooded and grazing land. There is neither much organized area nor much industry in these watersheds, with the result that the contribution of phosphorus would originate mainly from forest and pasture lands. The finding of this report shows a significant yield of phosphorus from the non-urbanized areas.

No relationship was found to exist between level of concentration in the tributary drainage and the rate of streamflow. The yield, however, depended on the fluctuations of flows because total yield incorporates within itself the effect of flows. Pronounced seasonal variations were noted in the yields of phosphorus from forest and grazing land areas. About 50% of the annual yield occurred in February, March and April.

It can be concluded from this study that there appears to be no relationship between the level of concentration of phosphorus and streamflows. However, it was found that concentrations of phosphorus in four streams was about twice as high in August than in March. This appears to differ from values reported by Owen and Johnson (2).

The analysis presented here could in general be used for the assessment of yields from other streams where adequate water quality monitoring data are available. But in order to obtain statistically significant results, water quality data for longer periods should be available. To increase the reliability of the findings presented in this case study, it is desirable to have more data, about 15 years.

REFERENCES

1. American Public Health Association. 1960. "Standard Methods for the Examination of Water and Wastewater". APHA Inc., New York. 626p.

2. Owen, G. E. and Johnson, M. G. 1966. "Significance of Some Factors Affecting Yields of Phosphorus from Several Lake Ontario Watersheds". Proc. Ninth Conf. on Great Lakes Research, Univ. Michigan, Great Lakes Res. Div., Pub. 15, 400-410.

3. Engelbrecht, R. S. and J. J. Morgan. 1961. "Land Drainage as a Source of Phosphorus in Illinois Surface Waters". Algae and Metropolitan Wastes, U. S. Public Health Service, SEC TRW 61-3: 74-79.

4. Sawyer, C. N. 1947. "Fertilization of Lakes by Agriculture and Urban Drainage". Jour. New England Waterworks Assn. 61: 109-127.

5. Smith, M. W. 1959. "Phosphorus Enrichment of Drainage Waters from Farm Lands". J. Fish. Res. Bd. Can. 16: 887-895.

6. Engelbrecht, R. S. and J. J. Morgan. 1959. "Studies on the Occurrence and Degradation of Condensed Phosphate in Surface Water". Sewage and Industrial Wastes 31: 450-478.

BIBLIOGRAPHY

1. Chapman, L. J. and D. F. Putnam. 1951. "The Physiography of Southern Ontario". Univ. of Toronto Press, Toronto. 284p.

2. Phinney, H. K. and Peek, C. A. 1960. "Kalamath Lake, An Instance of Natural Enrichment". Algae and Metropolitan Wastes, U.S. Public Health Service, SEC TRW 61-3.

3. Sylvester, R. O. 1961. "Nutrient Content of Drainage Water from Forested, Urban and Agricultural Areas" . Algae and Metropolitan Wastes, U. S. Public Health Service, SEC TR, W61-3: 74-79.